DIESEL MECHANICS

Second Edition

Erich J. Schulz

Formerly, Director of Training Programs
Pacific Vocational Institute—Burnaby Campus
Burnaby, British Columbia

Gregg Division/McGraw-Hill Book Company

New York Atlanta Dallas St. Louis San Francisco Auckland Bogotá Guatemala
Hamburg Johannesburg Lisbon London Madrid Mexico Montreal New Delhi
Panama Paris San Juan São Paulo Singapore Sydney Tokyo Toronto

Martin Rogers 6059

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Sponsoring Editor: D. Eugene Gilmore
Editing Supervisor: Larry Goldberg
Design and Art Supervisor: Karen Tureck
Production Supervisor: Priscilla Taguer

Text Designer: Karen Tureck
Cover Designer: Edward Smith Design, Inc.

Erich J. Schulz is the author of *Diesel Equipment I* and *Diesel Equipment II*. His other publications include *Heavy Duty Mechanics Workbook No. 1—Diesel, Heavy Duty Mechanics Workbook No. 2—Electrical,* and *Heavy Duty Mechanics Workbook No. 3—Hydraulics,* all published by the Operating Engineers Joint Apprenticeship Board. He is an associate member of the Association of Diesel Specialists and the Society of Automotive Engineers.

Library of Congress Cataloging in Publication Data

Schulz, Erich J.
Diesel mechanics.

Includes index.
1. Diesel motor—Maintenance and repair. I. Title.
TJ799.S38 1983 621.43'6'0288 82-23941
ISBN 0-07-055639-3

DIESEL MECHANICS, Second Edition

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ISBN 0-07-055639-3

ACKNOWLEDGMENTS

No mechanics' textbook would be considered complete, and few would be intelligible to the novice without graphs, photograph reproductions, and other illustrative material pertinent to the trade. To the numerous companies, therefore, which have consented to reproduction of art work from their service manuals and other literature to complement this textbook, I extend thanks and appreciation on behalf of my readers and myself. Specifically, I refer to Aeroquip Corporation; Allis-Chalmers Corporation Engine Division; American Bosch United Technologies Automotive Group; J I Case Company, Agricultural Equipment Division (TENNECO); Caterpillar Tractor Co.; CAV Limited; Chrysler Canada Ltd.; Chevron Research Co.; Cummins Engine Company, Inc.; Dana Corporation, Spicer Transmission Division; Delco Remy Division of General Motors Corporation; Detroit Diesel Allison, Division of General Motors Corporation; Eaton Corporation Transmission Division; Federal-Mogul Worldwide Marketing Group; GMC Truck and Coach Division; Greenfield Tap and Die Corporation; International Harvester Company; Mack Trucks Canada Limited; Owatonna Tool Company (Tools and Equipment Division); Robert Bosch GmbH, Stuttgart, West Germany; Sperry Rand Canada Ltd., Vickers Division; Stanadyne Diesel Systems; Stratoflex of Canada Inc.; Sunnen Products Company; Sun Oil Company; The L. S. Starrett Company; and The Weatherhead Co. of Canada Ltd.

I also gratefully acknowledge the myriad of hours contributed by my wife to the typing and retyping of this manuscript and her encouragement to its completion.

Last but not least I wish to thank my publishers, who recognized the need for this book by those training to become diesel mechanics.

Erich J. Schulz

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PREFACE

Great progress has been made in mechanical engineering since the time when wind and water were harnessed as the sources of mechanical power. The extent of this progress is particularly noticeable when one considers today's gas turbine, jet propulsion, and atomic power units.

The internal-combustion piston engine now appears to have lost its leading position as the source of mechanical power. A new era of engine development seems to be taking its place. In some cases this has already occurred. In the aircraft industry, for example, the gas turbine engine has replaced almost all piston-type engines and, especially in the larger power ranges, is now beginning to replace the diesel or diesel electric locomotive engines. Tests are also being made with on- and off-highway trucks and tractors to replace their piston engines with gas turbines. The rotary engine is still seriously being considered as a replacement for the reciprocating piston-type engine.

It would be presumptuous to forecast at this time what types of engines will be used after the turn of the century, but it appears certain that the internal-combustion diesel engine will be the main source of power for on- and off-highway motor trucks, truck tractors, buses, farm and industrial tractors, and other equipment. In addition, there is an ever-increasing trend to dieselize cars, light trucks, and recreational motor vehicles. It is estimated that in North America there are presently 8.9 million diesel engines in operation, and this number increases by 900,000 (minimum) per year, so that, by the year 2000, there will be at least 15 million diesel engines in operation.

Today's diesel engine does not yet perform anywhere near its maximum efficiency potential; however, if diesel engine technology continues to advance as it has in the last few years, it may reach 50 percent of its maximum in the very near future, or perhaps even higher. In addition to its present and potential high efficiency, a diesel engine is reliable, dependable, and extremely durable. Furthermore, its relatively clean emission gives it a laudable status in today's pollution-conscious society. For these reasons the diesel engine will survive as the main power source for nearly all applications.

Credit is due to Dr. Rudolf Diesel, a German engineer, for crystallizing engineering thought in 1892 on the importance of using high-compression air to attain the self-ignition of fuel oil. He obtained the financial backing of Baron Friedrich Alfred von Krupp and the giant Maschine-Fabrick Augsburg Nurnberg. Strangely enough, the engine got off to a very shaky start. Experiments that began with coal dust as fuel were dropped. Modifications were made, and in 1897 a successful compression ignition engine was built by Dr. Lauster and the engineering staff of the M. A. N. Company in collaboration with Dr. Diesel. A number of manufacturers were licensed to build similar engines. Adolphus Bush was one of those who bought a license to manufacture and sell compression ignition engines in the United States and Canada. A diesel engine built for his brewery was the first to go into service anywhere in the world.

The original oil-burning engine injected fuel by a high-pressure air blast. This high-pressure air blast atomized the fuel, and the resulting turbulence facilitated the mixing of the air and fuel with the compressed air in the cylinder. Because of Dr. Diesel's insistence that this engine operate at an almost constant temperature cycle, the engines were cumbersome and rotated at a slow speed.

With the lifting of this restriction and with the greater advancements in metallurgical and manufacturing technologies, the diesel engine and its fuel-injection system have been developed to make it the versatile engine that it is today. The introduction of a more refined fuel oil has also contributed to its success. Further metallurgical research into lightweight/high-strength materials, combined with refined engineering design concepts, will enable the diesel engine to meet the challenges of the energy and pollution crises and place it in the forefront of the world's industrial power units for many years to come.

The prime purpose of this textbook is to assist in the training of mechanics so they can diagnose, repair, and service today's diesel engines. The *Workbook for Diesel Mechanics* is intended to further this training by providing hands-on experience in the shop. The *Instructor's Guide for Diesel Mechanics,* available to instructors, supplies answers to the workbook questions.

The textbook, workbook, and instructor's guide have been constructed so that the instructor can begin with any unit and then progress from one unit to another. With a fairly advanced class, the instructor may wish to use the preliminary units simply as review material.

Dual dimensioning has been used throughout this program. Metric measurements are given in brackets following the English measurements. Metric conversion tables and a glossary of diesel terms are included at the back of the textbook.

It is hoped that this program will ensure that the students achieve sufficient knowledge and practical experience to make them employable in today's growing diesel field.

Erich J. Schulz

SECTION 1
INTRODUCTION TO THE DIESEL ENGINE
UNIT 1 • BASIC COMPONENTS

Diesel Engine versus Gasoline Engine The simplest way to describe a diesel engine is to compare it with an ordinary gasoline engine such as the one you have in your car. Both engines are of the internal-combustion design since they burn the fuel within the cylinders. Although they operate with the same major components, those of the diesel engine (of equal horsepower) are heavier since they must withstand greater dynamic forces and more concentrated stress and load due to the greater combustion pressure (Fig. 1-1).

The greater combustion pressure is the result of the higher compression ratio. In a gasoline engine the compression ratio (which controls the compression temperature) is limited by the detonation and preignition quality of the air-fuel mixture. In the diesel engine the compression ratio can be as high as desirable, say, 24:1, or as low as 14:1 because diesel engines compress only air. This is one of the factors which contributes to the high efficiency of the diesel engine.

Gasoline engines are self-speed-limiting because of their air-intake limitations. Engine speed is controlled by the butterfly valve in the carburetor which controls the airflow into the intake manifold. The airflow meters the gasoline flow and therefore limits the engine speed.

Diesel engines are not self-speed-limiting. Engine air intake for combustion is not restricted, and therefore the cylinders always have more than enough air to support combustion. The engine speed (revolutions per minute—rpm) is controlled by the amount of fuel injected into the cylinders. A manual fuel control is not possible since these engines can accelerate at a rate of more than 2000 revolutions per second (rev/s); therefore they require a speed limiter (the governor). A diesel engine requires no ignition system because the fuel is injected (forced into the combustion area) as the piston comes to the top of its compression stroke. The fuel vaporizes and ignites as it comes in contact with the hot air which has been compressed by the piston. The injection pump or fuel pump and the governor control the quantity of fuel injected by the fuel nozzles into the combustion chambers.

Cylinder Block, Crankcase, and Oil Pan The cylinder block and crankcase comprise the framework of a liquid-cooled diesel engine. It is generally a single unit made from cast iron. The air-cooled diesel engine usually has a separate cast-iron crankcase and individual cylinder blocks. The cylinder block has openings for the cylinder sleeve (cylinder liner), oil and water passages, and bores for the crankshaft and camshaft bearings.

The upper half of the cylinder block contains the water jackets. The lower half of the cylinder block where the crankshaft, camshaft followers, and pushrods are located is called the *crankcase*. An oil pan, which is bolted to the crankcase, forms the oil reservoir for the lubrication system (Fig. 1-1).

Piston and Piston Rings The piston and its piston rings act as a piston pump while moving up and down in the cylinder sleeve. Pistons are made from aluminum or cast-iron alloy. Piston rings are made from cast-iron alloy, and compression rings are commonly chrome-plated.

The two main functions of the piston and piston rings are to seal the lower side of the combustion chamber, and to transmit the pressure of compression and combustion via the piston pin and connecting rod to the crankshaft.

Connecting Rod The connecting rod is made from drop-forged, heat-treated steel and is the link between the crankshaft and the piston. It is bored at each end, and in the upper bearing bore (*piston-pin bore*) a bushing is inserted in which the piston pin oscillates. The lower bearing bore (*crankpin bore*), is split in half by the connecting-rod cap. One-half of the connecting rod bearing fits tightly into the rod cap and the other half fits into the connecting rod. When the connecting rod is bolted to the crankshaft connecting-rod journal and the crankshaft rotates, this causes the connecting rod and piston to move up and down.

Cylinder Sleeve The cylinder sleeve (cylinder liner) forms the combustion chamber walls. When the cylinder sleeve is in direct contact with the coolant it is referred to as a *wet sleeve*. When the cylinder sleeve is indirectly in contact with the coolant (that is, the sleeve is enclosed in the cylinder), it is referred to as a *dry sleeve*. In either case, it is through the cylinder sleeve contact with the coolant or cylinder

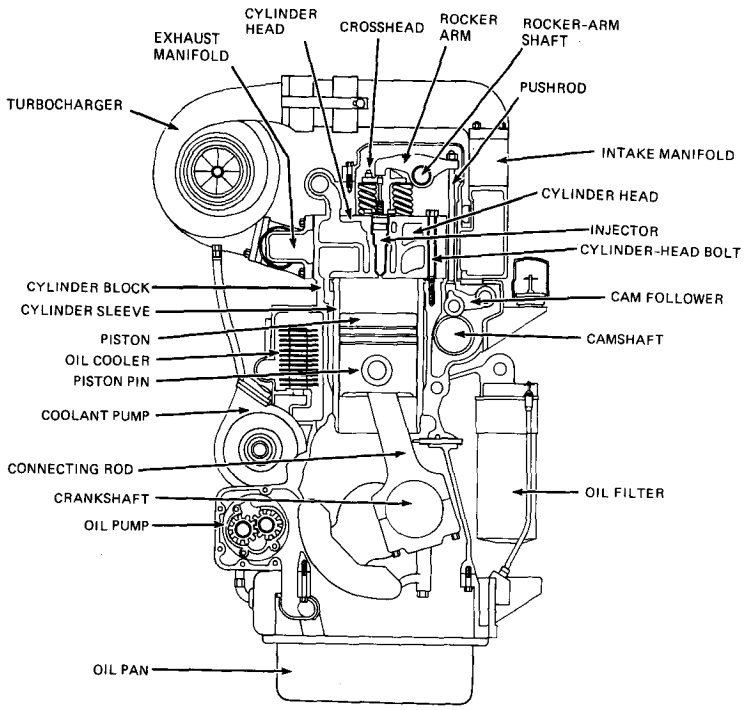


Fig. 1-1 Sectional view of a liquid-cooled engine. *(Cummins Engine Company, Inc.)*

block that efficient cooling is achieved. Wet sleeves have special sleeve seals which seal the coolant at the lower end of the cylinder sleeve and block. The accurately machined surfaces of the sleeve flange, cylinder block, and cylinder-head gaskets form the seal at the cylinder block surface (top deck).

Crankshaft The crankshaft, made of forged steel, has precision machined and hardened main bearings and connecting-rod journals (Fig. 1-2). The offset cranks of the crankshaft are balanced for proper weight distribution to ensure even force during rotation. Some crankshafts use counterbalance weights (or a gear train) to achieve balancing.

The shaft rotates in its main bearings and lubricating oil from the drilled passages within the crankcase feeds the main bearings. Drilled passages in the crankshaft pass lubricating oil to the connecting-rod journals. A thrust bearing is used to prevent excessive end movement.

Flywheel The flywheel serves three purposes. First, through its intertia, it reduces vibration by smoothing out the power stroke of the cylinders. Second, it is the mounting surface of the clutch pressure plate and the friction surface for the clutch. (When a fluid clutch is used, the impeller is splined or bolted to the flywheel.) Third, the "shrunk on" flywheel ring gear is used for transmitting cranking motor power to the crankshaft.

Vibration Damper (Balancer) A vibration damper is a unit which counteracts the twisting or torsional vibration caused by force variations (usually from about 3 to 10 tons [2724 to 9080 kg (kilograms)]) on the piston and subsequently the crank. Torsional vibration is an oscillation (rhythm) which occurs within every power stroke. The application of force, and its absence a split second later, cause the crank to be alternately twisted out of alignment and then snapped back into place. If a preventive measure were not taken against this, the engine would run rough and the crankshaft could crystallize and break.

Vibration dampers of the viscous or rubber-element design are fastened to the front of the crankshaft (Fig. 1-3). Since torsion vibration differs with engine design, vibration dampers are constructed to suit specific engines.

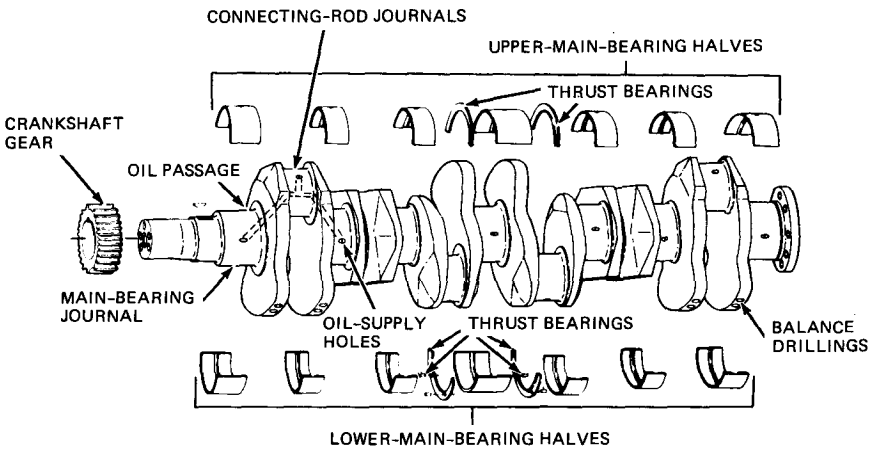


Fig. 1-2 Schematic view of a typical crankshaft and components.

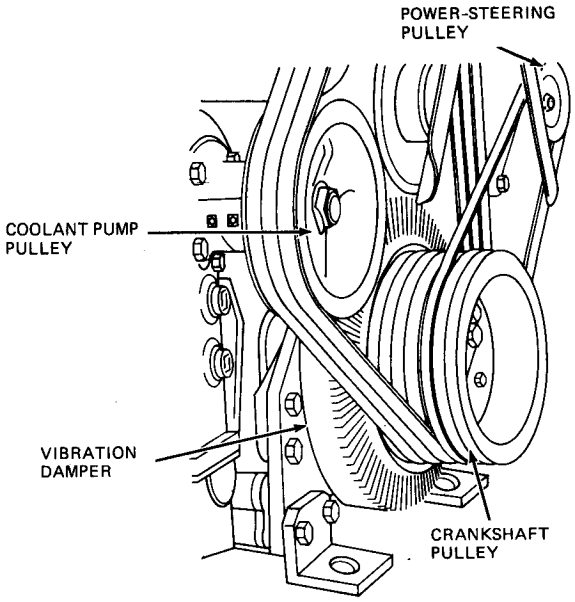


Fig. 1-3 Schematic view of pulleys and vibration damper mounting.

Cylinder Head and Valves The cylinder head is cast as a one-piece unit. It is the upper sealing surface of the combustion chamber. It may serve one, two, three, four, or six cylinders. The valve guides, which guide the valve stem during the opening and closing of the valve, are pressed into the cylinder head (see Fig. 1-4). The intake valve and seat, in conjunction with the valve mechanisms, control the entry of air into the combustion chamber via the intake manifold. The exhaust valve and seat, along with the valve mechanism, control and release the combustion pressure from the combustion chamber into the exhaust manifold(s).

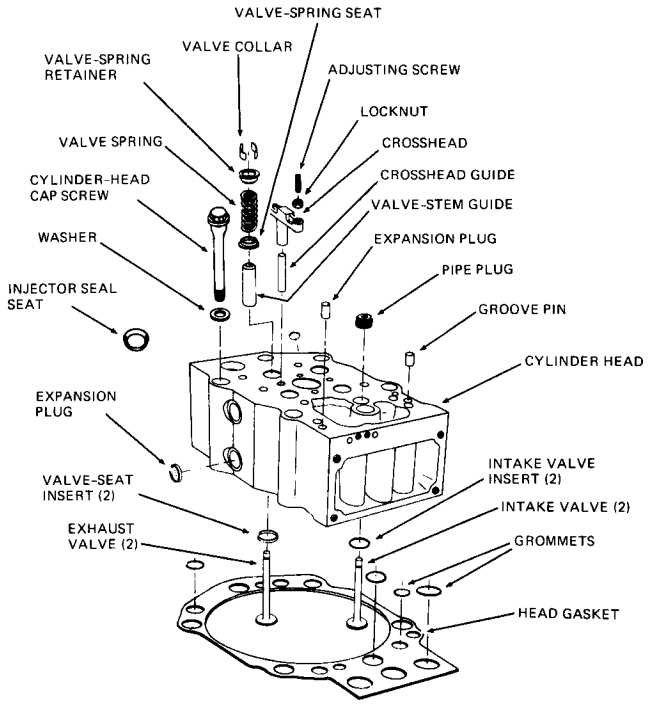


Fig. 1-4 Exploded view of K model cylinder head components. *(Cummins Engine Company, Inc.)*

Timing Gears, Camshaft, and Valve Mechanism The timing gears (see Fig. 1-5) transmit rotary motion to the camshaft and at the same time maintain a fixed relation between the crankshaft and camshaft. The camshaft rotates on friction bearings in the crankcase. The rotary motion of the camshaft is transmitted to the followers, thereby causing the followers and pushrods to reciprocate, the rocker arms to pivot, and the valves to move up and down within the valve guides. On engines where the camshaft is located above the valve stem (overhead), the cam lobes open and close the valves either directly or indirectly.

Timing-gear Cover and Valve Cover The timing-gear cover encloses the gear train, seals the crankshaft, and sometimes seals the external drive shafts. On some engines it has bearings or support shafts for the timing gear, idler gear, and fuel-injection-pump drive gear. The valve cover encloses the upper part of the cylinder head and the valve mechanism.

Gaskets and Seals Gaskets and seals are used to seal engine components which are bolted to the subframe, the cylinder block, and the crankcase.

Diesel Engine Support System A diesel engine requires five supporting systems in order to operate: cooling, lubrication, fuel injection, air intake, and exhaust. The function of each system is equally important to the engine as a whole.

Cooling-system Components The water (coolant) pump, in conjunction with the thermostat, internal cooling passages in the cylinder block and cylinder head, the radiator, and the fan, is responsible for maintaining an even cooling temperature during operation, of about 190°F (degrees Fahrenheit) [88°C (degrees Celsius)]. See Fig. 1-6.

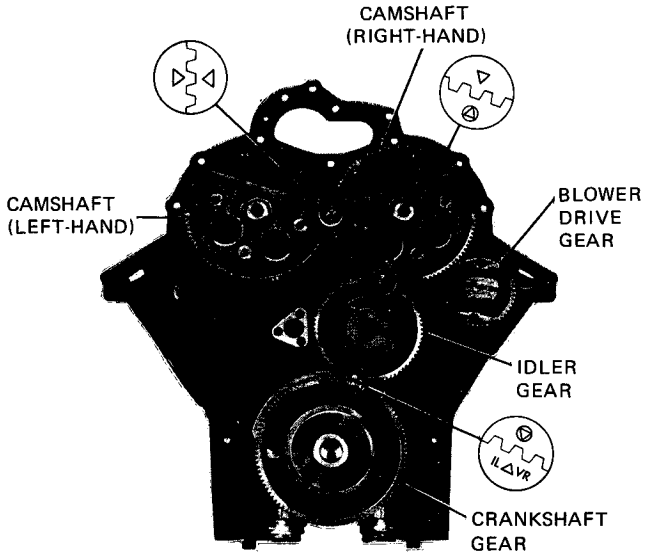


Fig. 1-5 View onto timing gears of a Detroit V engine. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

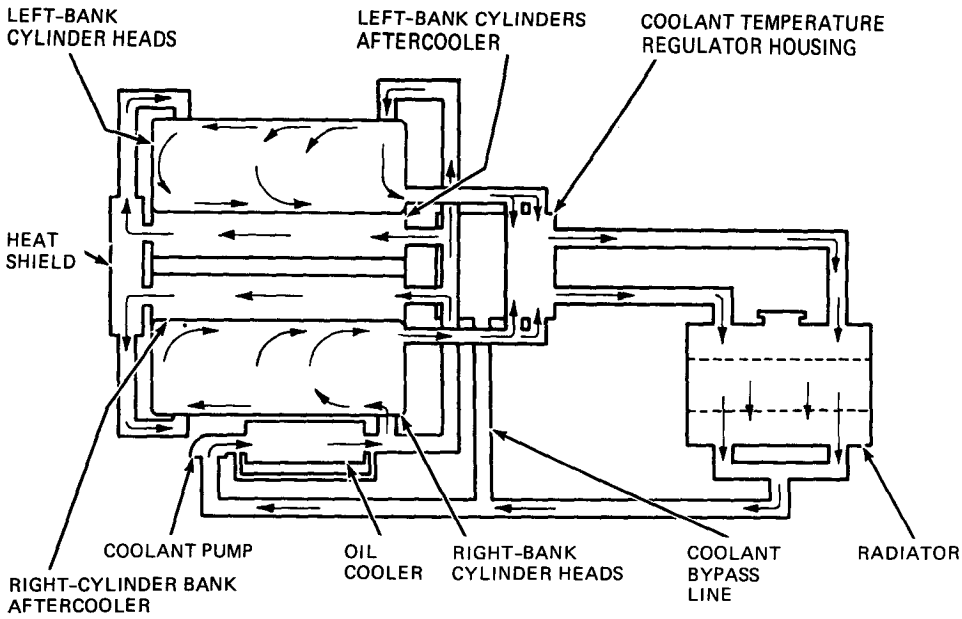


Fig. 1-6 Schematic view of cooling-system flow diagram. *(Caterpillar Tractor Co.)*

Lubrication System Components The oil pump, through the internal passages, is responsible to supply lubricating oil to the bearings, gears, and other components which need to be lubricated and cooled (see Fig. 1-7). (*NOTE: Most diesel engines also have an oil cooler to assist in cooling the oil.*)

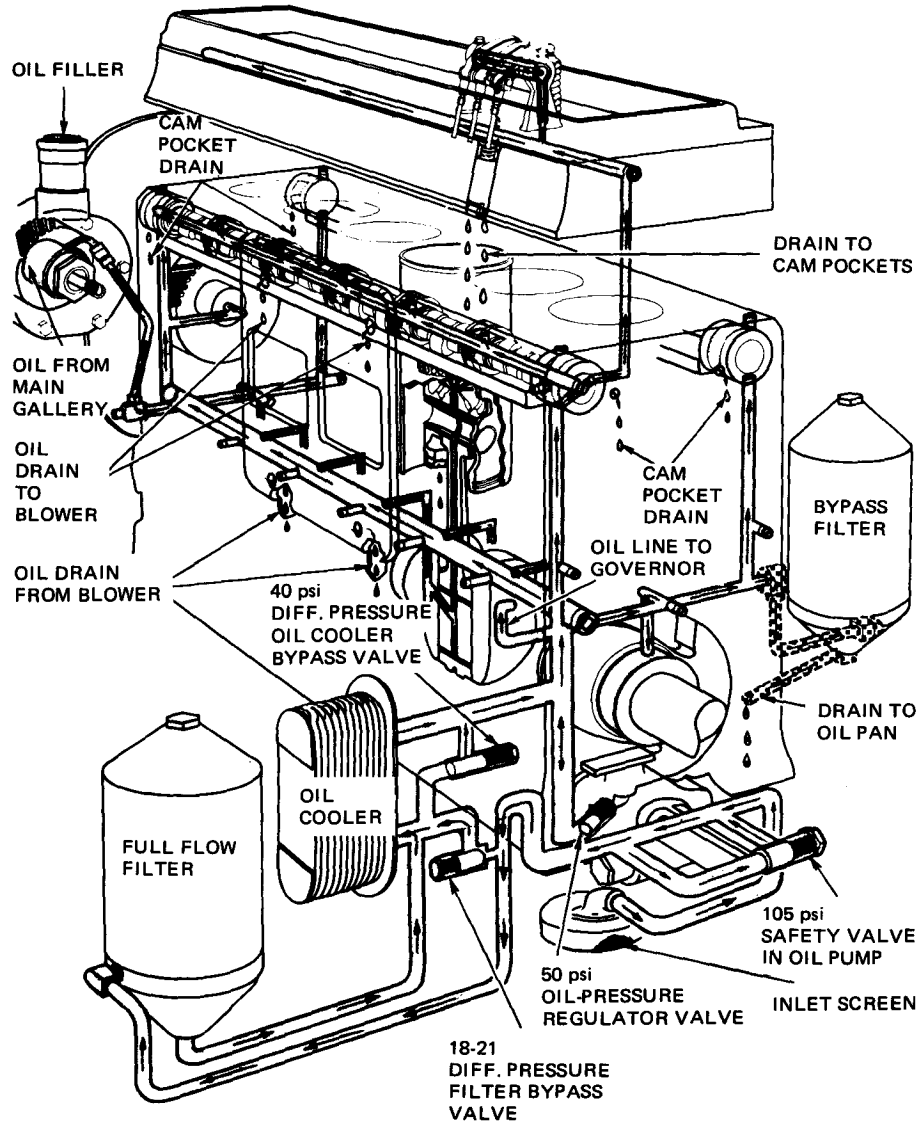


Fig. 1-7 View of a typical pressure lubrication system. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

Fuel-injection System Components The fuel tank is used not only to store the fuel but to clean it by permitting sediment to drop to the bottom. The fuel filters are required to remove contaminants and water from the fuel. The fuel-injection pump and the injectors are responsible for supplying and injecting (at the right time) the required amount of fuel into the cylinders.

Air-intake System Components The air cleaner, intake manifold, and on some engines also the turbocharger and aftercooler, are responsible for supplying clean cool air to the cylinders, for supplying air for scavenging, and for reducing the airflow noise. Two-cycle engines additionally require a blower for scavenging.

Exhaust System Components The exhaust manifold, pipes, and connections, as well as the muffler, are responsible for directing the exhaust gases into the atmosphere, to reduce the noise level and dampen the exhaust pressure waves. When a turbocharger is used, the turbine is connected, in series, into the system. Its function is to drive the compressor wheel.

Other Support Systems and Components A diesel engine has many additional components and two major support systems. All will be covered in later units. Before attempting to analyze individual components, however, you should first become acquainted with the mechanical terminology that relates to your job as a diesel mechanic.

UNIT 2 • ENGINE PERFORMANCE TERMINOLOGY

Bore and Stroke Bore and stroke refer to the cylinder size of an engine. The *bore* is the diameter of the cylinder. The *stroke* is the distance that the piston travels from bottom dead center (BDC) to top dead center (TDC).

Engine Displacement Engine displacement is the volume that is displaced by all the pistons during one upward stroke. Engine displacement is expressed in cubic inches (in^3) or liters (L). To find the engine displacement, multiply the volume of one cylinder by the total number of engine cylinders.

$$R^2 \times \pi \times \text{stroke} \times \text{no. of cylinders} = \text{engine displacement}$$

Suppose that the bore is 6.25 inches (in), the bore radius (R) is 3.125 in, the stroke is 6.25 in, and that there are six cylinders. The engine displacement is:

$$3.125^2 \times 3.14 \times 6.25 \times 6 = 1150\ in^3 \quad [\text{or } 18\ L^2]$$

Ratio Ratio is the relation between two numbers or two magnitudes of the same kind. For example, if the distance from the fulcrum to the lever on one side is three times greater than the distance from the fulcrum to the lever on the other side, then the ratio is 3:1. Likewise, when one gear has three times as many teeth as another, the ratio is 3:1.

Compression Ratio and Clearance Volume The amount of compression developed by a cylinder is expressed as the *compression ratio.* The value of this ratio is determined to a large extent by the efficiency with which the engine will convert the heat energy contained in the fuel to useful mechanical energy. The compression ratio compares the cylinder volume when the piston is at the bottom of its stroke (BDC) and the volume when the piston is at the top of its stroke (TDC) (Fig. 2-1).

The volume to which the air is compressed is the *clearance volume* (the space remaining in the combustion chamber). Combustion-chamber clearance volume can be extremely difficult to calculate because of the chamber's irregularity of shape. A common method, therefore, of measuring this clearance is to fill the chamber with oil, using a graduate [measuring glass graduated in cubic centimeters (cm^3)]. Fill the graduate with oil to the top centimeter (cm) level. Remove the injector from the cylinder head and bring the piston to TDC. Pour enough oil into the combustion chamber to fill it completely. Record the precise amount of oil remaining in the graduate.

Let us assume your graduate has a capacity of 100 cm^3 and after pouring the oil into the combustion chamber, 58.525 cm^3 still remains in the glass. It is evident that 41.475 cm^3 (100 − 58.525 cm^3) of oil is required to fill the combustion chamber. To convert

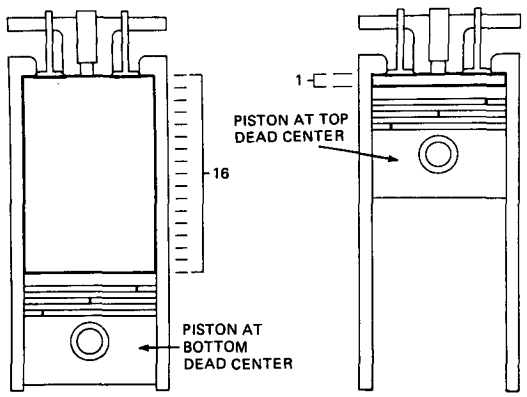


Fig. 2-1 Compression ratio. (Here it is 16:1.)

this volume (41.475 cm^3) to its equivalent expressed in cubic inches (in^3), multiply 41.475 by 0.061 (see Conversion Tables at end of text). This will equal 2.53 in^3.

To calculate compression ratio, you need to know the displacement volume, the clearance volume, and the following formula:

$$\text{Compression ratio} = \frac{\text{displacement volume + clearance volume}}{\text{clearance volume}}$$

Suppose that the engine displacement for a four-cylinder engine is 153.86 in^3. The displacement volume of one cylinder is then 153.86 divided by 4, or 38.465 in^3. If you use the clearance volume as calculated above (2.53 in^3), the compression ratio is (38.465 + 2.53)/2.53 = 16.2:1.

Hydraulics The word *hydraulic* comes from the Greek words *hydros,* meaning water, and *aulis,* meaning tube or pipe. Originally the study of hydraulics included the behavior of only water at rest and in motion but now covers the behavior of all liquids.

All liquids, such as fuel, oil, and water, possess characteristics of both solids and gases. The molecules of liquids are flexible yet firm enough to maintain a fluid distance between each other; they can change shape, divide into parts, and reunite.

How the foregoing relates to diesel engines becomes apparent to the mechanic who must understand fluids and fluid flow in order to service the various hydraulic systems (fuel, lubrication, and cooling). Since many other factors affect hydraulic action, the mechanic must also understand the concepts of force, pressure, specific gravity, atmospheric pressure, work, and power (hp) as they apply to the behavior of fluids.

Force When you use muscles to push or pull objects you are using *force*. Force, however, is not always correlated with motion. For instance, if two equal and opposite forces act on a body, there is no movement. On the other hand, if there is no resistance, there is no force.

Mass is a force caused by gravity acting on an object. For example, if an object is weighed on a scale at sea level, the scale will register more than it would if the same object were weighed on the same scale at the top of a mountain. This difference occurs from the gravitational force, that is, the different distances of the weigh-in areas from the center of the earth. The standard unit of measurement of force is pounds or ounces (lb or oz). In metric units, force is measured in newtons (N). A newton is that force which will give a mass of 1 kg an acceleration of 1 meter per second per second: (m/s^2) (1 kg) (9.8 m/s^2) = 9.8 kg × m/s^2 = 9.8 N or 4.448 lb.

Weight (Mass) In commercial and everyday use, the term *weight* is nearly always synonymous with mass. Thus, in speaking of a person's weight, the quantity referred to is mass. The newton is the unit of force and should be used in place of the kilogram-force. The kilogram (kg) is restricted to the unit of mass.

Pressure Pressure *P* is defined as force per unit area. For example, you can easily balance a crowbar across your hand, but if you try to balance it with the point on your hand you will find the experience a painful one. In either case the force on your hand is the same because the crowbar's weight does not change. The discomfort of the crowbar point is caused by the *pressure.* When calculating the force on a unit area of 1 square inch (in^2) you are calculating the pressure, that is, the pounds per square inch (psi). The formula to calculate pressure is: area divided into force equals pressure, or $F/A = P$. The metric unit for pressure is the pascal (Pa). 1 Pa = newton per square meter (N/m^2); 1 psi = 6.894 kilopascals (kPa).

Specific Gravity If a stone is thrown into water it will sink. It sinks because it is heavier than the water it replaces. *Specific gravity* is a comparison of the weight of an object with the weight of an equal volume of water. To compute specific gravity, divide the weight of an object by the weight of an equal volume of water. Because it is a ratio, specific gravity has no units.

Atmospheric Pressure The weight of the atmosphere also plays an important role in hydraulic systems. Its applied force acting over unit area introduces pressure. A column of air 1 in^2 extending upward to the atmospheric limit weighs, on the average, about 14.7 lb at sea level, or 101.35 kPa. This means at sea level the force of atmospheric presssure on 1 square foot (ft^2) would be well over a ton. At a higher elevation, the pressure is, of course, less.

When listening to a weather report you may hear, "barometric reading is 29.9 inches." When the barometer reads 29.9 in [75.9 cm], the air is exerting a pressure of 14.7 psi [101.35 kPa] on the earth's surface. In other words, 14.7 psi of atmospheric pressure forces the mercury 29.9 in up a tube. Changes in the weight of the surrounding air (air pressure) will change the barometric reading.

Work *Work* has a technical meaning as well as its common meaning of manual labor. In each case, however, a force is exerted which produces motion. Physicists interpret work as force acting through distance. The work done is expressed in foot-pounds (ft·lb) [newton·meter (N·m)]. The formula is force times distance equals work, or $F \times D = W$.

Torque *Torque* is the twisting effort applied to a crank at a 90° angle. The twisting effort on the shaft is equal to the distance from the center of the shaft to the point at which the force is applied. The standard unit of measurement for torque is the pound-foot (lb·ft) or pound-inch (lb·in) [newton·meter (N·m)].

Torque can only produce work when the applied torque is greater than the resistance. Torque can be increased by increasing the distance, the weight, or both.

Power (Horsepower) *Power* is the work done in a given time, or the rate of doing work. Power may be expressed in terms of work per minute or work per

second. However, in the English system of measurement it is expressed in horsepower (hp). This term was first used by James Watt as he tried to compare the power of a steam engine with the power of a horse. He found that a horse could lift a 150-lb load ⅔ feet per second (ft/s) doing 550 ft·lb of work every second, or 33,000 ft·lb of work every minute. From these observations came the horsepower (hp) unit, the unit of power in the English system of measurement.

In the metric system horsepower is measured in watts (W) or in kilogram-meters per second (kg·m/s). (1 hp = 745.7 W = 76.04 kg·m/s.)

Engines are rated according to their power output and torque. *Indicated horsepower* (ihp) is the power transmitted to the pistons by the gas in the cylinders. When designing an engine, engineers mathematically calculate the indicated horsepower. This calculation is about 15 percent more than the actual horsepower at the flywheel. Some latitude is allowed when calculating the length, height, and width of an engine in order to determine the dimension and mean effective pressure (mep). Designers, nevertheless, must consider: the length of the stroke, the rotation speed and the cross-sectional area of the cylinder, the number of cylinders, the compression ratio, and the volumetric efficiency. The formula used to calculate ihp for a four-cycle engine is:

$$\text{ihp} = \frac{R^2 \times \pi \times L/12 \times N \times P \times n}{33{,}000}$$

where $R^2 \times \pi$ = area of a cylinder, in^2
$L/12$ = length of stroke, in
N = engine speed, rpm
P = mean effective pressure, psi
n = number of cylinders

For a two-cycle engine the formula is

$$\text{ihp} = \frac{\left(\frac{R^2 \times \pi}{4}\right) \times L/12 \times N \times P \times n}{33{,}000} \times 2$$

Brake horsepower (bhp) is the rated horsepower, not the indicated horsepower, and it refers to the mechanical efficiency of the engine. Brake horsepower is the usable power of the engine.

Mechanical Efficiency *Mechanical efficiency* is the difference between indicated horsepower and brake horsepower. This difference arises from the friction within the engine and its associated components. The mechanical efficiency of a four-cycle engine is about 82 to 90 percent. This is slightly lower than the efficiency of the two-cycle engine. The piston and its rings, the pumping of air in and out of the cylinders, the friction of the bearing surfaces, and the weight of the moving components are the major contributors to the four-cycle engine's decreased mechanical efficiency. The water pump, oil pump, and fuel-injection pump can also add measurably to mechanical efficiency or inefficiency.

Dynamometer A *dynamometer* is an instrument which measures engine power or torque by means of a mechanical, hydraulic, or electrical device. When the dynamometer is scaled in pound-feet (lb·ft), the following formula is used to arrive at brake horsepower:

$$\text{bhp} = \frac{2\pi \times F \times R \times N}{33{,}000} = \frac{F \times R \times N}{5252}$$

where F = force, lb
R = brake arm radius, ft
N = engine speed, rpm

When a generator is used as a dynamometer, the scale is in watts (W) or in kilowatts (kW). Since 1 hp = 746 W, the following formula is used to arrive at horsepower.

$$\text{hp} = \frac{\text{total electrical watt power}}{746}$$

Volumetric Efficiency *Volumetric efficiency* is the ratio between the amount of air which *can* enter into a cylinder and the actual amount that *has* entered. *(NOTE: An increased volumetric efficiency means more complete combustion and, therefore, better fuel economy.)*

Mean Effective Pressure The *mean effective pressure* (mep) is the difference between compression pressure and expansion pressure. On a naturally aspirated engine the pressure difference is between 95 and 140 psi [666.9 and 965.3 kPa]. On a turbocharged engine it is between 150 and 300 psi [1034.25 and 2068.5. kPa].

Heat Heat is a form of energy which can raise the temperature of a body, substance, or material. It may be generated by combustion, friction, chemical action, radiation, conduction, or convection, and it can be converted into other forms of energy. The total absence of heat is known as *absolute zero* and corresponds to −459.6°F [−273°C or −546 Kelvin (K)].

EFFECT OF HEAT As the temperature changes, a substance will expand or contract. Some substances will expand to their limit, vaporize and then burn, while others will just vaporize. When heated or cooled beyond the point where their molecular structure is stable, some substances will destroy themselves; others actually change their state.

Temperature *Temperature* refers to the degree of heat in a substance as measured by a thermometer. Temperature is measured in degrees Fahrenheit (°F) or, in the metric system, degrees Celsius (°C). *[NOTE: For thermodynamics the Society of Automotive Engineers (SAE) recommends the Kelvin scale.]*

Both Fahrenheit and Celsius thermometers record the freezing and boiling points of water at a pressure of 14.7 psi [101.35 kPa] but use a different number of graduations between these points. The formula for converting degrees Fahrenheit to degrees Celsius is °C = ⅝ (°F − 32). Numerous temperature readings must be taken when servicing diesel equipment, such as oil, coolant, exhaust, and ambient temperatures. (Ambient temperature is the temperature of the air surrounding you.) Exhaust, oil, and coolant temperatures are the temperatures at any measurable point of the exhaust, lubrication, and coolant systems.

Thermometers are made of materials having different properties which change as temperature changes. The most commonly used are thermocouples and liquid tube thermometers.

Thermocouple A *thermocouple* consists of two dissimilar metals joined so as to produce a thermoelectric effect when the junction ends reach different temperatures. The thermocouple illustrated in Fig. 2-2 shows two twisted wires made from dissimilar materials connected to a galvanometer. A *galvanometer* is an instrument which detects and measures a small electric current. As the heat of one junction exceeds that of the other, a small current will flow. The voltage of this current will be indicated by the galvanometer. The scale used, however, can be calibrated in degrees thus permitting the needle to directly show the degree of temperature.

The amount of voltage produced depends on the difference in temperature between the opposite ends of the junction. The greater the difference in temperature, the higher the voltage.

Liquid Tube Thermometer The common liquid thermometer consists of a graduated glass capillary tube or stem with a bulb containing mercury or another type of liquid which will expand or contract as temperature rises or falls.

Expansion Ratio *Expansion ratio* is the ratio of the total combustion gas volume at the end of the power stroke to the total volume at the beginning of the power stroke. An increase is influenced by the following factors: a greater volumetric efficiency, a higher compression ratio, a higher air swirl, a uniform size and distribution of fuel droplets, a higher fuel volatility, and the bore and stroke ratio.

British Thermal Unit The British thermal unit (Btu) is used to measure the heat value of a fuel, or the amount of heat transferred from one object to another. It is derived from the amount of energy required to heat 1 lb of water 1°F at a barometric pressure of 14.7 psi. In metric units the heat value is measured in kilojoules (kJ). *(NOTE: 1 J = N·m; 1 Btu = 1.055 kJ.)*

Suppose that an engine on an engine dynamometer uses 4 gallons (gal) of fuel in 1 hour. [During this hour the continuous engine output (brake horsepower) is 100 hp, or 100 hp·h (horsepower-hours).]

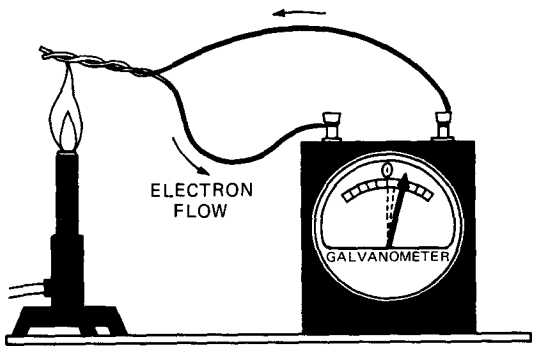


Fig. 2-2 Thermocouple principle. *(Ford Motor Company of Canada, Ltd.)*

Also, let us assume that the heat value of 1 gal (U.S.) of fuel is 135,000 Btu. We can say, therefore, that the engine uses 4 × 135,000, or 540,000 Btu in 1 hour.

Thermal efficiency is the total efficiency of an engine compared with the heat value of the fuel and the brake horsepower in British thermal units. If we continue with the example cited above, since 1 hp equals 2547 Btu, then 100 hp equal 254,700 Btu. Thermal efficiency may then be calculated as 254,700/540,000 = 47.16 percent.

Service manuals show fuel consumption in pounds per brake horsepower (lb/bhp) or miles per gallon (mi/gal), or horsepower-hours per gallon (hp·h/gal) and in metric units as kilometers per liter (km/L) or kilowatthours per liter (kWh/L). In the case illustrated above this would be the weight of fuel per gallon multiplied by the number of gallons used, divided by the brake horsepower or, since 1 gal (U.S.) of fuel weighs 6.8 lb, from the example above, (6.8 × 4/100) = 0.272 lb/bhp.

Boyle's Law and Charles' Law *Boyle's law* is a law in physics to the effect that the pressure exerted by a body of gas is inversely proportional to its volume if the temperature is held constant. For example, a given volume of gas under a pressure of 100 psi will occupy twice the space it will under a pressure of 200 psi.

Charles' law relates to volume and temperature in that the volume of gas is directly proportional to its absolute temperature if the pressure remains constant. The compression of a gas causes it to become heated, thereby causing an increase in pressure. Conversely, expansion causes cooling and a reduction in pressure.

The relevance of these laws to you as a diesel mechanic is that they help you understand what takes place inside a cylinder when the air is being compressed and what forces operate against the diesel engine components.

Questions

1. What is the engine displacement of a six-cylinder engine when the bore is 4 in and the stroke is 5 in?
2. What is the compression ratio of the engine in Question 1 when the clearance volume is 5.5 in^3?
3. Define *brake horsepower.*
4. Define *thermal efficiency.*
5. Convert the exhaust temperature of 1100°F to Celsius.
6. Convert the coolant temperature of 112°C to Fahrenheit.
7. What is the brake horsepower of an engine when it develops 650 lb·ft at 1825 rpm? What is the bhp reading in watts?
8. What is the indicated horsepower of a six-cylinder four-cycle engine that has a bore of 5 in, a stroke of 5.6 in, an engine speed of 2300 rpm, and an mep of 140 psi?
9. What is the thermal efficiency of an engine being tested on a dynamometer which has a fuel consumption of 97.6 lb/h, an engine output of 225 bhp during the hour tested, and a fuel heat value of 19,800 Btu/lb?

UNIT 3 • CYCLE OPERATION

Cycle The word *cycle* refers to a series of events that repeat themselves. Cycle, in relation to a four-stroke cycle engine indicates that it requires four strokes (intake, compression, power, and exhaust) and therfore 720° of crankshaft rotation (two full crankshaft rotations) to accomplish one working cycle (Fig. 3-1). With a two-cycle engine the entire event (that is, power, exhaust, intake, and compression) requires only two strokes and it is accomplished with one crankshaft rotation (360°) (Fig. 3-2).

HOW A FOUR-CYCLE DIESEL ENGINE OPERATES

To produce usable energy through combustion three elements, air, heat, and fuel (at a given ratio), are required. The air that is forced into the cylinder at the intake stroke is a mixture of 20 percent oxygen, 79 percent inactive gases, and 1 percent of other gases and minute particles; however, its density changes with ambient temperature and humidity. Heat is produced by compression on the compression stroke. Fuel is injected into the cylinder just before TDC. Assume you have a four-cycle, four-cylinder naturally aspirated diesel engine with a bore of 3.5 in [88.9 millimeters (mm)], a stroke of 4 in [101.6 mm], and a compression ratio of 16:1. Assume also that the firing order is 1-4-3-2, and the valve timing is as shown in Fig. 3-3. Therefore the crankpin of the No. 1 and No. 3 pistons would be in the same plane as would the No. 2 and No. 4 pistons. However, the No. 1 and No. 3 pistons would be 180° from the plane of the crankpin for the No. 2 and No. 4 pistons.

Intake Stroke As you (1) press the starter button or turn the key switch to start rotation of the electric

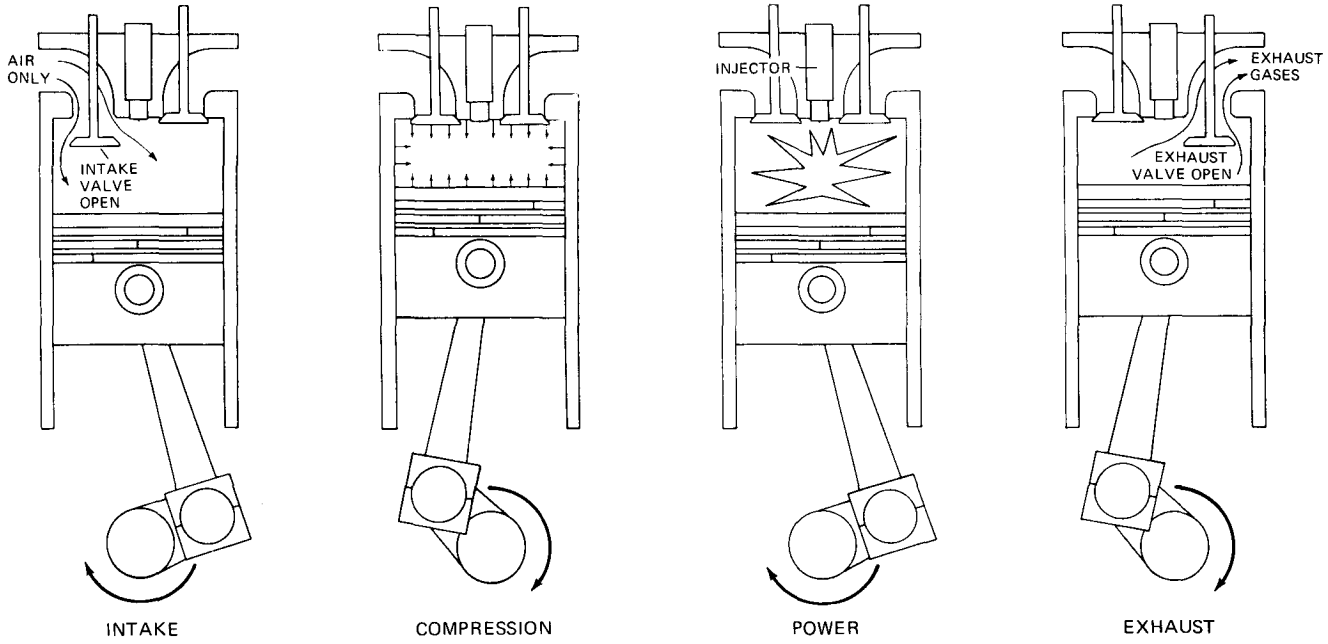


Fig. 3-1 One working cycle of a four-cycle engine.

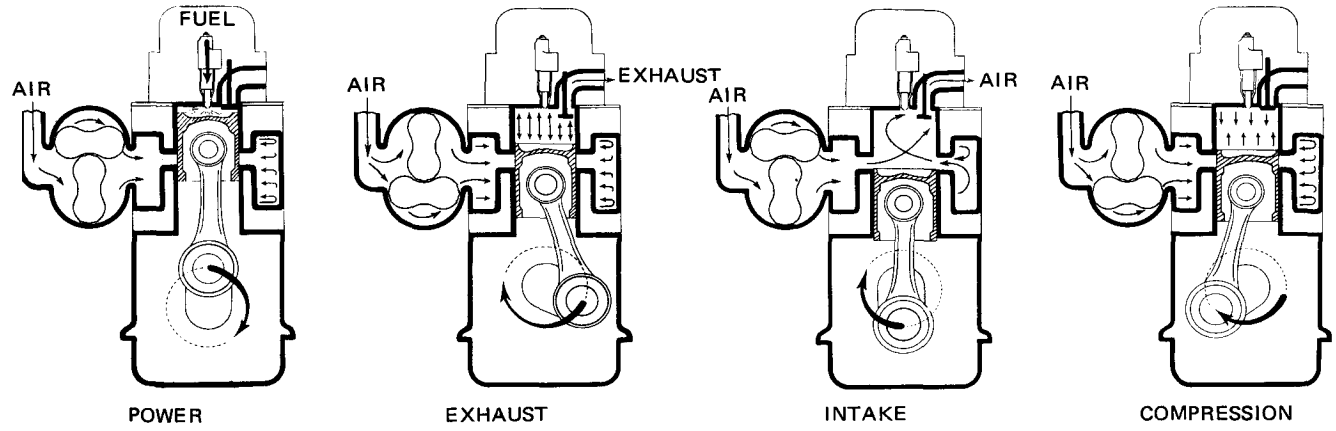


Fig. 3-2 One working cycle of a two-cycle engine.

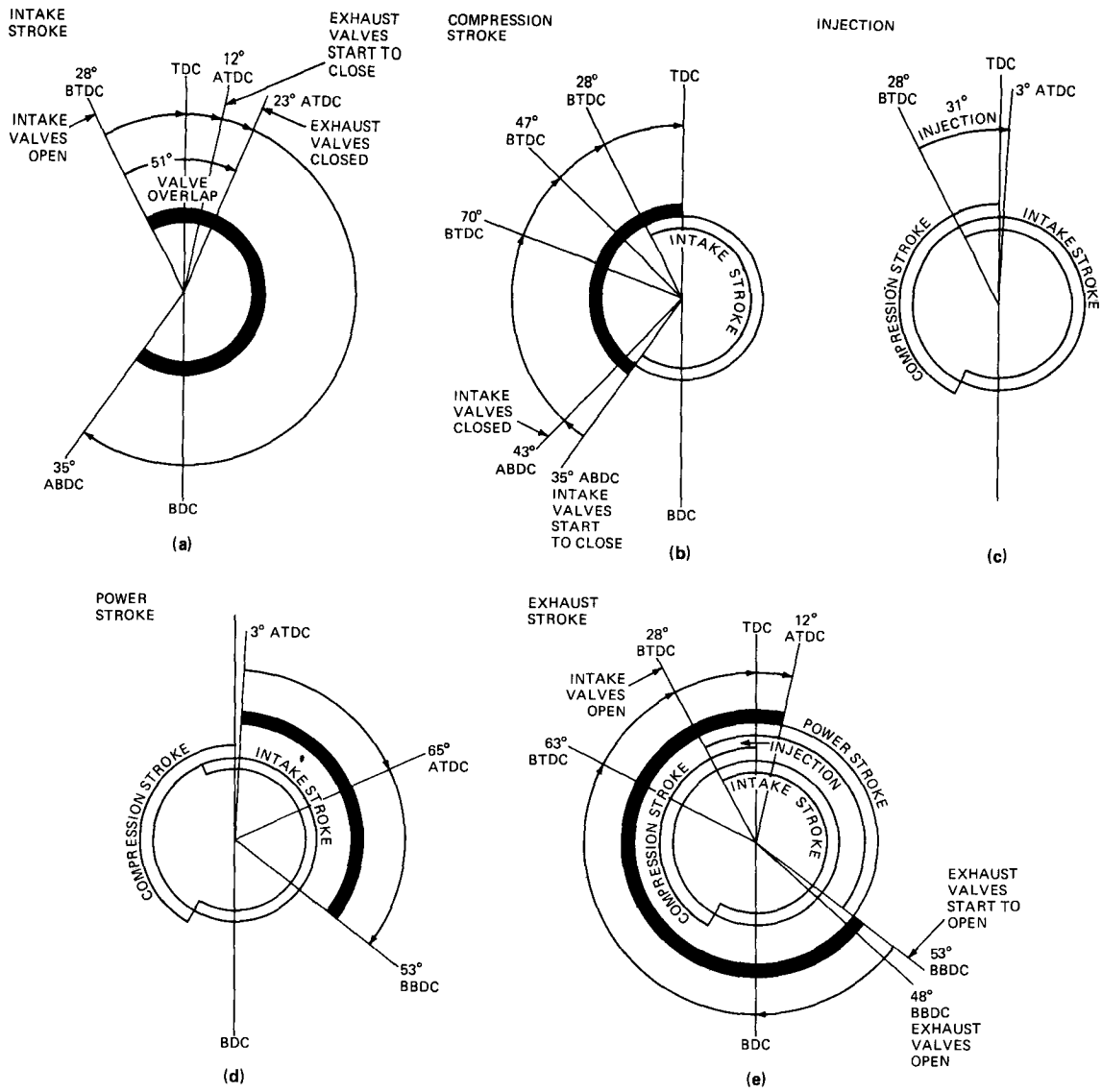


Fig. 3-3 Valve timing diagram of a four-cycle engine, showing the progressive steps in one working cycle: (*a*) intake stroke, (*b*) compression stroke, (*c*) injection, (*d*) power stroke, (*e*) exhaust stroke.

cranking motor, or (2) pull the control valve of a hydro starter, or (3) activate the air valve of an air starter, the cranking-motor pinion engages the ring gear and turns the crankshaft. The crankshaft, through the connecting rods, moves the No. 1 and No. 3 pistons upward, and the No. 2 and No. 4 pistons downward. The timing gear on the crankshaft turns the timing gear on the camshaft at a ratio of 2:1; that is, the crankshaft turns twice for every single revolution of the camshaft.

Using only the No. 1 cylinder, let us follow the cycles from beginning to end. As piston No. 1 nears TDC, precisely 28° before top dead center (BTDC) (Fig. 3-3*a*), the camshaft lobe starts to lift the intake-valve follower. The pushrod moves upward and pivots the rocker arm on the rocker-arm shaft. As the valve lash is taken up, the rocker arm pushes the valve inward, opening the combustion chamber to atmospheric pressure. The intake stroke now starts while the exhaust valve is still open. Exhaust gas flow has created a low pressure within the combustion chamber and the intake manifold; therefore atmospheric air enters the cylinder.

At about 12° after top dead center (ATDC), the exhaust valve follower moves from the cam nose to the closing flank and then to the base circle which is 23° ATDC. (See Fig. 7-2.) At the same time the valve spring closes the valve and transmits its force to the rocker arm, pushrod, and cam follower to maintain the follower on the camshaft cam.

A 51° duration (valve overlap) has been designed into the engine to force out the exhaust gases (scavenging) and draw in the oxygen-rich atmosphere.

The efficiency of an engine relies on the effectiveness of the scavenging and air intake. During the 51° duration, the piston has traveled about 0.310 in [7.874 mm] upward and 0.250 in [6.350 mm] downward, which is a very small distance in relation to crankshaft rotation.

As the piston reaches BDC it no longer creates low pressure. Nevertheless air still enters the cylinder since the air flow into the cylinder is restricted because of the air cleaner, intake manifold, and intake valve. Consequently, the intake valve remains open, thus maximizing the time for air to enter the cylinder. Once again the piston travel in relation to crankshaft

rotation is very small. The intake manifold, the cylinder head, and engine speed (engine design) govern the volumetric efficiency.

Volumetric Efficiency This is the ratio of the volume of atmospheric air at standard temperature 60°F [15.5°C] and pressure 14.7 psi [101.35 kPa] that actually enters the cylinder compared with the volume that could theoretically enter the cylinder.

$$\text{Volumetric efficiency} = \frac{\text{volume entering (60°F 14.7 psi)}}{\text{piston displacement}} \times 100 = \%$$

Compression Stroke At 35° after bottom dead center (ABDC) (Fig. 3-3*b*), the intake valve starts to close in a manner similar to that of the exhaust valve. At 43° ABDC (or 137° BTDC) the intake valve is on its seat and the piston at this point has traveled upward about 0.250 in [6.350 mm]. Given these circumstances, under normal atmospheric pressure (that is, at 14.7 psi [101.35 kPa]) and a temperature of 80°F [26.7°C] air would be trapped in the cylinder; see Table 3-1.

At about 70° BTDC the piston would have traveled 2.125 in [53.975 mm], or about half of its stroke, thus reducing the volume in the cylinder by half. The temperature would now double to 160°F [71°C] and the pressure would reach 34.2 psi [235.8 kPa].

At about 43° BTDC the piston would have traveled upward 3.062 in [77.775 mm] of its stroke and the volume would halve once again. Consequently, the temperature would again double to 320°F [160°C] and the pressure would rise to 85.2 psi [587.45 kPa]. When the piston has traveled upward to 3.530 in [89.662 mm] of its stroke, the volume would again halve, the temperature again double to 640°F [338°C], and the pressure reach 277.1 psi [1910.6 kPa]. When the piston has traveled to 3.757 in [94.428 mm] of its stroke, or the volume again halved, the temperature at this point would climb to 1280°F [695°C] and the pressure would reach 742.0 psi [5116.09 kPa]. This calculates to approximately 7135 lb [3236.46 kg] of force on the piston because the piston area is 9.616 in^2 [620.4 m^2]. The formula to calculate pounds of force on the piston is

$$R^2 \times \pi \times \text{psi} = 1.750 \times 1.750 \times 3.14 \times 742 = 7135.07 \text{ lb}$$

where R = radius of bore, in^2

These calculations would be applicable during the compression stroke, if heat were not lost to the pistons, cylinder sleeves, and the cylinder head. Heat is also reduced due to lower compression. The compression pressure is, in fact, lower than the calculation above because of engine breathing inefficiency and inefficient piston sealing, as well as the lower temperature caused by the heat losses.

In reality, the engine, when operating, reaches a compression pressure of 690 psi [4757.5 kPa], a combustion pressure of 780 psi [5378.1 kPa], and a combustion temperature of 2336°F [1280°C]. From these calculations you can see the enormous force acting on the pistons, wrist pin, connecting rod, bearings, crankshaft, crankcase, and the cylinder head. At this point you should also be reminded that any increase in temperature and pressure will destroy the molecular structure of the piston rings, pistons, and piston sleeves. Some of the main reasons for pressure and temperature increases are: loss of coolant, insufficient coolant, worn water pump, loose drive belts, restricted radiator, and coolant pressure loss. It is essential, therefore, to maintain and service cooling-system components as regularly and thoroughly as engine components.

Combustion Fuel in a liquid state is injected into the cylinder at a precise time and rate to ensure that the combustion pressure is forced on the piston neither too early nor too late. The fuel enters the cylinder where the heated compressed air is present; however, it will burn only when it is in a vaporized state (attained through addition of heat) and intimately mixed with a supply of oxygen. All these conditions are present in the cylinder. When the first minute droplet of fuel enters the combustion chamber, it is quickly surrounded by its own vapor because the compression temperature at this point is about 650°F [343°C]. Heat is withdrawn from the air surrounding the droplets causing them to vaporize. It takes time for the heat to build up again and cause the vapor to ignite since the core of the droplets are still liquid and relatively cold. Once ignition has started and a flame is present, the heat required for continuous vaporization is supplied from the heat released by combustion and the higher compression temperature. The liquid droplets, surrounded by their own vapor, burn as long as fresh oxygen is supplied and until all the fuel is burned.

TABLE 3-1

IDEAL TEMPERATURE AND PRESSURE IN RELATION TO PISTON TRAVEL

Piston position, °BTDC	Distance piston travels, in [mm]	Temperature, °F [°C]	Pressure, psi [kPa]
180	BDC	80 [26.7]	14.7 [101.35]
137	0.250 [6.350]	80 [26.7]	14.7 [101.35]
70	2.125 [53.975]*	160 [71]	34.2 [235.8]
43	3.062 [77.775]*	320 [160]	85.2 [587.44]
28	3.530 [89.662]*	640 [338]	277.1 [1910.55]
20	3.757 [95.428]*	1280 [693]	742.0 [5115.94]
0	TDC		

* Volume in the cylinder is halved.

Injection starts at 28° BTDC and ends at 3° ATDC (injection duration); see Fig. 3-3c. The fuel therefore is injected over a period of 31°. The piston, however, progresses upward, thereby raising the temperature and pressure. This creates quicker ignition (almost as the droplets leave the fuel nozzle) and instantly increases combustion pressure and temperature. At the end of injection, the oxygen is reduced and the process slows down.

Combustion as outlined above is called *thermodynamic*. "Thermo" refers to heat released during combustion and "dynamic" refers to mechanical action of doing work. During the combustion process a chemical reaction between the oxygen, hydrogen, and carbon takes place which combines the hydrogen and carbon into hydrocarbon to produce heat. The hydrocarbon compound and oxygen forms into a carbon dioxide gas.

The first phase of combustion (1 in Fig. 3-4) is the delay period in which some fuel has been injected but not yet ignited. However, the droplets have started to vaporize.

The second phase (2 in Fig. 3-4) shows the period where ignition starts, causing a rapid rise in temperature and pressure.

The third phase (3 in Fig. 3-4) is the period where the last fuel enters the combustion chamber. The fuel burns almost instantly and consequently maintains the combustion pressure and temperature.

Some engines may have only two phases and others have an undersirable fourth phase in which the unburned fuel mixes with the unused oxygen and burns.

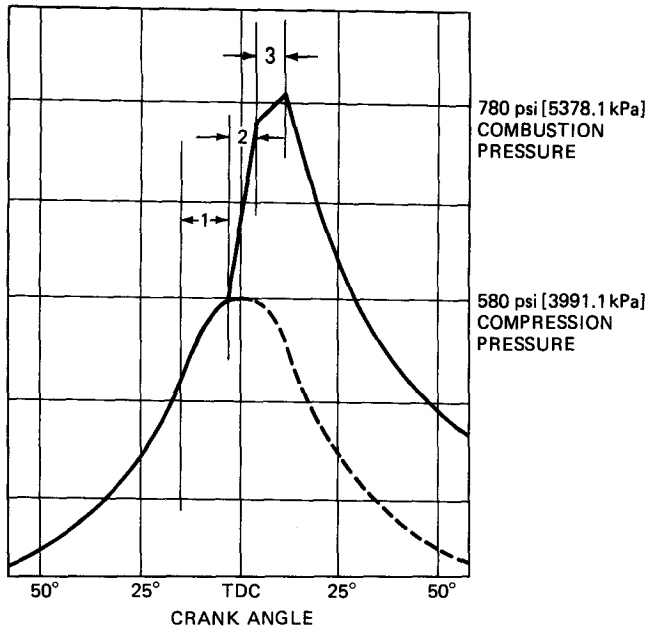


Fig. 3-4 The three phases in the combustion process.

FACTORS AFFECTING DELAY PERIODS Phase 1, the delay period, is needed to achieve complete combustion; however, it must be as short as possible to control the burning at the second phase. A short delay period results in a controlled pressure and temperature change and ultimately a smooth, efficiently running engine.

Because of many variable factors it is not easy for an engine designer to reduce the delay period and at the same time maintain constant speed and power and yet meet emission control standards. The ignition delay period depends, among other things, on engine timing (beginning of injection). When the timing is retarded, the delay period is shorter, fuel does not thoroughly mix with air, the combustion temperature is lower, hydrocarbon (HC) emissions are high, and the nitrogen oxide (NO_x) emissions are low. When the timing is advanced, the delay period is lengthened because of the lower compression temperature. Under this circumstance the combustion temperature is higher, and the NO_x emissions are high, but the HC emissions are low.

Ignition delay periods depend also on the air motion within the combustion chamber at the time of injection. If the air were motionless, only a certain number of fuel droplets would find the oxygen they need for combustion. On the other hand, if the droplets and air travel at the same velocity, the droplets would also lack oxygen and be smothered. A controlled airflow (air swirl) is needed to bring a steady supply of fresh air to each vaporizing or burning droplet. The means by which engine manufacturers have achieved a controlled air swirl is outlined in Combustion Chamber Design (Unit 4).

Other factors which affect the delay periods are: the droplet size, velocity, injection pressure, and spray pattern. To date, an ideal condition has not been completely realized. The droplets are not uniform and are smaller on the outside of the spray cone than on the inside. Since the smaller droplets have less velocity, they soon travel at the same speed as the air and consequently are suffocated by their own combustion. Furthermore, injection pressure is not constant during injection; therefore, the droplet size varies as does the spray area. So far, fuel-injection manufacturers have achieved droplets sufficiently large, uniform, and evenly distributed to give a fairly low-pressure rise in the second phase of combustion. *(NOTE: When servicing an injector do not forget the importance of the pressure, the hole size, and the spray pattern.)*

Volatility will also increase or decrease the delay period as will the self-ignition temperature (cetane number) of the fuel (refer to Unit 24, "Diesel Fuel").

A fuel of low volatility and high cetane should be used when the engine speed is high and the load and the ambient temperature are low. This aids in maintaining a constant time in the delay period since the compression temperature under the circumstances mentioned above would be low. Conversely, with a low speed, high load, and high ambient temperature, a fuel with high volatility and a low cetane number should be used.

Although at first it may seem possible to maintain an even or higher compression temperature by simply increasing the compression ratio, this actually only solves part of the problem. With a higher compression ratio the compression space is very small and dead-volume pockets are formed which cannot be reached by the fuel droplets. Obviously these pockets do not utilize the air in the second and third phases of combustion, so there is a power loss during the power

(expansion) stroke. Also, with a higher compression ratio, precise tolerances are essential since the clearance between the valves, piston, and piston cylinder head is reduced. For this reason and because a higher compression ratio would lower the volumetric and mechanical efficiency and also would increase pollution problems, for direct injection engines manufacturers keep the compression ratio within a range of 15:1 to 18:1.

To increase the compression temperature various precombustion chamber designs are used. These chambers store heat, stabilize the temperature, and shorten the delay period. There is very little uncontrolled burning; the heat which is released proceeds smoothly but rapidly, although relatively late in the cycle. Note that engines with precombustion chambers are low in HC and NO_x emissions.

Power (Expansion) Stroke After the piston passes TDC, heat is rapidly released causing a rise in pressure. This rise in pressure forces the piston downward and increases the force on the crankshaft. During this time (to about 65° ATDC) (Fig. 3-3*d*) the force on the crank remains nearly constant because the expansion of gases causes a counteracting pressure and temperature loss. The crankshaft, in relation to the force applied, gains advantage because of an increasing angle between the connecting rod and the crankshaft. From that point on the force on the crankshaft decreases as the temperature of the expanding gases decreases.

Engine Heat Balance The thermal distribution of a two-stroke diesel engine is about one-third power, one-third cooling, and one-third exhaust. When turbocharged and aftercooled it is about 38 percent power, 30 percent cooling, and 32 percent exhaust. However, a turbocharged and aftercooled four-stroke engine is more efficient, because more heat energy is produced during combustion and converted into power. An engine of this type may have a thermal distribution of 42 percent power, 30 percent exhaust, and 28 percent cooling. During the periods of combustion, expansion, and exhaust, 28 to 33 percent of the heat, plus heat generated by friction and the rings, is given up by conduction, convection, and radiation. (See Fig. 3-5.) Let us define these three terms:

- *Conduction* is the transmission of heat through matter without conducting body motion.
- *Convection* is the transfer of heat from one body to another through a liquid or gas by motion of its parts.
- *Radiation* is a transmission of heat in the absence of a gas, liquid, or physical conductor, and by the energy of molecules and atoms undergoing internal changes.

Note that the heat balance diagram (Fig. 3-6) does not include the heat carried away by the lubricating oil or that given up by radiation or convection through the external walls of the engine or its components.

The heat balance figures given relate to engines at full load. On a four-cycle engine at reduced load the flow of heat through the cooling medium is less than that of a two-cycle engine.

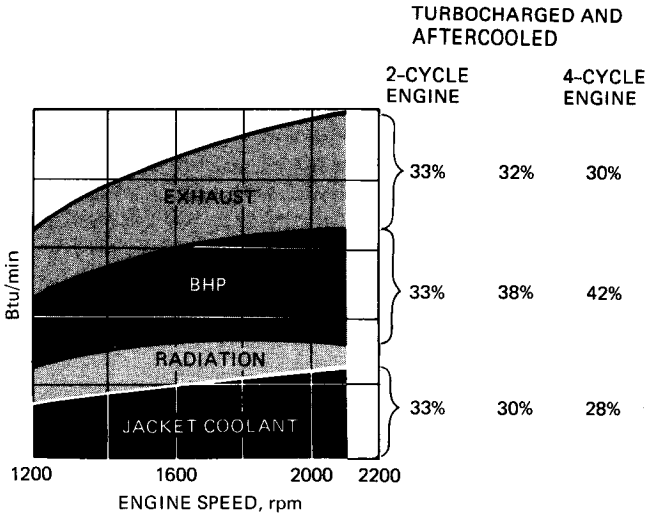


Fig. 3-5 Typical heat balance of two- and four-cycle engines.

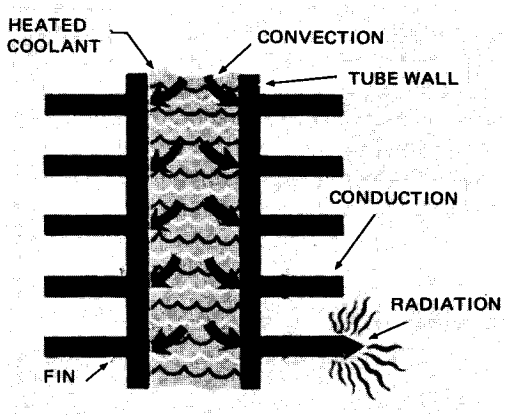


Fig. 3-6 Principles of conduction, convection, and radiation.

Exhaust Stroke At 53° before bottom dead center (BBDC) the cam of the exhaust valve forces the follower upward. At about 48° BBDC the exhaust valve lifts off its seat and exhaust gases enter the exhaust manifold and pass into the atmosphere. *(NOTE: The exhaust temperature changes with engine speed and load.)*

After stopping BDC, the piston moves upward and accelerates to its maximum at 297° or 63° BTDC and from there on the piston decelerates. As the piston speed slows down, the velocity of the gases creates a pressure slightly lower than atmospheric pressure. At 28° BTDC the inlet valve opens. Since the exhaust and intake valves are open (valve overlap), fresh intake air sweeps across the piston and causes a scavenging effect. This intake air not only removes the remaining exhaust gases from the cylinder but also cools the exhaust gases, the valves, the piston, and the cylinder sleeve. This point also marks the start of a new working cycle.

Relation Between Time and Crankshaft Rotation Time is required to move exhaust gas out and move air into the cylinder, to compress the air, and to inject and burn the fuel. Although this time is extremely short, each of the events just mentioned must be timed to the crankshaft rotation. The position

of the crankshaft governs the movement of the pistons, valves, and the beginning of injection.

Refer to the piston-travel diagram (Figs. 3-7 and 3-8) to trace the movement of the piston and valve action. If the same engine were governed at 2100 rpm high idle, the crankshaft would turn 35 rotations (12,600°) in 1 second or the crank would advance 1° in 0.00008 second. This leaves only 0.03288 second to remove the exhaust gases and bring fresh air in, and about 0.00248 second to inject the fuel; in other words, the piston has to travel in its stroke a distance of 4 in in about 0.01440 second. *(NOTE: The average piston speed for diesel engines is between 6 and 10 m/s.) Piston speed* is the distance measured in meters or feet that a piston travels in 1 second.

Relation Between Force and Crankshaft Position When the piston is at TDC and a force is applied on the piston, there is no rotation, but there will be a great force placed on the piston, connecting rod, bearings, crankshaft, and engine crankcase. As the crankshaft rotates to 20° ATDC the relation between connecting rod and crankshaft creates a 30 percent torque advantage. At about 63° ATDC the centerline of the connecting rod and crank form a 90° angle, thereby achieving the greatest torque advantage. As the crank angle increases, the torque advantage decreases in proportion to that which it gained.

HOW A TWO-CYCLE DIESEL ENGINE OPERATES

The occurrence of intake, compression, expansion (power), and exhaust of a two-cycle diesel engine is confined to two strokes (one complete crankshaft revolution or 360°) (see Fig. 3-9). With each downward piston movement there is a power stroke and with each upward piston movement a compression stroke. The intake and exhaust stroke may be considered a unit which is part of the power and compression stroke. It begins after completion of the power stroke as the exhaust valves open, and ends after the piston closes off the inlet ports on the compression stroke.

About 44 percent (or 160°) of the total working cycle is needed to remove the exhaust gases and bring in fresh air. In comparison to a four-cycle diesel engine, this time is relatively short because a four-cycle engine requires about 411° of crankshaft rotation; in other words, nearly three times as much as a two-cycle engine. A two-cycle diesel engine requires an air pump (blower) capable of pumping air at a pressure of about 2 to 7 psi [13.79 to 48.26 kPa] into the cylinder to replace the exhaust gases with fresh air.

The process of driving exhaust gas out of the cylinder and replacing it with fresh air is called *scavenging*. Scavenging effectiveness depends on air volume pumped through the cylinder which is about 30 to 50 times the volume of the cylinder. This excessive volume of air is necessary because the exhaust gases, to some extent, resist motion and therefore mix with the incoming air. However, scavenging also has the beneficial effect of cooling the exhaust gases, the valves, cylinder head, cylinder sleeve, and piston.

Detroit Diesel engines use Roots-type blowers exclusively. As positive displacement blowers they operate with little mechanical friction, operate reasonably well at low speed, require no internal lubrication, and therefore deliver oil free air to the cylinders.

NOTE: The reciprocating components (pistons, connecting rods, and crankshaft) are used exclusively to generate power and therefore have less friction loss than those in the four-cycle engine.

The reciprocating components of a four-cycle engine require about 411° of a crankshaft rotation to pump exhaust gases out of the cylinders and draw fresh air in. The four-cycle engine gives very little supporting power for scavenging or charging of the cylinders.

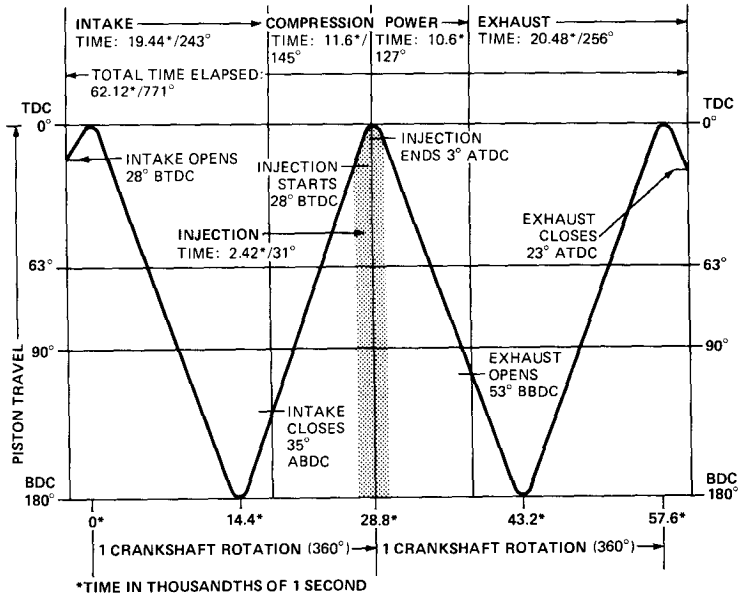


Fig. 3-7 Piston travel diagram when engine speed is 2100 rpm.

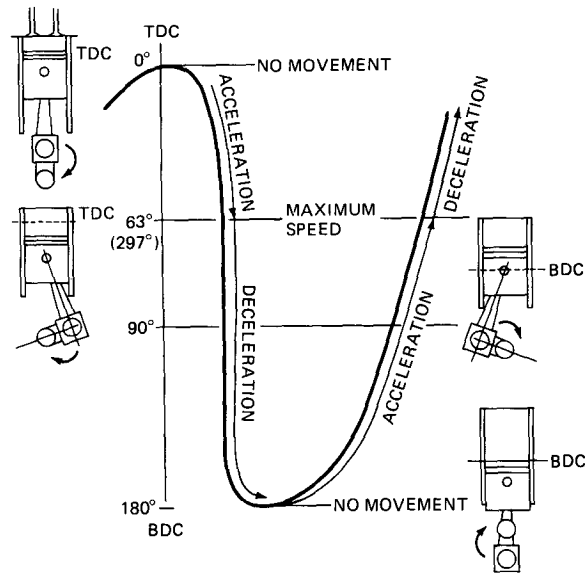


Fig. 3-8 Piston travel related to piston speed and crankshaft angle.

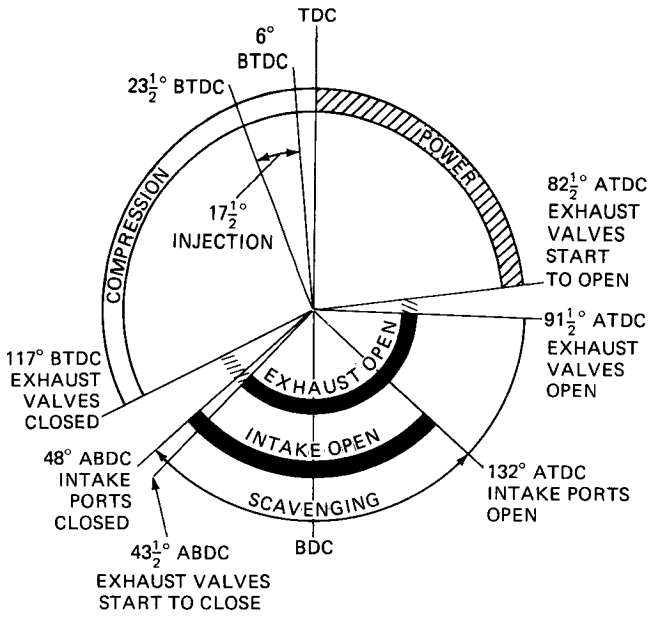


Fig. 3-9 Valve timing diagram of a two-cycle engine.

You may conclude, when comparing a two-cycle engine with a four-cycle engine having the same displacement, stroke, compression ratio, and rpm, that the two-cycle engine would have twice the horsepower. This is incorrect because the power stroke of the two-cycle engine has to be shortened by about 20 percent and the compression stroke by about 12 percent to gain time for scavenging and charging the cylinder with air. Also, the blower on the two-cycle engine requires engine power to pump the air into the cylinder. However, the blower of a two-cycle engine increases the volume within the cylinder, and as a result, the temperature and pressure during compression are nearly the same as those of a four-cycle engine. The exhaust temperature, on the other hand, is slightly higher than that of a four-cycle engine because of the shorter expansion stroke.

Although the power of a four-cycle engine usually is related to breathing efficiency and the area of the cylinder, the power of a two-cycle engine depends on cylinder volume. (A reminder here—do not confuse power with torque. Torque is governed by the length of the stroke and the time in degrees of the power stroke.)

The stroke of a two-cycle engine is limited, since the lower part of the piston (piston skirt) must cover and seal the inlet port when the piston is at TDC. As a result, the piston of a two-cycle engine must be approximately 10 percent longer than its stroke.

The Action of a Two-stroke Diesel Engine Assume that you have an engine having a valve timing as shown in Fig. 3-9 which has been cranked over, started, and is running. Let us then follow one of its pistons for one complete revolution (one working cycle); refer to Figs 3-2 and 3-9 as you read. Do not forget that the crankshaft and camshaft turn at the same speed.

At 82½° ATDC, with the piston near the end of its power stroke, the exhaust cam begins to lift the follower. The valve lash is then taken up and 9° later the rocker arm forces the exhaust valve off its seat. Exhaust gases escape into the exhaust manifold and cause the cylinder pressure to decrease. This is the first phase of scavenging.

After the piston has traveled three-quarters of its (down) stroke (132° of crankshaft rotation), the piston opens the inlet ports to begin the second phase of scavenging. The blower pressure, being slightly higher than cylinder pressure, creates an airflow through the open ports. Consequently, any remaining exhaust gases are forced out through the open exhaust valve. Detroit Diesel Allison engine manufacturers have established for these engines a maximum time allotment of 96° of crankshaft rotation.

At 43½° ABDC the camshaft has rotated sufficiently so that the follower is resting on the closing flank of the cam. Spring pressure forces the exhaust valves to close and at 117½° BTDC the valves are on their seats. In the same period of time, at 48° ABDC the piston, has closed the inlet ports.

NOTE: This is 4½° after the exhaust valve starts to close. Also note that the exhaust valves of turbocharged engines close before the inlet ports close. Cylinder pressure and volume then increase, as does the power.

Let us stop for a moment and analyze the foregoing as it relates to service. Consider first the timing of the crankshaft gears to the idler and camshaft gears. If the camshaft gears are out of time, the relation between exhaust valve and port opening changes. If the ports open too early or too late in relation to the exhaust valves, the air volume and power output are affected. When the exhaust valve lash is too small, the power stroke is reduced. When it is too large the compression stroke is reduced, and again a loss in power is noticeable.

Compression Stroke After the exhaust valves are seated, the compression stroke begins. The temperature and pressure rise is nearly the same as that of a four-cycle engine. At 23½° BTDC the injector cam on the camshaft starts to lift its follower and pushrod. As the rocker arm pivots, the injector is forced downward, causing fuel to be injected. After 17½° (6° BTDC) of camshaft rotation, the fuel injection ends (when the engine operates at full throttle and load). The fuel injection does not end by the cam action. It ends as the helix passes the lower port. (See Unit 31, "Detroit Diesel Fuel-injection System".)

Let us review the beginning of injection in relation to engine performance. If the unit injector is adjusted too high or too low the injection occurs too late or too early, resulting in a loss of power.

POWER STROKE OF A TWO-CYCLE ENGINE Combustion pressure forces the piston downward and at 91½° ATDC the exhaust valves are open and a new working cycle begins.

Supercharging Some of the objectives of diesel engine manufacturers are to increase engine power output (hp), increase thermal efficiency, improve reliability, and hold down maintenance costs while keeping within imposed emission standards. These

objectives have been met by modifying air motion, fuel spray characteristics, combustion chamber configuration, compression ratio, injection timing, (variable timing) fuel-injection rate, and, by supercharging the engine. (An engine is referred to as *supercharged* when the manifold pressure exceeds atmospheric pressure.)

While at first it may seem feasible to increase the piston diameter and the stroke or to increase the number of cylinders to augment the power, size, and weight of an engine, none of these changes increase the mean effective pressure (mep) or engine efficiency. It is possible to increase engine speed (piston speed), but this would increase the inertia force. Furthermore, inertia force demands greater engine strength; therefore, a heavier engine would be needed. Greater engine speed also increases friction losses, produces lubrication and wear problems, and greatly increases maintenance problems and costs. It also increases the airflow rate, but there is a limit to which the manifold, valves, and cylinders can take in the airflow without being supercharged.

The most effective gain in mep, and consequently a corresponding gain in power output and thermal efficiency, results from supercharging, since this increases the mass of air handled by a given swept volume. Supercharged experimental engines have been developed with an mep of 350 psi [2413.2 kPa].

Mechanically driven air pumps such as the positive displacement Roots blowers or the nonpositive centrifugal blowers are not used on modern four-stroke diesel engines, mainly because Roots blowers are limited to a rotating speed of about 6000 rpm and a pressure of about 20 inches of mercury (inHg) [50.8 centimeters of mercury (cmHg)]. Centrifugal blowers are very efficient and have a relatively high ratio (about 3:1). However, they require a complicated drive arrangement to achieve the compressor speed of 20,000 to 60,000 rpm. Since both types require power from the engine to drive the air pump, the total power output gain is small. Nearly all modern engines are now supercharged, by using (turbocharger) exhaust-gas-driven turbines to drive the compressor.

Questions

1. What are the four main differences between a two-cycle and a four-cycle engine?
2. Draw a valve-timing diagram patterned after Fig. 3-9 for an engine which has the following specifications: intake valve opens at 36°, intake valve closes at 48°, exhaust valve opens at 53°, exhaust valve closes at 23°, injection starts at 15°.
3. Explain why a piston travels a greater distance on the first 90° of its down-stroke travel of crankshaft rotation than on the remaining 90°.
4. What factors affect the delay period?
5. List four reasons why a two-cycle engine with the same displacement, compression ratio, and speed as that of a four-cycle engine does not have twice the power of the four-cycle engine.
6. Why do two-cycle engines require a blower?
7. List several engine components which dissipate heat through conduction and through convection.
8. List several reasons why some diesel engines have a greater valve overlap than others.

UNIT 4 • COMBUSTION CHAMBERS

Combustion Chamber Design To achieve complete combustion, gain power and thermal efficiency, and to stay within imposed emission standards, a maximum of inhaled air (or forced air) must be brought into contact with the injected fuel during the combustion process.

In order to achieve this objective, a relatively high velocity is needed between the fuel droplets and the air. The air inlet passages to the cylinder, the combustion chambers, or special chambers, are specially designed to control the airflow, velocity, and direction. There must be no interference since this can reduce the volumetric efficiency. The pressure at the beginning of combustion is also used to control airflow and velocity (squish). Fuel velocity is controlled through the opening pressure of the nozzle, the hole size, the spray angle, and the fuel nozzle location so that the fuel spray covers the total airflow area.

Classification of Combustion Chambers The various combustion chamber designs may be classified as: (1) open combustion (direct-injection) chambers, (2) precombustion chambers, (3) turbulence combustion chambers, (4) air cell type (power cells or energy cells).

The new diesel engines used in motortrucks, truck-tractors, marine or industrial applications, and on farm tractors use direct injection. The exceptions are: Caterpillar 3400 and the 3000 Series engines which use precombustion chambers. However, the 3400 Series is also available as a direct injection engine. The other two are the new International Harvester Company 6.9-L engine and the John Deere engine which use turbulence chambers. The advantages of direct injection outweighs its disadvantages, and outweighs the advantages of using a precombustion chamber. Direct-injection combustion chambers, though relatively similar, have subtle differences to accommodate the particular engine application.

Open Combustion Chamber A typical open or direct-injection combustion chamber is shown in Fig.

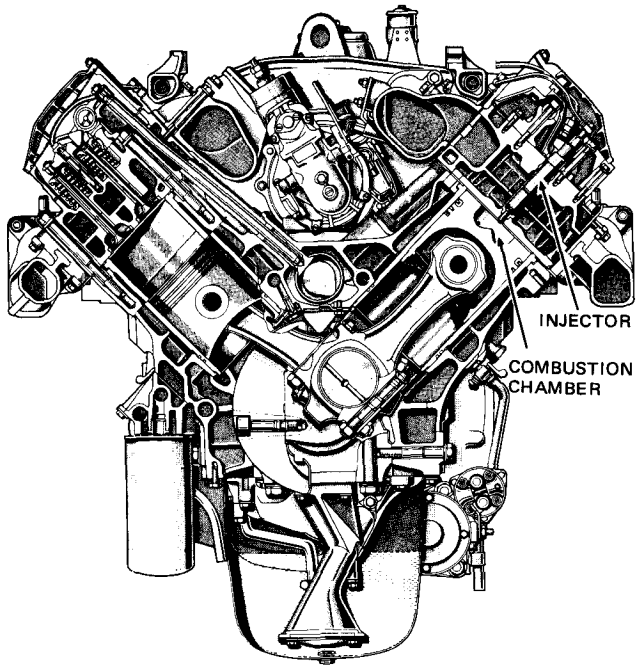


Fig. 4-1 Sectional view of a direct-injection engine. *(Allis-Chalmers Corp. Engine Division.)*

4-1. The main combustion chamber is formed in the pistonhead and the injector nozzle tip is positioned over the center of the piston so that the spray from the multiorifice nozzle will be distributed evenly. This spray must coincide with the air and droplet movement in order to eliminate the dead air space within the combustion chamber.

NOTE: The combustion chamber diameter, the depth of the bowl, and the tip height varies from engine to engine.

Action within an Open Combustion Chamber

As the piston moves downward, atmospheric pressure forces air through the scroll-shaped intake passage and promotes a circular air motion. This circular airflow then passes through the intake valve opening(s) into the cylinder (Fig. 4-2*a*) and helps to fully charge the cylinders.

As the piston comes up on compression stroke, it accelerates air motion by reducing the area in which the air is rotating (Fig. 4-2*b*). As the piston approaches the top of its stroke, the confined swirl of air is forced into an even smaller area in the pistonhead (Fig. 4-2*c*). This area has an inverted cone-shaped center (sometimes called *Mexican head*) which adds an even further rolling motion to the air. Fuel is evenly injected into this bowl of accelerated swirl, in four, or as many as eight, directions (Fig. 4-2*d*). The tip of the fuel spray hits the rim of the bowl rather than the outer circle of the piston or the comparatively cool cylinder walls.

The open combustion chambers used by Maschinenfabrick Augsburg-Nurnberg A.G., Kloeckner-Humboldt Deutz A.G., and some International engines have the following similarities. They use a special intake duct configuration to impart greater air motion in the cylinders during the intake stroke and their spherical combustion chamber is located within the piston. The nozzle tip, during injection, lies in the piston snout which is an extension of the chamber. The injector nozzle, which is either single or pintaux, sprays the fuel against the spherical combustion chamber walls. The fuel forms a thin coat over the hot walls, ensuring favorable conditions for vaporization. The fiery spinning vortex causes the vaporized fuel to come off the combustion chamber walls in layers, thus bringing about complete combustion. See Fig. 4-3.

Advantages of Open Combustion Chamber

1. It has high brake thermal efficiency.
2. All energy produced by the fuel acts directly on the pistonhead.
3. The cylinder and piston suffer minimum effects of combustion due to the low combustion temperature.

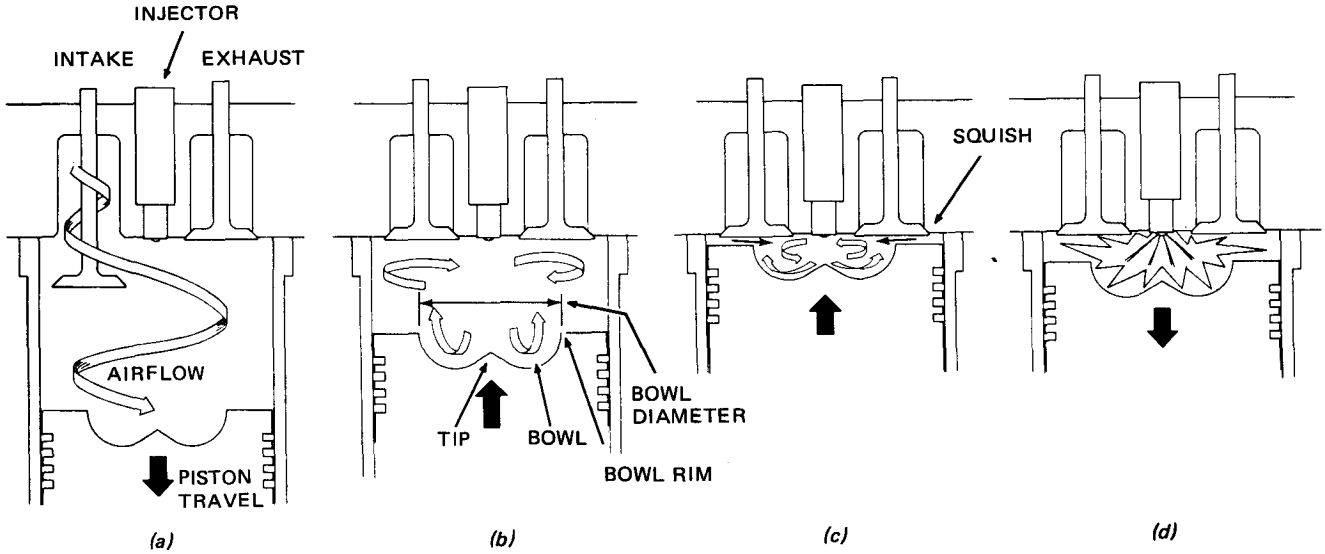


Fig. 4-2 Air action in an open combustion chamber: (*a*) intake, (*b*) compression, (*c*) extreme compression, (*d*) power.

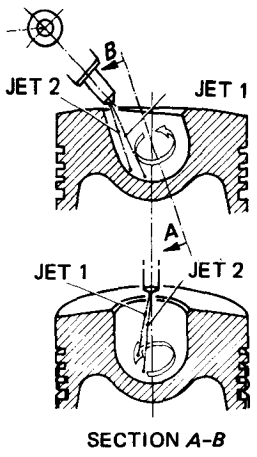


Fig. 4-3 Schematic view of a direct-injection combustion chamber. *(International Harvester Company.)*

Disadvantages of Open Combustion Chamber

1. Emission control is difficult.
2. The engine tends to run rough due to a shorter delay period. This delay causes a high and rapid pressure rise.
3. It is sensitive to fuel and timing.
4. The multiorifice nozzles and high injection pressure tends to increase fuel-injection problems.

Specially Designed Combustion Chamber

All specially designed combustion chambers are separate units which are bolted or screwed into the cylinder head. They connect by a passage to the cylinder above the piston. Fuel is injected directly into the chamber by a single hole, pintle, or delay nozzle. A portion of the clearance volume is inhaled into the chamber. Some companies still produce these specially designed chambers because of their great success in controlling hydrocarbon (HC) and nitrogen oxide (NO_x) emissions. Carbon monoxide (CO) emission levels from precombustion-chamber diesel engines remain relatively low because the burning time (in degrees of crankshaft rotation) of the fuel is shorter by about 15° than that of a direct-injection engine.

Precombustion and Turbulence Chambers

The injector nozzle of a precombustion chamber engine is located in the specially formed chamber which contains about 30 pecent of the total clearance volume. Most chamber openings point toward the center of the piston.

The Caterpillar Tractor Company uses precombustion chambers on some engine series (see Fig. 4-4).

A turbulence chamber engine is one which has the injector nozzle located in a specially formed chamber containing about 80 percent of the clearance volume. The chamber passage to the cylinder is large and the chamber is located on one side of the cylinder (Fig. 4-5). Since the injector is located on the other side of the cylinder, it will not interfere with large valves. The volumetric efficiency and mean effective pressure are, therefore, higher than those of the precombustion chamber.

Action within Precombustion and Turbulence Chambers The action within the precombustion and turbulence chambers is as follows: On the compression stroke, air is pumped at high velocity through the restricted passage into the chamber, thus causing a high turbulence within the chamber. As the piston approaches TDC the injector discharges fuel into the chamber at a relatively low pressure. Combustion then causes the pressure to rise, forcing the fiery droplets, air and gases, at high velocity, into the main combustion area. Although this causes a high turbulence within the main combustion chamber, burning nevertheless is controlled by the dependency of combustion on injection. Controlled burning means that combustion catches up with injection and then progresses with it.

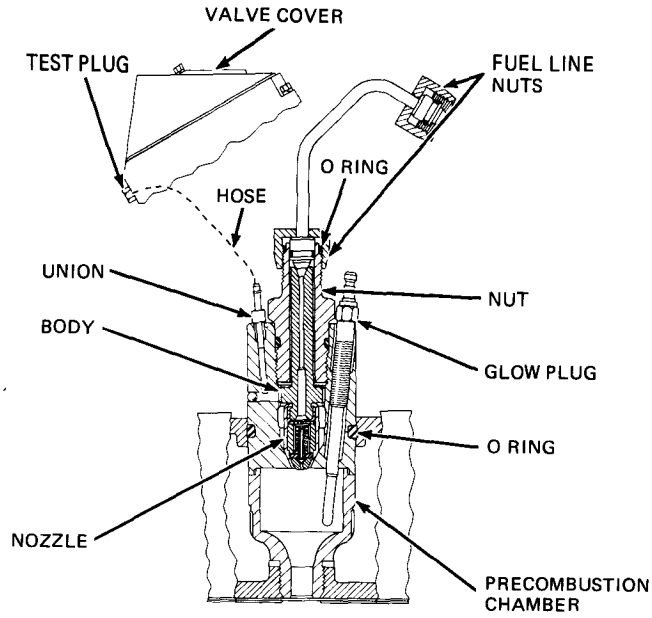


Fig. 4-4 Cross-sectional view of a precombustion chamber and fuel-injection valve. *(Caterpillar Tractor Co.)*

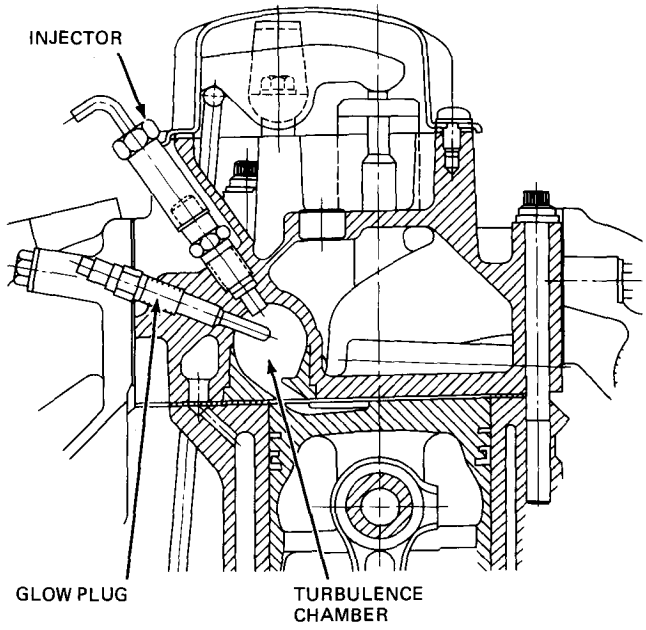


Fig. 4-5 Schematic view of a turbulence chamber. *(International Harvester Company.)*

Energy and Power Cells Another type of combustion chamber in current use has the energy or power cell located on one side of the cylinder head and the injector positioned across from the main combustion area. With this design, manufacturers generally use a flat-head piston with the oval-cylindrical main-combustion chamber located in the cylinder head.

These types of cells have the same advantage (over the direct-injection engine) as the precombustion and turbulence chambers, that is, a continuous mixing of fuel and air. This gives a controlled combustion rate and a lower peak pressure than the direct-injection engine. The engine runs smoothly, with less noise, with generally good fuel economy, and with low emissions.

Questions

1. Why is the (atomized) injector spray of an engine directed into the piston bowl instead of the outer circle of the piston?
2. What factors control fuel velocity during compression and ignition?
3. List the advantages and disadvantages of an open combustion chamber.
4. What are the main differences between a precombustion chamber and an energy cell?
5. List the main advantages of an energy cell over the open combustion chamber.
6. Outline the action within a Caterpillar precombustion chamber from the beginning of the intake stroke to the beginning of the power stroke.

UNIT 5 • ENGINE DISASSEMBLY

This unit introduces you to the working components of a diesel engine, their design, and their operating principles. It outlines the general procedures of how to remove the engine from the vehicle, and then how to disassemble it. (Servicing is detailed in later units.) Students who have very limited experience with tools will find it most beneficial to review Sec. 6, "Shop Equipment," before proceeding with this unit.

Safety Procedures When working with machines having hydraulically, mechanically, and/or cable controlled equipment—such as shovels, loaders, dozers, scrapers, etc.—be certain those parts are lowered to the ground before servicing, adjusting, and/or repairing. If it becomes necessary to partially or fully raise such equipment to gain access to the engine, be sure the equipment is adequately supported by a device other than the hydraulic lift cylinder, cable, and/or mechanical apparatus used for controlling it.

Starting and Stopping a Diesel Engine Before servicing or disassembling an engine, get the motor vehicle, if possible, into your shop rather than attempting to work on it at the breakdown location. If the machine is one that you have not previously driven, you should familiarize yourself with the location of the dashboard instruments, the throttle, brake system, hydraulic control, and transmission shift mechanism before starting the engine. If you have not been informed about the engine's present condition, you should also check the coolant, the oil level and, if applicable, the hydraulic and transmission oil levels *before* moving the vehicle. Make certain that no other person has previously worked on the engine and removed parts that when removed might cause damage to the engine or its accessories when starting.

You can then place the transmission in neutral position. Move the throttle to half engine speed and, if a master switch is used, close the switch. If an engine preheater (glow plug) is used, turn it to the "on" position if necessary. After about 15 seconds, engage the electric, hydraulic, or air starter; hopefully the engine will start after about three full revolutions.

Once the engine is running, check the oil and fuel pressure. Closely watch the coolant temperature and air-pressure gauges. If the air-pressure gauge does not come up to "set pressure," the air tank drain may not be closed. Close it.

NOTE: Operate the engine at low idle for 3 to 5 minutes then increase the engine speed to about 1000 rpm. When the engine has reached an even temperature, you can move the vehicle into the shop.

Before you stop the engine, reduce the engine temperature to about 160°F [71°C] by reducing the engine speed to around 1000 rpm. Reduce the engine speed to low idle and then use the fuel stop mechanism to prevent fuel flow to the injectors. Use the decompressor or the emergency shutdown device only in an emergency.

Before leaving the motor vehicle or equipment, lower the hydraulic equipment, if applicable, and block it in such a way that it will not interfere with your service work. Apply the parking brakes. The engine is now ready to be removed.

Removal of Engine It is not possible, for obvious reasons, to list a common set of procedural steps to remove an engine from a truck, tractor, crane, loader, or boat. The service manual for each particular vehicle should always be referred to first, but if a service manual is not available, the following rules will serve as a general guide.

1. Before steam-cleaning the engine and its surrounding area, visually inspect and make a record of the overall condition of the engine and its components in regard to oil, fuel, and coolant leaks. This

will reveal a great deal about the service required on each component.
2. Secure or remove all hydraulic equipment which may interfere with the engine removal. Remove electrical components (including the battery), and tag the electrical wires to speed up reassembly.
3. Completely drain the lubrication, fuel, and coolant systems. Bleed the air system if an air system is used.

NOTE: Do not drain the cooling system when the engine is hot as this could damage the engine.

4. Cover any electrical components which are not removed to protect them from direct steam.
5. Steam-clean the engine first, to remove accumulated road grime, grease, and oil. This will permit external visual inspection and will also speed up disassembly.
6. Clean the area around the engine so that the lifting device will not be obstructed when the engine is being lifted from its mounting.
7. Remove the radiator hose connections and power-steering hoses (if used). Disconnect fuel, oil, and coolant gauges, and connections to the pyrometer, if used.
8. Remove the coolant, oil, fuel filters, and their connections. Remove the mechanical controls, the tubings, or hoses from the turbocharger. Remove the air cleaner, the exhaust pipes, and the transmission (if necessary).
9. Cover all openings, hoses, and tube ends to protect them from dirt.
10. Attach lifting eyebolts or brackets at the specified mounting points to assure lifting at the proper balance point.
11. When possible, use an adjustable lifting beam with an adjustable pull point. If a chain or cable is used, it must be parallel and as near perpendicular as possible to the object to be lifted. Be sure that the eyebolts or bracket bolts are threaded into the hole a depth of at least 1½ times their diameter to give proper thread strength.
12. After positioning the hoist (or other lifting device) properly and taking up the slack, remove the engine mounting bolts. Begin lifting the engine. Check that the load is in balance and again check for obstructions which could interfere during lifting (Fig. 5-1).

CAUTION Stay clear of the load and lift only to the height required to swing the engine free. With a rope, guide the engine clear during the lifting. Lower the engine to a few inches from the ground, then guide it to your work area.

Mounting Engine to Engine Stand Before mounting the engine on the engine stand you may have to remove components and parts (mounting brackets, clamps, belts, etc.). Do this in a systematic order. Identify mounting components as to the location from which they were removed. Place parts and components as units on a rack or in a tray. Remove the turbocharger, exhaust and intake manifolds, water pump, water manifold and thermostat housing, oil cooler and connections. If the fuel-injection pump is so located that it could be damaged, it should also be removed.

As each component is removed, check it visually for distortion of flanges and brackets, cracked or broken flanges, discoloration, and damaged threads. Examine gaskets and seals to determine if they caused the air, oil, coolant, or fuel leakage. Bolt the recommended mounting adapter plate securely to the engine and position the engine on the stand before releasing the hoist or lifting device.

Disassembly Procedures Because there are so many engine designs, it is only possible to recommend basic disassembly procedures. They are as follows:

1. Always use the correct hand and power tools. Do not use a punch and hammer where a puller should be used.
2. When lifting heavy components, make sure that the hoist has sufficient lifting capacity and the load is properly secured. When disassembling, take care not to drop components.
3. Store subcomponents separately and as units.
4. Identify all removed parts and mark their original location on the engine so that they can be replaced quickly after inspection and/or diagnosis.
5. It will save time in the long run if you inspect each component or part during disassembly and make a record of the parts which need to be replaced.

Intake Manifold The intake manifold is bolted to the cylinder head and connects the intake ports of a row of cylinders. The inlet port of the intake manifold may be connected with the air cleaner or aftercooler, or connected to the compressor housing of the turbocharger—or the aftercooler may be placed inside the manifold (Fig. 5-2).

The intake manifold is a one-piece cast-iron alloy or aluminum-alloy casting and is designed to aid scavenging. The mounting flanges are machined to seal (with a gasket) the inlet ports to the cylinder head and to seal with the connecting components.

Exhaust Manifold The exhaust manifold is manufactured from a cast-iron alloy so that it will with-

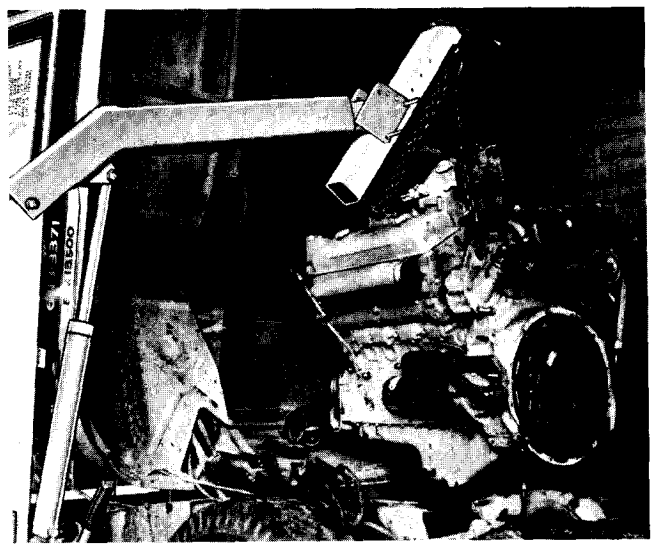


Fig. 5-1 View of lifting out an engine.

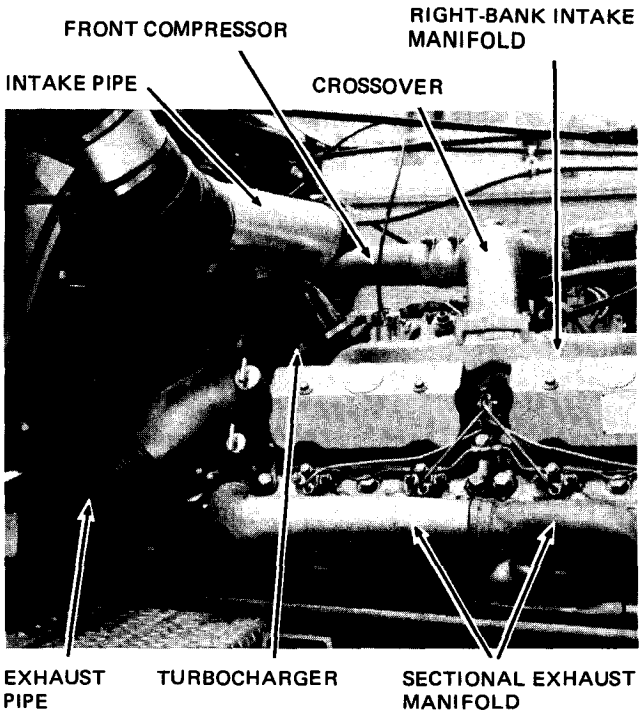


Fig. 5-2 View of intake and exhaust system.

stand temperature changes without cracking or distorting. It is designed to aid scavenging and may be built as a one-piece unit or in sections, or it may be designed as a pulse manifold. The exhaust manifold's function is to discharge exhaust gases into the atmosphere from the cylinders' exhaust ports. When a turbocharger is used, the exhaust manifold is connected to its turbine housing and from there exhaust gases are directed through pipes into the atmosphere (Figs. 5-2 and 19-2).

The mounting flanges of the exhaust manifold are machined to seal (with steel gaskets) the exhaust ports to the cylinder head and to seal the turbocharger or the exhaust pipe flange with the outlet flange. When multisectional manifolds are used, leakfree slip joints connect their ends to the center section. The manifolds of motor vehicles and engine equipment are air-cooled whereas marine manifolds are cast with an integral water jacket surrounding the exhaust manifold and a coolant bypass from the cooling system is directed through the water manifold to increase cooling capacity.

Turbocharger A turbocharger is an air pump which utilizes exhaust-gas energy to drive a centrifugal blower (compressor). The turbocharger's turbine housing is connected directly to the exhaust manifold and the outlet side is connected through pipes to the muffler. The compressor-housing inlet is connected to the air cleaner and its outlet is connected to the intake manifold or aftercooler, and then to the intake manifold (See the schematic view of a turbochargers in Fig. 5-3.)

The horsepower gain when using a turbocharger may range from 50 to 150 percent depending on the boost pressure and the efficiency of the aftercooler. The average exhaust temperature at lower engine load is about 500°F [260°C], and the boost pressure may be about 5 inHg [12.7 cmHg]. At maximum engine load (maximum torque), the exhaust temperature may reach 1000 to 1200°F [537.7 to 649°C]. At this stage the turbine speed is at its maximum designed speed and has reached its maximum designed or controlled boost pressure. Engine torque reduction, however, reduces exhaust pressure and rapidly decreases turbine speed and boost pressure.

To balance the quantity of fuel being injected with the boost pressure, various control devices are used. A fuel ratio control or an aneroid is used to control the fuel-rack movement or to control the metering valve, or to control the fuel pressure (Cummins). Each of these devices reduces exhaust smoke during acceleration and deceleration. A throttle-delay mechanism (Detroit Diesel) is used to postpone fuel-rack movement when the engine is accelerating. (See Unit 26, "Antipollution Control Devices.")

To remove the turbocharger, remove the oil inlet and outlet hose connections first, and then the turbocharger. Cover the turbocharger openings to protect the turbocharger from contaminants. Remove the locks, nuts, or bolts from the exhaust manifold and then remove the exhaust manifold itself from the cylinder head(s). *(NOTE: If a section manifold is used, remove it as a unit.)*

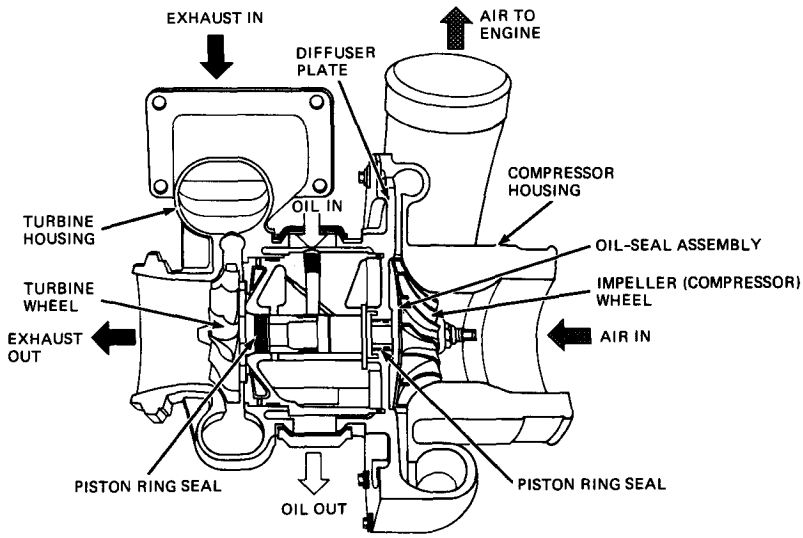


Fig. 5-3 Schematic view of a turbocharger.

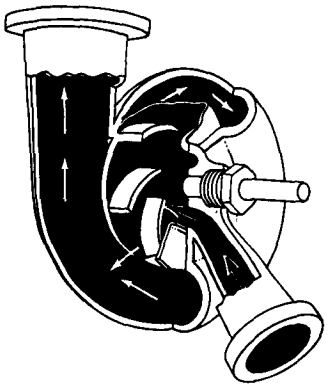


Fig. 5-4 Schematic view of an impeller pump. (The arrows show the fluid flow.)

Nonpositive Displacement Coolant Pumps Nonpositive displacement pumps are those which supply a continuous flow until the resistance in the discharge line equals the designed capacity of the pump.

Impeller-design Pump Nonpositive displacement pumps of the centrifugal design, that is, the impeller design, are used as coolant pumps (Fig. 5-4). Basically they are designed with an impeller which has straight, curved, or coned-shaped blades. The impeller is positioned on a shaft in a spiral- or volute-shaped housing. The fluid inlet is near the center of the housing and the outlet is on the outer circumference of the housing.

When the impeller is driven, the fluid starts to revolve and the centrifugal force moves the liquid out between the blades to a greater and greater radius. This increases the tangential velocity and centrifugal force. The liquid thrown off the tip of the blades follows the contour of the housing. From Fig. 5-4 you will see that the pump chamber (in which the impeller rotates) gradually increases in area toward the outlet port. (Also see Unit 20, "Cooling System.")

This design allows the velocity head to be converted gradually to a pressure head. When the resistance in the discharge line and the liquid force of the pump are equal, there is no flow. However, the impeller still moves the liquid within the pump housing and produces heat. The design and the rpm determine the maximum pressure and volume. No pressure relief valve is needed.

Removal of Coolant Pump Remove the necessary coolant hose, the transfer, and the coolant bypass tube connections. Remove the mounting bolts and lift the pump from the engine.

Removal of Fuel-injection Pump Remove the high-pressure injection lines from the injection pump and injectors. Cover the openings of the injectors, injection-pump discharger fittings, and both sides of the injection lines.

CAUTION Use two wrenches when loosening the nuts to avoid bending or kinking the fuel lines.

Remove the fuel lines leading from the second-stage filters to the injection pump and cover the openings. Remove the mounting bolts, lift the injection pump from the engine, and store it in a safe place.

Removal of Valve Cover The valve mechanism cover is made from cast iron, cast aluminum, or is metal-stamped. Simply remove the necessary bolts and lift the cover from the cylinder head.

Decompression Lever Assembly The decompression mechanism is an assembly of levers and shafts that open either the intake or exhaust valve(s). When actuated, the engine can turn freely since it does not have to compress the air.

Rocker Arm and Shaft The rocker arm pivots around the rocker-arm shaft to transmit motion from the camshaft to the valve stem (see Fig. 5-5). On Detroit Diesel engines, Cummins engines, and the 3000 Caterpillar Series diesel engine an additional pushrod activates the unit injector or the injector.

Rocker arms are made of forged cast alloy or laminated steel. A ball socket is screwed into the pushrod or tube end to accommodate valve or injector adjustment. The other end, which contacts the valve stem, is especially hardened or has an insert of high-quality steel. The contour of the contact area is ground so that a minimum of side thrust is exerted on the valve stem or bridge as the rocker arm pivots. When an overhead camshaft is used, the rocker arm has a cam roller on one end, or the camshaft lobe may act directly on the follower assembly (Fig. 5-6). Some rocker arms are cross-drilled to supply lubrication to both ends. A bushing is pressed into the bore of the rocker arm to reduce friction and to increase service life. The fulcrum point is closer to the adjusted end to multiply the camshaft lift to a ratio of about 1:1.5. The hollow or solid rocker-arm shaft is made of hardened steel. It is supported either in a separate rocker-arm housing or by two or more rocker-arm-shaft brackets. Holes are drilled into the shaft at precise locations to lubricate each rocker-arm bushing. Lubrication commonly is supplied to the rocker-arm shaft through the rocker-arm bracket or through a separate connection.

The decompression lever assembly usually is removed before the rocker-arm assembly. When overhead cams are used, remove the camshaft assembly or lever housing.

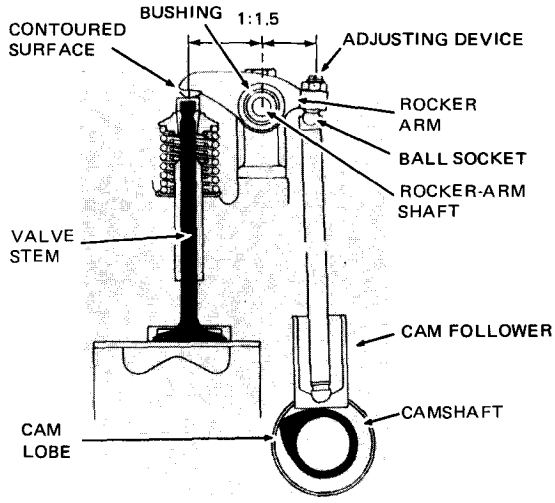


Fig. 5-5 View of valve train components. *(Cummins Engine Company, Inc.)*

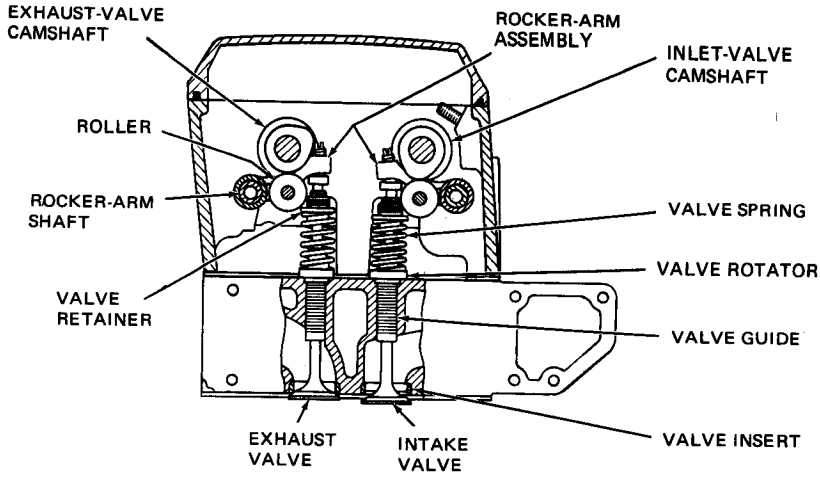


Fig. 5-6 Valve and valve mechanism—Caterpillar D348 engine. *(Caterpillar Tractor Co.)*

CAUTION It is essential to release the rocker-arm shaft tension evenly because the valve springs force the assembly upward. Hex bolts and nuts must, therefore, be loosened one after another, a little at a time.

If special hex bolts are used to pass oil from the cylinder block to the cylinder head in order to lubricate the rocker-arm assembly, be sure to mark their location. When valve bridges (crossheads) are used, remove them before removing the pushrods and followers and place them in a holder in the order of their removal.

Cylinder Head All cylinder heads are made of a special iron alloy casting containing carbon, silicon, and copper. This alloy mixture provides elasticity and good thermal conductivity, and has a low thermal expansion rate. The size of the cylinder head is not determined by the number of cylinders but rather by such factors as the overall cost of the engine, the cylinder block design, the number of main bearings, the expected thermal stress, and the anticipated cooling and sealing difficulties (of the cylinder head). Factory complications in casting or foundry work can also affect cylinder-head size.

Whether an individual cylinder head is used for each cylinder (Fig. 5-7) or whether the cylinder head covers two, three, four, or six cylinders, it must nevertheless have adequate strength and stiffness. It must act as a sealing surface between the cylinder sleeve, cylinder-block top deck, and oil and cooling passages, without distorting the sleeve or valves. The cylinder head must be sufficiently strong so that it does not crack between the cylinder-head bolts (studs), between the intake and exhaust valve, or between the valves and injector (sleeve or bore).

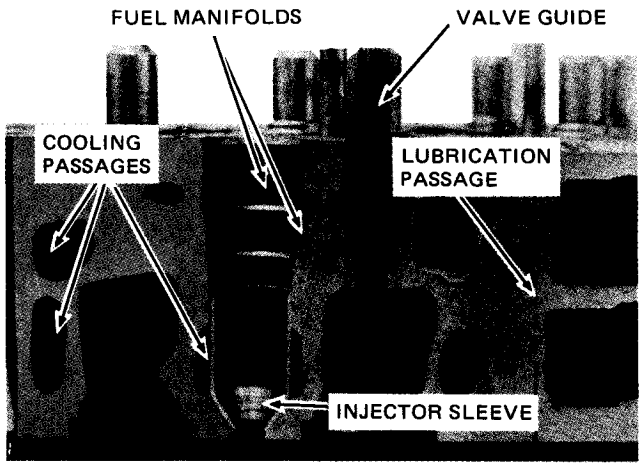


Fig. 5-7 Sectional view of a cylinder head.

The internal cooling passages must be located to ensure that the coolant flow has a high velocity at and around the valves and injector tubes. It must remove heat (steam bubbles) and prevent the accumulation of deposit or scale. The passages should have no dead ends. The external openings must prevent turbulence and permit unrestricted circulation from the cylinder block to the cylinder head and from the cylinder head to the radiator.

The valves must be located so that the fuel spray can reach the total combustion area, but they must be far enough apart so that the coolant can circulate freely betweeen them, thereby preventing the cylinder head from cracking between the valve seats.

The location of the valve passages and openings as well as the valve throats must assist rather than reduce breathing capacity (refer to Combustion Chamber Design in Unit 4.)

The location of the injector, precombustion chamber, turbulence chamber, and the air cells must ensure good fuel droplet precipitation to aid in combustion and cooling.

Removal of Cylinder Head Care should be taken when removing the cylinder-head bolts or nuts and a reverse-tightening sequence should be used to prevent cylinder head distortion.

CAUTION Never remove the cylinder head when it is hot because it will become distorted (warped).

If the cylinder head is very heavy, use a hoist to lift it from the cylinder block. If it is small, screw the lift handles into the cylinder head to lift it from the block. If a cylinder head is excessively tight, do not drive a chisel or screwdriver between the cylinder block and head to remove it, as this will damage both surfaces. Lightly tap the cylinder head with a bronze or lead hammer or use a block of wood to break it loose.

Carefully inspect the combustion chamber once it is exposed. Close scrutiny can often reveal the cause of high oil consumption, overfueling, water leakage, or overheating. Damage to pistons, cylinder sleeves, and cylinder block can also be seen.

CAUTION When removing the cylinder head, take care not to damage it or the cylinder block surface or threads. If studs are used, take care not to bend them. After removal, place the cylinder head in a holding fixture, or if it happens to be square, you may place it on a workbench.

Intake Valves and Exhaust Valves Valves are exposed to extreme temperature changes, to hammering against the valve seat, to corrosion from combustion, and to constant changes in direction. The composition of the intake valves may range from a low-alloy steel to an alloy of chromium with carbon added. Exhaust valves may have the same alloy base or they may have nickel, manganese, or nitrogen added.

The external appearance of valves is reasonably similar (see Fig. 5-8 and 5-9). There are major differences, however, in the dimensions of the valve stem and head, the collet grooves (valve keeper grooves), and the seat angle. The *seat angle* is the angle of the valve face surface against the horizontal surface of the insert and is either 20°, 30°, or 45°. The angle is governed by such factors as the valve throat, the valve lift, and whether the engine is naturally aspirated or supercharged.

A 45° valve has about 20 percent more seating force than a 30° valve and it produces a better cleaning action against accumulated carbon deposit. However, a 45° valve tends to deform the valve seat faster because of the greater valve-spring force. (Consequently many engines are designed with a valve rotator.) Intake valves are generally about 40 percent larger in area than exhaust valves in order to increase breathing capacity.

There are other differences in the valves which are not immediately visible. For instance, valves may be welded, or part of the valve stem may be composed of one alloy while the rest of the stem and the valve head may be composed of another alloy to make it more durable (resist corrosion and withstand high temperatures). Some valves are faced and/or the head is coated, or the stem ends may be hardened to corrosion and wear resist. Other valves are hollow and filled with metallic sodium to reduce valve-head temperature by convection (see Fig. 5-9). Valve-head temperature can be reduced about 200°F [111°C] when this type of valve is used.

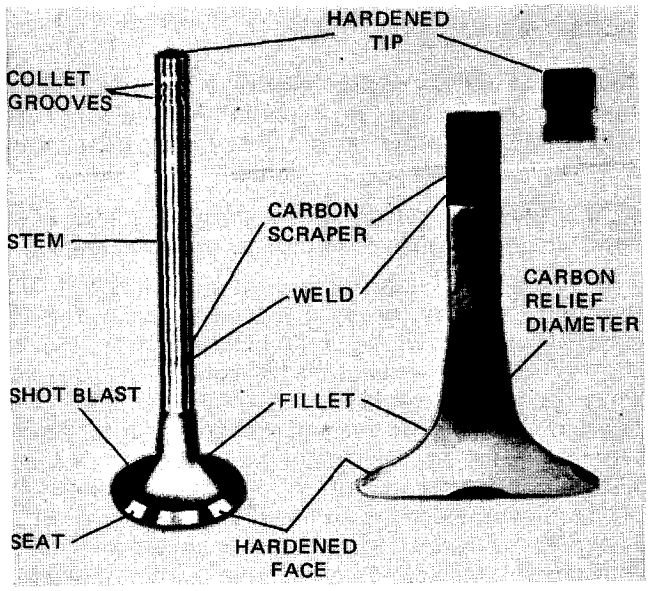


Fig. 5-8 View of typical valve design and construction. *(Cummins Engine Company, Inc.)*

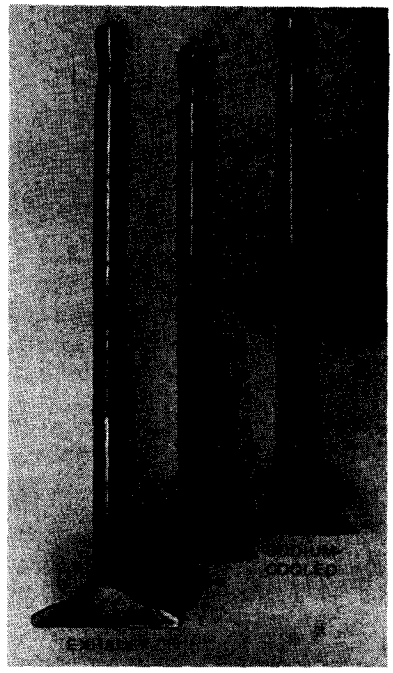


Fig. 5-9 View of typical valve design.

Removal of Valves and Injector Use a valve-spring compression tool, as shown in Fig. 5-10, to remove, in sequence, the valve keeper, valve-spring cap or valve rotator, valve spring, valve-spring seat, and valve. Throughout removal, place each valve in correct order in a holding fixture.

Remove bolts or nuts from injector hold-down studs and then carefully remove the injectors. When removed, the injectors must be kept in numerical order and placed where they cannot be damaged. If an injector is stuck in the head, use two prybars (injector bars) to loosen it, or use the tool designed for this purpose. Grip close to the injector body and ease out evenly so that the injector comes straight out of the bore. If the injector is exceptionally tight because of carbon formation or corrosion buildup between the injector and the sleeve or bore, use penetrating oil on the stud and body to ease removal.

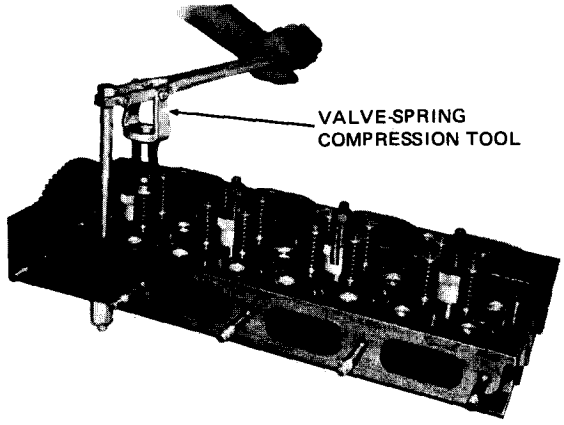


Fig. 5-10 View of removing a valve-spring retainer.

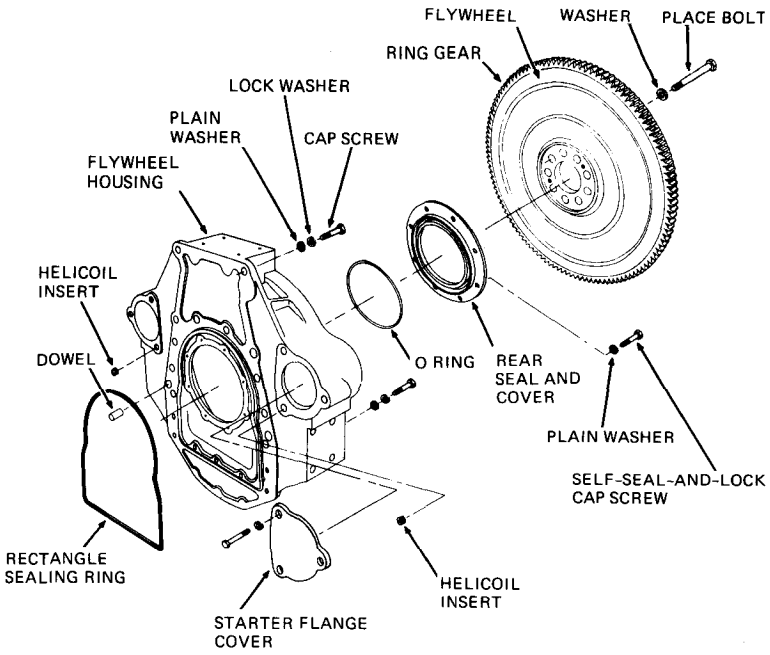


Fig. 5-11 Exploded view of flywheel housing components and parts.

Flywheel Housing The flywheel housing is a one-piece casting, ribbed for strength, positioned with dowel pins, and secured with hex bolts to the cylinder block. The flywheel housing covers the flywheel and is the mounting surface for the transmission and the cranking motor. It is usually the mounting surface for the rear engine mount, and it can also act as the timing-gear housing. Flywheel-housing size as well as bore diameter, bolt hole spacing, and hole size vary with engine design. Accordingly, SAE recommends nine designs from SAE00 to SAE6. The crankshaft rear oil seal is pressed into the flywheel housing. When a rear seal cover is used, the seal is in the cover and the seal cover is bolted to the crankcase or flywheel housing (Fig. 5-11).

Flywheel and Ring Gear The *flywheel* is one-piece cast iron. Its size and weight are determined by the engine speed, the number of cylinders, and whether it is a two- or four-cycle engine. The flywheel is machined to provide a true fit with the crankshaft flange, pressure plate surface, and clutch friction surface, or with the clutch-drive ring gear or torque-converter impeller mounting ring.

A flywheel used for a double-disk clutch is machined on the inner circumference and drive pins (drive locks) hold and drive the intermediate plate. The center of the flywheel has either a machined bore into which the pilot bearing or bushing is press-fitted, or it has a splined drive flange bolted to it to drive an auxiliary shaft. The flywheel bolt holes are precise in dimension and usually one hole is offset to ensure that the flywheel fits onto the crankshaft in only one position. Part of the outer circumference is machined to provide the seating area for the ring gear.

A *ring gear* is a steel ring with external teeth which is shrunk to the outer circumference of the flywheel (see Fig. 5-11). It is the drive link between the cranking motor pinion and the engine. Ring gears are designed to smoothly engage and disengage the cranking motor drive. The average gear ratio between the pinion and the ring gear is about 25:1.

Removal of Flywheel and Flywheel Housing To remove the flywheel, bend the lock plates free from the flywheel hex bolts. Install the lift hook as shown in Fig. 5-12, and then remove the flywheel hex

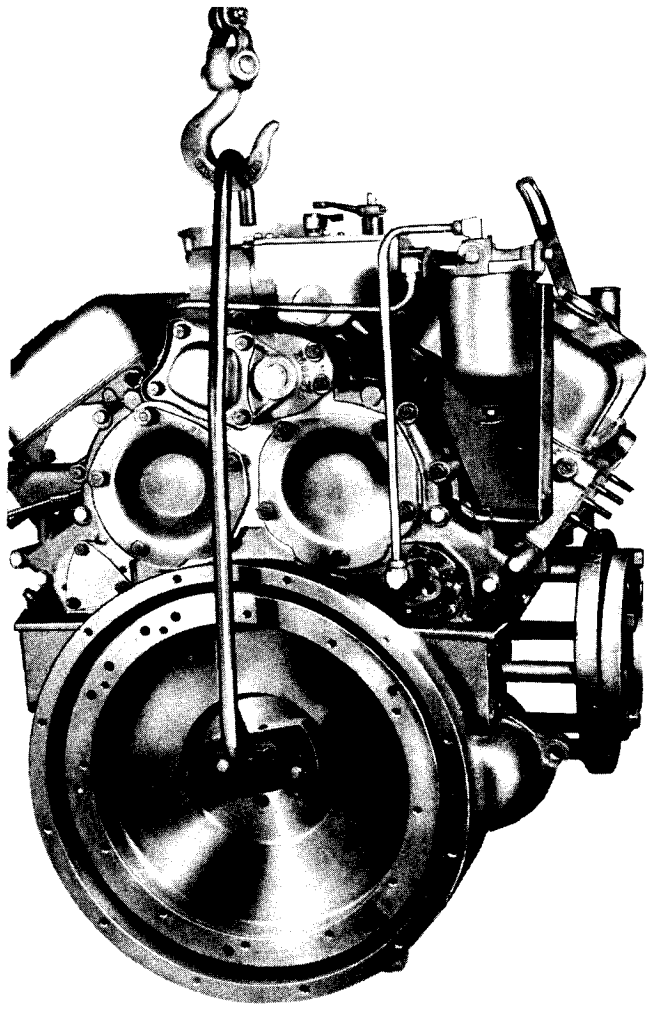


Fig. 5-12 Removing a flywheel. *(Detroit Diesel Allison, Division of General Motors Corportion.)*

bolt. When necessary use two hex screws threaded their entire length to act as jack screws to pull the flywheel from the crankshaft. Using a sling and lift, raise the flywheel housing from the cylinder block.

Vibration Damper Diesel engines which are required to operate throughout a wide speed range are protected against normal operation frequencies, vibration (roughness), and stress, by means of a vibration damper. Two types of vibration dampers are used: rubber element and viscous element.

The *rubber-element damper* is made of an inner iron-alloy steel flange or has a mounting facility, and an outer cast-iron alloy weight assembly (inertia mass). The inner flange is bonded to the outer weight by a rubber compound (Fig. 5-13).

The *viscous damper* is a two-piece housing. A weight (inertia mass) and a special greaselike fluid is placed between the two pieces which then are welded together. The clearance between the housing and the weight is about 0.010 in [0.25 mm] on all sides. It is this space which is filled by the viscous fluid (Fig. 5-14).

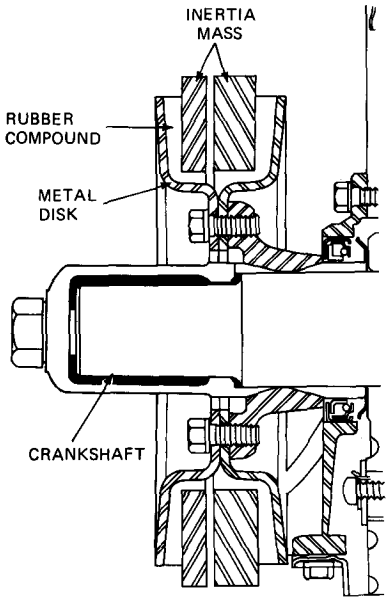


Fig. 5-13 Cross-sectional view of an installed rubber-element vibration damper.

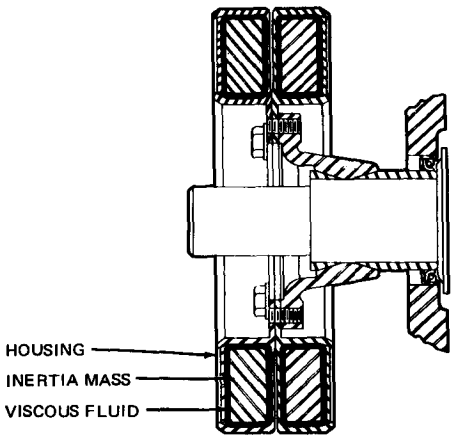


Fig. 5-14 Cross-sectional view of an installed viscous vibration damper.

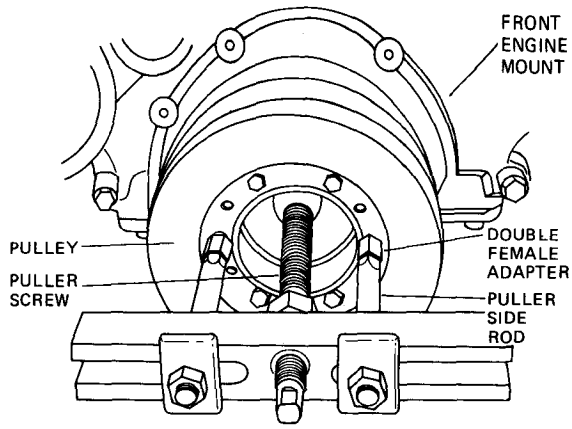


Fig. 5-15 Removing a viscous vibration damper.

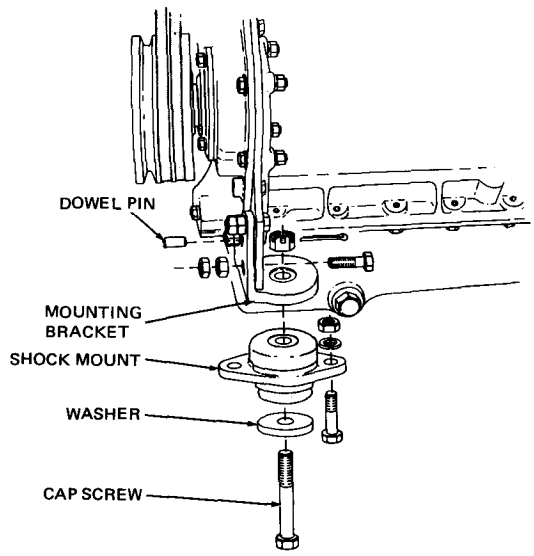


Fig. 5-16 Exploded view of engine front support. *(Allis-Chalmers Corp. Engine Division.)*

Removal of Crankshaft Pulley, Vibration Damper, and Front-mounting Bracket Some crankshaft pulleys and vibration dampers are bolted together, press-fitted, and keyed to the crankshaft; some are separately keyed and are pressed onto the crankshaft; others are bolted and doweled to a hub which is keyed and pressed onto the crankshaft. Regardless of the crankshaft pulley and vibration damper arrangement, always use a puller similar to the one shown in Fig. 5-15. *Never* drive the vibration damper assembly from the crankshaft assembly with a hammer. Improper removal will damage a vibration damper as it is precision-built for a close fit.

It is common practice to replace the viscous vibration damper during major engine overhauls. After removing the hex bolts from the front-mounting bracket, remove and discard the synthetic liners but retain the mounting bracket and cap as a unit. One of many engine front-mountiing brackets is shown in Fig. 5-16.

Oil Pan The oil pan is the reservoir for the lubrication system. It allows sediment to settle at the bottom. In addition it dissipates heat by radiation from the external walls or by use of internal or external radiation devices.

The oil pans used on diesel engines are machined cast iron, cast aluminum alloy, or metal-stamped. To strengthen the oil pan, internal and external reinforcement struts are integrally cast or pressed. The oil pan usually is constructed as a single unit. Less common are the two-piece oil pans (designed for special applications) which have an upper and lower section. Most oil pans have a large rear sump. When the engine position or the operating condition does not exceed a 10° longitudinal incline, flat oil pans are used. Some pans have large inspection covers and clean-out covers with drain plugs, while others have only a drain plug. Some have magnetic chip detectors. All oil pans have oil baffles (separator plates) to prevent the lubricating oil from splashing onto the connecting rods. Some engines use a steel ribbon-type oil level indicator (dipstick) whereas others have high and low oil-level check point plugs.

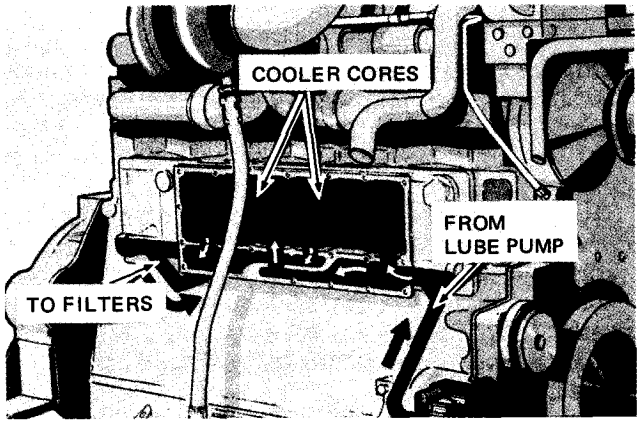


Fig. 5-17 Schematic view of oil flow through the oil coolers. *(Cummins Engine Company, Inc.)*

Oil Cooler The lubricant temperature must be kept within 180 to 250°F [82 to 121°C] if it is to maintain viscosity and absorb and dissipate heat. Under normal conditions a safe operating temperature can be achieved by increasing oil pan capacity. However, if the equipment is operating on a slope, the rotating components may be hitting the oil, thereby causing the oil temperature to increase.

An oil cooler can more effectively control oil temperature than the system previously mentioned. As illustrated in Figs. 5-17 and 5-18, oil is first pumped through the oil cooler, where it is cooled. From there is passes through the oil filter, and finally into the lubrication system.

Some oil coolers have many copper tubes welded or soldered to a seal ring. The assembly is sealed in a shell-type housing. Coolant is passed from one end to the other through the copper tubes. Lubricant enters the shell at one end, surrounds the tubes, and leaves the shell at the other end. The coolant usually enters in the direction opposite to the lubricant. (This is a very effective cooling method.) With other types of oil coolers, the cooler is connected directly to the lubrication pump or main oil gallery by an opening in the cylinder block. Both types of oil coolers use a relief valve to supply the engine with oil in case of an oil-flow blockage.

Lubrication Pump Most diesel engines use gear-type pumps to circulate sufficient oil to lubricate, cool, clean, and seal the components. Engines used in in-track or wheel-type loaders or dozers require an additional scavenging gear pump or a tube scavenging system to maintain a constant supply to the lubrication pump when the machine is working on a grade (see Fig. 5-18).

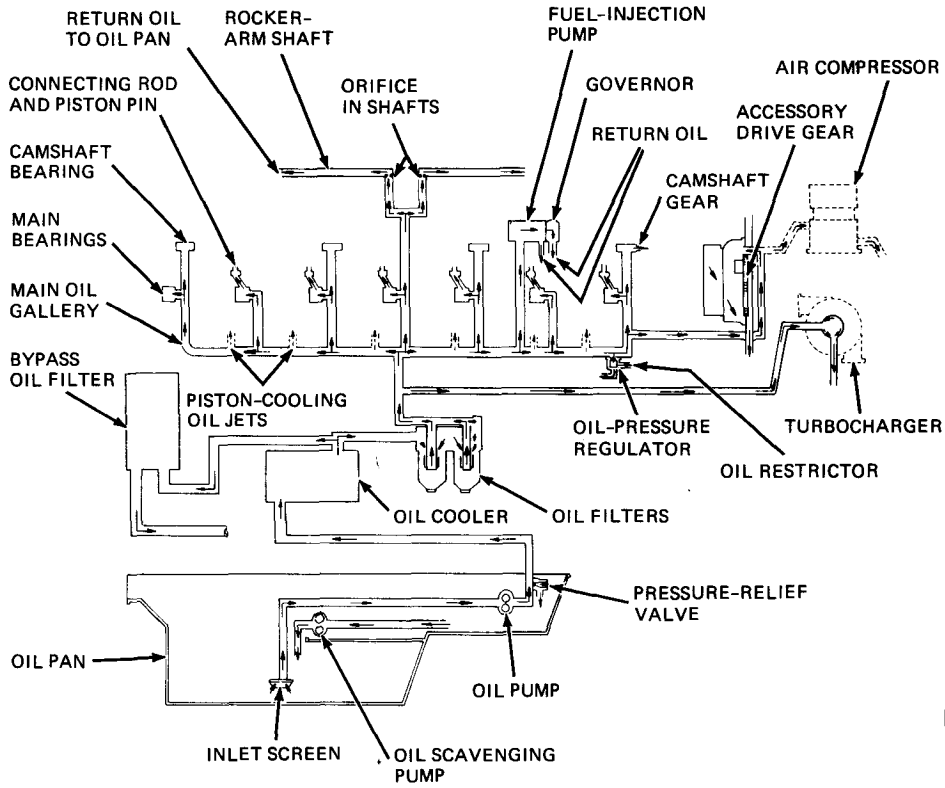


Fig. 5-18 Schematic view of engine-lubricating oil-flow diagram. *(Allis-Chalmers Corp. Engine Division.)*

The lubrication pump is driven directly from the crankshaft timing gear, through an idler, or from a gear on the camshaft. The oil pressure is maintained within the engine through the close tolerance of the restrictive oil passages and drillings. The system is protected from overpressurization by a relief valve.

All oil pumps are of positive displacement design, and therefore require a valve to relieve displacement once the maximum operating pressure has been reached.

Since the pumping elements form a near-positive seal between themselves and the housing, they have very little volumetric slip when the pressure increases at the discharge port. The efficiency of any pump depends on the design of its rotating members and its ability to maintain its sealing effectiveness at various pressures and temperatures.

Pump Rating Whether a pump is positive or non-positive, it is rated according to its performance. Performance is judged by the specific pump volume at a specified rpm against a fixed resistance measured in psi [kPa].

Rotary Pumps Rotary pumps are generally classified according to the type and construction of their rotating members. The three most common rotary pumps used as lubrication pumps are: the external gear type, the internal gear type, and the gerotor type.

External Gear-type Pump In the external gear-type pump, fluid under atmospheric pressure exists at the inlet (Fig. 5-19). As the power source rotates the drive gear (which is in mesh with the driven gear), a partial vacuum is created at the inlet side of the pump. When the gear teeth unmesh, fluid flows to fill in the space. This fluid is carried in an opposite direction around the pockets formed between the gear teeth, the wear plates, and the center section (the housing). These components and the oil form a seal; therefore, fluid cannot pass to the inlet side of the pump. As the gear teeth mesh on the outlet side, they force the fluid out of both pockets against the system pressure.

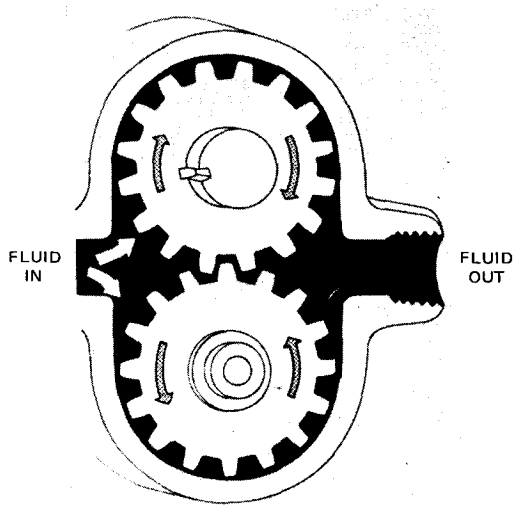


Fig 5-19 Schematic view of a gear-type pump.

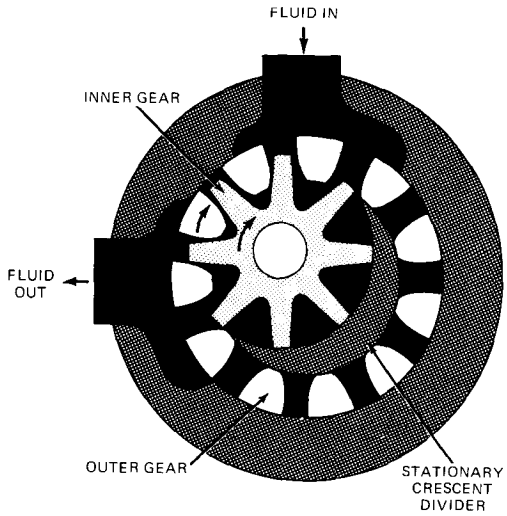


Fig. 5-20 Schematic view of an internal gear pump.

Internal Gear Pump The drive gear in an internal gear pump is an inner gear with outward projecting teeth (Fig. 5-20). The teeth of the outer gear (driven gear) project inward and are in mesh with the inner gear teeth.

The drive shaft of the pump is set off-center in a circular chamber. This chamber is the bearing and support of the outer gear. Opposite to the inlet and outlet port there is a crescent-shaped seal which is machined into the pump housing. This seal is positioned between the gears, providing them with a close clearance.

The pumping principle of the internal gear pump follows the familiar pattern of all other gear pumps. The shaft rotates the inner gear which, in turn, causes the outer gear to rotate. Since the two gears are in mesh, eveything within the chamber rotates (except the crescent). This motion traps oil between the gear teeth as it passes the crescent. It is then carried between the gear teeth from the inlet side to the outlet side. From there it is forced out of the pump by the meshing of the gears. As the fluid is carried away from the intake side of the pump, pressure is reduced, allowing more fluid to enter.

Gerotor Pump The gerotor pumping element consists of a pair of strange-looking gears, one within the other, in a housing (see Fig. 5-21). The inner gear, which has always one tooth less than the outer gear, is the drive gear. At least four teeth at a time are in sliding mesh with the outer gear ring. At all times one pair of teeth is in full mesh position.

In Fig. 5-21 the full mesh position is shown at the top (*X*). Note that when the inner gear is driven, the inlet pockets (1–2) increase in size while the discharge pockets (3–4) decrease in size. By following the diagram you will notice that the pockets on the right-hand side increase while those on the left-hand side decrease in size. From this you can determine that the pump intake is on the right- and the discharge is on the left-hand pump side.

The advantage of this type of pump design is that the outer gear rotates at a greatly reduced speed in comparison to that of the drive gear. This reduces component wear.

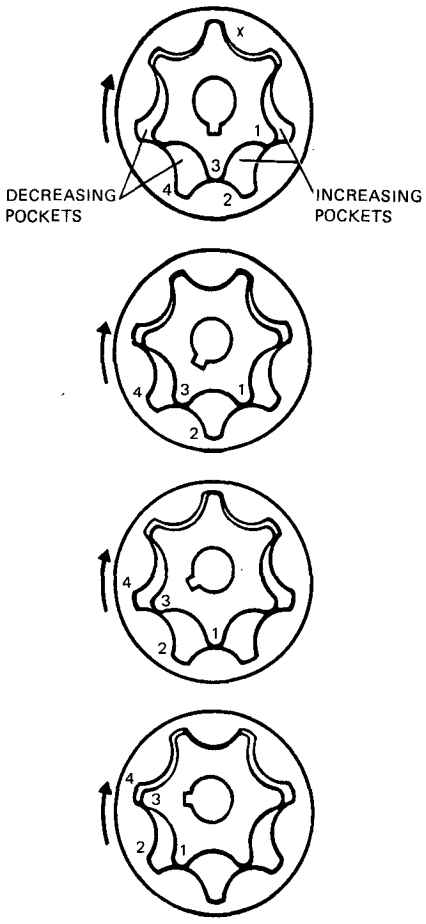


Fig. 5-21 Schematic view of a gerotor pump.

Removal of Oil Pan and Oil Pump To remove the oil pan, turn the engine over and remove the hex bolts which hold the oil pan to the crankcase. If the oil pan is dowel-fitted, remove the dowel bolts with a soft-face hammer. Do not drive a chisel or screwdriver between the oil pan and crankcase because this will damage the mating surfaces. Use a lead hammer and gently tap the oil pan loose.

Remove the necessary tube connections. Loosen and remove the oil pump from its mounting.

NOTE: Some oil pumps are doweled and may have shims between the mounting surfaces for adjusting drive gear backlash. Take extra care when loosening these pumps from their mountings.

Timing-gear Cover The timing-gear cover is usually cast as one piece and is commonly mounted to the front of the cylinder block. On some engines, however, the timing gear cover and the flywheel housing are designed as a single unit. See Unit 16.

Removal of Timing-gear Cover The timing-gear cover can be removed easily from small engines. However, when the timing gears are at the rear of the engine and the engine is large, the following procedures should be followed:

1. Attach a suitable hoist and sling to the timing-gear (cover) housing.
2. Remove the bolts which secure the timing-gear housing to the crankcase and cylinder block.
3. Remove the timing-gear housing, taking care not to damage the inner bearings which support the various drives and idler gears. When the timing gears are at the rear, only a front cover which has the crankshaft seal and bearing support for the front-mounting brackets is used.

Camshaft Camshafts are made from special high-tensile strength iron alloy. The bearing journals and cam lobes are heat-treated and precision-ground. Usually one bearing journal is positioned between two cam lobes to support the camshaft. The contour of the lobes varies with the engine design to conform to predetermined valve duration, valve lift height, and lift velocity (the speed with which the valves open and close). Cummins engines, Detroit Diesel engines, and the 3000 Caterpillar Series diesel engine use one extra lobe for each cylinder to actuate the injector-operating mechanism.

V engines may have two camshafts which rotate in opposite directions (Fig. 5-22), or they may have only one camshaft (Fig. 5-23) to actuate the valve mechanism of the left- and right-hand cylinder banks. Some in-line engines have two camshafts; one camshaft actuates the intake valve mechanism and the other camshaft actuates the exhaust valve mechanism. See Fig. 5-6.

Thrust bearings, thrust plates, or thrust washers, located between the camshaft gear and the shoulder of the first journal, position the camshaft in the cylinder block. Some engines are designed with a spring-loaded plunger to hold the camshaft in place, others have two thrust washers to take up the camshaft thrust. (It is the helical gear that causes the thrust on the camshaft.) One washer is located between the rear thrust surface and the other between the bearing and camshaft gear. In the latter design, the camshaft is held in place by the camshaft gear.

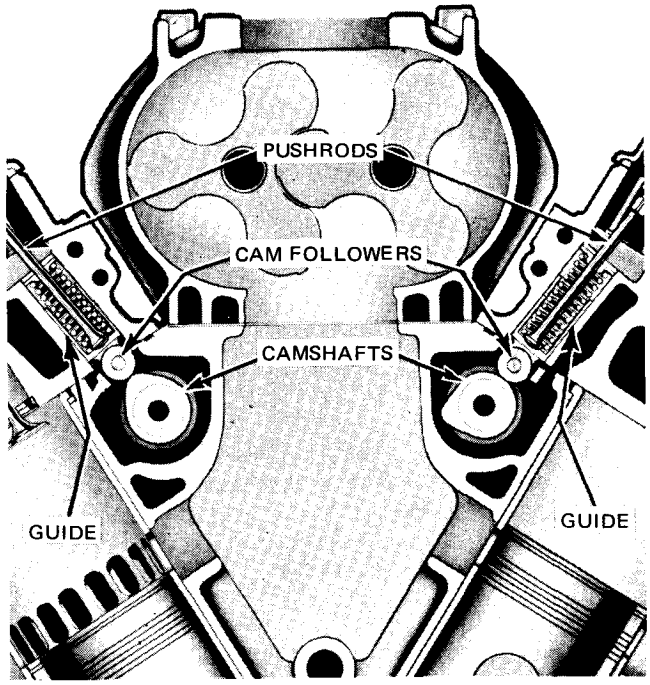


Fig. 5-22 View of a V engine having two camshafts. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

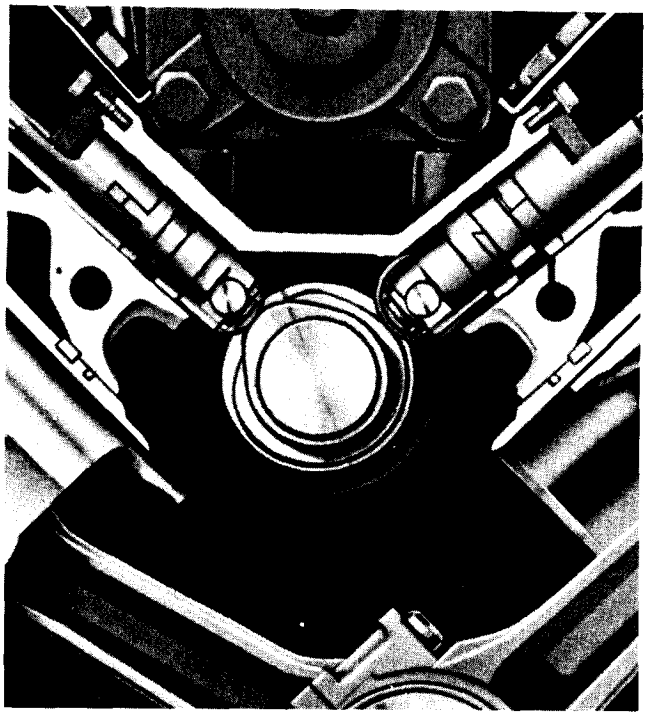


Fig. 5-23 View of a V engine having one camshaft. *(Cummins Engine Company, Inc.)*

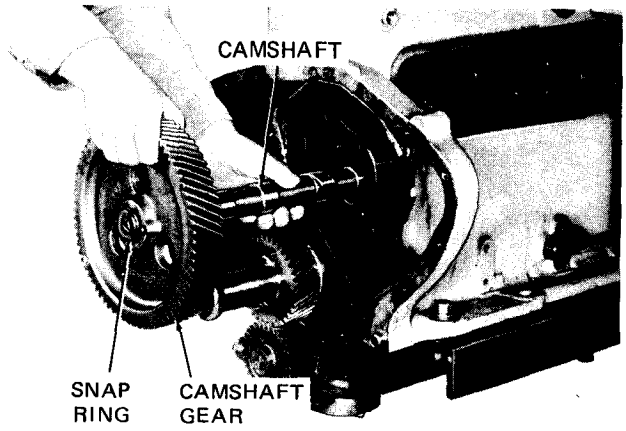


Fig. 5-24 Removing the camshaft. *(Allis-Chalmers Corp. Engine Division.)*

Removal of Camshaft, Timing Gears, and Accessory Drive Gears It is wise to measure the timing-gear train for excessive backlash before removing the camshaft or the accessory gears to determine if they are reusable. However, this is only possible when the wear on bearings and bushings does not exceed service manual specifications.

In most cases the camshaft and gear can be removed as a unit once the thrust plate bolts are removed (see Fig. 5-24). When it is necessary to remove the camshaft timing gear, always use a suitable puller. Take care when removing the idler accessory drive gears to arrange them in a systematic order.

Connecting Rod Connecting rods for the trunk-type piston are made of drop-forged steel, with one small and one large closed hub (see Fig. 5-25). The two connecting-rod ends are first bored, then the large end is cut in half, holes are drilled and tapped, and its surface machined. Then they are bolted together with specially designed bolts or with stud bolts and nuts. They are again machined to a precise dimension, heat-treated, and electronically balanced.

Some connecting rods are center-drilled to provide lubricant to the piston pin. Some have, in addition, an orifice at the lower end which is press-fitted into the counterbore to control the oil flow. These connecting rods require helical grooved bushings with a space between them to assure good lubrication of the piston-pin bushings. Many engine manufacturers use a controlled oil flow (from the spray nozzle) to lubricate the piston pin and to cool the underside of the piston head. (See Unit 13, "Lubrication Pump and Oil Cooler.")

Another connecting-rod design has a funnel shape cut in the upper end of the rod to store the oil. This oil is used to supply lubricant to the single- or double-radial or spiral piston-pin bushing. Yet another connecting rod design is one which has serrated mating surfaces to increase rigidity and to place the load uniformly on both the connecting-rod cap and the connecting rod. When the (larger) end of the connecting rod will not pass through the cylinder sleeve because of its size in relation to the cylinder bore size, manufacturers simply change the separation point of the cap. This changes the connecting-rod bolt position, which reduces its outside dimension.

The connecting rod shown in Fig 5-25*d,* is a crosshead piston type used with the Detroit Diesel 71, 92, and 149 Series engines. You will notice that the piston-pin bore and bushings have been replaced with a saddle. The piston pin is held rigidly by two bolts which reach from below through the saddle and into a special nut inserted in the piston pin. Note the bending stresses imposed on the piston pin in a conventional trunk-type piston as opposed to the central force on the crosshead piston.

All connecting-rod bolts, or stud bolts, are made from special steel and are specially designed to assure proper alignment between the rod and the cap and to prevent any spreading of the connecting-rod bore radius under maximum combustion pressure.

Pistons Today's diesel engines operate at a higher speed and, at the same time, produce more power than in previous years. The pistons (balanced to close limits) and the piston rings must meet this challenge. Most pistons, therefore, are manufactured of an aluminum alloy made chiefly of magnesium and copper or of magnesium and nickel. This alloy is light in comparison to its size, yet it is strong enough to withstand pressure, speed, and quick changes in direction. More important, pistons of this composition are able to transmit heat three times faster than malleable iron pistons. However, because of the thermal expansion rate, piston dimensions must be precise in order to ensure the exact clearance. (Silicon is added to the aluminum alloy to reduce thermal expansion.)

There are many different types of pistons in use today, the most dissimilar being the trunk and crosshead designs.

Trunk Pistons Most motortruck engines, earth-moving machinery, light marine vessels, and farm

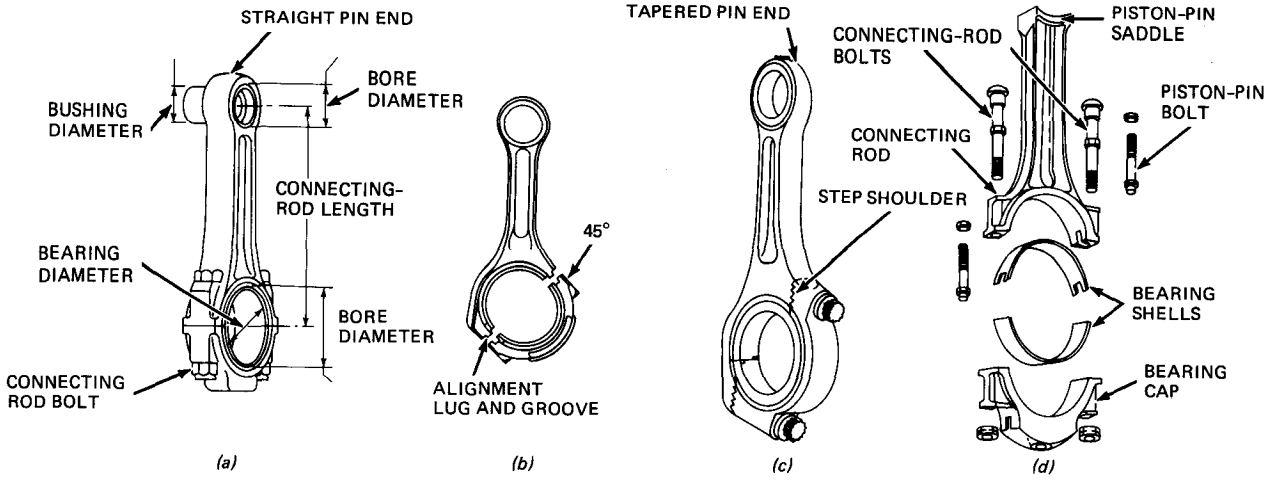


Fig. 5-25 Connecting-rod design: (*a*) to (*c*) trunk-type pistons, (*d*) crosshead-type pistons.

tractor engines use trunk-type pistons. Exceptions are some Detroit Diesel 71 Series, all 92 Series, and all 149 Series engines. These engines use crosshead pistons.

Trunk-type pistons are one piece, precision-machined, internally reinforced, and designed to transfer heat from the piston crown to the ring groove and skirt area (see Fig. 5-26). The pistons are usually splash-cooled at the inner side of the piston crown and indirectly cooled through conduction and convection. However, some are lubricated and cooled through a jet oil spray into a cooling gallery cast in the piston crown. (See Unit 11, "Piston and Rings.") This lowers the bowl temperature by about 104°F [58°C] from the average of about 610°F [320°C]. Some trunk pistons are tin-plated to reduce scuffing and to permit a closer fit.

The area above the rings is known as the *piston crown.* The crown diameter is slightly smaller than the diameter of the ring area and is tapered to overcome distortion when the piston becomes hot. Unfortunately this creates a high dead-air volume and its air cannot be used for combustion, thus reducing efficiency and increasing the hydrocarbon emission. To compensate, the top ring groove is moved upward, thereby reducing the dead volume by about 50 percent. The top of the crown is irregularly shaped and forms the combustion chamber bowl. High compression ratio engines using direct-injection or combustion chamber design require valve reliefs to prevent the valves from interfering with the piston when in TDC position.

Caterpillar engines which use precombustion chambers have a stainless steel heat plug cast into the top of the crown. The heat plug prevents the high pressure and high heat which escape from the combustion chamber orifice from damaging the aluminum surface. This plug absorbs the heat, then transfers it to the underside of the piston crown where the heat dissipates.

The ring groove area is located below the crown. The ring grooves, which hold and guide the rings, are diverse in shape and spacing. The surface between them is called the *ring land.*

Most pistons are equipped with a cast-iron band or BOND-O-LOC insert to reduce the wear rate of the top ring groove. Behind and slightly below the lower ring groove, oilholes are drilled through the piston wall to allow the oil to escape after it is wiped off the cylinder wall by the oil-control rings. Some engines are designed to utilize this escaped oil to cool the crown of the piston and to lubricate the piston-pin bushings.

The region below the ring grooves is the piston skirt area. It may be divided into three sections; the area below the ring grooves, the pin bore, and the skirt area.

The large skirt area spreads the force evenly against the cylinder walls thereby preventing the piston from cocking as it moves up and down. The piston may have either a full skirt or a semislipper-type skirt. When the stroke equals the bore dimension, the engine is said to be "square." When the stroke is shorter than the diameter of the bore, it is said to be "undersquare." In either case, the connecting rod or the crankshaft could interfere with the piston skirt when the crankpin is at a 90° angle; for this reason the skirt is partly removed.

The surface of the piston skirt (which reduces friction and scuffing) can have various finishes. A popular finish is the interrupted surface. It has high points

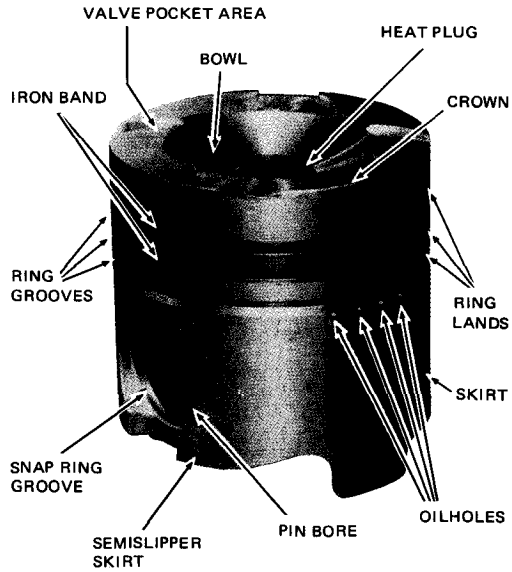


Fig. 5-26 View of trunk-type piston design, with terminology. *(Caterpillar Tractor Co.)*

and plateaus parallel to the top of the piston. Another popular finish is the diamond-shaped raised surface. On their large engines Cummins Engine Company, Inc., uses Teflon inserts in the piston skirts to reduce cylinder sleeve vibration and piston and sleeve pitting (Fig. 5-27).

Large-diameter aluminum pistons are usually *cam-ground*. This means that the piston is oval with the narrowest diameter across the piston-pin bore. This feature is necessary because the added material used to strengthen the piston-pin area does not allow the piston to expand uniformly when it becomes hot. However, when the piston approaches operating temperature, it expands to become round.

Two-cycle Detroit Diesel engines have oil-ring grooves in the lower part of the skirt which seal (block) the scavenging air to the crankcase (Fig. 5-28) and prevent oil entering from the crankcase into the air box. Holes drilled through the walls of the piston, below and through the lower oil groove, allow any excess oil which has collected to return to the crankcase.

The reinforced piston-pin bore (*boss*) into which the piston pin is fitted is precision honed or machined to accommodate the two helical oil groove bushings, which provide bearings for the floating piston pin. The piston pin is the link between the piston and the connecting rod.

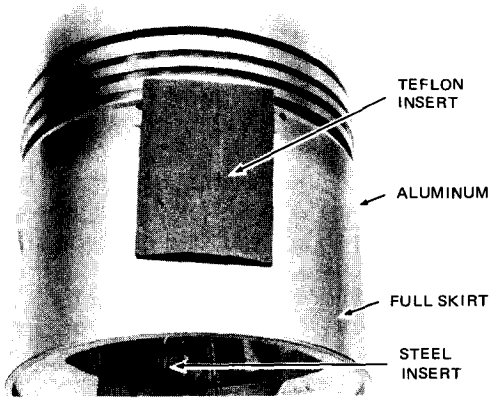


Fig. 5-27 View of Cummins insert on piston skirt. *(Cummins Engine Company, Inc.)*

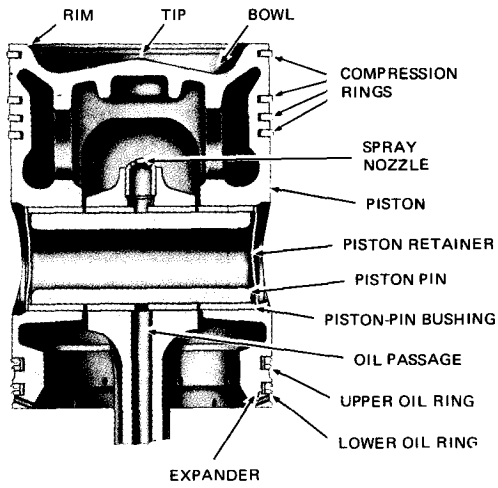


Fig. 5-28 Sectional view of a Detroit trunk piston. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

Piston Pin The hollow piston pins are made from special-quality high-carbon steel to withstand fatigue failure. The pin is hardened and ground, then its surface is lapped and polished to extremely close tolerances to reduce friction and wear.

Most diesel engines use a full-floating piston pin. This means that the piston pin is free to move in the connecting-rod bushing and in the piston-pin bore.

Most piston-pin bore ends are grooved, with snap rings fitted into the grooves to hold the piston pin in place. Some manufacturers provide a clamp bolt to hold the piston pin to the connecting rod while others have the connecting rod bolted directly to the piston pin. Some piston pin bores are slightly enlarged to accommodate the piston-pin retainers. On Detroit Diesel two-cycle engines these retainers prevent air from passing by the piston-pin bore and entering the crankcase. On many pistons, the piston-pin boss area is tapered off to allow the piston pin to flex. This technique reduces pin seizure and prevents the pin bore from cracking.

Crosshead Piston The crosshead piston used in Detroit Diesel 71, 92, and 149 T Series engines consists of two major pieces: the piston crown, which has the compression-ring grooves, and the skirt which has two oil ring grooves. These are held together as a unit by the piston pin. Those engines also employ a piston ring as a seal between the piston crown and the skirt.

The two major pieces of the floating piston in the nonturbocharged 149 Series engine consist of the carrier and the piston. These are held together by a snap ring.

Detroit Diesel crosshead pistons are designed with a half-bearing which is locked in the upper half of the piston-pin bore (see Fig. 5-29). The connecting rod is bolted to the piston pin. The combustion force of the floating piston (149 Series) is transmitted from the piston to the thrust washer onto the carrier, half-bearing, piston pin, connecting rod, and crankshaft. In the 71, 92, and 149 Series the force of the combustion is from the piston crown directly onto the half-bearing and the piston pin. The skirt, being separate,

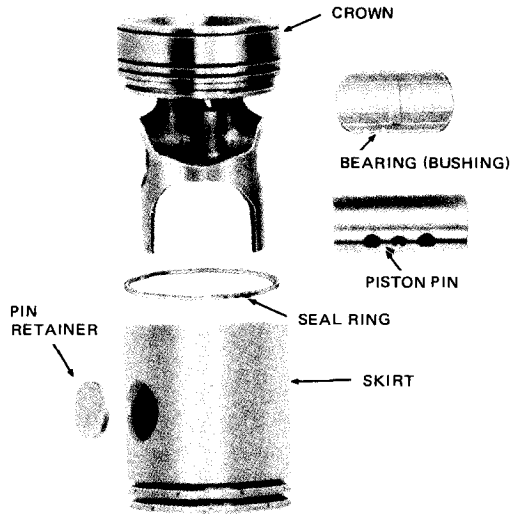


Fig. 5-29 Exploded view of a Detroit crosshead piston. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

is freed from vertical load distortion and thermal distortion since the hotter crown expands during engine operation.

In the Detroit Diesel 71, 92, and 149 T Series engines, oil under pressure is forced through a drilled passage in the connecting rod, through the piston pin, and then into the cocktail shaker. This increases lubrication and reduces piston temperature.

In the Detroit Diesel (nonturbocharged) 149 Series floating-piston design, oil under pressure is forced through the bushing and carrier, onto the piston. A percentage of oil is also forced along the groove of the half-bearing to the area between the carrier and the piston, where it is trapped during piston reciprocation; a percentage of oil drains through two holes in the carrier into the crankcase.

Removal of Piston and Connecting-rod Assembly Turn the engine right side up and clean all carbon from the upper inside of the cylinder sleeve. If the ring travel ridge is so deep that it is difficult to remove the piston, the ridge must be removed. (Use a hone or a ridge reaming tool similar to that shown in Fig. 5-30.) Install the ridge-removal tool so that the cutting guide is below the ridge and the lower part of the cutting tool is tight against the cylinder sleeve. Hold the cylinder sleeve with a clamp to prevent it from turning in the cylinder block. Release the spring force. This will force the cutting blades outward and produce a clean cut when the tool is turning.

Turn the engine 90° and remove the hex bolts or cotter keys and nuts from the connecting rods. Remove the caps. If the caps are excessively tight, tap them gently with a lead hammer to break them loose. Remove the half-bearing from the rod and cap. Tape mating bearing shells together and make a note from which connecting rod and cylinder you have taken the bearings so that you can correctly diagnose the cause of failure. Place components which are to be reused in a safe place. With a soft tool, push the connecting rod and piston out of the cylinder bore. (Hold the piston as it emerges from the bore.) Mark each connecting rod and cap as soon as you remove it, if not already identified by the manufacturer.

CAUTION Take care not to damage the connecting-rod journals or the finish of the cylinder sleeves when removing the piston assembly.

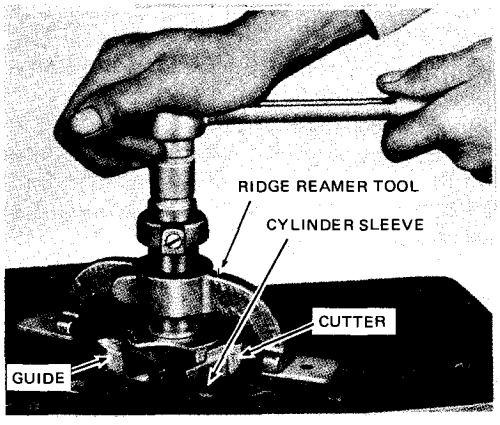


Fig. 5-30 Ridge reaming. *(Allis-Chalmers Corp. Engine Division.)*



Fig. 5-31 Removing piston rings. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

Removal of Piston Rings and Connecting Rods from Pistons To remove a trunk-type piston from the connecting rod, first hold the connecting rod in a vise fitted with protected jaws. Use a piston-ring installing tool, as shown in Fig. 5-31, to remove the rings. Do not break the rings to remove them as this could damage either the ring lands or the ring grooves. Next, remove the two snap rings, and push the piston pin from the piston and connecting rod, while holding the piston.

To remove the connecting rod from a crosshead piston, clamp the rod in a vise fitted with protected jaws. To remove the piston-pin retainers, use a small punch and drive a hole into one of the retainers and pry it out of the pin bore. Repeat this procedure with the other piston-pin retainer. Loosen the two bolts which secure the connecting rod to the piston pin and then remove the connecting-rod assembly from the vise. Place the piston, crown down, on the work bench. Remove the two bolts and spacers, and the connecting rod. Push out the piston pin and lift the skirt, the seal ring, and the half-bearing from the piston crown.

Cylinder Sleeve Generally speaking, two types of cylinder sleeves (wet and dry) are used (see Fig. 5-32). Both types are made from cast-iron alloy and machined to dimension. The inner wall is then surface-hardened, ground, and honed, and sometimes chemically treated. Since the degree of cylinder inner-surface hardness varies among manufacturers, piston rings should be selected from those recommended by the applicable manufacturer, to obtain maximum piston and sleeve service life.

Both the wet-type and dry-type cylinder sleeves are inserted into the cylinder bore from the top, and are

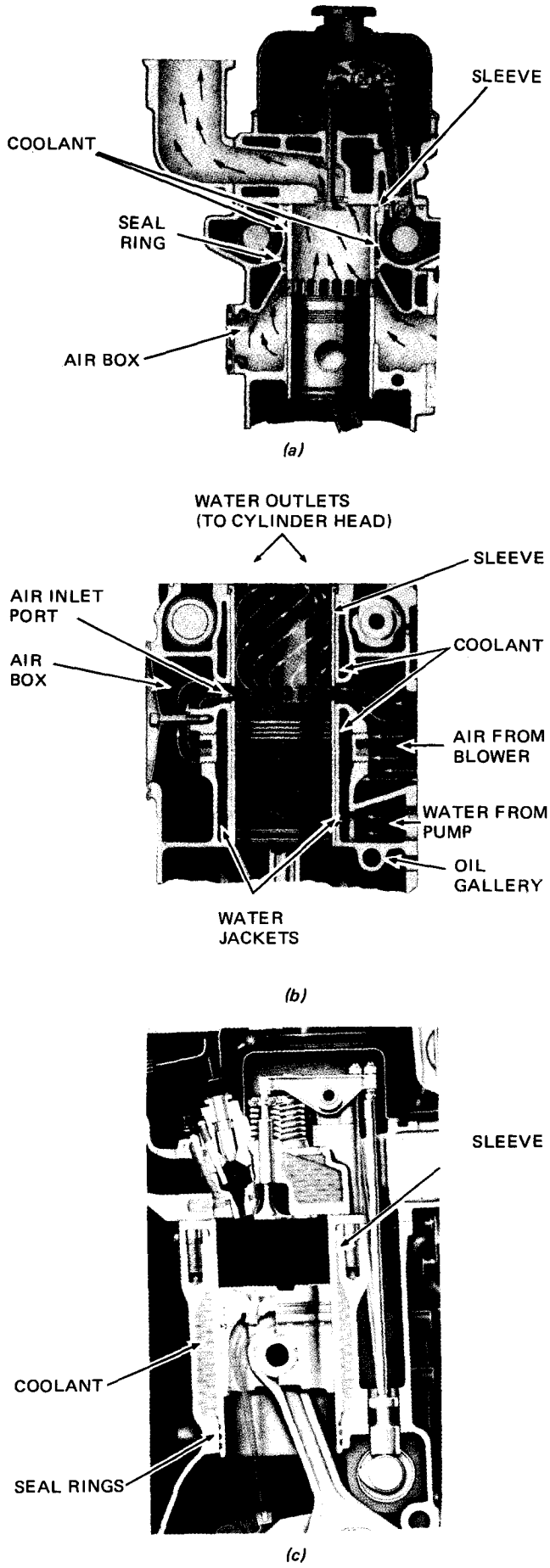


Fig. 5-32 Sectional view of sleeves installed: (*a*) wet and dry sleeve, (*b*) dry sleeve, (*c*) wet sleeve.

held at the top by the flange which fits into the machined counterbore in the cylinder block. The cylinder-head gasket, or individual-head gasket, is compressed between the flange and the cylinder head, holding the cylinder sleeve in place and sealing off the coolant, lubricating oil, and pressure. The wet-type cylinder sleeve uses silicon or Buna seal rings fitted into grooves, either in the lower part of the cylinder bore or in the lower outside circumference of the cylinder sleeve (see Fig. 5-32). This seals off the coolant, preventing it from leaking into the oil pan.

In the Detroit Diesel 53, 91, and 149 Series engines the seal is placed between the flange and the water jacket. Additionally, the upper half of the cylinder sleeve is (a wet type) surrounded by the water jacket. The lower half, which is a dry-type sleeve, and includes the oval-shaped inlet ports, is surrounded by the scavenging air (Fig. 5-32*a*).

The wet-type cylinder sleeve of a four-cycle engine is surrounded completely by the water jacket. It extends from the sealing rings to the flange of the cylinder sleeve (Fig. 5-32*c*). The dry-type cylinder sleeve used on four-cycle engines is thinner; however, the total material thickness of the cylinder bore and cylinder sleeve is nearly the same as that of the wet-type cylinder sleeve.

The Detroit Diesel 71 Series two-cycle engine, which uses dry-type cylinder sleeves, has an upper and lower water jacket divided at the inlet port, but connected by hollow struts. Coolant from the water pump enters the lower water jacket, and passes through the hollow struts into the upper water jacket, and then passes into the cylinder head (see Fig. 5-32*b*).

Removal of Cylinder Sleeves The following rules apply to the removal of all cylinder sleeves:

1. Do not use a punch and hammer or a prybar to remove a cylinder sleeve because they can damage the cylinder block or the sleeve. Use only the correct pullers and clamps (Fig. 5-33).
2. To remove a sleeve using a slide hammer, insert the lower puller clamp by twisting it on the tapered seat so that it will slide down the sleeve. As the clamp clears the bottom of the sleeve it will fall back on its tapered seat.
3. Slide the upper clamp into place against the top end of the sleeve. Hold the puller rod, and thereby the lower clamp, against the cylinder sleeve. Using sharp blows, slide the hammer puller weight against its stop to release the sleeve from its bore.
4. When an aluminum block is used, immerse the cylinder block in water heated to 180°F [82°C] or force hot water through the cylinder block. Allow sufficient time for the bore to expand so that less effort will be required to remove the sleeve.

NOTE: If for some reason the cylinder sleeve is to be replaced but the crankshaft is to remain in place, you must protect (with cardboard or gasket material) the crankshaft and the inside of the crankcase from contaminants and from coolant fluid.

Crankshaft The crankshaft of almost all diesel engines is made from drop-forged and heat-treated

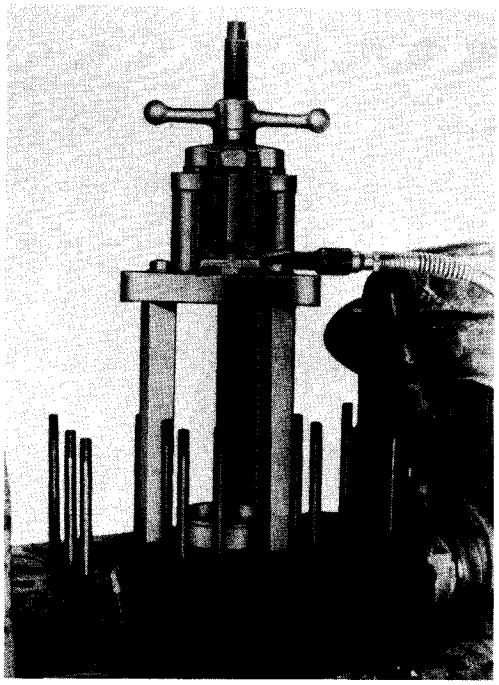


Fig. 5-33 Removing cylinder sleeve.

steel, to assure the utmost strength and durability (see Fig 1-2). The accurately ground main and connecting-rod journals are induction-hardened. Counterweights are integrally forged with the crank or bolted to the crankshaft. All crankshafts are dynamically balanced for proper weight distribution to assure even force during rotation. They are T-drilled to pass lubricating oil (under pressure) from the main bearings to the connecting-rod bearings. One main journal is especially machined with two thrust surfaces to control the end thrust in conjunction with thrust washers. Sometimes the end play is controlled by a set of special main-bearing shells.

The number of main journals and connecting-rod journals depends on the number of cylinders and the design (in-line or V block). The surface area of the journals is governed by the potential engine speed and combustion pressure. The crankshaft-throws arrangement determines the firing order.

Removal of Crankshaft Main Bearing

1. Turn the engine upside down and remove the cotter keys and nuts (or hex bolts) from the main-bearing caps.
2. Make sure that all bearing caps are marked so that they can be installed later in their original location.
3. Remove the main-bearing caps from the dowels. Some manufacturers recommend the use of a special main-bearing-cap puller.
4. Using protective hooks, remove the crankshaft. Alternately, wrap two throws of the crankshaft with cloth to protect the bearing surface and then use a sling, as shown in Fig. 5-34, to hoist the crankshaft out of the upper bearings. Take care not to damage the threads or bend the studs (if used).
5. Remove the bearing shells from the cap and crankcase. Tape the mating halves of the bearing shells together after identifying their original position.
6. Immediately check the crankshaft for any other signs of heavy damage that cannot be corrected by reconditioning.
7. Store the crankshaft, well secured, in a protected place. Stand it on its flywheel flange to prevent crankshaft distortion.

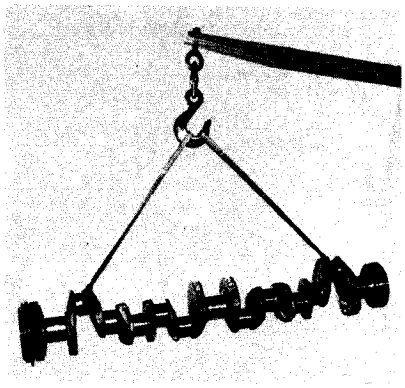


Fig. 5-34 Removing crankshaft using nylon slings. *(Caterpillar Tractor Co.)*

Cylinder Block Once you have removed all the components, you are left with the cylinder block. This main structural part of the engine is cast in one piece. It is made of cast-iron alloy with internal and external transverse members. Large diesel engine cylinder blocks are cast with a deep skirt whereas some of the smaller blocks are cast with a half-skirt. The deep skirt provides excellent rigidity and strength, and reduces noise. Together with the transverse members it assures accurate crankshaft alignment and prevents cylinder-block top-deck distortion. The half-skirt design is not quite as strong and creates a higher noise level during engine operation. The cylinder-sleeve support bores are so located within the cylinder block to prevent sleeve distortion and thereby allow the manufacturers to use a closer clearance between the piston and sleeve. To prevent crankshaft bending and vibration, each cylinder on in-line engines (or two cylinders on V-type engines) is supported by two main bearings. Newer smaller diesel engines in the displacement range of 4 to 10 L, such as the Detroit Diesel four-cycle Fuel Pincher, Case-Cummins Family 1 Series engine, Caterpillar 3208 Series engine, and International-Harvester D466 and 6.9-L engines, have a cylinder block design which does not use either a wet or dry sleeve. The cylinder is cast as an integral part of the cylinder block (see Fig. 5-35).

The walls of all cylinder sleeves, support bearing bores, upper half of the crankshaft, main bearings, camshaft, etc., and all openings and passages for

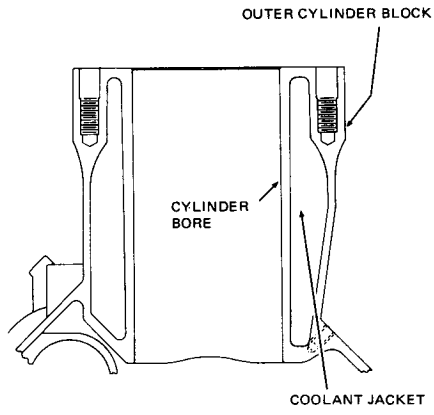


Fig. 5-35 Sectional view of one cylinder.

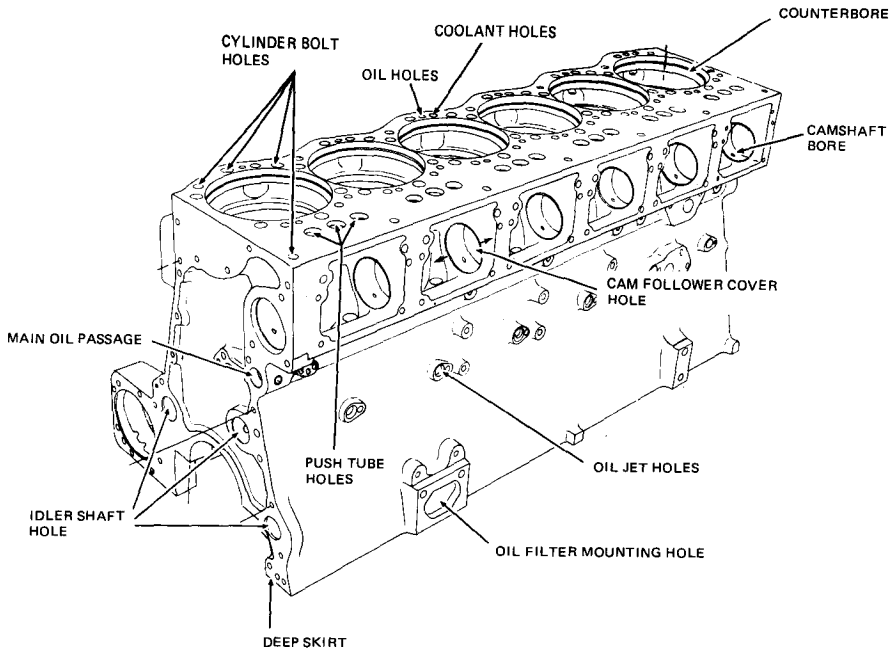


Fig. 5-36 Schematic view of a typical cylinder block. *(Cummins Engine Company, Inc.)*

the coolant and lubrication system, being part of the cylinder block, are integrally cast (Fig. 5-36). Detroit Diesel engines, in addition, have air-box (passage) openings within the cylinder block (see Fig. 5-32). The main bearings and the camshaft bores are line-bored or honed to assure longitudinal and horizontal alignment. Most cylinder blocks have one main oil gallery which extends lengthwise through the cylinder block. Internal passages direct oil from the main oil gallery to the crankshaft main bearings and through vertical passages to the rocker-arm assemblies, timing gears, fuel-injection pump, and the various components which require lubrication.

Cleaning Components Some components can be inspected for excessive wear or cause of failure before cleaning. Others need to be cleaned first and then followed through by inspection. Typical component cleaning procedure is as follows:

1. Remove all seals, gaskets, and plugs from the dissembled components.
2. Steam-clean and dry the dissambled components with compressed air. Units such as oil pans, cylinder blocks, cylinder heads, oil coolers, aftercoolers, valve covers, and rocker-arm assemblies should be cleaned immediately after they are disassembled to prevent accumulated grime and other foreign substances from congealing to their surfaces.
3. Use a glass-bead cleaner for components such as valves, pistons, cylinder heads, water pump housings, and impellers, etc. Bead size U.S. Sieve No. 70 is recommended with an operating pressure of not more than 90 psi [620.5 kPa].
4. Do *not* expose the components to the bead blast any longer than is absolutely necessary. This is especially important when cleaning soft material. Be sure to remove all glass-bead substance and other foreign material by washing the parts in solvent and then drying them with compressed air.
5. It is wise to clean all other components in a hot tank either as a unit or, if disassembled, in a wire-mesh basket. *(NOTE: Never clean soft metal parts in hot tanks.)* Check manufacturer's recommendations as to solution concentration, etc. Most solutions should be heated to 180 to 200°F [82 to 93°C].
6. Make certain that all coolant passages and oil galleries have been cleaned thoroughly and that the coolant jackets are free of scale.

Questions

1. List the steps to be taken when removing an engine.
2. What poor work habits, when removing an engine, could cause damage to components and create removal difficulties?
3. Why should all components be promptly examined when they have been removed from the engine?
4. Select a service manual for a particular engine. From the manual list the steps to be followed when disassembling this engine.
5. Outline the procedures to remove a piston assembly from the engine, the piston rings, and the piston from the connecting rod.
6. How would you remove a cylinder sleeve using the tools shown in Fig. 5-33?
7. Why should you tape and identify the connecting-rod shells and the main bearing shells upon disassembly?
8. When components have seals, plugs, etc., why should they be removed before cleaning the component?
9. How is the crankshaft protected against vibration and bending?
10. List 10 safety precautions to be followed when cleaning components with solvent, a hot tank, glass beads, and compressed air.

SECTION 2
ENGINE COMPONENTS
SERVICE
UNIT 6 • CYLINDER BLOCK

Inspecting Cylinder Block After the cylinder block has been properly cleaned and dried with compressed air, it should be moved to a flat surface for inspection. A thorough inspection will reveal whether it can be refinished and serviced, or whether is should be discarded.

Again, make sure that all solvent or hot tank solutions are removed. Check to determine if there is any loose scale present in the water jacket or passages and that the openings have not been reduced by corrosion. At the same time check for eroded or pitted water holes which could prevent proper sealing of gaskets or O rings (grommets). If applicable, use a counterboring tool and insert a sleeve to restore the coolant hole. Check for cracks, porosity, and leaks. Using dye penetrant over areas where flaws are suspected, apply developer over the dried surface. Flaws will be detectable by the appearance of solid or dotted lines of dye penetrant at the surface. Flaws will also be detectable by pressure-testing the cylinder block.

Pressure-testing Cylinder Block A cylinder block can crack open between the cylinder bores, the water jacket and crankcase, the water jacket and oil passages, the water jacket and air box, and in many other places. It may crack from overheating due to insufficient coolant and/or oil; from an improperly functioning coolant pump, fan, or shutter; from extremely high friction of one or more moving components within the engine; from inadequate cylinder-head torque; from vibration; or from internal or external casting damage due to mechanical failure of one or more components.

Many manufacturers recommend that the cylinder block be pressure-tested before any servicing takes place. Others do not give explicit instructions, relying, instead, on the mechanic's ingenuity in locating cracks or flaws. Lack of instructions may also be attributed to the fact that blocks have chronic locations where cracking takes place and which are known to all seasoned mechanics.

When the cylinder block warrants a pressure test, insert coolant-, coring-, and drill-plugs into the block. Seal all coolant openings with plates, gaskets, or O rings. When wet-type sleeves are used, also insert and position the cylinder sleeves.

Fill the coolant jacket with an antifreeze solution. Not only is its surface tension lower than that of water, permitting it to penetrate small cracks, but its color will also help you to locate any cracks. Pressurize the coolant passages to about 80 psi [551.6 kPa] and maintain the pressure for about 2 hours.

Another method (actually the most effective one in determining cylinder block cracks) is the use of a hot water tank. The same preparation just described is required with the exception that instead of antifreeze, compressed air is used.

After you have pressurized the coolant jacket to about 80 psi [551.6 kPa], immerse the cylinder block in the solution which has been heated to about 180°F [82°C]. After the cylinder block has reached the same temperature as the solution, again check the coolant-passage air pressure. Watch the solution for bubbles as they indicate a leak.

CAUTION Make certain that the bubbles are not caused by poor cylinder seals, sealing plates, O rings, gaskets, or plugs.

Check all mounting surfaces for flatness with a straightedge. Check for any raised areas at the stud or bolt holes. If required, refinish surfaces according to the manufacturer's recommended procedures.

Check all threaded holes and, when necessary, restore any damaged threads. If this is not possible, drill and tap the hole for a helical thread insert (coil).

Check the top (deck) surface of the cylinder block for flatness with a straightedge, both transversely and longitudinally. Compare the results with the specifications given in the service manual. Should the tolerance exceed the specifications, the surface must be refinished; otherwise, it will be difficult to maintain compression coolant and oil sealing. Check all stud bolts for damage and replace where necessary.

If it is necessary to refinish the top surface of a cylinder block (using either a milling machine or a large surface grinder), do not refinish the block to a height less than the manufacturer's specification.

Check the cylinder-block bores, the mounting surfaces of components, and sleeve counterbores for corrosion and erosion. Discard the cylinder block if the areas cannot be cleaned, refinished, or resleeved.

Engines using dry-type cylinder sleeves depend on good cylinder sleeve-to-cylinder bore contact since cooling is accomplished through conduction. Excessive clearance or cylinder-bore distortion re-

duces heat transfer. Therefore, before measuring the cylinder-block bores for out-of-roundness or taper, clean the bores using an adjustable rigid hone having a 120-grit stone.

Honing Cylinder Bore (Dry Sleeve) Honing the bore should be done with an adjustable rigid hone (Fig. 6-1) because such a hone will not follow the irregularities of the bore as does the spring-loaded deglazer hone.

A ½- or ¾-in electric drill will provide the right speed and torque to drive the hone. Use either wet or dry 120-grit stones. Install the honing mast so that the center of the hone is in the center of the cylinder bore and so that the spring-tension position of the hone is about ½ in [12.7 mm] above the cylinder block top surface. Adjust the stones so that they lie firmly against the smallest measured section. This will ensure good honing and prevent the hone from fluttering.

Start the drill. Irregularities will be felt by an increased drag on the stones. Move the drill up and down with short strokes concentrating on the high spots first. Readjust the hone as necessary to assure a firm surface and good stone contact. When using dry stones, frequently clean them with a wire brush to prevent stone loading.

CAUTION On two-cycle engines, do not hone too long at the air inlet port area. The hone cuts more swiftly at this area than in the rest of the bore.

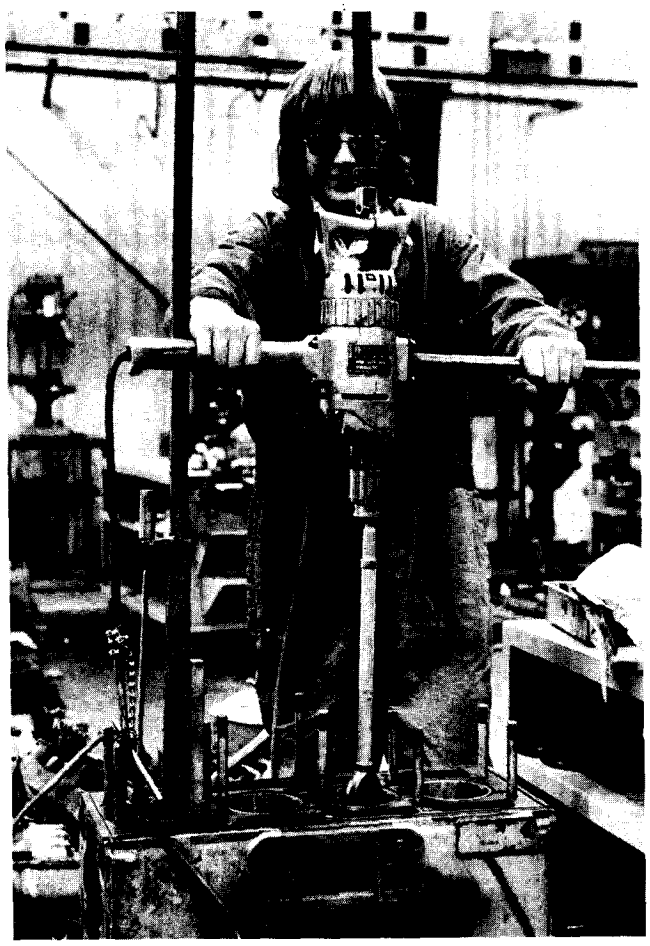


Fig. 6-1 Honing a cylinder bore.

When honing drag is fairly even, hone several times more over the length of the bore.

CAUTION Do not allow the stones to protrude more than 1 in [25.4 mm] above or below the cylinder bore. Do not pull the hone out of the cylinder bore when the hone is spinning.

It is essential to continually measure and inspect the bore and continually clean the stone if a perfect bore is to be achieved. A perfect bore means that the dimension over the total area is within the minimum allowable tolerance. The unhoned area must not be larger than 1 in [25.4 mm] in diameter. *(NOTE: The same honing procedure is applicable to cylinder blocks when the cylinder is an integral part of the cylinder block and oversize pistons are used.)*

Measuring Cylinder Bore First, clean the cylinder bore with soap and hot water. Dry it with compressed air, and coat it thoroughly with clean lubricating oil. Use paper towels to wipe the lubricant from the walls of the cylinder bore. Repeat the procedure until there is no residue on the paper towel.

To determine the diameter of the cylinder bore, measure it with an inside micrometer or use a telescopic gauge. When you use the telescopic gauge, set and adjust the gauge (using an outside micrometer) to the cylinder bore's maximum diameter. (Refer to Unit 50, "Measuring Tools," for procedures regarding these and other hand measuring tools.)

Usually neither method will produce a precise measurement because the tool measuring points are difficult to align to the cylinder sleeve. A cylinder or an out-of-round gauge which has a dial indicator calibrated in thousandths of an inch [hundredths of a millimeter] is more suitable for measuring the cylinder bores. To adjust the dial indicator of either tool to zero, place the gauge in a master ring, or between the anvils of an outside micrometer (adjusted to the maximum wear specification), and set the dial indicator to zero. Insert the tool into the cylinder bore, as illustrated in Fig. 6-2, and record your measurement. If the pointer moves to the left of the zero mark, the cylinder bore's diameter is larger than maximum allowable wear. If the pointer moves to the right of the zero mark, the diameter is less than the allowable wear. The measurement is determined by the millimeter or fraction of a millimeter that the pointer has moved from zero. Repeat the measurements at each point recommended in the service manual. *(NOTE: A Detroit Diesel engine requires 24 measurements per sleeve bore.)*

Boring Cylinder Bore When the cylinder bore does not meet specification or does not clean up through honing, the dimension of the bore must be increased to accommodate an oversized cylinder sleeve. This can be done with a special precision cylinder honing machine or with a portable boring bar.

When you use a Sunnen honing machine or boring bar to oversize the cylinder bore, always follow the manufacturer's instructions. Make certain the main-bearing caps are torqued to specification. Be sure that the cutting tool is sharpened properly and positioned tightly in the holding fixtures. Be sure that the

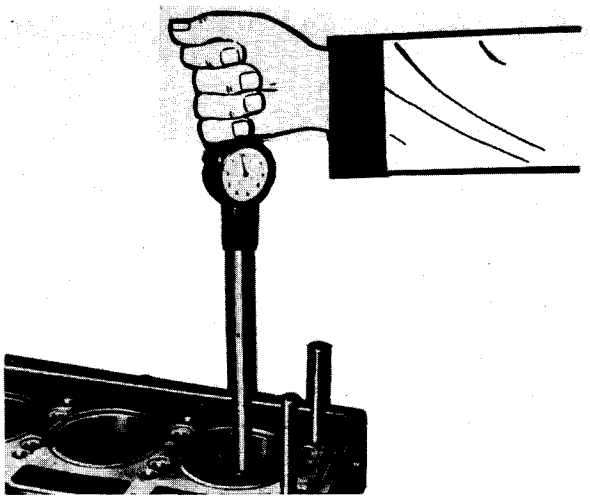


Fig. 6-2 Measuring a cylinder bore. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

boring bar is centered with the counterbore and that the boring bar is clamped securely. Cut the bore 0.001 in [0.025 mm] smaller than the intended completion size. When the hole is bored, back off the cutter and then manually remove the bar. Always sharpen the cutter after each hole is bored. Use a hone to remove the tool marks and to bring the bore to the specified dimension. [See Honing Cylinder Bore (Dry Sleeve), above.]

CAUTION Remember that boring causes a heat buildup. Therefore, allow the block to cool before measuring the cylinder bore. Again, because of heat, it is advisable to bore alternate cylinder holes to reduce the chance of hole distortion.

Checking and Measuring Cylinder-sleeve Protrusion Check the counterbore surface for distortion because the cylinder sleeve may have moved due to incorrect cylinder-head torque or insufficient cylinder-sleeve protrusion. Make certain that the cylinder-sleeve flange fully contacts the counterbore.

There are several methods for measuring or checking sleeve protrusion. One method is to measure the width of the cylinder-sleeve flange and the depth of the counterbore at four or more locations, using a depth micrometer or a dial indicator. (See Fig. 6-3.) Subtract the counterbore depth from the width of the cylinder-sleeve flange. The result is the sleeve protrusion. Note, however, that the counterbore measurement must not vary more than specified in the service manual.

Another method is to insert the cylinder sleeve into the cylinder bore without any shims or seal ring. Clamp the sleeve firmly in place. Use the specially designed dial tool and hold it onto the clean cylinder top deck or onto the spacer plate, then zero the dial. Now, move the dial stem onto the sleeve flange. The dial gauge will indicate direct sleeve protrusion. Measure the protrusion in at least four places.

If the protrusion is not within specification, select a shim with the correct thickness to achieve specified protrusion and place it in the counterbore. Mark each sleeve to identify its position within the bore to which it must be reinstalled.

If shimming does not correct the cylinder-sleeve protrusion, if the counterbore is distorted, or if the cylinder-sleeve protrusion between the adjacent sleeves is more than specified, the counterbore must be machined. Check to make sure the sleeve is not contacting the lower cylinder-block bore. If it is, the counterbore must be machined or resleeved.

Resurfacing Cylinder-sleeve Counterbore Counterbore tools should always be used according to the procedures set out by the manufacturers. Although the following procedures are usually among those recommended, they are often overlooked by the mechanic:

1. Make certain that the lower and upper cylinder bores are free of carbon, scale, or corrosion. Failure to clean adequately can cause the tool to misalign and therefore cut an untrue seat.
2. Secure adapter plate. An improperly secured adapter plate can cause an untrue seat and/or enlarge the diameter.
3. Adjust the cutting tool against the shoulder. Improper diameter adjustment can cause an oversize diameter or a step shoulder in the counterbore.
4. Use a sharp tool bit. A loose or improperly sharpened tool bit can cause an untrue surface.
5. Do not exceed a cutting rate of 0.001 in [0.025 mm] per revolution. To do so can cause an untrue surface.
6. Measure depth frequently. Neglecting to do so may result in the counterbore being machined too deep. This causes intolerance with the adjacent cylinder.
7. Thoroughly clean the cylinder block. Haphazard cylinder cleaning after machining can destroy the total engine.
8. On engines using wet-type sleeves you must check the lower cylinder sleeve bore for damage or corrosion, and measure the bore diameter and also the alignment. If the lower sleeve bore is not within specification you can nevertheless salvage the cylinder block by machining the bore and installing a salvage sleeve.

Checking Main-bearing Caps and Bores Check the mating surface of each cap, the upper

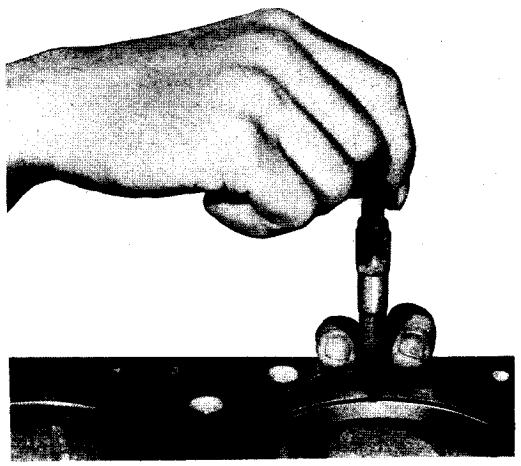


Fig. 6-3 Measuring the depth of the counterbore. *(Allis-Chalmers Corp. Engine Division.)*

main-bearing support, and the bearing surface for wear, nicks, and burrs.

Make certain that the correctly numbered (or otherwise identified) cap is in the proper position and fits with no perceptible clearance. If there is no clearance, the cap will not rock. The machined surface of the cap must rest fully on the mating surface of the block, otherwise the main bearing cap will be distorted during tightening.

Install caps and tighten hex bolts or nuts to the specified torque. Measure the main-bearing bores horizontally, vertically, and diagonally with an inside micrometer or with a dial gauge which has been properly zeroed to an outside micrometer or ring gauge (Fig. 6-4).

When the main-bearing bores are within specification, check them for alignment. Misalignment may result from overheating, overspeeding, vibration, broken crankshaft, or other severe stress. Alignment of main bearings can be checked with a master bar or with the boring tool. When a master bar, which is about 0.005 in [0.127 mm] less than the main bearing bore, is used, remove the bearing caps, place the alignment shaft in the cleaned and lubricated upper bearing support, then install the caps and tighten them to the specified torque. A method most commonly followed when individual engines are serviced is to install a new or reground crankshaft, using new bearing shells of the correct size. Apply adequate lubrication and make sure that the bearing caps are torqued to specification. The main-bearing alignment is correct when the crankshaft can be rotated freely by hand.

When the main-bearing bore(s) is (are) out of alignment, damaged, distorted, or too large in dimension, the cylinder block must be discarded. When it is possible to salvage the block by using replacable main-bearing caps, then the main-bearing bores must be serviced.

Replacing Main-bearing Caps Most manufacturers produce semifinished or finished main-bearing caps for the purpose of restoring the cylinder block. However, it is not unusual to experiment with several finished replacement caps before one will fit and align correctly.

When it is necessary to use semifinished replacement caps to restore the cylinder block to usefulness, the task can be somewhat difficult. To begin with, all main-bearing cap ends must be ground to reduce the bore diameters and then the main-bearing bores must be machined (line-bored) or honed to specification. In many cases the replacement caps have to be redoweled. *(NOTE: When resizing the main bores, the cylinder block must rest on a flat surface. Before making any adjustment or starting to line-bore or hone the main-bearing bores, the cylinder block should be allowed to stabilize at room temperature.)*

Checking and Measuring Camshaft Bores It is common practice to replace the camshaft bearings when a major overhaul is made. Camshaft bores and/or balance shaft bores of a cylinder block are rarely distorted, worn, or damaged. Nevertheless the bores must be checked for nicks and burrs that may have occurred because of improper removal of the camshaft bearings. Bearing bores and oil passages should be cleaned thoroughly and the oil passages checked for restriction. When it is doubtful that the replacement bearings will press-fit into the bores, measure the bores with an inside micrometer or with a telescopic gauge (Fig. 6-5).

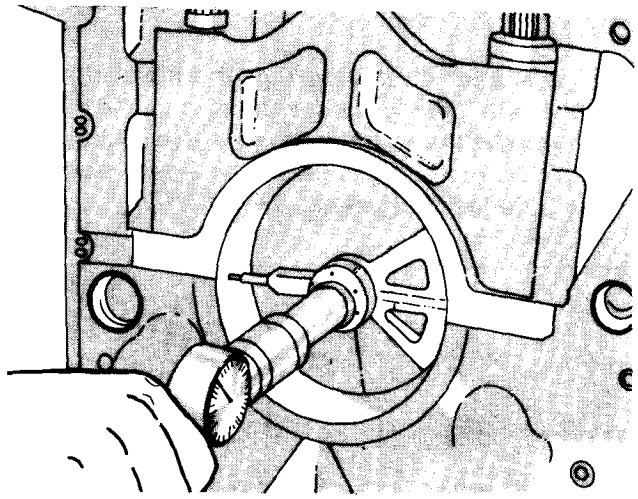


Fig. 6-4 Measuring a main-bearing bore.

Removing and Installing Camshaft Bearings (Bushings) The precision replacement camshaft bearings (bushings) are available in standard sizes and in 0.0010 in [0.25 mm] undersizes. The camshaft location differs with the engine design. It could be in the crankcase, in the upper part of the cylinder block or, when overhead camshafts are used, in a special housing.

The average clearance between the camshaft journals and bearings is 0.002 in [0.050 mm]. When the clearance is 0.008 in [0.203 mm], a replacement is needed. To determine the running clearance with the camshaft removed, measure the inside diameter of each bearing and compare it with the manufacturer's

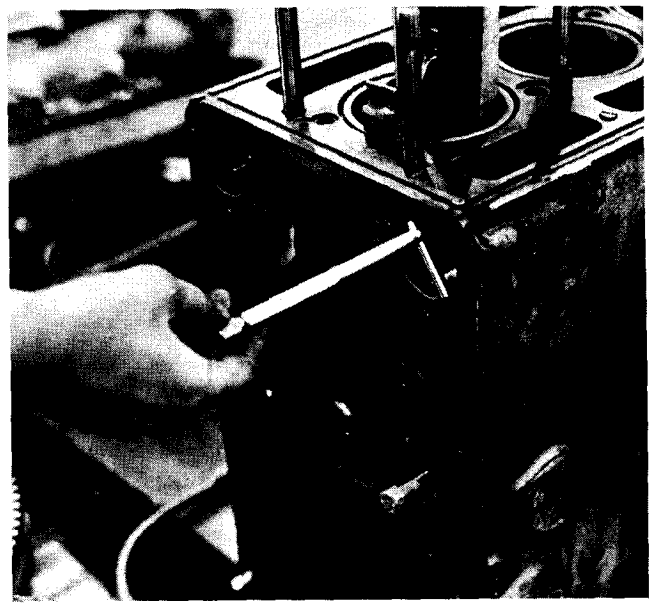


Fig. 6-5 Measuring the camshaft bearing bore with a telescopic gauge.

specification. Then measure each camshaft journal and subtract this measurement from the bearing measurement. The result will be the running clearance.

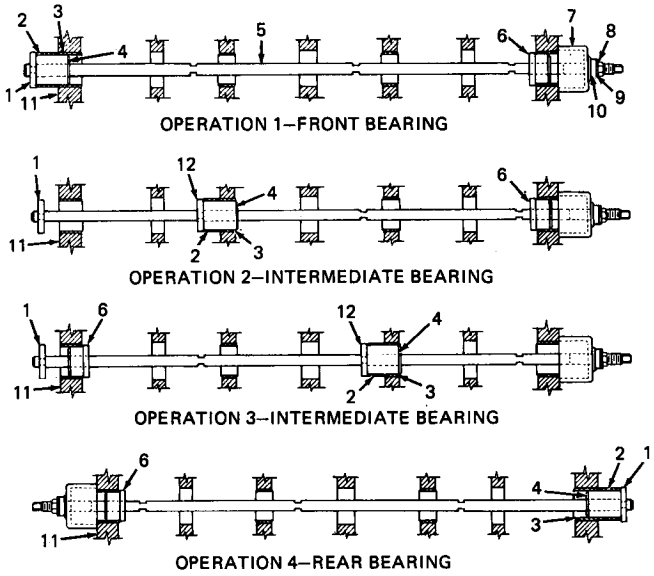
Use the same tools to install the camshaft bearings that you used to remove them. Visually check the camshaft bores, particularly for nicks and burrs which could damage the bearings during installation, and remove such imperfections when present. Lay out the bearings on the cylinder block in the order in which they are to be installed; camshaft bearings are not all of the same width nor are the oil supply holes situated in corresponding locations.

To assure precision hole alignment, mark the location of the oilhole on the cylinder block. Lubricate the bore and the outside of the bearing, draw a line on the sleeve or washer to indicate the oilhole, and then install it as shown in Fig. 6-6. When pulling the bearing into place, be sure that it does not turn out of position. Take care that the oilholes of the bearing and block do not restrict one another. Since there are different tools available for removal and installation of bearings, make sure you use a tool which "pulls" the bearing in and out of the bore to prevent damage to the bearing or bore.

It is good procedure to check the dimension of newly installed bearings with an inside micrometer or telescopic gauge for possible out-of-roundness.

Detroit Diesel 149 Series engines use camshaft bearing shells and caps to support the camshaft, and a thrust plate to take up the thrust (Fig. 6-7). Part of the camshaft cap is used for the rocker-arm-shaft support, and the cam lobes act directly on the rocker arm.

Caterpillar overhead-camshaft engines have the



1. C washer (stop plate)
2. New camshaft bearing
3. Old camshaft bearing
4. Installing pilot
5. Puller shaft
6. Shaft pilot
7. Collar
8. Hex nut
9. Fat washer
10. Thrust washer
11. Front machined surface of cylinder block
12. C washer

Fig. 6-6 Sequence of operations for removing and installing camshaft bearings. *(Allis-Chalmers Corp. Engine Division.)*

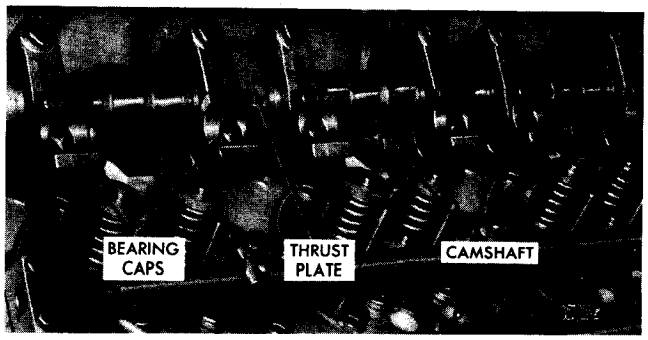


Fig. 6-7 View of camshaft bearing caps and thrust plates. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

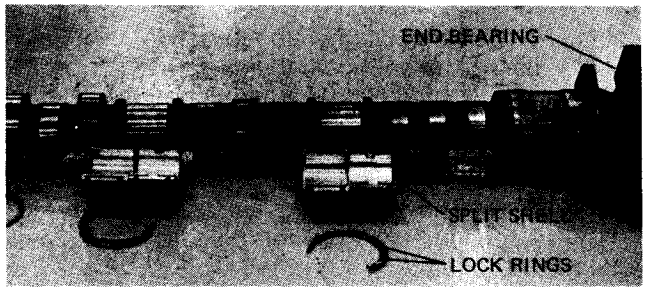


Fig. 6-8 Camshaft and camshaft bearings.

camshafts located in a separate camshaft housing bolted to the cylinder heads. One-piece bearings are used to support both camshafts. The inlet valve camshaft is driven at the front of the engine through the idler gear in a counterclockwise direction and the inlet camshaft gear drives the exhaust valve camshaft gear and camshaft in a clockwise rotation. At the rear of the engine the idler gear drives the exhaust-valve camshaft, and the exhaust-valve gear drives the intake-valve camshaft gear.

The Detroit Diesel 53, 71, and 92 Series engines (Fig. 6-8) use two solid end bearings which are bolted to the front and rear cylinder blocks. The remaining intermediate camshaft bearings are made up of split shells, which are held together by two lock rings and positioned in their bores by a setscrew.

The camshaft bearing checks and measurement procedures for the Detroit Diesel engines are the same as for the conventional camshaft bearing.

The removal and installation checks and measurements of overhead-camshaft bearings are also the same as those for conventional camshaft bearings.

Questions

1. List the visual checks you must make when examining the cylinder block.
2. Detail the steps you must take when preparing to hone a cylinder bore.
3. What is the importance of having a good contact between the cylinder bore and the outside diameter of the cylinder sleeve?
4. Why is sleeve protrusion necessary?
5. List the steps to prepare a cylinder block for the pressure test.
6. Crankshaft bore alignment must not exceed (*a*) 0.015 in, (*b*) 0.005 in, (*c*) 0.0015 in, or (*d*) 0.0035 in?

UNIT 7 • CAMSHAFT

Checks and Measurements Wear of camshaft journals and camshaft cam lobes is minimal if the engine always operates with clean oil and has regular maintenance. Checks and measurements, however, are important when servicing the camshaft.

To service camshafts having oil galleries, first remove the end plugs and clean the galleries with compressed air. Check the surface condition of the journals and cam lobes for roughness and scoring. Check the thrust surfaces and the keyway threads for damage. When the journals, cam lobes, or keyways are damaged, the camshaft must be replaced. (No major engine manufacturer recommends regrinding camshaft lobes or building up the cam lobes by welding or spraying.)

If the keyway threads, journals, and cam lobes are in good condition, place the camshaft on V blocks and use a dial indicator to measure the runout (Fig. 7-1). The runout at the center bearing should not exceed 0.002 in [0.050 mm].

Measure the camshaft bearing journal; the average maximum wear limit is 0.004 in [0.101 mm]. Should the measurement exceed the manufacturer's wear limit specifications, the camshaft should normally be replaced. However, some manufacturers recommend regrinding the bearing journals, using a small crankshaft grinding machine, and installing undersize camshaft bearings.

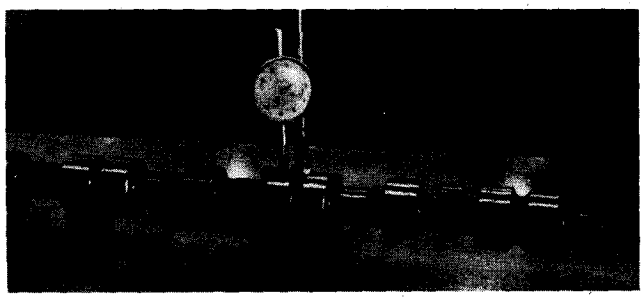


Fig. 7-1 Measuring camshaft runout.

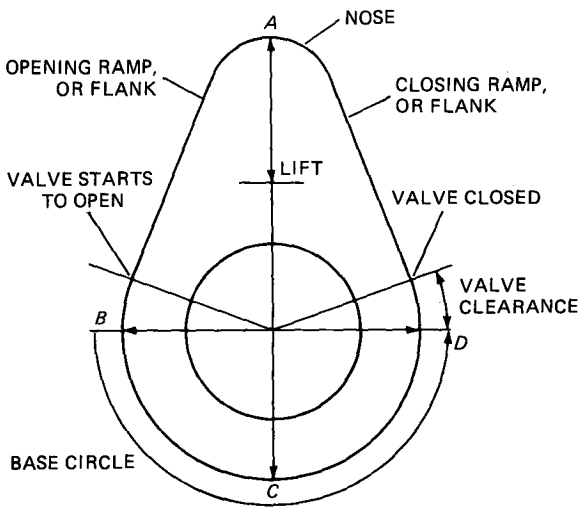


Fig. 7-2 Cam lobe terminology.

Measure the intake and exhaust lobes (Fig 7-2) by taking micrometer readings at *A–C* and *B–D;* then subtract *B–D* from *A–C*. This will give you the lobe lift. Some manufacturers specify maximum lobe and lift wear, others do not.

Check the thrust-bearing plate washer for wear. Replace it if the wear area is rough or if the wear exceeds specification.

Installing Camshaft Gear and Camshaft Before you install the camshaft gear, check it for wear, nicks, and scored or damaged teeth. If the bore is so enlarged that a press-fit, say 0.002 in [0.050 mm], is no longer possible, or if the keyways are damaged, the gear must be replaced. On Cummins V-type and Detroit Diesel 71 Series engines, which may require an offset key to time the camshaft to the engine, always refer to the service manual to determine the correct key. Some manufacturers stress (because of the close fit between gear and camshaft) heating the camshaft gear evenly to 400°F [204°C], while others recommend pushing it, cold, into position.

To install the camshaft gear, cold, use a split yoke or parallel bar. Support the camshaft in the press with the yoke or bar at the first bearing journal so that it rests parallel to the base of the press. Be certain that the camshaft is lubricated at the camshaft gear location, that the thrust plate or washers are in place, and that a new key in installed. Position and align the gear keyway to the key, then push the gear straight on.

Check the clearance between the thrust face of the camshaft (or bearing) and the thrust plate (or camshaft gear). The average clearance should measure about 0.004 in [0.101 mm]. It is wise to recheck the running clearance between camshaft journal and bearings, especially if you were not the only mechanic to work on the engine.

After lubricating the camshaft bearings and journals, carefully insert the camshaft. Do not scratch or burr the bearings; use a pilot support which prevents any damage to the bearings. Before the camshaft gear comes in mesh with the crankshaft or idler gear, align the thrust plate or washer and the timing marks of mating gears. Slide the camshaft into place, and recheck that the timing marks of mating gears are aligned.

When working on Detroit Diesel engines you will find that some require standard timing while others require on-tooth advanced timing on the timing gear.

CAUTION Never drive the camshaft gear onto the shaft as this will damage the shaft journals and/or the gear bore, and may push out the expansion or cup plug or camshaft bearing support at the rear of the cylinder block.

Your final check should be the gear backlash. Using a dial indicator and mount, as shown in Fig. 7-3, make certain that the dial stem rests squarely on the helical tooth before zeroing the dial.

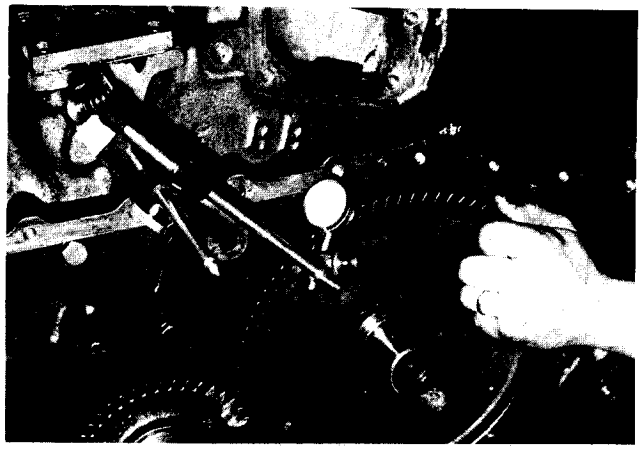


Fig. 7-3 Checking camshaft-gear backlash using a dial indicator. *(Cummins Engine Company, Inc.)*

The average backlash is from 0.002 to 0.006 in [0.050 to 0.152 mm]. Should the maximum backlash exceed specification, one or both gears must be replaced. At this time recheck the end play. *(NOTE: If an expansion or cup plug is used, install it at the rear camshaft opening.)*

Measuring Camshaft Wear and Lobe Lift with Camshaft Installed On occasion it becomes necessary to check camshaft wear and lift to locate engine trouble involving valve action or reduced compression. To check the lobe lift, install a dial indicator as shown in Fig. 7-4. Rotate the crankshaft until the dial indicator needle no longer moves. At this point the cam follower is resting on the cam base circle. Zero the dial indicator and then rotate the crankshaft clockwise until the dial indicator needle stops moving (or just starts to move in the opposite direction). The cam follower is now on the cam nose and you can read the valve lift directly from the dial gauge. Record this measurement and compare it with the manufacturers specification. Repeat this procedure with the remaining valves.

To check camshaft and bearing wear, remove whatever components or parts are necessary to pry the camshaft up. Install a dial indicator, either directly or indirectly, to the camshaft. Zero the dial and pry the camshaft up. The maximum needle graduation indicates the total wear of the journal and bearing.

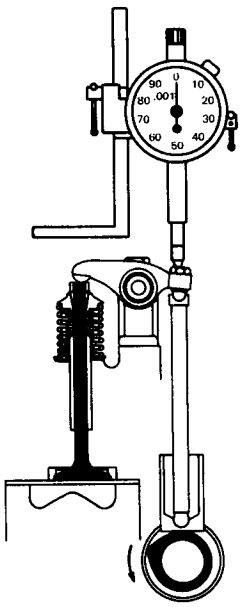


Fig. 7-4 Measuring cam lobe lift with the camshaft installed. *(Cummins Engine Company, Inc.)*

Idler and Auxiliary Gears Many engines, because of their camshaft location, require one or two idler gears between the camshaft and crankshaft timing gears. The idler gears have an odd number of teeth to prevent meshing of identical teeth with each revolution. As a result, tooth life is increased and gear noise reduced. Most engines require additional drive gears to drive the fuel-injection pump, the compressor, or the blower. The idler or auxiliary gears rotate on bushings or bearings on a dummy shaft or hub and are pressure-lubricated.

Inspecting and Servicing Idler or Auxiliary Gear After all parts are cleaned and dried with compressed air, examine the dummy shaft for wear or grooving. When the shaft also acts as the bearing surface of the idler or auxilliary gear bushing, measure the shaft with a micrometer, and compare the diameter size with specifications. Measure the bushing and check for grooving and pitting. On engines which have a bushed dummy shaft, the idler or auxiliary-gear bore is also the bearing surface. Check the gear teeth for scoring, pitting, and chipping. To replace the bushing, use the correct size bushing installer and firmly support the gear before pressing the old bushing out and the new bushing in. Make certain that the oilholes are in line with the supply holes.

When tapered roller bearings are used and the bearings need to be replaced, place the gear squarely on the press bed to ensure that the gear is well supported. Match-mark the bearing cup and cone; then, if reusable, they can be reassembled as a unit. Always examine the bearing cups and cones carefully. If they are unevenly worn, the bearings are running too loose. Also check the bearings and cups for pitting, scoring, and flat spots.

Checking Bearing Preload Tapered roller bearings require either a preload or end play (depending on application) to ensure long bearing life and to provide a rigid support for the rotating gear [see Tapered Roller Bearings (Unit 17)].

To check the preload for this type of mounting, mount the idler gear shaft in a vise. Attach a small cord to a short piece of welding rod and lay the rod between the teeth of the gear, then wrap the cord a couple of times around the gear. Attach a spring scale, calibrated in pounds [kilograms] to the other end of the cord. Pull steadily on the spring scale. The idler gear should rotate freely and produce an even scale reading. The preload is correct when the pull required produces an even scale reading and does not exceed the manufacturer's specifications.

Questions

1. Why is it important to measure the camshaft journals, the lobes, and the runout?

2. Describe camshaft timing for the engine on which you are working.
3. Explain how to measure the camshaft and bushing wear when the camshaft is installed.
4. Why do idler gears have an odd number of teeth?
5. Worn camshaft lobes of an engine could cause (*a*) valve noise, (*b*) valve "float" at higher engine speeds, (*c*) loss of engine power, or (*d*) camshaft follower breakage.
6. Camshafts are timed to (*a*) the valves, (*b*) the pistons, (*c*) the crankshaft, (*d*) engine firing order, (*e*) only have one valve open at a time, or (*f*) (*e*) is correct and (*a*), (*b*), (*c*), and (*d*) are wrong.

UNIT 8 - CYLINDER SLEEVE

Checks and Measurements When the cylinder sleeve meets the service manual specifications, it can be serviced without removal. However, an external examination of the cylinder sleeve or cylinder block will not apprise you of the true condition of the lower and upper sealing surfaces of the sleeve or block; therefore the cylinder sleeve should be removed. After removal, inspect the water jacket, counterbore, and (lower) cylinder bore. This will give you a clearer picture of doubtful functioning components.

If circumstances require that the sleeve remain in position, check the sleeve and block for vertical and horizontal cracks, scores, excessive wear, and heat marks. Measure sleeve protrusion and sleeve dimension.

The cylinder sleeves shown in Fig. 8-1 are comparable to those you may be called upon to service. You must learn to recognize the cause of their deteriorated condition and how to correct it. The illustrations shown are divided into two groups: Group 1 failures are the result of parts not being serviced to specification, or of being carelessly intalled or handled. Group 2 failures are caused by an unbalanced condition between coolant and temperature, by chemical or mineral content in the coolant, or by improper coolant-system maintenance (see Unit 20, "Cooling System").

Before honing or deglazing a cylinder sleeve, wash the sleeve in water and detergent using a bristle brush. Rinse it thoroughly or steam-clean it and then blow it dry with compressed air. If it is not to be honed immediately, coat the liner generously with engine oil. Next, place the sleeve in a holding fixture or in an old cylinder block. Under no circumstances should a vise of any kind be used. The sleeve must be held only at its flange to prevent distortion.

After the cylinder sleeve has passed superficial inspection, it should be measured for out-of-roundness and taper with a bore gauge or inside micrometer. The average allowable taper and out-of-roundness for a 4- to 6-in [101.6- to 152.4-mm] sleeve bore is about 0.002 in [0.050 mm].

The cylinder sleeve should be measured in two directions for wear (see Fig. 8-2)—first, parallel to the crankshaft and second, at a 90° angle to the crankshaft at *A* and *B*. Measurement should be taken just below the top of ring travel at *C* and also at several locations within the area of piston travel, *D, E, F,* and *G* (Fig. 8-2).

A normal wear pattern will show maximum wear at the top tapering off at about three-quarters ring travel (see Fig. 8-2). From the measurements taken you will know whether it is necessary to replace, to hone, or deglaze the cylinder sleeve to specification. (Possibly honing will enlarge the bore beyond the specified limit.) The average wear limit is about 0.008 in [0.2 mm] for a 4- to 6-in [101.6- to 152.4-mm] cylinder bore. Most manufacturers do not supply oversized pistons; consequently, when the sleeve bore exceeds specification it must be replaced.

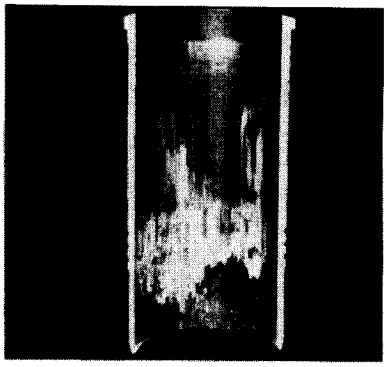
Honing or Deglazing Cylinder Sleeve If the cylinder sleeve can be reused, the glazed surface area of the piston-ring travel must be refinished. Deglazing of the walls assures the shortest break-in period. By honing the bore, the high spots of the cylinder-sleeve surface are removed, the bore is made round, and the taper is removed. At the same time, the surface is roughened to a precise microfinish. If the surface finish is too rough, the ring wear will be too great and the piston ring or the piston land will be susceptible to breakage. If the surface is too smooth or if the crosspattern is not within 25 to 35° (Fig. 8-2), the piston rings will not seat within 200 to 300 hours of operation. This prolonged break-in period will cause high oil consumption, lack of power, and hard starting, and possibly will prevent the ring from seating perfectly.

Whether the cylinder sleeve should be honed or deglazed will depend on the variation of the sleeve bore measurements. If the variation of out-of-roundness and/or taper is larger than 0.001 in [0.025 mm], but it is within specification, a rigid adjustable hone should be used to restore the cylinder-sleeve bore.

To hone or deglaze a cylinder sleeve, select a ½- or ¾-in electric drill for correct power and speed (about 500 rpm). Select deglazing stones with a grit size of 180 to 220. These honing stones produce a surface finish of about 25 μm (micrometer) (25 millionths of a meter). Coat the surface generously with honing or engine oil. Insert the deglazer and adjust spring tension so that the stone rests with a light-to-medium pressure on the surface of the sleeve wall.

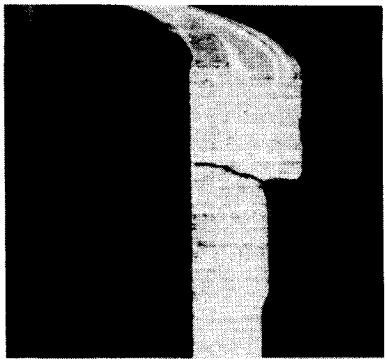
Start the drill and feel out the bore for high spots which cause the stone to grab. Deglaze the high spots first. Be careful not to allow the stone to protrude more than 1 in [25.4 mm] above the lower or upper sleeve surfaces. Move the drill about 30 strokes

GROUP 1



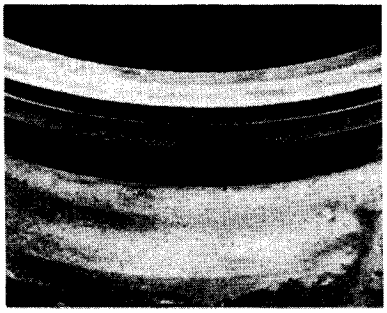
SCORING

POSSIBLE CAUSES:
Rings scuffing, piston scoring, improper cold start, honing debris, dirt in intake air, broken snap ring or ring land (insert), improperly installed cylinder sleeve or sealing (packing) rings, distortion of cylinder-block bore



CRACKING

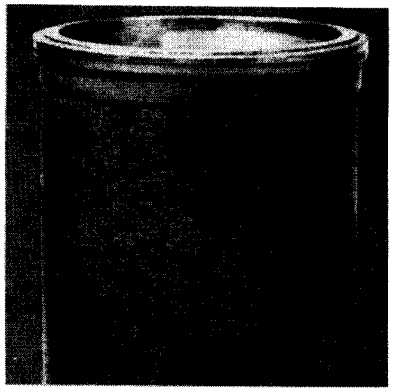
POSSIBLE CAUSES:
Improper machining of flange counterbore, improper press fit, improper shimming of flange counterbore area, overtorqued head cap screws, improper protrusion, upper block distortion. Cracks at lower liner due to packing-ring problem, overheating or hot spot, corrosion, scoring.



FRETTING

POSSIBLE CAUSES:
Improperly torqued head cap screws, uneven liner protrusion, loose liner press fit, damaged or worn head gasket

GROUP 2



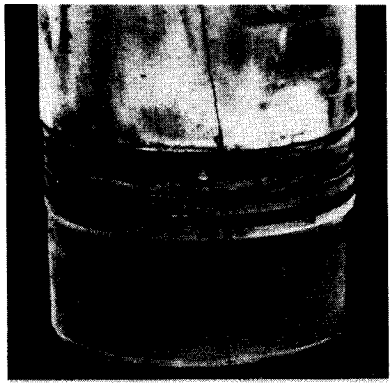
CORROSION

POSSIBLE CAUSES:
Lack of water treatment, long storage without coolant drain, improperly maintained corrosion resistor, high mineral and/or chemical content in coolant



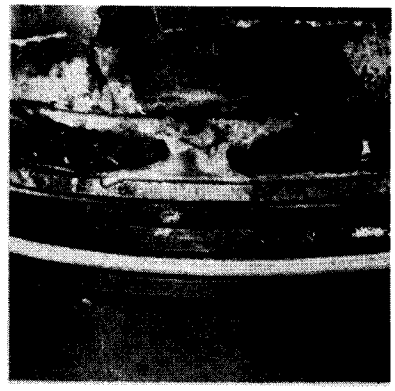
CAVITATION

POSSIBLE CAUSES:
Aerated coolant, liner movement, high coolant temperature, inadequate coolant treatment, low coolant flow



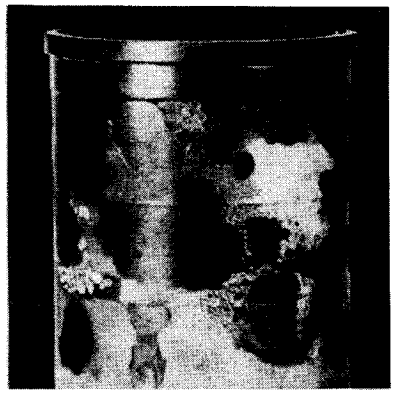
VERTICAL BREAKS

POSSIBLE CAUSES:
Handling damage, severe cavitation, result of piston seizure



ABRASIVES IN COOLANT

POSSIBLE CAUSES:
Core sand or cleaning abrasives, sand or grit in coolant



SCALE

POSSIBLE CAUSES:
Inadequate coolant treatment, high mineral and/or chemical content in coolant



DISCOLORATION OF LINER OD

POSSIBLE CAUSES:
Light or medium gray normal discoloration due to chromates in coolant system. Beige or brown usually denotes overheating

Fig. 8-1 Cylinder-sleeve failure conditions and possible causes. *(Cummins Engine Company, Inc.)*

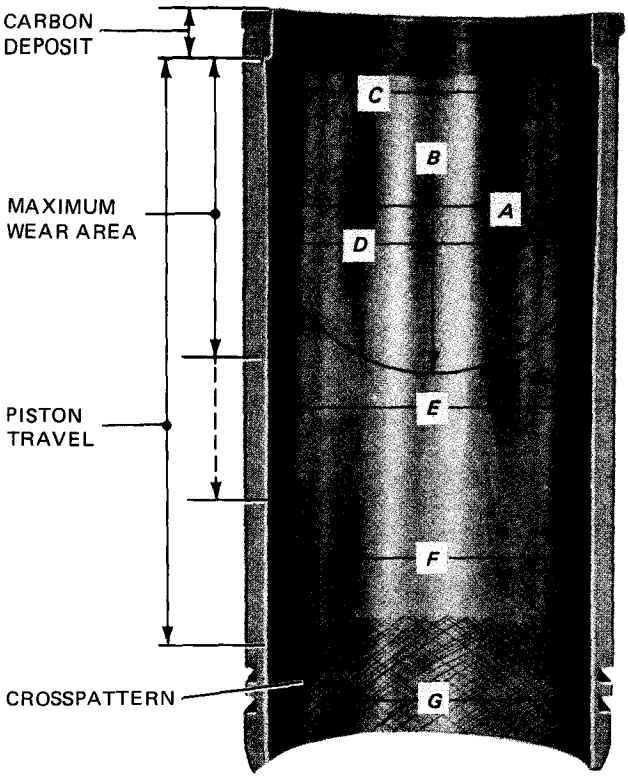


Fig. 8-2 Normal wear pattern on a cylinder sleeve. *[J.I. (Case Agricultural Equipment Division (TENNECO).]*

per minute over the total sleeve area to achieve the desired crosspattern.

After about 15 strokes, stop the drill and remove the deglazer while holding the stones compressed. Check the bore for low spots and crosspattern. Measure for taper and out-of-roundness. Repeat the procedure until the low spots are removed and the bore shows an even crosshatch pattern. Manufacturers now recommend the use of a 180-grit flex-hone. The flex-hone procedure and the end result are the same as when using a deglazer.

The deglazing procedure for sleeveless cylinder-block bores is the same as outlined above. However, when the cylinder bore exceeds specification and oversize pistons would restore the cylinder block, the bore must be machined and then honed, or honed to the specified oversize dimension.

NOTE: At this time Cummins Engine Company, Inc. does not recommend deglazing their cylinder sleeves.

After you have deglazed or honed the cylinder wall, glass-bead (peen) the area of the sleeve flange and sealing rings. Wipe abrasives from the walls and then clean the surface with hot water and detergent. (Do not use solvent as it will not remove the abrasive particles.)

Dry with compressed air and generously coat the surface with engine oil, then, using paper towels, wipe off the oil. Repeat this procedure until there is no residue on the paper towels. It is also advisable to clean new cylinder sleeves to ensure that no abrasives are present.

Do not reuse the cylinder liners that have: (1) tangible grooves on the inside surface, (2) any cracks or top flange damage, (3) rust showing on the inside surface, (4) any excessively shiny internal areas, (5) excessive outside pitting. However, if the pitting is minor, you may install the pitted side facing the front of the engine.

Installing Wet-type Cylinder Sleeve Be certain that the counterbore and the lower cylinder bores are clean. When reinserting cylinder sleeves make sure that they are deposited into the original bore and in the original position. The sleeve should fit in place without force and be turnable in the bore by hand. A sleeve which has been forced into place will not turn freely and will, therefore, require additional cleaning or realignment of the counterbore to the lower cylinder bore.

To install the cylinder sleeve seal rings, stand the sleeve on a clean workbench and install the seal rings in the grooves of the cylinder sleeve, or install the seal rings in the lower cylinder bore. The seals must not be twisted during assembly as leakage may result. To prevent twisting the seals, slip a finger or pencil under the rings and run it two to three times around the sleeve under the sealing rings. Withdraw the pencil and allow the sealing rings to slide back into the grooves without twisting.

Some manufacturers use three types of seal rings. For example they use in the top groove a broad neoprene O ring, in the center groove a Buna O ring, and in the lower groove a silicone O ring. It is therefore essential that you follow the manufacturer's instructions regarding position and lubricant (Fig. 8-3). If there are no instructions concerning lubricant, apply liquid soap or petroleum jelly to the lower cylinder bore and sealing rings.

With extreme care slide the cylinder sleeve through the upper cylinder bore into the lower bore. Firmly force the cylinder sleeve into position. (Some manufacturers recommend using a seal-protecting tool to ensure that the seal rings are not cut on the sharp edges of the bores while being installed.) After the cylinder sleeve is installed, check the protrusion and out-of-squareness between the cylinder-sleeve counterbore and cylinder centerline.

Installing Detroit Cylinder Sleeve The servicing or installation procedures of a Detroit Diesel dry-type or wet/dry-type cylinder sleeve are the same as those outlined above. The wet/dry sleeve should push-slide into position without the use of excessive

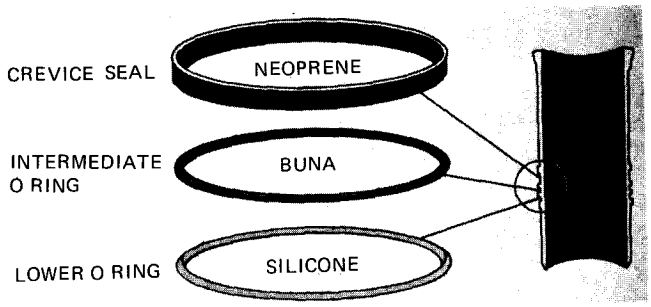


Fig. 8-3 Cummins cylinder-sleeve packing rings. *(Cummins Engine Company, Inc.)*

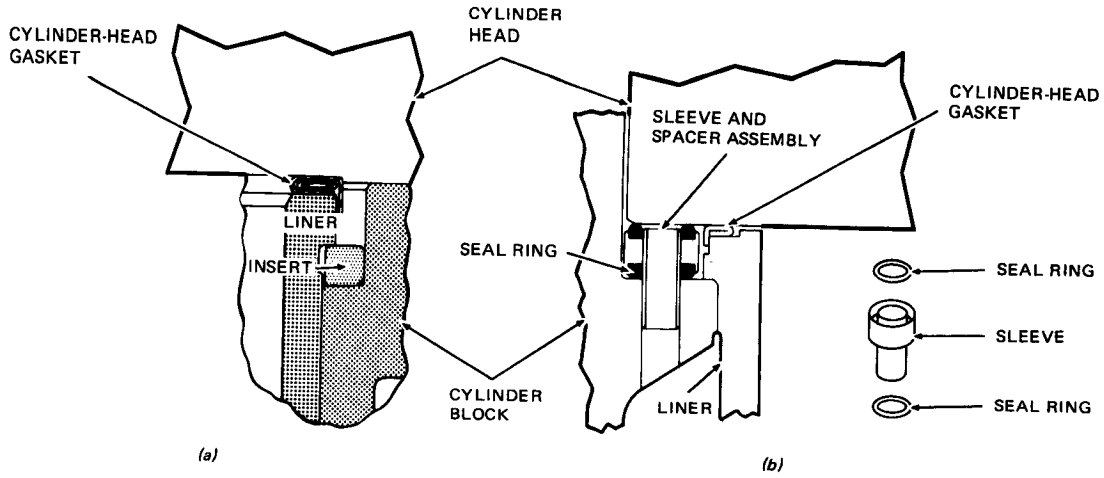


Fig. 8-4 Schematic view of cylinder liner (sleeve) installed: (*a*) 71 and 92 Series engine, (*b*) 149 Series engine. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

force and without turning. Excessive force will cause cylinder-sleeve distortion and may damage the rings or piston. If the sleeve does not slide into position, remove it, turn it 90°, and try again. If it still will not slide into position, remove it once more and measure the cylinder bore. It may need to be rehoned.

On Detroit Diesel 71 and 92 Series engines drop the insert into the counterbore and then insert the sleeve. On Detroit Diesel 53 and 149 Series no inserts are used—but note, on the 53 Series the sleeve rests in the counterbore of the cylinder block whereas on the 149 Series engine it rests on the top cylinder deck (Fig. 8-4). When the sleeve is installed, secure it to the cylinder block and measure the protrusion. If a shim is required to obtain proper cylinder sleeve protrusion, install the shim between the insert and the cylinder block on the 71 or 92 Series, or place it between the counterbore and flange on the 53 Series. Mark the sleeve and cylinder bore so that the sleeve can be returned to the same bore and position. When removing the sleeve, do not remove the shim or the insert.

Installing Dry-type Sleeve Dry-type sleeves having no counterbore flanges are press-fitted into the cylinder bore. The bore is honed to about 0.003 in [0.076 mm] smaller than the outside diameter of the sleeve. The sleeve is placed in dry ice or alcohol for 25 minutes and then pressed into position. When the temperature has stabilized, the sleeve bore must be measured and if necessary honed to specified diameter.

Questions

1. Explain in detail how to determine whether or not a cylinder sleeve requires servicing.
2. When should a cylinder sleeve be deglazed?
3. When should a cylinder sleeve be honed?
4. Why should the cylinder sleeve and the cylinder bore be marked after being fitted?
5. Explain in detail how to deglaze a cylinder-sleeve bore.
6. Before installing a wet-type cylinder sleeve, what two important checks must be made to the outer surface of the liner which is exposed to the water?
7. List four checks to be made prior to installing a wet-type cylinder sleeve into a cylinder block.
8. What precautions must be taken with regard to the lower cylinder-sleeve seals when installing a wet-type cylinder sleeve?
9. List four checks to be made prior to installing a dry-type cylinder sleeve into the cylinder bore of a two-cycle engine.
10. Dry sleeves which are fitted too loosely in the cylinder bore could cause (*a*) poor cooling, (*b*) head-gasket failure, or (*c*) too tight a piston fit.
11. A wet-type cylinder sleeve must (*a*) fit tight at the bottom so that it will not leak, (*b*) be a loose fit so that it will not distort under heat, (*c*) be sealed only at the bottom, (*d*) not protrude above the cylinder block, (*e*) have the same fit as a dry liner, or (*f*) have clearance at the top and bottom.
12. What is the difference between a clearance fit and an interference fit (dry-type sleeve)?

UNIT 9 • CRANKSHAFT

Preliminary Inspection To determine if the crankshaft can be reused, or if it should be reground, a preliminary inspection must be made. Visually inspect the journals and side walls for chatter marks, bearing smear, embedded materials, scratched journals, discoloration, and/or metal displacement. Overheated journals show usually as bluish discoloration. Check visually for cracks at the oilholes and fillets. Check for wear steps and corrosion on the thrust faces and for damaged or loose counterweight(s) and keyway(s), and check the pulley and oil seal surfaces for excessive wear. If the seal sur-

faces cannot be restored by polishing with emery cloth or crocus cloth, you may have to use a wear sleeve to salvage the crankshaft.

If visual inspection indicates that the crankshaft can be reconditioned, remove all plugs and place the shaft in a caustic bath, a vapor degreaser, or a steam cleaner solvent to clean it. After the external cleaning, use a wire brush to clean the oil passages. Again clean the crankshaft and dry it with compressed air.

Locating Fine Cracks When the crankshaft is cleaned, it must be rechecked for cracks which were not immediately visible. Several methods are used: dye penetrants, magnetic field and iron particles, magnetic field fluorescent, and x-ray. The magnetic field fluorescent method is most commonly used since it is the least expensive and yet detects very fine cracks. The other methods (with the exception of x-ray) are not as dependable.

If you use the magnetic field fluorescent method to test the crankshaft for flaws, first spray the shaft with the special solution containing magnetic fluorescent particles. These will glow under black light (invisible ultraviolet rays). Slide the powerful electric magnetic ring slowly over the crankshaft with the light pointing at the shaft. Magnetic particles are attracted to the edges of any cracks by the magnetic force. Cracks or flaws are visible under the black light as a white line, whereas the undamaged shaft shows up as dark blue (Fig. 9-1).

Causes of Crankshaft Failure The crankshaft seldom fails (breaks or cracks) when installed correctly and operated under normal conditions, but should failure occur the cause must be determined promptly and corrective measures taken. Some conditions which will promote crankshaft damage, breakage, or cracks, are

1. Improper storage or handling.
2. Overspeeding the engine. This can produce crankshaft vibration that exceeds vibration damper control.
3. Incorrect radii at journal fillets and oilholes. Either can create fatigue cracks (Fig. 9-1).
4. A vibration damper or crankshaft balance weight that is loose because of insufficient torque or that has been damaged during storage or installation. Under such circumstances the crankshaft vibration cannot be controlled and the result is torsional stress at the connecting-rod journal areas.
5. Improper bearing cap fit, loose bearing cap, or an obstruction between the bearing cap and the upper cap surface. This leaves the crankshaft unsupported causing it to bend with each revolution.
6. Misalignment of the main-bearing bores, too high a runout of the shaft, or worn bearings. Any of these can cause the crankshaft to bend in two directions.
7. Misalignment of the torque converter, transmission, generator set, etc., to the flywheel housing. Misalignment causes excessive side load on the rear main-bearing and connecting-rod journals.
8. Excessive end thrust or improper end clearance. In either case the result is a lack of oil between the thrust wear surfaces causing fatigue cracks, wear, and overheating. The combination of abrasion and heat can wipe out a main bearing, leaving the crankshaft without support. This imposes a bending stress on the shaft.
9. Inadequate oil, improper grade of oil, or oil that is contaminated because of careless engine service or improper maintenance. (See Unit 12, "Engine Oil.")

Measuring Crankshaft Measure each bearing journal with a micrometer, as shown in Fig. 9-2. Start with the main journal. Write the out-of-roundness measurement of each main journal on the balance weight (plus or minus), so that when measuring the runout (alignment) the out-of-roundness is taken into consideration. Failure to take this measurement will give you an incorrect runout reading.

Continue to measure each journal until the smallest diameter is obtained. Take three measurements at the smallest location on the journal—one on the left, one at the center, and one on the right-hand side—and record the readings. Take a separate set of measurements 90° to the first set and record them. The difference between the two sets of recorded figures will give you the out-of-roundness and the taper of the journals. Do not forget to measure the thrust flange for wear (Fig. 9-3).

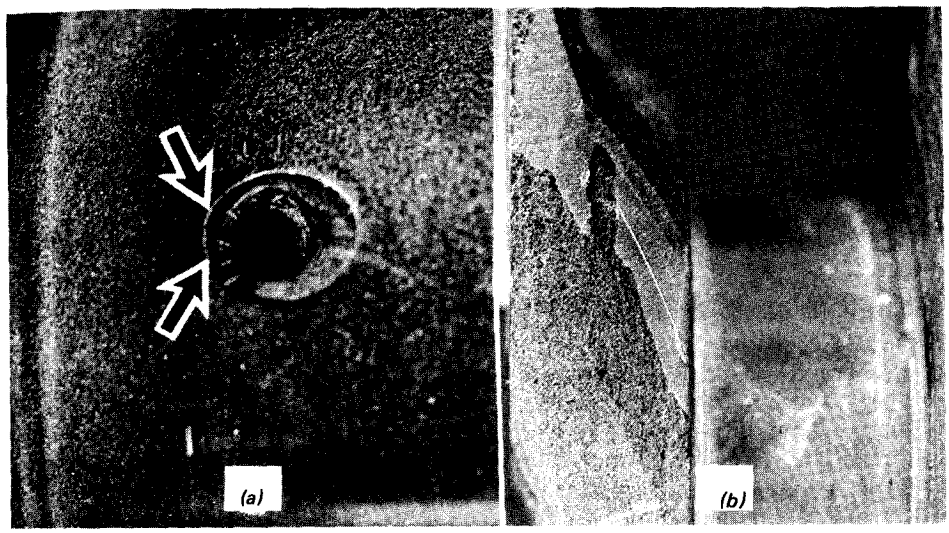


Fig. 9-1 Common areas of fatigue cracks: (*a*) oilhole, (*b*) web.

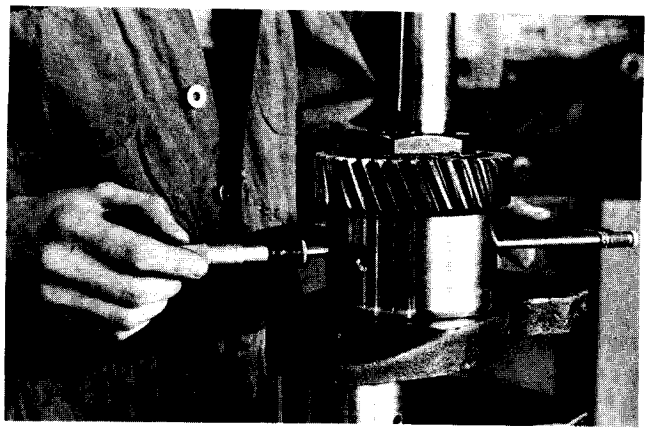


Fig. 9-2 Measuring the main crankshaft bearing.

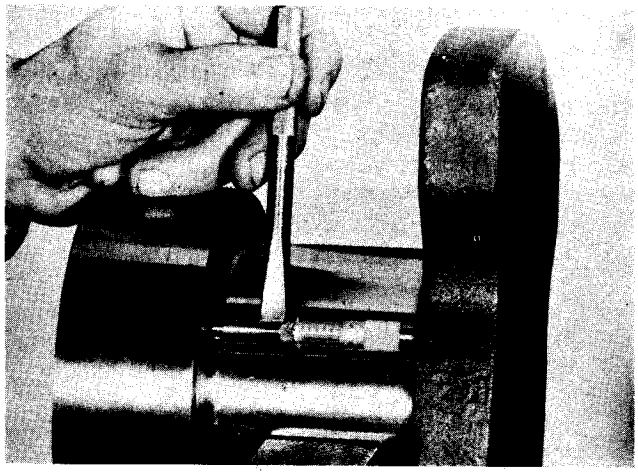


Fig. 9-3 Measuring the thrust flange for wear. *(Cummins Engine Company, Inc.)*

When measuring the connecting-rod journals, you will notice that the wear, out-of-roundness, and also perhaps the taper, are greater than on the main journals. This occurs because the connecting-rod journals have less oil pressure and volume, and because a greater force is placed on them.

To measure the crankshift runout, support the crankshaft on its front and rear main journals in lubricated V blocks, or between the centers in a lathe or crankshaft grinder. For large models, it may be necessary to support the crankshaft on its center journal to prevent sagging.

Place the dial indicator onto the center main journal first. Set the dial to zero, slowly turn the crankshaft, and then write down the reading. Be sure that the dial indicator is resting on a smooth surface and that the base is securely mounted so that it cannot move. The average allowable runout reading is about 0.0025 in [0.0635 mm].

Check all main-bearing journal readings. Say, for example, one journal reading is +0.001 in [0.025 mm] and the adjacent journal reading is 0.002 in [0.050 mm]. In this case the runout would be 0.003 in [0.076 mm]. If the runout exceeds specification the shaft must be straightened.

CAUTION Do not forget to take the out-of-roundness into consideration when measuring runout.

When all journals are within specification and in a serviceable condition and the runout is within the specified limit, the crankshaft must then be polished and reinspected to ensure that all light scratches, water marks, bearing smear, corrosion, and any embedded material have been removed. If one journal exceeds the allowable out-of-roundness, taper, or diameter specification, the crankshaft must be reground. It must also be reground under the following circumstances: if the surface shows groove steps or wear steps greater than 0.0002 in [0.005 mm], if cross scratches appear half the journal length, if there are corrosion, water, chatter, or heat check marks, if the journals are pitted, or if the thrust face is scratched or damaged. However, sometimes the shaft will not sustain further regrinding and must be replaced because of its reduced journal diameter, or because the shaft's surface hardening has already been ground off.

Polishing Crankshaft If the journals are within the out-of-roundness or taper tolerance, and if the surfaces show only minimum roughness, grooving or scoring, less than 0.0005 in [0.0127 mm], the crankshaft should nevertheless be polished before being reinstalled.

To polish the crankshaft, mount it in a lathe and rotate the shaft about 100 rpm. Wrap wet and dry 600-grit emery cloth or crocus cloth around the journals. Apply moderate force in a shoeshine motion. After polishing the shaft, thoroughly clean its surface, and the oil passages, to remove any abrasive residue.

Grinding Crankshaft Crankshaft grinding is a special field which requires precision grinding equipment and a specialized operator. It is not practical for most service shops to maintain such equipment since only a few crankshafts or camshafts need to be ground. It is cheaper to send the camshaft or crankshaft to a specialty shop which has these grinding tools and employs a qualified machinist.

Before grinding the crankshaft, your first step should be to measure the shaft runout. If this measurement is more than specified, the crankshaft must be straightened before being ground.

First, the 80-grit grinding wheel is dressed, and then the shaft is mounted in the cross-sliding chucks and adjusted to the grinding wheel. Next, the shaft journals are measured. The journal with the lowest measurement is used to determine the undersize of all main or connecting-rod journals.

The crankshaft is driven in one direction and the grinding wheel in the opposite direction. Large shafts must be supported by a steady bearing. The operator must proceed with caution to avoid localized heating, which may produce cracks, and to prevent wheel chatter marks. (Coolant should be used generously.) Oilholes and sharp edges must be removed within the radius specified by the engine company.

The journals then are polished to an undersize diameter of approximately 0.0002 in [0.005 mm]. This removes any grinding marks and permits a finer microfinish. At this time the fillet radius is also polished. The shaft is again checked for cracks and surface flaws, after which the crankshaft is thoroughly cleaned, lubricated, and stored. After cleaning (and before storing), the machinist usually installs all drill

plugs. If the crankshaft is stored for more than two months, the journals and oil passages must be protected with a rust inhibitor and stored in a wooden box. Under these conditions each main journal must be individually supported.

Selection of Bearings Most manufacturers furnish replacement bearing shells in undersizes of 0.002, 0.010, 0.020, and 0.030 in [0.050, 0.254, 0.508, and 0.762 mm] for service purposes. Whether to use standard or 0.002-in [0.50-mm] undersize bearing shells depends on the extent of the journal wear, that is, if minimum bearing clearance can be maintained. The average main-bearing clearance is about 0.004 in [0.101 mm] for a 3-in [76.2-mm] journal, and about 0.006 in [0.152 mm] for a journal above 3 in. If the minimum clearance is not obtained, the crankshaft bearing may seize, and ruin both the bearing and the shaft.

Installing Crankshaft Seal Sleeve When a sleeve (wear ring) is used and the seal surface of the front or rear seal area is damaged, the sleeve must be replaced.

To install a sleeve, first heat it in an oven, or use a heating torch (not a cutting torch), to about 400°F [205°C]. Then slide the sleeve in place. The temperature can be checked with a heat stick. If the service manual does not recommend heating the sleeve, use the correct sleeve driver and drive the sleeve in place.

Installing Crankshaft Whenever a new or reground shaft is to be installed, new bearings and thrust washers must be used. *(NOTE: Always check the components for the correct part number.)*

The bearing sizes must coincide with the main and connecting-rod bearing sizes, and with the sizes of the thrust washers which are stamped on the crankshaft. The most accurate way to measure the bearing size or to determine its wear is to measure each shell with a micrometer, as shown in Fig. 9-4, and compare the reading with the manufacturer's specification.

Check that all crankshaft plugs are correctly installed and torqued to specification.

To install the crankshaft gear, coat the shaft at the gear location with high-pressure lubricant. Install the gear key and heat the crankshaft gear to about 400°F [205°C]. Position the gear keyway to the key. Using the correct driver, work as quickly as possible while driving the gear onto the shaft in order to prevent gear seizure due to cooling.

To install the main bearings, remove the main-bearing caps and place them, in sequence, on a clean block surface. Recheck the bearing surfaces of the caps and the upper bearing supports for nicks and burrs. Remember that 15 percent of all bearing failures are caused by improper installation or careless assembly.

Remove the new bearing shells from the packaging material one at a time, and before installing them, make sure that the bearing-shell backs are completely free from dirt, grit particles, and oil. Install the upper bearing shell (with oilhole and groove) in the upper bearing support (Fig. 9-5). Install the lower

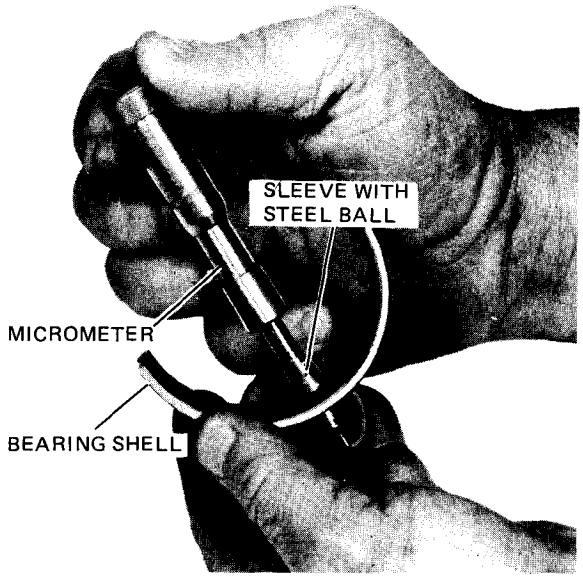


Fig. 9-4 Measuring bearing shell thickness. *(Allis-Chalmers Corp. Engine Division.)*

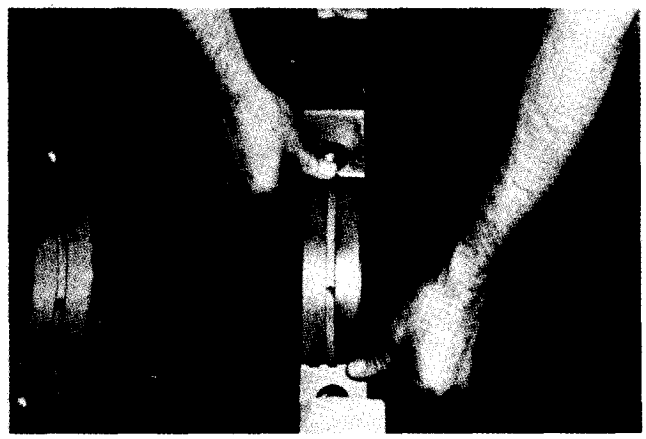


Fig. 9-5 Installing the upper bearing shell. *(Cummins Engine Company, Inc.)*

bearing shell (without oilhole or groove) in its bearing cap, and in the same sequence, install the remaining bearing shells. Make certain that the bearing shells snap into place and that the shell lock tang is in the cap and in the upper bearing support groove. Also, when using special thrust main-bearing shells, be certain that they are fitted snugly into the bearing seats. *(NOTE: Make sure that all oilholes align since all oilholes are not drilled at the same angle. Do not use a lubricant of any kind between the bearing shell and bearing support.)*

If the thrust surfaces have been refinished, it is so marked on the crankshaft and the appropriate oversize thrust rings (washers) (bearings) which coincide with the oversize markings must be installed. Install the upper half of the crankshaft thrust rings and then install the lower half into the cap.

NOTE: The grooved sides of the crankshaft thrust washers must face the thrust surface of the crankshaft to assure their adequate lubrication (Fig. 9-6).

Clean and lubricate the crankshaft main journals, bearing surfaces, and thrust washers, including the

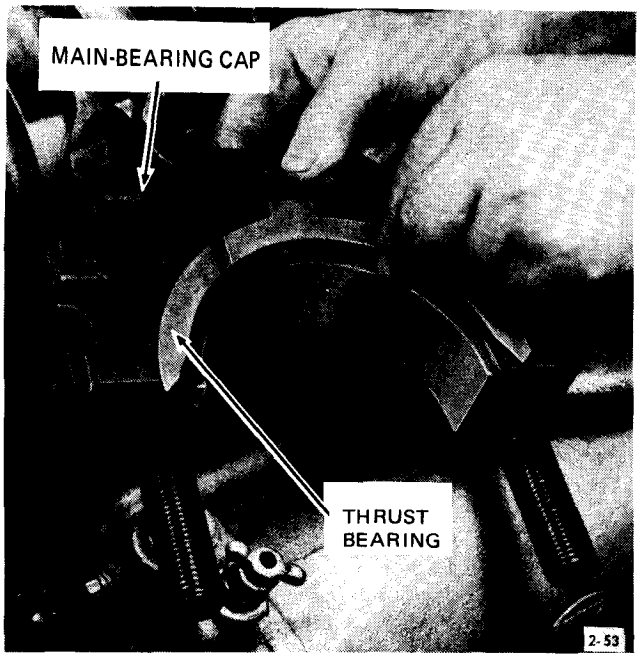


Fig. 9-6 Positioning thrust bearing onto main-bearing cap. *(Mack Trucks Canada Limited.)*

bearings in the caps, with the lubricant recommended by the manufacturer. (Some manufacturers recommend special grease while others recommend engine oil.)

Lift the crankshaft into place, aligning the timing marks, if applicable, lower it into the main bearings, and then place the bearing caps firmly into position. Lubricate all hex or stud bolt threads, if so recommended. Tighten the bolts snugly and at the same time check to see that the crankshaft rotates freely. *(NOTE: Most manufacturers recommend a three-step torque procedure, or the procedure shown in Table 9-1.)*

Starting with the center-cap hex bolts, screw each bolt uniformly tight to its first specified torque. After the center-cap hex bolts, tighten the hex bolts of the nearest main-bearing cap to the right. Next, tighten the bolts of the main-bearing cap to the left. Continue in this sequence until all the bolts are uniformly tightened to specification.

NOTE: Continuously check the rotation of the crankshaft. Then, in the same order, torque the hex bolts to the second torque specification, and finally to the recommended final torque.

TABLE 9-1

MAIN BEARING CAP SCREW TIGHTENING— ft·lb [N·m]

Step	Torque reading
1. Tighten to	190–200 ft·lb [258–271 N·m]
2. Advance to	440–450 ft·lb [597–610 N·m]
3. Loosen all cap screws	remove all tension
4. Tighten to	190–200 ft·lb [258–271 N·m]
5. Advance to	440–450 ft·lb [597–610 N·m]

Some manufacturers recommend the torque-turn method to tighten cap hex bolts. This method places an additional tension on the hex bolts or studs after the final torque. When using the torque-turn method, the first step is to tighten the hex bolts or nuts to the recommended torque value, using the sequence just outlined. With a washable marker, identify each hex bolt or nut to indicate its position on the main-bearing cap. Turn each nut or bolt an additional turn as suggested in the service manual. This will stretch the hex or stud bolts and place additional tension on them, holding the bearing cap firmly in place (Fig. 9-7). Regardless of the method used, if the main-bearing caps and bearing shells are correctly installed and the crankshaft bore, the runout, the end play, and the bearing clearances are within specification, the crankshaft will turn freely.

NOTE: Some manufacturers have, in addition, side main-bearing tie bolts. This arrangement ties the crankcase to the main bearing, which provides additional cylinder-block strength. These tie bolts must also be torqued in the correct sequence and in three steps.

How to Measure or Check Bearing Clearance

The bearing clearance may be measured by using a plastic strip or a virgin lead wire manufactured for this purpose. With either method, you must remove the main-bearing or connecting-rod cap and clean any lubricant from the bearing shell and exposed journal.

After placing a suitable length of virgin lead wire or a plastic strip across the bearing surface, install the cap, nuts or bolts, and then torque them to specification. On installation, the lead wire or plastic strip will crush (flatten) to the thickness of the bearing clearance between the bearing shells and the journal. When using a virgin lead wire, remove the bearing, gently remove the virgin lead, and measure its thickness with a micrometer. If a plastic strip is used, however, it is not removed. Instead, the graduation scale from the strip's original envelope is used to measure the width at the widest point of the flattened plastic material (Fig. 9-8). After having used either method to check the bearing clearance, make sure that you relubricate the bearing journals and bearing shell and use the torque method outlined to retighten the bolts.

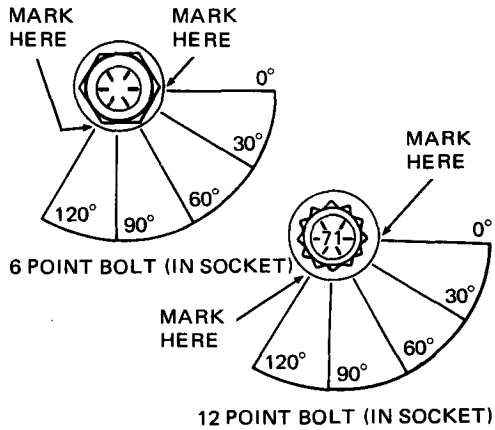


Fig. 9-7 Principle of torque turn method. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

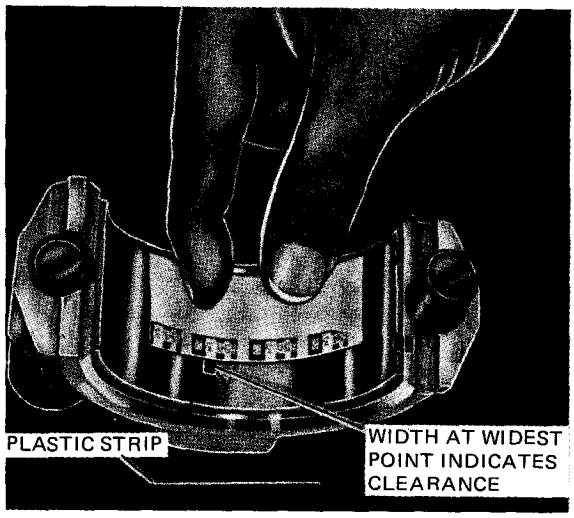


Fig. 9-8 Checking bearing clearance. *(Mack Trucks Canada Limited.)*

Crankshaft End Play Crankshaft end play can be checked with a feeler gauge or with a dial indicator. The average end play is around 0.0010 in [0.25 mm].

To check the end play, force the crankshaft with a soft-face hammer or prybar against one side of the thrust surface. Insert various thicknesses of feeler gauge stock between the thrust surface of the crankshaft and thrust washer until one slides in with only slight drag. When using the dial indicator method, force the crankshaft to one side, set the dial indicator in place, and zero the dial. With a prybar, force the crankshaft in the opposite direction to obtain the end-play reading.

Replacing Main Bearings with Crankshaft Installed Occasionally main bearings are replaced without the engine being removed. In such circumstances, the procedure set out below should be followed:

1. Steam-clean the engine thoroughly.
2. Follow all safety rules with regard to hydraulic equipment and accessories.
3. Allow yourself room to work without obstruction.
4. Drain the oil from the crankcase, then remove the oil filters, oil pan, oil pump, and also the oil tubing, if used.
5. To allow the crankshaft to turn freely, remove the injectors from the engine (or release the compression release if one is used). Cap all fuel lines.
6. Remove one main-bearing cap at a time and check the bearing journals. Measure the bearing wear with a micrometer. If a plastic strip or virgin lead is used, apply a slight upward force, with a jack, against the crankshaft to keep the shaft in contact with the upper bearing shell. This assures a true measurement since the weight of the crankshaft is not resting on the measuring material while the main-bearing cap is being torqued. To measure the main-bearing journals for out-of-roundness, take another measurement after the crankshaft has been turned 90°.
7. Evaluate all your measurements, the surface condition of the journals, and the condition of the bearing shells. You will then know whether to install new standard shells, or whether, in fact, it is necessary to regrind the shaft.

CAUTION Do not install a mixture of new and old or standard and undersize bearing shells. To do so will cause an uneven crankshaft support and, eventually, crankshaft failure.

8. Remove the lower bearing shell from the bearing cap and check the cap for nicks and burrs. Remove the upper bearing shell by turning the crankshaft to a position where you can insert a special removal lug or a cotter pin (with the head flattened) into the oilhole (Fig. 9-9). Turn the crankshaft in a direction that will allow the asserted force to induce the shell to rotate, tang first, from the bore. Make sure that the insert does not interfere with the bore.
9. If it appears practical to reuse the bearing shell, you should check the bearing spreads against specification to determine if the shell will fit snugly into the bearing bore. If no specifications are available, make sure that the shell snaps into place or can be gently forced into place. It is not always necessary to discard bearing shells merely because they do not fit snugly into the bearing bore. Excessive or insufficient spread can be corrected as shown in Fig 9-10.
10. Installation of main bearings with the crankshaft installed requires as much, if not more, attention than when the crankshaft is removed. Furthermore, it is difficult to see dirt or lint in the upper bearing bore. It should therefore be checked very carefully before rolling the lubricated upper shell around the crankshaft journals into place. Remember, too, that the upper bearing must be installed in a direction opposite to which it was removed, until the tang on the bearing shell is positioned in the bearing support slot. Lubricate the bearing shell in the main bearing cap and place it on the upper bearing support. Install hex bolts or nuts and tighten them to the specified torque.
11. Installation procedure for the thrust washers with the crankshaft in place is the same as that with the crankshaft removed. *(NOTE: Check end play.)*
12. Always check the operating condition of the lubrication pump and the pressure relief valve before reinstallation.

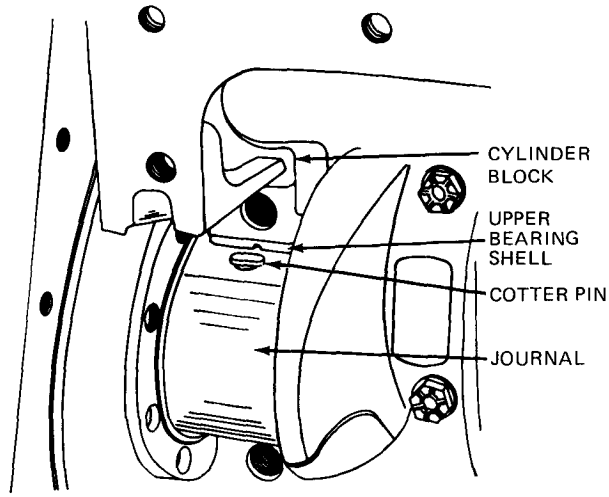


Fig. 9-9 Removing the rear main-bearing upper shell. *(Allis-Chalmers Corp. Engine Division.)*

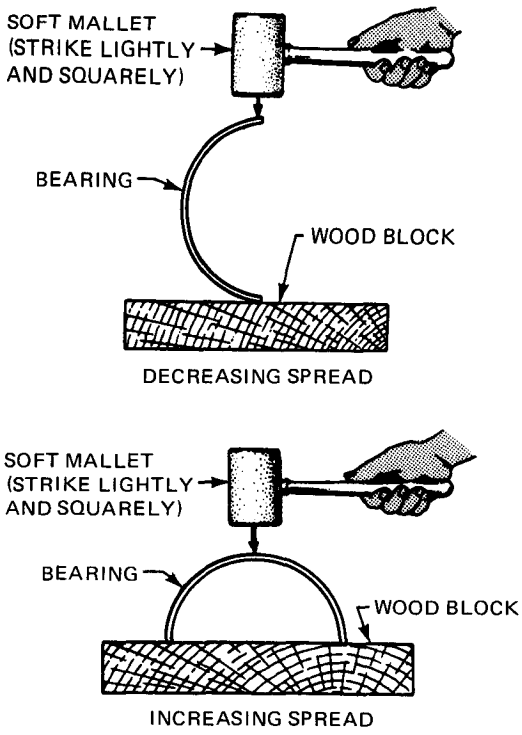


Fig. 9-10 Adjusting bearing spread. *(International Harvester Company.)*

13. The completion of installation is simply the reverse procedure of removal.
14. Fill the crankcase with the lubricant specified by the engine manufacturer, and replace oil filters. Run the engine up to operating temperature, recheck the oil level, and check for oil leaks.

Engine Counterbalancer Some engines are equipped with an inertia balancer to counteract the secondary forces created because of piston acceleration and deceleration. It should not be confused with a torsional damper which is fastened to the front of the crankshaft to reduce the torsional stress in the crankshaft, and not as a means of reducing secondary inertia force.

Although the two set of pistons in a four- or six-cylinder in-line engine are equal in weight and move in opposite directions, their vertical inertia forces do not completely neutralize one another. Since the secondary forces, which tend to limit the smoothness of an engine, occur at twice the speed of the engine, these vertical forces can be canceled by rotating two counterweights at twice the speed of the crankshaft.

When the total secondary force is downward, it is counteracted by the two counterweights exerting an equal upward force. When the total secondary force is upward, it is counteracted by the counterweights exerting an equal downward force.

When the secondary forces are canceled out (because of piston position), the counterweight forces are also canceled out and only the natural inherent balance of the engine exists.

Questions

1. What is the main difference between the crankshaft of an in-line engine and the crankshaft of a V engine?
2. Draw the crankshaft throws of a six-cylinder in-line engine which has a firing order of 1-5-3-6-4-2.
3. List the visual inspections you must make when checking a crankshaft.
4. What measurements must be taken to determine the condition of a crankshaft? Explain how these would be made.
5. Describe how to measure one main journal.
6. List several causes of crankshaft failure.
7. What is the reason for measuring crankshaft runout?
8. List the steps to be taken to install a crankshaft.
9. Why is it essential to follow the manufacturer's torque sequence when tightening main-bearing cap screws?
10. Explain how to measure the running clearance of the main bearings using plastic strip.
11. Outline the procedure to replace a set of main bearings with the crankshaft installed.
12. Why do crankshafts require end play? How is end play checked?
13. The average main-bearing clearance for a 76.2-mm journal should be about (*a*) 0.152 mm, (*b*) 0.330 mm, (*c*) 0.008 mm, or (*d*) 0.076 mm.

UNIT 10 - CONNECTING ROD

Connecting-rod Failure Although design and construction ensures negligible connecting-rod problems, this does not mean connecting-rod problems do not exist. However, when difficulties arise, they are inevitably due to improper operation or inadequate service and maintenance.

Connecting-rod failure over which you as a mechanic have no control is caused by stress raiser fatigue, overspeeding, seized pistons, foreign material in the cylinder, or hydraulic lock. However, connecting-rod failure due to worn bearings or bushings should not occur because it can be prevented by a good maintenance program. Proper assembly, torquing the connecting-rod cap bolts to specification, and checking and measuring the given tolerances are among the good procedures that will ensure longer connecting-rod service life.

Inspection Before you commence inspection or perform any service, you should first thoroughly clean the connecting rod, but make certain the rod and cap are kept as an assembly. Before you check the connecting rods for alignment, magnaflux them to reveal cracks. Pay particular attention to the center web

above the large connecting-rod bore and below the piston-pin bore because these areas are prone to cracking.

If you have determined that the connecting rod is serviceable, you should then check that the connecting-rod bolts or nuts rest squarely on the machined surface without interfering with the connecting-rod or cap fillet (Fig. 10-1).

Check that the threads are not distorted, that the bolt diameter is within specification, and that the alignment rings or dowels are not damaged. If any are damaged, the bolt and/or ring must be replaced. Make sure that the cap and the connecting-rod holes are not worn or enlarged. (The connecting-rod bolts must fit tightly in the bores.) *(NOTE: Connecting rods on engines having 100 hp per cylinder commonly use four connecting-rod bolts to provide good alignment and clamping force.)*

You should then check the piston-pin and crankpin bores. Measure the crankpin bore 30° above and below the parting line using an inside micrometer, a dial bore gauge, or a telescopic gauge, or as shown in Fig. 10-2. The average allowable tolerance for the crankpin bore is 0.001 in [0.025 mm].

Resizing Crankpin Bore If the internal surface of the crankpin bore is damaged, or out-of-round, you should assess whether or not the bore can be resized. You should begin by measuring the length of the connecting rod with an alignment or checking fixture since it is impossible to resize the crankpin bore if the rod is too short. To set up the connecting rod for measuring, tighten the cap to specification and position the rod as illustrated in Fig. 10-1. Insert the master pin instead of the reamer and if the master pin fits into the piston-pin bore, the connecting-rod bore can be resized. Remove the dowel (if applicable) and then grind about 0.009 in [0.23 mm] from the connecting-rod and cap surface with a connecting-rod resizing grinder (Fig. 10-3). Make certain that the cap or connecting rod is clamped sufficiently tight so that it cannot move during the grinding operation. This will assure alignment of connecting-rod bolts with bores, and proper contact of the mating surfaces. It is usually necessary to lap the mating surfaces to ensure at least an 80 percent contact. The contact area can be checked by bluing the mating surfaces, then rubbing them together. The contact area should be around the connecting-rod bolts and not toward the center of the crankpin bore.

Bolt the mating cap to the connecting rod. When you torque the bolts or nuts to specification, hold the connecting rod in a special vise or hold it in a soft-jaw vise to prevent it from twisting or bending. Measure the bore with an inside micrometer or with the special gauge on the honing machine to determine if it is out-of-round (see Fig. 10-3).

Honing Crankpin Bore When using the Sunnen honing machine, make sure that you select and install

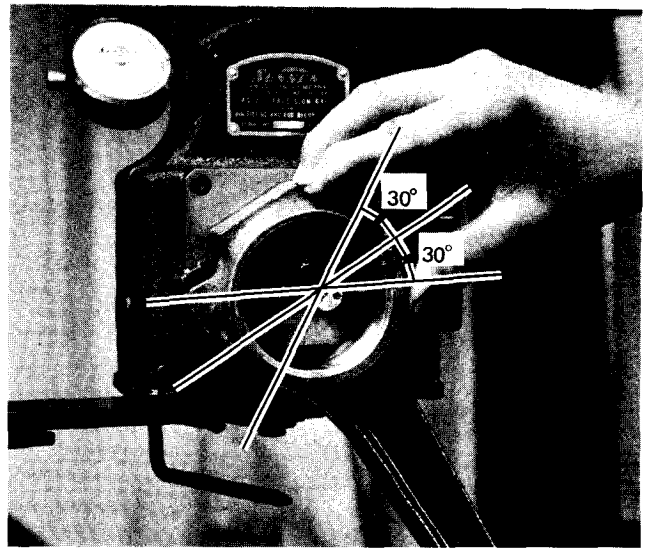


Fig. 10-2 Measuring the bore with the special gauge on the honing machine.

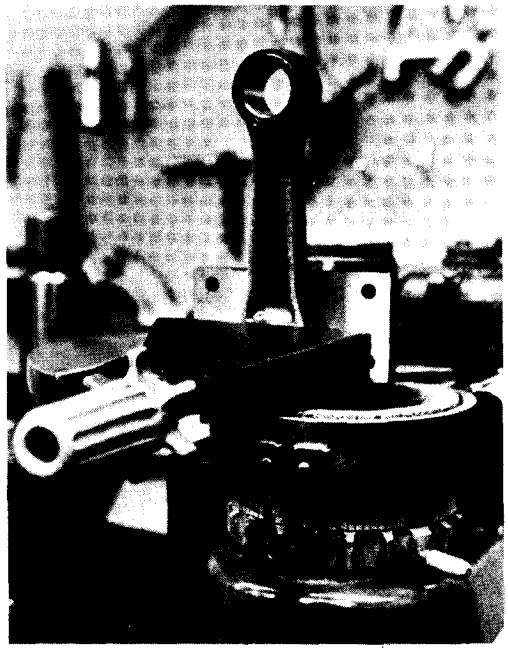


Fig. 10-3 Precision connecting-rod grinding.

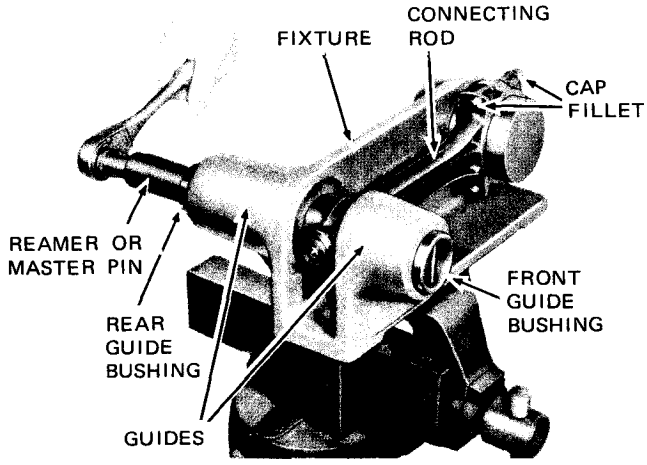


Fig. 10-1 Connecting-rod all-purpose fixture. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

the correct hone. The stones selected should give you a 70-micrometer (μm) finish bore or better. True the stones.

Check the bronze bearing supports. When necessary, use an oil stone to remove high spots to ensure a true bore.

Slide the crankpin bore over the hone, adjust the stone tension, and direct the spout of the honing oil onto the lower part of the hone. Support the rod on the support arm of the honing machine. Start the motor and again adjust the stone tension until you feel no chatter. Then move the connecting rod back and forth over the stone while maintaining snug stone tension (Fig. 10-4). Frequently check the inside dimension to prevent an oversize bore. The average allowable tolerance is 0.0005 in [0.012 mm].

When the piston-pin bushing(s) are not damaged and do not appear to be excessively worn, measure the exact amount of wear. The average wear limit is 0.005 in [0.12 mm] and the average clearance between the piston pin and bushing (when new) is 0.001 to 0.002 in [0.025 to 0.050 mm]. If the wear exceeds the maximum limit, remove the bushing and measure the piston-pin bore. The average tolerance is 0.0005 in [0.012 mm]. If the bore is not within specification, it must be resized, or the connecting rod must be replaced.

Replacing Piston-pin Bushings Position the connecting rod in a holding fixture according to the service manual recommendations. With a bushing driver, press or drive out the bushing. Before you reinstall new standard or oversize bushings, lubricate the bore and carefully align the oilhole in the bushing with the outside of the bore. Using the same bushing driver, press or drive the bushing flush with the outside of the bore. Do not concern yourself with the location of the bushing split but rather with the oilhole alignment.

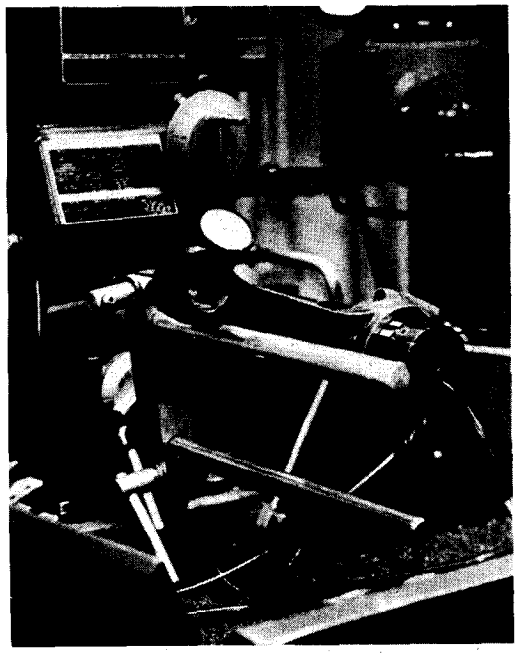


Fig. 10-4 Honing the crankpin bore.

Some manufacturers recommend broaching the bushing (that is, pressing a broaching tool into the bushing bore) instead of reaming to ensure that the bushing fits tightly against the bore surface to prevent the bushing from turning and to give a uniform bore size. A tight-fitting bushing also transfers heat well.

Servicing Piston-pin Bore When it becomes necessary to rebore the piston-pin bore, mount the connecting rod in a holding fixture and bore or ream the hole to specified oversize. Remove any sharp edges with a taper reamer. (Refer to the manufacturer's instructions for using the boring machine.)

Reaming Piston-pin Bushing The connecting-rod length is very important in establishing the compression ratio and in preventing piston interference with the valves. The piston-pin bushing, therefore, must be reamed in a fixture to assure a precise center-to-center length (Fig. 10-1).

When reaming a bushing, gently insert the reamer into the guide bushings to ensure perfect alignment and then carefully ream the bushing. Do not force (crowd) the reamer or turn it in a counterclockwise direction because this will produce a rough finish. After reaming, check the bushing surfaces for even thickness and smoothness, then measure the diameter. When the thickness of the bushing varies or the reamer has failed to give a full surface contact, the connecting rod is bent or twisted and must be straightened and reserviced, or discarded.

Checking Connecting-rod Alignment Many different alignment fixtures are used to check connecting-rod alignment; one of the simplest is shown in Fig. 10-1. To check the alignment using this type of tool, place the crankpin bore on the large pin and push the piston-pin bore end down between the guides. If the piston-pin bore end does not fit between the guides, the rod is twisted or bent. The average allowable twist or bend is 0.008 in [0.20 mm].

A more reliable alignment tool is shown in Fig. 10-5. Direct measurements for bend, twist, and connecting-rod length can be taken with this tool.

When working on Detroit trunk-type piston connecting rods, you should, in addition to the procedure previously outlined, clean and check the oil passage, the orifice, and the spray nozzle to ensure that the piston pin receives lubrication and the piston adequate cooling (Fig. 10-6).

NOTE: The piston-pin bushing split must be positioned below the spray nozzle. Also note that the bushing of turbocharged engines is not replaceable.

NOTE: Connecting rods which have crankpin-mating surface alignment devices such as shoulders and grooves or serrations cannot be serviced when the bore is out-of-round or the surface is damaged.

Crosshead-piston Connecting Rod The checks, tests, and service procedures for a crosshead-piston connecting rod are almost identical to those for trunk-type-piston connecting rod. However,

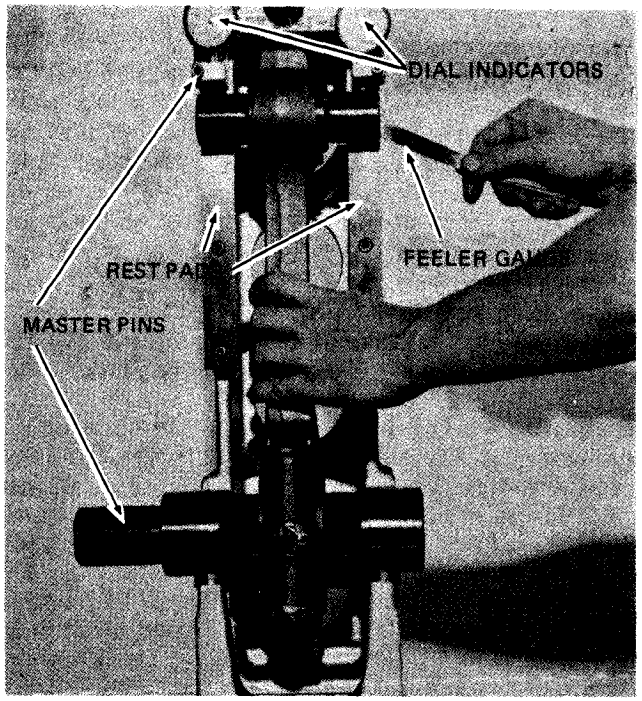


Fig. 10-5 Alignment fixture: showing dial indicators to check bend and a feeler gauge to check twist. *(Cummins Engine Company, Inc.)*

with the crosshead type you must check saddle alignment, and if the crankpin bore exceeds specification limits, the rod must be replaced.

Questions

1. State the three ways in which alignment is maintained between the connecting rod and the cap.

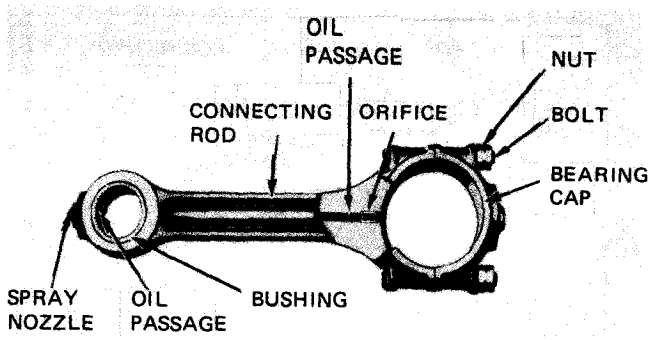


Fig. 10-6 Detroit two-cycle trunk-type connecting rod. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

2. Outline the procedure used to measure the connecting-rod bore when using an inside micrometer.
3. Why is it very important to have the connecting rod length, from the center of the pin bore to the connecting-rod bore, within correct specification?
4. If a connecting rod is installed which is twisted beyond the allowable specification, how would it affect the piston, the connecting rod, the connecting-rod bearing, and the journal?
5. Why should a piston-pin bushing be reamed in a holding fixture rather than honed?
6. Bent connecting rods may be caused by (*a*) water in the cylinders, (*b*) preignition, (*c*) excessively worn connecting-rod bearings, or (*d*) excessive crankshaft end play.
7. One of the most common connecting-rod problems encountered when replacing bearings is (*a*) bent rod, (*b*) twisted rod bolts, (*c*) rod bore stretched out-of-round beyond specifications, or (*d*) mismatched bearings.
8. Connecting rods and piston assemblies should (*a*) be given a complete and careful alignment check with every ring job; (*b*) be corrected if out of alignment; or (*c*) be replaced if out of alignment.

UNIT 11 • PISTON AND RINGS

Maintenance A good maintenance program begins with a thorough break-in (see Break-in Run, Unit 52); thereafter the engine should be tuned up regularly and components repaired as soon as they become defective. Component replacements should be made *only* from those recommended by the manufacturer. Oil filters should be changed regularly and any oil or coolant losses should be serviced promptly. A damaged muffler or pipe that may cause restrictions and thereby increase combustion temperature should be promptly replaced. These procedures will extend the service life of pistons, piston rings, and cylinder sleeves.

Following is a list of negative practices which, if carried on, would promote engine failure. Do not:

- Shut down an engine when it is hot
- Operate an engine above 1000 rpm before it has reached ambient temperature
- Use starting aids excessively (ether)
- Adjust the governor or fuel above specifications
- Neglect the exhaust system
- Allow dirt to get into or onto the components.

Piston Failure Figure 11-1 illustrates piston failures that result from poor workmanship or poor maintenance.

Figure 11-1*a* shows a piston with score marks on each side of the piston-pin bore. These marks could have been caused by low coolant, restricted coolant flow, continuous improper cold starting, hot shutdown, or improper piston-pin-to-bore fit.

Figure 11-1*b* shows a piston with irregular score marks from the skirt area to the crown. These marks could have been caused by low coolant, restricted coolant, a partly plugged radiator, high coolant temperature (due to defective radiator cap, loose fan belt, damaged water pump), continuous improper cold

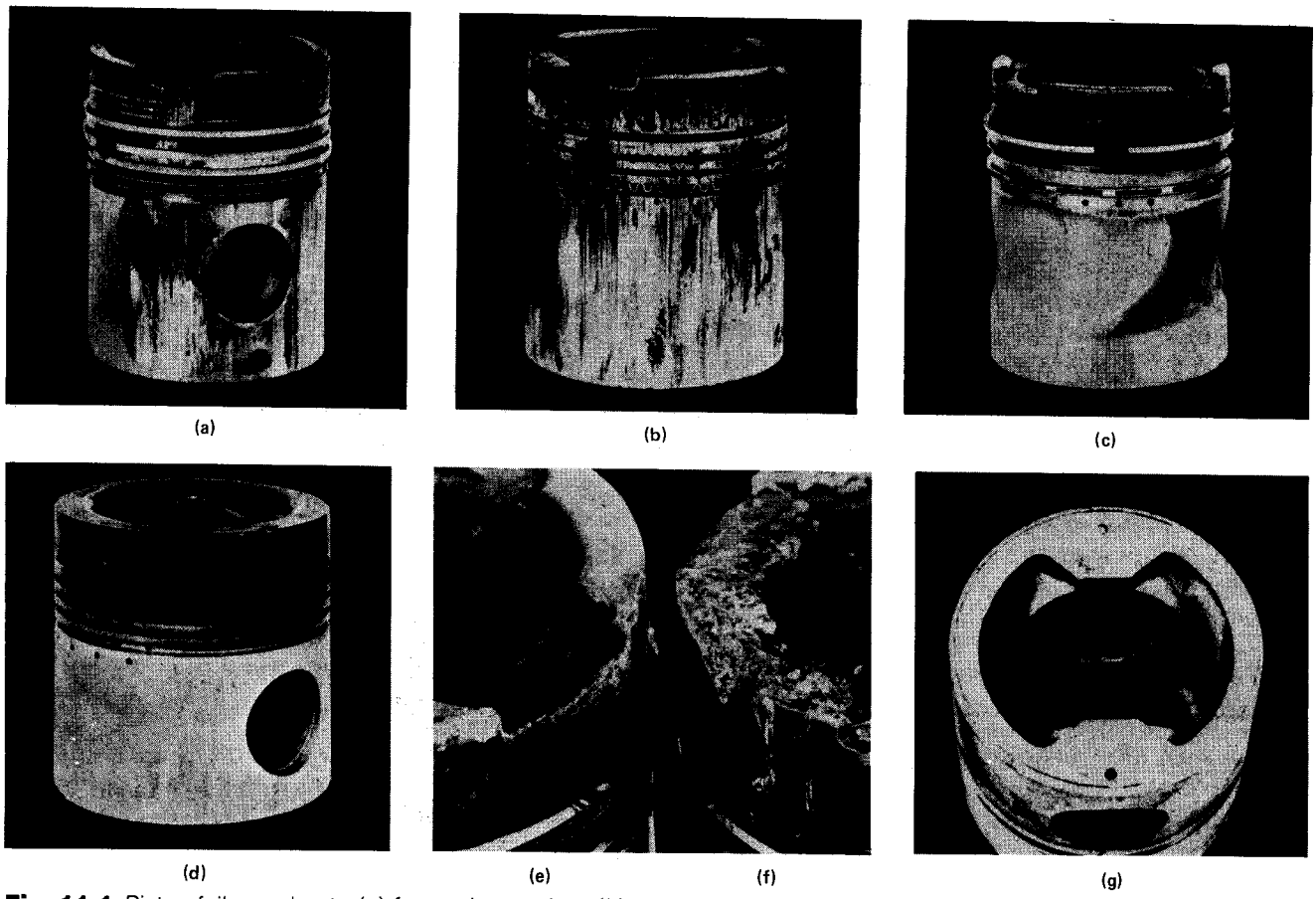


Fig. 11-1 Piston failures due to (*a*) four-point scoring, (*b*) irregular scoring, (*c*) thrust or antithrust scoring on skirt, (*d*) burning, (*e*) damaged crown, (*f*) ring fracture, (*g*) piston fracture. *(Cummins Engine Company, Inc.)*

starting, hot shutdown, lack of lubrication, overfueling (due to damaged turbocharger), faulty injector, and/or improper adjustment of the fuel-injection pump.

Figure 11-1*c* shows a piston with vertical score marks. These marks have developed over a long period of time on the thrust and antithrust side of the piston skirt. They could have originated from scuffed rings, overfueling, piston distortion due to thermal expansion, distortion of cylinder-sleeve bore and/or cylinder-sleeve O rings.

Figure 11-1*d* shows a piston that has started to erode (burn) on the outside of the piston crown. The erosion could have originated through detonation, restricted air supply, excessive use of ether (for starting), overfueling, faulty injector, and/or enlarged nozzle orifice.

Figure 11-1*e* shows a piston with a damaged crown. The damage may have originated from improper ring installation which caused the ring or the ring land to break, from valve or valve insert failure, from extremely worn connecting-rod bearings, or from foreign particles in the combustion chamber which entered through the intake system.

Figure 11-1*f* shows a damaged piston due to a broken ring land. This damage could be the result of improper compression-ring installation, ring breakage or ring-land damage prior to installation, or manufacturer's casting porosity. It may also be the result of excessive use of ether for starting, or extreme detonation.

When the piston (including the skirt area) shows black or brown deposits, it is an indication that engine oil or combustion gases have passed by the rings. Combustion gases can pass by the rings if there is poor ring sealing, poor quality oil used, high oil level in the crankcase, high oil temperature, aerated lubricant, or excessive intervals between oil changes.

Piston fracture, such as that shown in Fig. 11-1*g*, can be caused by detonation, overfueling, or continuous overloading of the engine. Piston fracture, when it occurs because of defects in the manufacturer's casting, will commonly show on top of or below the crown.

Piston-ring Failure Ring scuffing (Fig. 11-2) is by far the major cause of hard starting, loss of power, and high oil consumption due to loss of compression. Ring scuffing also causes piston and cylinder wall scoring.

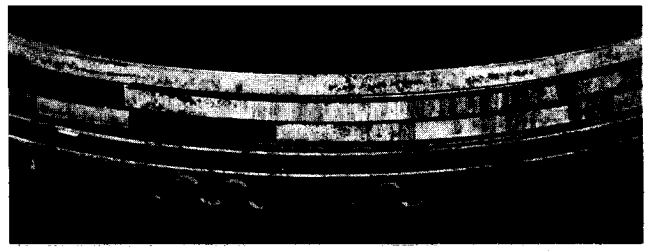


Fig. 11-2 Ring scuffing. *(Cummins Engine Company, Inc.)*

Ring scuffing may originate during the assembly by failure to maintain specified piston and/or ring clearance, by improper surface characteristics, and/or by improper maintenance of lubricant, coolant, and air-intake systems. Other causes of ring scuffing are: improper adjustment of fuel-injection pump, turbocharger failure, thermostat failure, plugged radiator, nonworking radiator shutter, improper engine break-in, or engine misuse during the first few hundred miles of operation.

The use of keystone rings virtually eliminates ring sticking. However, should this problem occur, the cause may be traced to running the engine when it is too cold, say, −50°C, allowing too long an interval between oil changes, or intermittently overheating the engine.

Ring breakage usually arises from a damaged piston crown and/or piston land, or it can occur after excessive detonation. The greatest percentage of ring breakage, however, is due to improper installation procedures, incorrect ring-gap clearance, or damage to the ring land while inserting the piston into the cylinder sleeve. Another cause of ring breakage, though not common, is failure to remove the ring ridge in the cylinder sleeve, as this can cause the first compression-ring piston land to break.

Piston-cooling Jets or Nozzles Normally, engines other than turbocharged have the piston crown and ring groove cooled from the oil thrown off the main and connecting-rod bearings and from the oil that is scraped off the cylinder walls, or additionally through the oil passage in the connecting rod. However, since these cooling methods are not adequate for turbocharged engines by themselves, most such engines are equipped with a jet or nozzle to direct oil to the underside of the piston crown. This additional oil cools the piston and lubricates the piston pin. The Caterpillar 3500 Series engine uses one additional oil jet (see Fig. 11-3) to spray oil into a vertical piston passage which leads to a groove located in the piston crown. The ring and crown area are further cooled, thus extending the piston and ring service life. The oil supply to the jets comes either from the oil manifold or from the camshaft oil gallery. Larger engines use a check or bypass valve to block the oil flow to the piston-cooling nozzles during start-up, thereby providing a quick oil pressure buildup. When the oil pressure reaches, say 40 psi [275.8 kPa], the check or bypass valve opens and allows oil to flow through the nozzle.

NOTE: The importance of the position and condition of the piston nozzle cannot be overemphasized. If the nozzle is damaged or deformed, no attempt should be made to straighten it; it should be replaced. (A plastic target is sometimes used to check the alignment.)

Piston Inspection and Service Pistons should be replaced under the following conditions:

- If the piston pin bore, ring land, or crown is damaged
- If any part of the piston is fractured

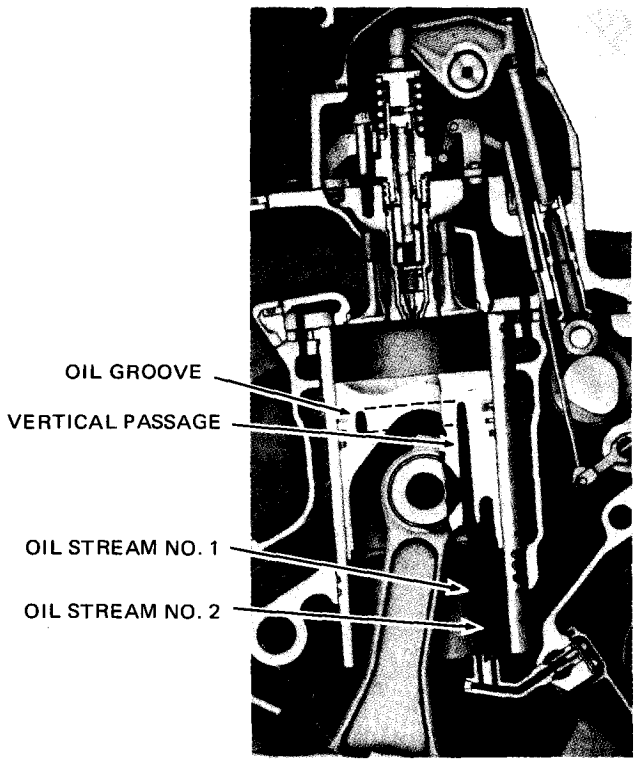


Fig. 11-3 Schematic view of piston cooling jets and oil streams. *(Caterpillar Tractor Co.)*

- If metal particles are embedded in the skirt or crown
- If deep valve-contact marks are visible
- If the top-ring iron band is separate from the piston
- If seizure marks can be seen on the skirt
- If the piston-ring grooves are worn beyond specification

When a piston has passed inspection, it should be cleaned externally and internally with solvent or fuel to remove any gummy substance or carbon deposits. Some manufacturers recommend glass-beading to clean or remove light score marks from their pistons (see your service manual for specific instructions).

CAUTION Be selective when using solvent because some contain a chemical which attacks aluminum alloy. Do not use a wire brush to remove deposits from aluminum pistons because it may damage the surface. Furthermore, if the skirt is coated, a wire brush could remove this coating.

When there is carbon in the ring grooves, remove it with a ring-groove cleaner. Do not cut any material from the ring lands or from the bottom of the groove. Another method of cleaning the ring grooves is to break a discarded ring in half. File the butt ends to form a sharp corner which may be used as a scraper to clean the ring grooves. Do not forget to check the oil return holes in the piston wall. If the solvent has not cleared the holes, use a drill (correct size) to remove the deposit.

After the piston has been cleaned and dried with compressed air, reinspect it, particularly in the piston-pin boss area. Next, check the piston-ring grooves for wear. Use a feeler gauge or wear gauge (Fig. 11-4) at several points around the circumference of the ring grooves. The average maximum wear limit

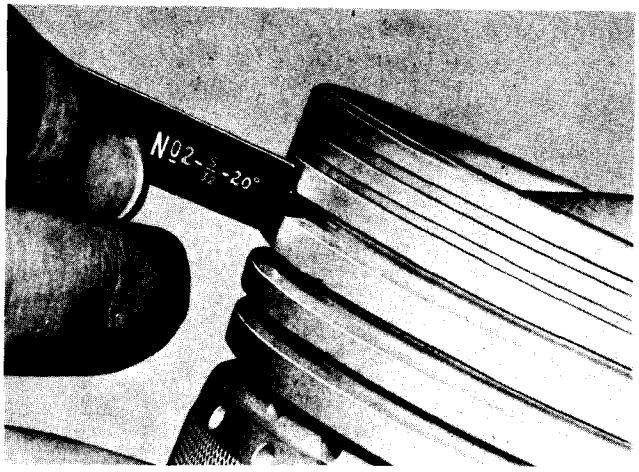


Fig. 11-4 Checking ring groove wear with a wear gauge. *(Cummins Engine Company, Inc.)*

is about 0.006 in [0.152 mm]. If the wear exceeds this, replace the piston.

Pistons are usually replaced because of excessive clearance in the first or second compression-ring grooves (caused by normal wear) and not because of normal wear in the oil-ring groove, piston skirt, or piston bores. No diesel engine manufacturer recommends extending the service life of the piston by restoring the ring grooves. Do not recut the ring grooves with a manual lathe to accommodate a top ring-groove spacer.

Check the piston-to-sleeve clearance (running clearance) by measuring the piston diameter and comparing it with the inside diameter of the cylinder sleeve. The average running clearance is about 0.006 in [0.152 mm] and not less than 0.002 in [0.050 mm]. Insufficient clearance will cause premature piston and/or cylinder-sleeve failure.

The procedure to measure the pistons is not identical for all pistons. You must, therefore, check the appropriate service manual: For instance, the measurement of a cam-ground piston is taken at right angles to the piston-pin bore. For a straight or tapered piston (Fig. 11-5) it is taken at *A* and at *B*.

NOTE: All measurements should be taken at 70°F [21.1°C].

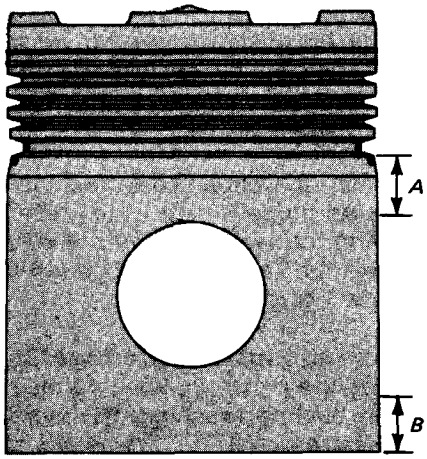


Fig. 11-5 Measuring a straight or tapered piston. *(Cummins Engine Company, Inc.)*

For straight pistons, the out-of-roundness should not exceed 0.0005 in [0.001 mm]. The running clearance of all straight pistons can also be measured by the method shown in Fig. 11-6. When using this method, lubricate the piston (without rings) and cylinder sleeve with a thin film of light oil. Insert, say, a 0.004-in [0.01-mm] feeler gauge in the cylinder sleeve as shown. Insert the piston, bottom up, about 2 in [50 mm] below the block surface with the piston-pin bore in line with the crankshaft. When the spring scale indicates the recommended force in pounds [kilograms] as the feeler gauge is being withdrawn, the running clearance is correct. (The running clearance is actually about 0.001 in [0.025 mm] greater than that of the feeler gauge.)

Take at least one more measurement, about 90° from the first one, to confirm correct measurement. When the running clearance exceeds 0.010 in [0.254 mm], the piston (and at times the cylinder sleeve) must be replaced.

Although not recommended by diesel engine manufacturers, a stop-gap method to increase the skirt diameter is through knurling. *Knurling* is the process of actually displacing the skirt surface metal by forcing it between the teeth of the knurling tool. By controlling the force and the position of the tool, a narrow ridge occurs on the outer surface of the skirt thereby increasing the skirt diameter.

Measuring Piston Pin and Bore Before you measure the piston-pin bore, check the piston temperature because a temperature variation above or below 70°F [21.1°C] affects the bore size. Measure

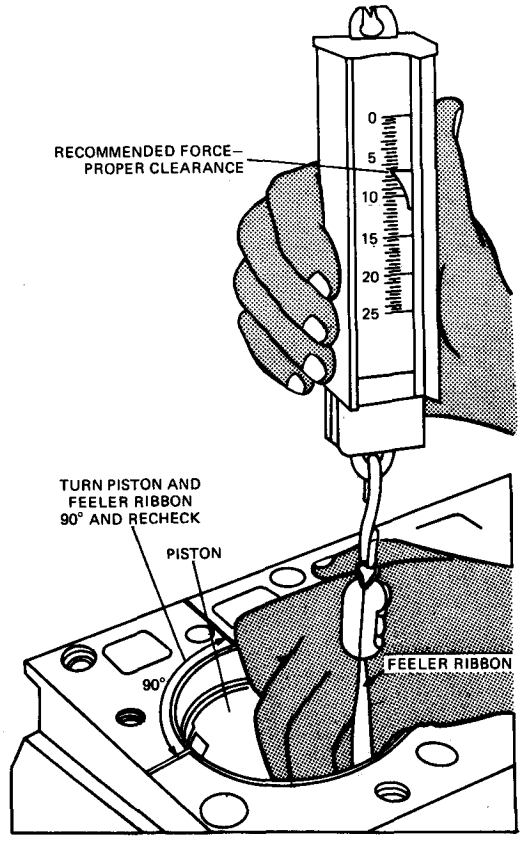


Fig. 11-6 Measuring the running clearance of a straight piston.

the bore with an inside micrometer, as shown in Fig. 11-7. Next, inspect and measure the piston pin. If it is out-of-round more than 0.001 in [0.025 mm], or if it shows signs of etching and/or corrosion, or if it is worn to its limit, the piston pin must be replaced.

Rarely should you ream or hone the piston-pin bore and substitute an oversize piston pin. Reaming or honing may result in misalignment and can cause piston seizure or connecting-rod-bearing failure.

Removing and Installing Piston-pin Bushings Piston-pin bushings are generally used with cast-iron pistons. If it is necessary to replace them, take extreme care not to damage the piston when pushing or driving the bushings in or out. Always use the correct fixture to support the piston. Position the joint of the bushing toward the lower end of the skirt to increase bearing support. Do not hone or ream the bushings free hand as this can cause misalignment; use the reaming fixture recommended in the service manual.

Assembling Trunk-type Piston to Connecting Rod When you assemble the connecting rod, make sure that the rod, cap, and piston identification numbers coincide. If you are reassembling a used connecting rod and piston, check the piston-pin fit in the connecting rod and piston, as shown in Fig. 11-8*a*. However, first check the appropriate service manual because some pistons must be heated to about 210°F [98.9°C] before the piston pin is installed to prevent damage to the piston-pin bore. The piston pin should fit snugly. In other words, considerable hand pressure is required when inserting the pin into the piston. The fit in the connecting rod, however, should be comparatively loose.

When you assemble the connecting rod to the piston, place the piston in a holding fixture or place the connecting rod in a soft-jaw vise. Apply clean engine oil to the piston-pin bore, connecting-rod bushing, and piston pin.

Install one snap ring into the groove or install a piston-pin retainer into the piston-pin bore. Force the piston pin through the piston-pin bore until a slight protrusion is noticeable, align the piston position

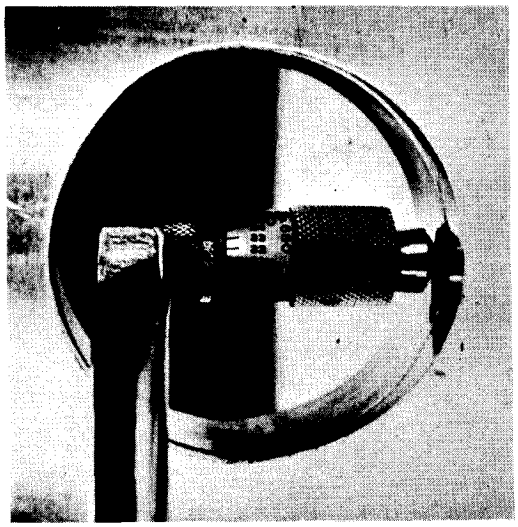


Fig. 11-7 Measuring the piston-pin bore with an inside micrometer.

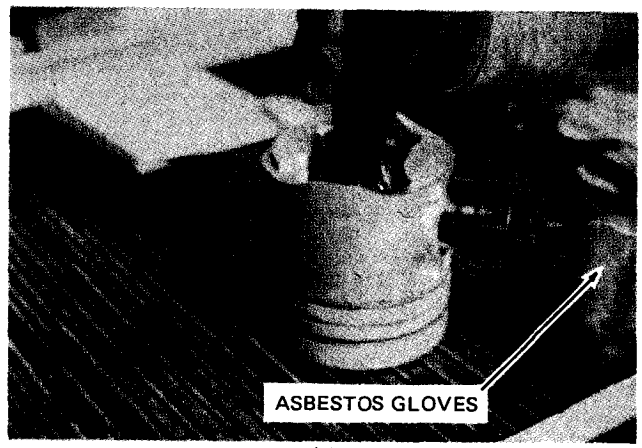


Fig. 11-8 (*a*) Checking the fit of the piston pin. (*b*) Checking the piston-pin retainer for proper sealing. *(Cummins Engine Company, Inc.)*

mark with the connecting rod or vice versa, then place the connecting rod with its piston-pin bore onto this protrusion. Force the piston pin through the bore against the snap ring.

Install the other snap ring or piston-pin retainer. Make certain that the recommended clearances exist between the snap ring and piston pin and also between the connecting rod and piston-pin boss.

NOTE: When installing pistons having valve reliefs, check the service manual to determine in which direction the valve relief should be pointing. The manual will also indicate the direction in which the connecting rod must face. If you have no service manual, check the marking on the piston crown for piston direction. As a general rule the connecting-rod number faces toward the camshaft on in-line engines and toward the outside on V engines.

The piston-pin retainer on Detroit Diesel two-cycle engines serves a second purpose, that is, to prevent air-box air from entering the crankcase. After the retainer is installed, use the leak detector gauge to check for air leaks (see Fig. 11-8*b*).

Assembling Crosshead Piston to Connecting Rod (Fig. 11-9) Lay the piston crown on a clean surface and insert the bearing (bushing) by forcing the half-bushing into its seat. *(NOTE: The clearance between the edge of the bushing and the groove in the piston crown varies between engine series.)* One

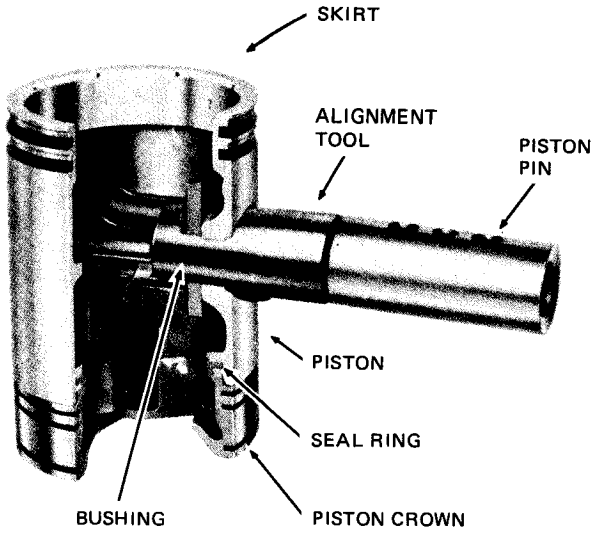


Fig. 11-9 Sectional view of a partly assembled crosshead piston. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

of two types of seal rings is used between the crown and skirt: a seal ring with an inside bevel, or a seal ring which is marked "top." Lubricate the seal ring as well as the ring groove. Use a ring-installation tool to install the seal ring to the crown so that either the inside bevel or the ring marked "top" faces toward the top of the piston crown. The seal ring must not stick in its groove, and the clearance must not exceed specification. Lubricate the seal-ring surface of the piston skirt. Compress the seal ring with a special ring compressor, and slide the skirt over the crown. The skirt should rotate freely by hand pressure to assure satisfactory piston performance.

Align the skirt and piston crown, lubricate the pin bores, piston pin, and bushing, and then install the piston pin. Place the spacers on the connecting rod bolts, lubricate the threads, align the connecting rod and piston-pin holes, and install and tighten the bolts fingertight. Clamp the connecting rod in a vise and torque the bolts to specification. Next, install the retainer and check it for air leaks.

Piston-ring Design Since manufacturers have so far been unable to design a multipurpose piston ring that will seal the combustion chamber, control the oil on the cylinder walls, dissipate heat from the piston to the cylinder wall, withstand heat and pressure, and have a long service life, they have produced a great variety of piston rings. The material from which pistons are made is one of the variables. Piston rings may be made from cast iron, malleable iron, or ductile iron with the addition of other elements such as carbon, silicon, graphite, manganese, phosphorus, chromium, copper, molybdenum, or vanadium. Most compression rings and some oil-control rings are plasma- or chrome-faced to reduce friction and to ensure longer service life.

All piston rings have a built-in controlled ring tension and are precision-machined and lapped to specific dimension. In a free state, the piston rings are oval. When confined to the cylinder, they fit flat against the piston-groove sides and the ring face conforms to the cylinder wall to ensure proper sealing and oil control.

Compression and Oil-control Rings (Fig. 11-10) All compression rings use the inherent ring tension, the combustion pressure on the power stroke, the exhaust pressure on the exhaust stroke, the crankcase pressure on the intake stroke, and the compression pressure on the compression stroke to seal between the moving piston and the cylinder wall. In addition, they effectively control the oil film on the cylinder walls and thus prevent metal-to-metal contact between the piston rings and the cylinder sleeves. However, too much static pressure causes scuffing, scoring, and excessive wear. Insufficient static pressure results in less oil control and high oil consumption; therefore, when you install piston rings, use a ring-installation tool to prevent piston-ring distortion or overexpansion during installation.

Oil-control rings are used to limit the oil film on the cylinder walls and to provide adequate lubrication to the compression rings. If the oil film left on the cyl-

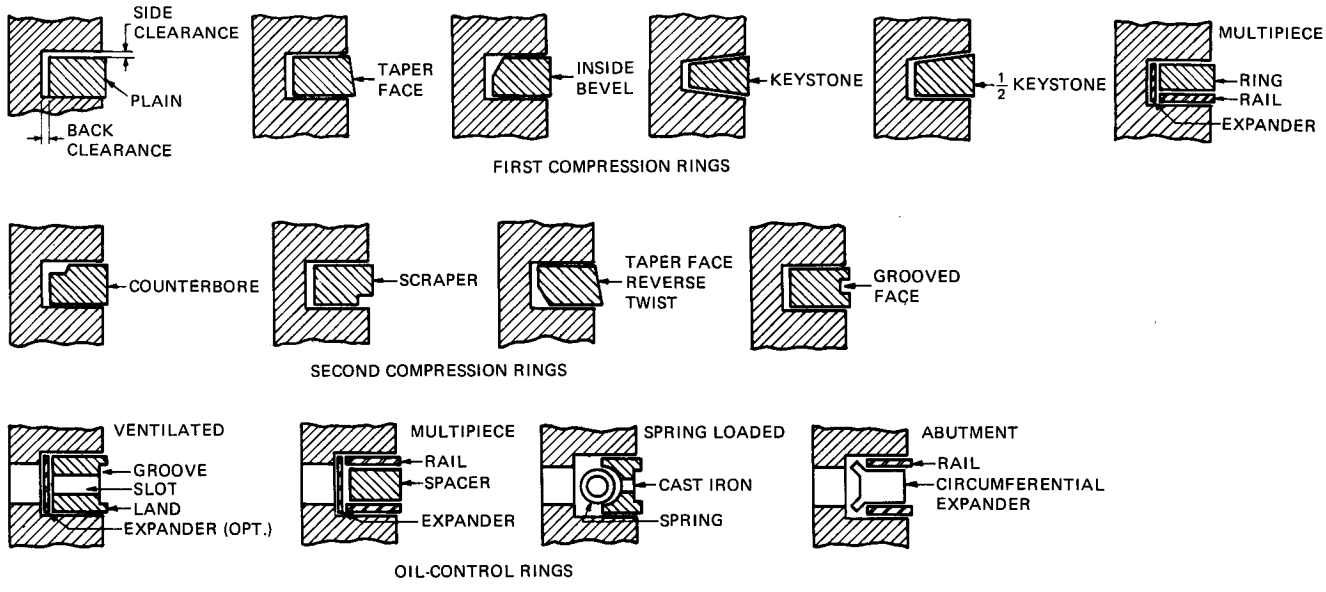


Fig. 11-10 Compression- and oil-control-ring designs.

inder walls is excessive, it cannot be controlled by the compression rings and it therefore enters the combustion chamber. Insufficient oil film on the walls will allow metal-to-metal contact between the compression rings and cylinder walls and will result in scoring and scuffing.

Figure 11-11 shows an installed oil-control ring and the openings or passages from the face to the back of the rings. These passages allow the oil that is wiped from cylinder walls as the piston moves downward to pass into the ring grooves, piston wall openings, and back into the crankcase (Fig. 11-11*a*). At the same time, this oil dissipates heat from the piston (Fig. 11-11*b*). On some engines it also lubricates the piston pin.

Most oil-control rings use some type of expander to force them, or the rails, against the cylinder wall (see Fig. 11-10). This force is a major oil-control factor and should never be altered.

Checking Piston-ring Gap Before you install the piston ring onto the piston, you should check each piston ring for correct ring gap. Insufficient gap will cause damage to the piston, piston ring, and cylinder walls. Excessive ring gap can cause compression losses or a buildup of carbon in the combustion chamber or on the piston crown, or can allow oil to enter the combustion chamber.

To check the ring gap, insert each ring into its cylinder sleeve. With a piston, push the ring down half the distance of piston travel so that it rests square to the cylinder sleeve. With a feeler gauge, measure the space (the gap) between the ends of the piston ring (Fig. 11-12).

Do not file chrome-plated piston-ring ends because the chrome plating may loosen and, at a later date, damage or score the cylinder sleeve or piston.

When it becomes necessary to increase the ring gap, clamp a mill file or an oil stone in a vise. The width of the file or stone should be the same as that of the ring gap, to assure proper ring-end angle. Hold the ring in alignment when forcing both ring ends against the file or stone. Cut from the outside of the ring surface to the inside only.

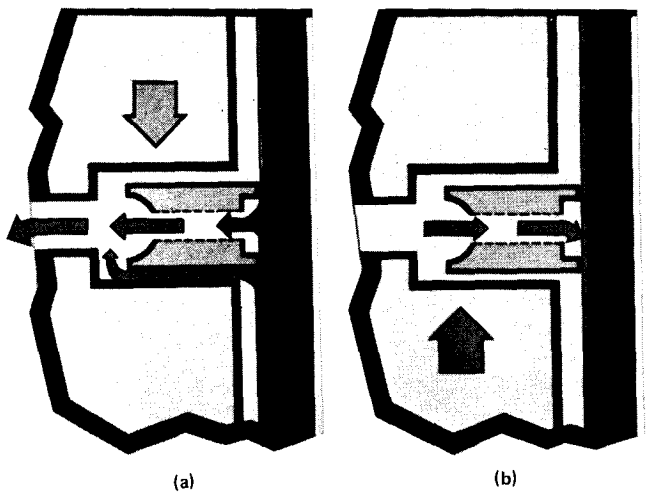


Fig. 11-11 Oil-control-ring action during the (*a*) down and (*b*) up strokes.

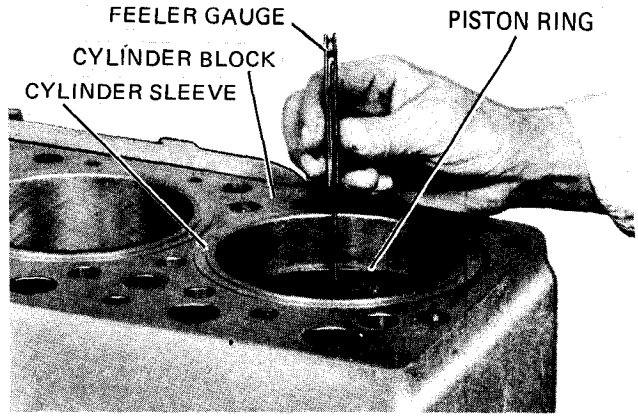


Fig. 11-12 Checking piston-ring gap. *(Allis-Chalmers Corp. Engine Division.)*

Installing Piston Rings After all piston rings are checked (and, if required, fitted), clean the piston assembly and rings with compressed air, then generously lubricate the piston and piston rings with engine oil. Clamp the connecting rod in a vise so that the piston skirt rests on the vise jaws. Install the lowest piston ring first. Follow the manufacturer's service manual procedure, but if a manual is not available, use the following guidelines: Compression rings marked with a "T" or a dot, or having an inside bevel or a counterbore, must be installed with the mark facing toward the crown. The scraper compression ring (outside counterbore) must be installed toward the skirt (Fig. 11-13).

When you install a three-piece oil-control ring, be certain that the butt ends of the expander do not overlap. The ends must be located above the piston-pin bore area and the color indicators must be visible at the expander gap. Install the rail (starting with the gap) about 45° from the piston-pin bore, then roll the rail into the ring groove. It is advisable to hold a thumb over the expander gap to prevent it from overlapping. Use a shim stock under the sharp edge of the rail end to prevent the piston from scoring. The second rail gap, when installed, should be 180° from the first rail gap.

Some Detroit Diesel engine pistons employ two, three-piece oil-control rings. Others have a three-piece oil-control ring in the lower groove and a two-piece oil-control ring in the second groove. When you install either type, make certain that you follow service manual instructions. The expander should not overlap, the scraping edge should face downward, and the ring gaps must be properly spaced.

CAUTION Never shorten an expander. To do so can reduce oil control and possibly result in cylinder damage.

After the piston rings are installed, check them for freeness in their grooves and make certain that the ring face can retract (about 0.002 in [0.050 mm]) below the piston land.

Ring-gap Spacing Always follow the manufacturer's instructions about ring-gap spacing. The ring gaps should not be in line with each other. They should not be placed over the piston-pin bore or on the thrust or antithrust sides of the piston skirt.

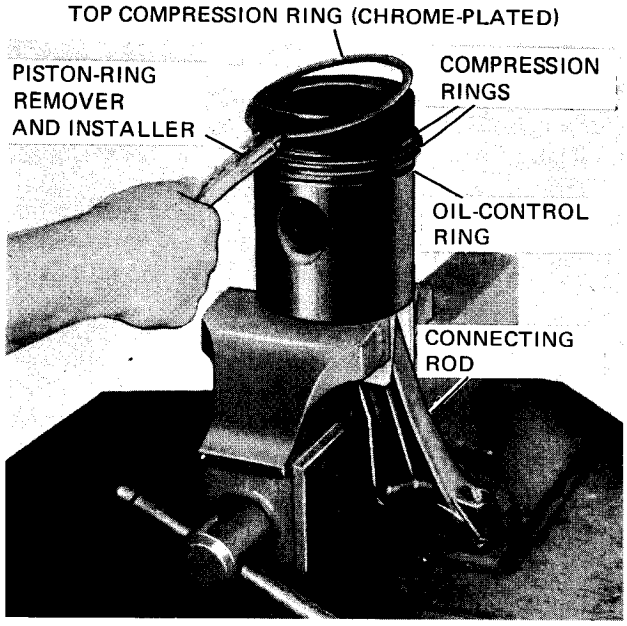


Fig. 11-13 Installing piston rings. *(Allis-Chalmers Corp. Engine Division.)*

Installing Piston Assembly and Connecting Rod Check and clean the cylinder sleeve, connecting-rod journal, and piston assembly before coating it generously with engine oil. Check and clean the connecting-rod bore and remove the connecting-rod cap.

Position the crankshaft journal at BDC. Recheck the ring spacing and see that the connecting-rod numbers correspond with each other as well as with the cylinder number.

Install the ring compressor or, when a tapered sleeve is used, place the sleeve onto the cylinder bore. Remove one connecting-rod bearing set from its packing. Check that the backs of the bearing shells and connecting rod and cap are free of dirt. Install the bearing set in the connecting rod and cap. Make certain the shells snap into place. Generously lubricate both halves of the bearing shells. Align the connecting-rod numbers and then slide the assembly into the corresponding cylinder, being careful not to damage the walls with the connecting-rod bolts. Some manufacturers recommend placing a plastic tube over the connecting-rod bolts to protect the walls.

Align the piston and if piston-cooling nozzles are used take care not to bend the nozzle tube. You may have to insert the piston a few degrees out of alignment in order to clear the nozzle (Fig. 11-14).

With a hammer handle, push or tap the piston into its bore until it is flush with the cylinder block. If you have difficulty inserting the piston, the piston rings may be improperly installed, the piston and/or the rings may not have been properly checked for clearance, the ring gap may be insufficient, or the ring grooves may not be thoroughly clean. In any event, the assembly must be removed and the problem located and corrected.

Align the lower end of the connecting rod with the crankshaft journal after ensuring there is no dirt on the bearing shell or journal. Pull the connecting rod into place by hand or with a tool that is designed for this task.

Recheck the bearing shell for correct position in the connecting rod and cap; then install the connecting-rod cap. The cap identification number must correspond with the rod number; the numbers must also align and must face in the direction indicated in the service manual.

Some manufacturers recommend inserting two strips of feeler gauge stock (the size of the connecting-rod clearance) at the connecting-rod parting line before tightening connecting-rod bolts to specification. This is to ensure proper connecting-rod-to-cap alignment because no dowels are used.

With the recommended lubricant, lubricate the connecting-rod bolts, nuts, or stud threads to ensure proper torque.

Check the running clearance between the connecting-rod bearing and journal by the same method you used to check the running clearance of the main bearings. The average running clearance is about 0.003 in [0.076 mm] when new. The average maximum running clearance is about 0.007 in [0.18 mm]. Check to be sure there is sufficient side clearance between the connecting-rod side face and the journal face. The average side clearance is about 0.005 in [0.13 mm] for in-line engines, and about 0.007 in [0.12 mm] for V engines.

When servicing Detroit Diesel two-cycle engines, install the connecting-rod and piston assembly into the matching cylinder sleeve, as shown in Fig. 11-15. When you do this, position the cylinder-sleeve mark toward one corner of the wooden block. Position the piston-ring gaps, align the connecting rod to the sleeve mark, lubricate the piston and the ring compressor, and then insert the assembly as shown in operation 1, Fig. 11-15. Next, insert the assembly as shown in operation 2. Check and, if necessary, realign the connecting-rod identification number to the sleeve mark. Force the connecting rod downward until the ring compressor is free from the piston. Remove the connecting-rod cap and the ring compressor. Install the upper half of the connecting-rod-bearing shell (the one without oil grooves), and then push the piston down until the compression rings clear the sleeve inlet ports. With the crankshaft journal in its

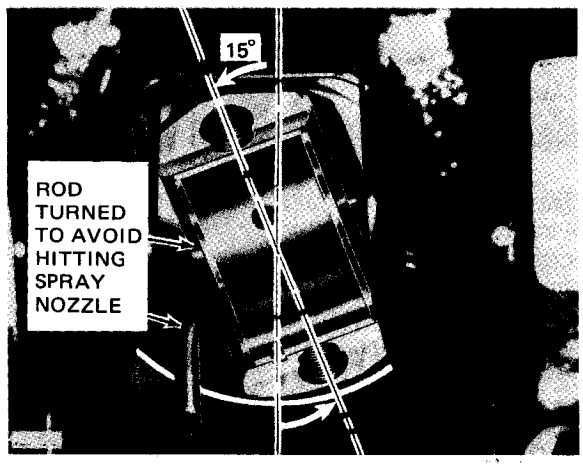


Fig. 11-14 Installing piston assembly. *(Mack Trucks Canada Limited.)*

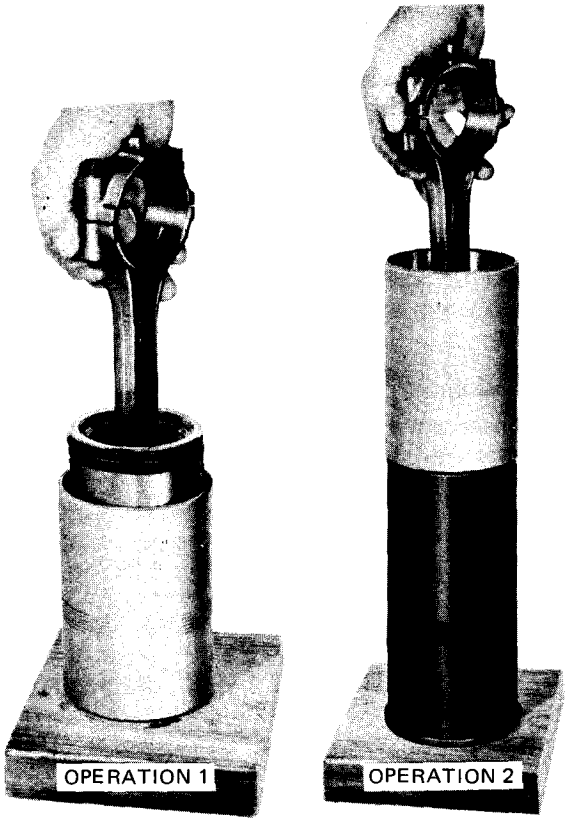


Fig. 11-15 Installing the piston and connecting-rod assembly in the ring compressor and cylinder sleeve. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

lowest position, carefully guide the assembly into the cylinder bore.

Align the corresponding sleeve and cylinder-block marks and force the cylinder-sleeve flange against the counterbore. Make sure that the journal and bearing shell are clean. Lubricate both of them thoroughly, then align the connecting rod and pull it onto the crankshaft journal. After the connecting-rod cap bolts are torqued to specification, place a holddown clamp on the cylinder sleeve. This prevents the sleeve from being forced out when the crankshaft is rotated for the next piston assembly installation.

Questions

1. What are the main differences between a trunk-type piston and a crosshead piston?
2. Why is the surface of the piston skirt rough-ended?
3. Why are holes drilled in the oil-ring groove and below the oil ring (on the thrust and antithrust side)?
4. List several reasons why a piston should not be cleaned with a wire brush.
5. Give several reasons why a singularly designed piston ring (compression ring) and/or oil-control ring cannot be used on all engines.
6. What checks and measurements must be made before installing the piston rings to the piston?
7. Why should a piston-ring installer and removal tool be used to remove or install piston rings?
8. Why is ring-gap spacing so important?
9. Name the three methods used to cool a piston.
10. Failing to remove the cylinder ridge when installing new piston rings could cause (*a*) compression leakage, (*b*) broken rings and piston-ring lands, (*c*) misfiring cylinders, and (*d*) piston slap.
11. Excessively worn compression rings in an engine with a low total number of operating hours is probably a result of (*a*) engine overspeed, (*b*) glazed cylinder liners, (*c*) improper maintenance of the air-intake system, or (*d*) mixing the SAE weights of oil in the crankcase.
12. The proper wrist-pin-to-bushing clearance for a 25.4-mm wrist pin is (*a*) 0.0076 mm, (*b*) 0.127 mm, (*c*) 0.076 mm, or (*d*) 0.381 mm.
13. Low cylinder compression is an indication of (*a*) compression rings worn, stuck, or broken; (*b*) partially clogged exhaust parts; (*c*) excessively worn oil-control rings; or (*d*) excessive exhaust-valve clearance.
14. Scuffing or scoring of pistons, rings, and cylinders can result from insufficient lubrication because of (*a*) lean air-fuel ratio, (*b*) excessive clearance at camshaft or main bearings, (*c*) insufficient connecting-rod bearing clearance, (*d*) overadvanced ignition timing, (*e*) excessive clearance in oil pump, (*f*) failure to service air cleaner, or (*g*) broken oil-pressure relief-valve spring.

UNIT 12 • ENGINE OIL

Lubrication System One of the greatest enemies of an internal-combustion engine is the damaging heat created through friction. To reduce friction, oil is pumped by the lubrication pump through passages, drillings, and openings, to the rotating, sliding, or rocking components. This oil prevents metal-to-metal contact and thereby minimizes wear as it removes heat and cleans the components. In addition, the cushioning affect of the oil between the components reduces engine noise. In many cases engine oil is used as a power source for the hydraulic action of the engine brakes.

Engine Oil Requirements Engine oil must be able to withstand extreme temperatures and shock loads without breaking down. Although it must form a sliding seal between the piston rings and cylinder walls, the oil film must be thick enough to seal, but thin enough to minimize fluid friction. It also functions as a semipurifier by holding solid particles in suspension until they are removed by the filter. Some particles are so fine that they cannot be filtered out, and therefore they remain in the oil until it is changed.

As pointed out, high effectiveness of the engine oil ultimately extends the life of the engine. To achieve

maximum effectiveness the engine oil should possess the following qualities: good wetting ability, correct viscosity, minimum evaporation during service, relative nontoxicity, no damaging sediments, and no tendency to deposit varnish, gum, or sludge deposits. However, unless the air-intake system, the coolant system, and the fuel-injection system are maintained properly and the oil and filters changed regularly, the engine oil can not perform satisfactorily.

Crude Oil Crude oil is a complex mixture of hydrocarbons and other substances. The crudes differ in chemical structure and, as a result, in boiling point.

The four main types of hydrocarbons found in crude oil are parraffinic, naphthenic, asphaltic (naphthenic/aromatic), and mixed base (parraffinic/naphthenic/aromatic). Their complex differences in chemical structure dictate the refining processes required for each crude and influence the viscosity, viscosity index (VI), the oxidation stability, the volatility, and the wax content of the final product. Naphthenic-base crudes produce a lubricant of medium viscosity index whereas parraffinic-base crudes produce a lubricant with a high viscosity index and are less volatile than naphthenic-base crudes.

REFINING CRUDE OIL Since the process of refining different crude oils into various petroleum products is highly technical, only a brief description of the basic stages follows. Refer to Fig. 12-1 as you read.

The first stage of refining of all types of crude oils is distillation, which separates the lighter fractions from the residual (topped crude). Distillation is carried out at atmospheric pressure in a fractionating column by heating the crude oil rapidly to a constant temperature of 662°F [350°C]. The hydrocarbons which have a lower boiling point vaporize first and, as the temperature of the crude oil rises, other hydrocarbons vaporize (Table 12-1).

TABLE 12-1

DISTILLATION VAPORIZATION POINTS

Hydrocarbon	Degrees Farenheit	Degrees Celsius
Gasoline	86–392	30–200 (approx.)
Kerosene	284–536	140–280
Diesel fuel	392–662	200–350
Topped crude	662	350 upwards

SOURCE: Chevron Research Company.

As the vapor cools it changes back to liquid. An unavoidable overlapping in boiling range occurs between the various products (fractions).

In the second stage of refining, feedstock from the atmospheric distillation is distilled under vacuum since these stocks cannot be heated under pressure above 662°F [350°C] without rupturing the molecular structure (cracking). This method requires a temperature of 662°F [350°C] but with lower pressure. By lowering the pressure, more vaporization occurs and further fractions such as fuel and lubricating oil feedstock are collected. The remaining residual mixtures from the crude have very high boiling points and therefore cannot be vaporized even under vacuum distillation. The character of this residue emanates from the original crudes. From parraffinic-base

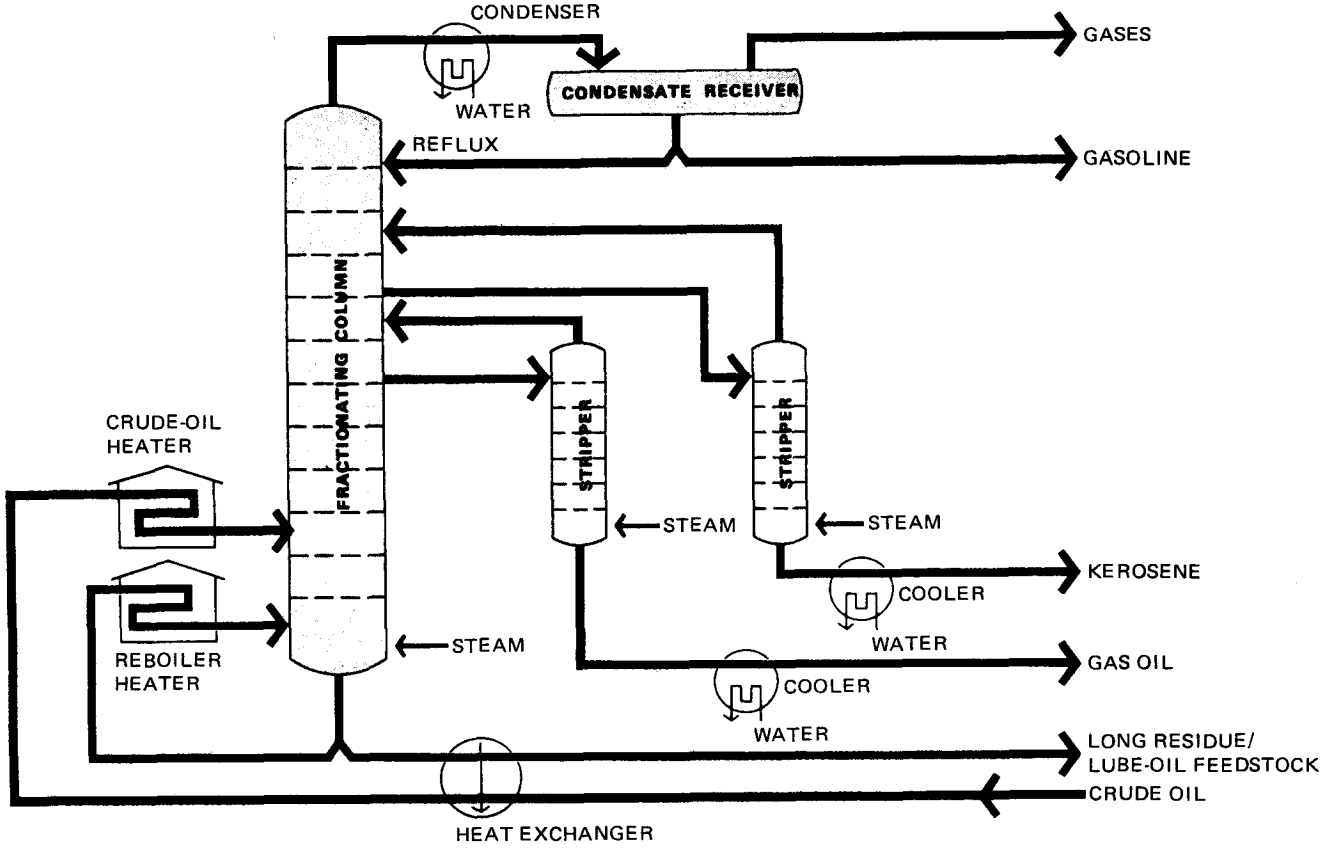


Fig. 12-1 Crude oil refining process. *(Allis-Chalmers Corp. Engine Division.)*

crudes comes lubricating oil (residual), from naphthenic-base crudes comes asphalt, and from mixed crudes comes fuel (residual).

From this point lubricating-oil feedstock is processed through a separate though related lubricating-oil refinery where it is transformed into a variety of clean, bright lubricating-oil blending stocks. Natural contaminants are removed, together with wax and any unstable molecules from the original crude.

Finished oils are then manufactured by blending the base stocks and fortifying them with potent additives in order to produce lubricants best suited to their intended end uses.

Viscosity Viscosity is the physical property of an engine oil with which the mechanic is most concerned. Viscosity is a measurement of fluidity or resistance to flow. Fluidity or resistance to flow changes with temperature; therefore its measurement is always related to temperature. Of the many instruments developed to measure viscosity, the one most used by technicians and engineers is the Saybolt Universal viscometer. This viscometer consists of a calibrated reservoir (in which the test oil is placed) with a fixed (universal) orifice at the bottom. The reservoir is surrounded by a bath, which is heated by heating coils to bring the test oil to the temperature at which the viscosity of the oil is to be measured. A container marked at the 60-cm^3 level is placed under the orifice. When the test oil reaches the desired temperature, the orifice is opened. The number of seconds it takes for the oil to reach the 60-cm^3 level is expressed in *Saybolt Universal Seconds* (SUS), also referred to as *Seconds Saybolt Universal* (SSU).

A recent method of testing the viscosity of engine oil at 210°F [98.8°C] uses a kinematic viscometer tube. A measured amount of test oil is drawn into a viscometer tube and placed into a bath heated to 210°F [98°C]. The time that it takes for the measured amount of oil to flow through the small diameter tube (called a *capillary tube*) is then recorded. The pressure which causes the flow in this instrument is the height of the column of oil above the tube (gravity) plus the density of the oil. The viscosity determined in this way is called *kinematic viscosity*. It is expressed in Saybolt Universal Seconds (SUS) and is converted into engineering units, that is, *centistokes* (cST). Centistoke viscosity is calculated by multiplying the SUS by the correction factor of the viscometer.

A recent method of testing the engine oil viscosity at 0°F [−18°C] to simulate cold starting is by measuring, under precise conditions, the shear strength of a film of oil. The measurement is taken at 0°F [−18°C] and in centimeters, grams, and seconds. The unit is called a *poise* (P) or *centipoise* (cP).

The SAE crankcase oil-viscosity number chart (Table 12-2) specifies ranges of viscosity at low and high temperatures. SAE viscosity numbers without the letter W are based on 210°F [98.8°C] viscosity. SAE viscosity numbers with the letter W are based on 0°F [−18°C] viscosity.

MULTIVISCOSITY OIL A *multiviscosity oil* is one which at a viscosity of 0°F [−18°C] falls within the range of one of the W numbers and at a viscosity of 212°F [100°C] falls within the range of one of the non-W numbers. Thus an oil with a viscosity in the range of 1200 to 2400 cP at 0°F [−18°C] and in the range of 9.6 to 12.9 cST at 210°F [98.8°C] is a multiviscosity oil of 10W-30.

NOTE: Viscosity is the fluidity of the oil and is not a classification of the quality of the oil.

Viscosity Index The *viscosity index* (VI) is a numerical method of indicating the extent to which an

TABLE 12-2

SAE VISCOSITY NUMBERS FOR CRANKCASE OILS

Viscosity number	Viscosity units*	Viscosity range† at 0° F [−18°C] Min.	Max.	Viscosity number	Viscosity units*	Viscosity range† at 210°F [98.8°C] Min.	Max.
SAE5W	Centipoises (cP)		Less than 1,200	SAE20	Centistokes (cST)	5.7	Less than 9.6
	Centistokes (cST)		1,300		Saybolt Universal Seconds (SUS)	45.0	58.0
	Saybolt Universal Seconds (SUS)		6,000				
SAE10W	Centipoises	1,200‡	Less than 2,400	SAE 30	Centistokes	9.6	Less than 12.9
	Centistokes	1,300	2,600		Saybolt Universal Seconds	58.0	70.0
	Saybolt Universal Seconds	6,000	12,000	SAE40	Centistokes	12.0	Less than 16.8
SAE20W	Centipoises	2,400§	Less than 9,600		Saybolt Universal Seconds	70.0	85.0
	Centistokes	2,600	10,500	SAE50	Centistokes	16.8	Less than 22.7
	Saybolt Universal Seconds	12,000	48,000		Saybolt Universal Seconds	85.0	110.0

SOURCE: Sun Oil Company

* The official values in this classification are based upon 210°F viscosity in centistokes (ASTMD 445) and 0°F viscosities in centipoise (ASTMD 2602). Approximate values in other units of viscosity are given for information only.

† The viscosity of all oils included in this classification shall not be less than 3.9 cST at 210°F (39 SUS).

‡ Minimum viscosity at 0°F may be waived provided viscosity at 210°F is not below 4.2 cST (40 SUS).

§ Minimum viscosity at 0°F may be waived provided viscosity at 210°F is not below 5.7 cST (45 SUS).

oil changes viscosity with changing temperature. Oil with a high viscosity index changes less with temperature changes than oil with a low viscosity index. For example, oil with a VI of 100 will thin out less than oil with a VI of 50 when they are both heated to the same temperature.

Pour Point The *pour point* is the point at which an oil solidifies either through the formation of wax crystals or through a gradual increase in viscosity as the ambient temperature drops. Pour point is only of concern when the engine operates where the ambient temperature is lower than 10°F [−12°C].

Flash Point The *flash point* is the temperature at which an oil vaporizes and ignites from a source of ignition. The flash point of oil varies with the viscosity and quality of the oil. It can range from 380 to 500°F [193.3 to 260°C] or more. When the flash point falls below 320°F [160°C] because of contamination by fuel of lower volatility, a crankcase explosion could occur.

Specific Gravity *Specific gravity* is the comparison of the weight of an oil with the weight of an equal volume of water; it does not relate to the viscosity or quality of an oil. However, the specific gravity of a diesel fuel is a very important factor because it determines the heat value of the fuel (see Unit 24, "Diesel Fuel").

Engine Oil Additives The success of today's engine oils relates highly to the complex chemicals (additives) which are blended into the engine oil base stock. Many of the additives affect more than one of the oil's characteristics.

OXIDATION INHIBITORS To prevent varnish and sludge formation and to prevent corrosion, organic compounds, containing sulfur, phosphorus, or nitrogen (such as organic amines, sulfides, or phenols), are used. Metals such as tin, zinc, or barium are often incorporated.

ANTICORROSION (RUST) ADDITIVES To minimize failure of alloy bearings and to prevent other metal surface corrosion, metal salts of thiophosphoric acid and sulfurized waxes are added in addition to the organic compounds mentioned previously.

DETERGENT ADDITIVES To keep metal surfaces clean and to prevent any type of deposit formation, metallo-organic compounds such as phosphates, phenolates, sulfonates, alcoholates, or soaps containing metals like magnesium, barium, calcium, or tin are added. These additives are used basically to prevent corrosive acids or sludge particles, produced as a result of combustion, from forming deposits and to hold such particles in suspension.

ANTISCUFF AND ANTIWEAR ADDITIVES These additives reduce friction and prevent galling, scoring, and seizure and also give the oil extreme pressure properties. Organic compounds containing chlorine, phosphorus, and sulfur such as chlorinated waxes, and organic phosphates are used. Phosphates such as tricresyl phosphate and zinc dithiophosphates are used.

FOAM INHIBITORS Because of engine operating conditions and the effects of contamination, an engine oil without the additives (silicone polymers) would form small air bubbles. The additives combine the small bubbles and the larger bubbles, which separate faster.

Engine Oil Classification For many years the American Petroleum Institute (API) provided an engine oil classification system that related to engine operating conditions. However, because of the increasing demands placed on engine oil, the API, in cooperation with SAE, American Society for Testing and Materials (ASTM), and various car, truck, and engine manufacturers published (in 1970) a new engine oil classification system. This system, based on a letter designation, refers to precise engine operating conditions and oil performance properties in regard to engine design and construction.

SA (OLD CLASSIFICATION ML) Refers to oil to be used primarily for gasoline- and diesel-engine service, under such mild conditions that the protection afforded by compounded oils is not required.

SB (OLD CLASSIFICATION MM) This oil is designed for medium-duty gasoline engine service. It provides only antiscuff capability, resistance to oil oxidation, and bearing corrosion.

SC (OLD CLASSIFICATION MS) An oil designed for use in gasoline engines to provide control of high- and low-temperature deposits and to give protection against wear, rust, and corrosion.

SD (OLD CLASSIFICATION MS) An oil designed for gasoline engine service. It gives more protection against high- and low-temperature engine deposit, wear, rust, and corrosion than an oil of the SC classification.

SE (NO OLD CLASSIFICATION) An oil used for modern gasoline engines. It is designed to provide more protection against oil oxidation deposits, high-temperature engine deposits, rust, and corrosion than oils of the SD or SC classifications.

CA (OLD CLASSIFICATION DG) An oil used for light-duty diesel engine service to provide protection against bearing corrosion and from high-temperature deposits in naturally aspirated diesel engines.

CB (OLD CLASSIFICATION DM) An oil used for moderate-duty diesel engine service. It is designed to provide necessary protection against bearing corrosion and from high-temperature deposits in naturally aspirated diesel engines which use higher sulfur fuels.

CC (OLD CLASSIFICATION DM) An oil used for moderate-to-severe-duty diesel and gasoline engine ser-

TABLE 12-3

PROPERTIES OF CD CRANKCASE OIL

Property	10W	20/20W	30	40	50
Gravity °API*	31.7	29.1	28.8	275	27.4
Color ASTM†D1500	L2.0	L3.0	L3.0	3.0	3.0
Flash point, °F [°C]	420 [215.5]	450 [232.2]	470 [243.3]	490 [250.0]	520 [271.1]
Pour point, °F [°C]	−25 [31.7]	−15 [−26.1]	−5 [−20.6]	0 [−17.8]	0 [−17.8]
Viscosity poise at 0°F [−18°C]	18.5	62			
SUS at 100°F [37.8°C]	198.8	346	566	742	1276
SUS at 210°F [98.8°C]	46.8	57.5	67.1	76	100
Viscosity index ASTM D2270	106	112	97	96	94
Sulfated residue, wt. %	0.83	0.83	0.83	0.83	0.83
TBN—AP‡	7.2	6.7	6.4	6.7	6.7
Calcium, wt %	0.23	0.23	0.23	0.23	0.23
Zinc, wt %	0.075	0.075	0.075	0.075	0.075
Copper corrosion at 212°F [100°C]	Negligible	Negligible	Negligible	Negligible	Negligible
ASTM foam test	Passes	Passes	Passes	Passes	Passes

SOURCE. Sun Oil Company.
*Degrees American Petroleum Institute.
† American Society for Testing and Materials.
‡ Total Base Number—aromatic paraffinic crude oils.

vice. Used in motortrucks, industrial and construction equipment, and farm tractors. It provides protection from high-temperature deposits in lightly supercharged diesel engines and also from rust, corrosion, and low-temperature deposits in gasoline engines.

CD [OLD CLASSIFICATION DS (SERIES 3 OIL] An oil used for severe-duty diesel engine service. It provides protection against bearing corrosion and from high-temperature deposits in supercharged engines when fuels of a wide quality range are used.

Table 12-3 is a typical property chart of a CD crankcase oil.

An example of how the API classifications are used is the Cummins Engine Company recommendations that an SC lubricant which has low-temperature sludge protection be used for their naturally aspirated engines in stop-and-go service. Lubricant of the CC performance level is recommended for the same engine when used in heavy-duty operations. For Cummins turbocharged engines, on the other hand, a CD performance level lubricant is recommended. *(NOTE: Tests proved that the engines performed extremely well under the circumstances outlined when the three different classifications of oil were used. There was no carbon or lacquer buildup on the piston crown, crown-land surfaces, No. 1 and No. 2 ring grooves, ring land between grooves, or the piston skirt.)*

Storing and Handling Crankcase Oils To reduce the risk of contaminating the lubricant, store oil drums indoors, on an oil-drum rack. Always keep the drum heads, taps, measuring cans, dispensers, and surrounding area clean. Never use empty antifreeze cans for dispensing any oil. Identify each oil clearly to reduce the possibility of dispensing the wrong oil. Use a power dispenser or a separate measuring can for each product. When possible use taps for each drum to prevent damage to the bungs or to prevent lubricant contamination. Bungs and drum heads must be replaced and tightened immediately after use. Use only a bung wrench in order to prevent damage from frequent opening and closing.

Use only lintfree rags when cleaning the dispensers because lint can accumulate and stop oil circulation. If you must store the drums outside, tilt them slightly with the bungs at 3 o'clock and 9 o'clock or lay them on their sides so that water cannot enter. Always wipe up any spilled oil around the drums. Do not use sand or a chemical to soak up the oil. Not only is a chemical a fire hazard, but it may get into the oil.

Questions

1. List the various purposes of an engine oil.
2. Why can't one oil serve all engines?
3. Which type of crude oil is the most suitable for use as an engine oil?
4. Why are viscosity and the viscosity index more important to the mechanic than the pour point and the flash point?
5. What is the difference between an SAE multiviscosity 10-30 oil and an SAE 10 oil?
6. What effect has a low VI oil on the oil pressure when the engine is at operating temperature?
7. What are the major differences between an oil with an SA classification and one with a CC classification?
8. List some changes (in your shop area) which in your opinion would improve the handling and storing of fuel oil and grease.

UNIT 13 • LUBRICATION PUMP AND OIL COOLER

Disassembling Lubrication Pump Before you disassemble the lubrication pump, clean the pump assembly. Remove the oil screen, drive gear, and pump cover. With a felt-tipped pen, identify the pump gears so that the teeth will be in the same mesh when reinstalled. Remove the gear along with the drive shaft, idler shaft, or driven shaft. Remove the relief valve assembly and wash component parts in clean fuel or solvent.

Inspecting and Measuring the Lubrication Pump Check the pump gear faces and the gear teeth sides for burrs, scoring, and grooves. If excessive damage is apparent the gear set must be replaced. Measure the bushings and shaft for wear. If the clearance is more than 0.003 in [0.076 mm], the bushings and/or shaft must be replaced. Check the pump cover and the sides of the gear housing for wear and scoring. If the wear pattern on the low-pressure side (pump intake) has passed 3 o'clock, the housing must be replaced.

Another method of checking the amount of wear is to measure the clearance between the pump body and the gear teeth by placing the gears in the pump body and using a feeler gauge to measure the wear on the low-pressure side (see Fig. 13-1). When the radial clearance exceeds 0.004 in [0.101 mm], the pump body must be replaced. The pump body and cover must be smooth and must show no scratches, score marks, or rough spots.

Measure the height of the gears with a micrometer and, with a depth micrometer, measure the depth of the body to determine the running clearance of the gears. *(NOTE: When you take this measurement, do not forget to place a new gasket on the housing before measuring the body depth. When the running clearance exceeds 0.005 in [0.127 mm], replace the pump body and/or gears. Lapping the housing to reduce clearance is not recommended.)*

Another way to measure running clearance is with a plastic strip (Plastigage) (see Fig. 13-2).

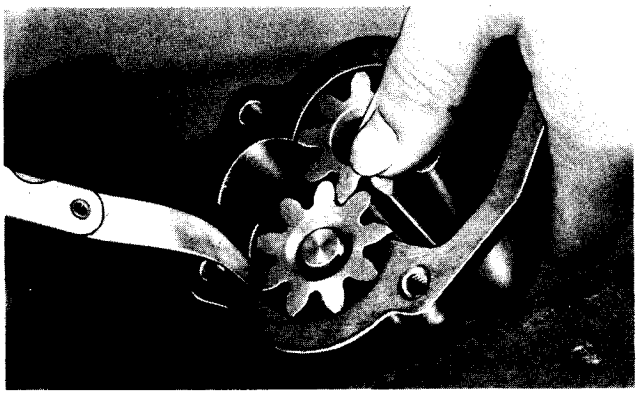


Fig. 13-1 Measuring pump-gear-to-body wear. *(International Harvester Company.)*

Servicing and Reassembling the Lubrication Pump Remove nicks and burrs from gears, cover plate, shafts, keyways, and splines. If bushings need to be replaced, do so with a bushing remover adapter. Press the old bushing out and the new one in, to the depth indicated in your service manual. It will also recommend reaming the bushing.

Check bushing-to-shaft clearance against a new shaft. After you clean the oil screen, check for broken or loose screen wires before you reinstall the screens into or onto the oil-pump cover.

Clean and polish the relief-valve bore and plunger. Measure the relief-valve spring height and, if it is below specification, replace it. Do not stretch the spring.

Lubricate all parts and components with engine oil and reassemble them in precisely the reverse sequence of disassembly.

When new pump gears are used, check their backlash with a feeler gauge. Make certain that the relief-valve plunger will not stick and that the assembled pump can turn without binding. Do not force the drive gear onto the drive shaft. It should be heated and installed as outlined in Installing Crankshaft (Unit 9).

Installing Lubrication Pump to Engine Most lubrication pumps are doweled to their mounting support so that the backlash, when properly adjusted, cannot change. The backlash of some oil-pump drive and driven gears is adjusted by placing (or removing) shims between the mounting surfaces. On other oil-pumps the backlash is adjusted by moving the pump sideways, then drilling dowel holes into the locating

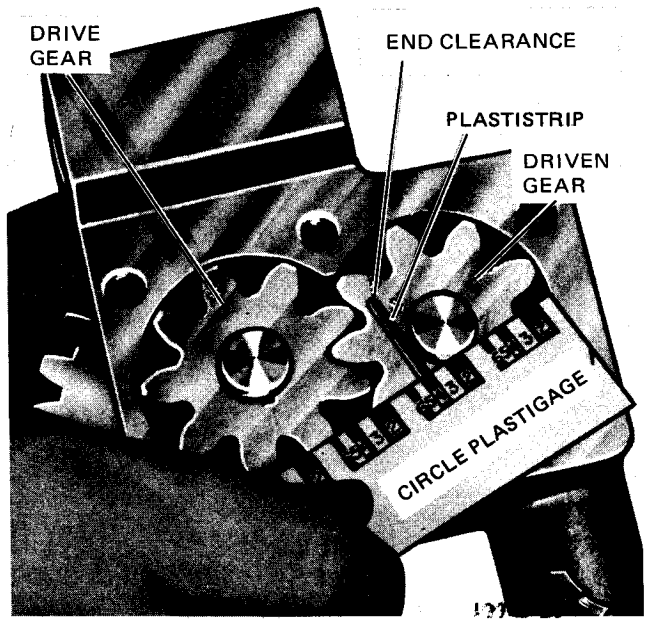


Fig. 13-2 Measuring pump-gear running clearance. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

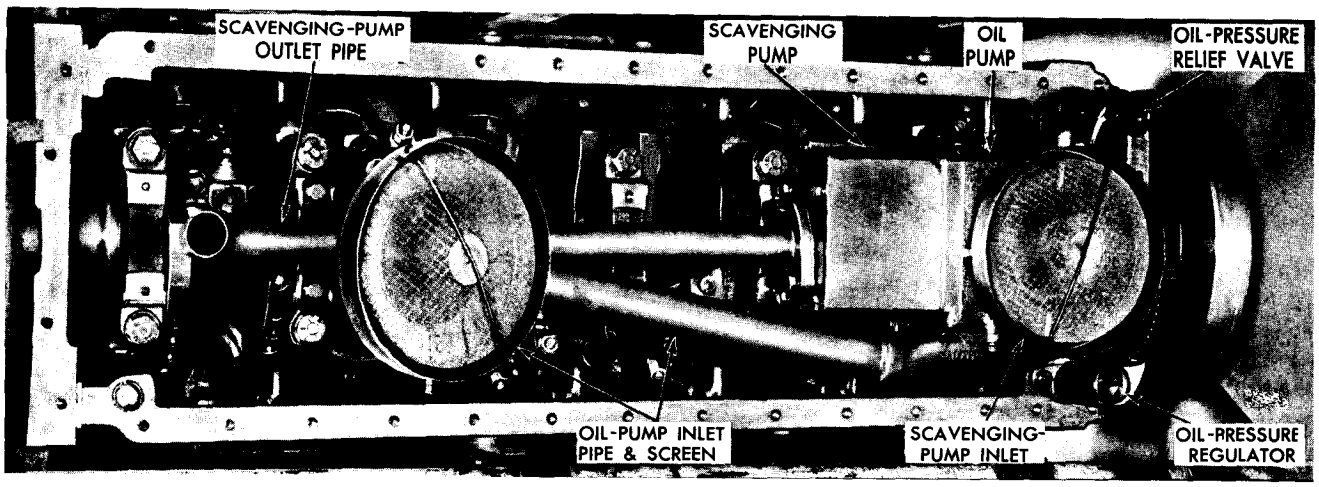


Fig. 13-3 Typical oil-pump installation and piping. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

plate. Regardless of the installation method, the backlash must be within specification.

When the lubrication pump is bolted in place and torqued to specification, the necessary tubes are then connected to the pump and the cylinder block (Fig. 13-3). Larger engines and/or engines of earth-moving equipment commonly utilize a scavenging pump, in which case the oil pump has two sets of pump gears. The purpose of the scavenging pump is to draw oil from the rear end to the front end of the oil pan.

Inspecting and Servicing Oil Pan After you have thoroughly cleaned the oil pan and removed the old gasket material from the mounting surfaces, check the oil pan for dents, cracks, or loose baffle plates. Make repairs when possible; otherwise, replace the oil pan. Inspect the condition of the flanges, the bolt holes for elongation, and the condition of the threaded bores.

When necessary, straighten the metal-stamped flanges. Check for obstructions in the oil-pan passages, if applicable, which direct oil to the main oil gallery. Particularly check the threads and the sealing surface of the oil drain and the oil level plugs. Damaged threads can be repaired with a helicoil or a new plug assembly can be welded or soldered to the oil pan.

Installing Oil Pan Make a cursory check to ensure that all assembled components or parts are in place, properly torqued, and secured. Check the oil pan and cylinder block mating surfaces for cleanliness. Make sure the oil baffles are securely in place and that the oil pickup screen and seal (if used) are in place. Use a nonhardening sealing compound to cement, when recommended, a new gasket to the front and side rails of the oil pan. Alternately, use the methods shown in Fig. 13-4 to mount the new gasket. For easier installation, install guide studs to each corner of the cylinder block. If sealing rings are used, hold them in place with shim stocks.

Place the pan in position and install all oil-pan bolts. (Sometimes two or more dowels or aligning bolts are used to position the oil pan.) Remove the guide studs, gasket, and holding device. Install the aligning bolts and remaining oil-pan bolts, then tighten them in the recommended sequence to the specified torque.

NOTE: Some oil pans are bolted to the front or rear plate or to the flywheel housing. When this is the case, use a nonhardening sealing compound in the corner of the oil pan and housing to improve sealing. To ensure a leakfree joint, you must be particularly careful to tighten the oil-pan and flywheel-housing bolts.

Finally, install the clean-out cover or inspection cover as well as the oil level plug and drain plug or bolts.

Servicing Oil Cooler Before you disassemble a tube-type oil cooler for service, fill the cooler housing, through its ports, with mineral spirits (or a similar cleaning fluid) to loosen the oil residue and contaminants within the cooler; otherwise it may be difficult to remove the element.

After a period of time, say 1 hour, remove the plug and drain the fluid. You could, in the meantime, clean the waterside (the inside) of the copper tubing. To do this, immerse the cooler in a solution of 9 parts water to 1 part muriatic acid. Add oxalic acid and pyridene in proportion to the solution (strength) required. For example, when using 9 gal (U.S.) [7.44 gal (Imp.) or 33.82 L] water, and 1 gal (U.S.) [0.83 gal (Imp.) or 3.78 L] muriatic acid, add to this 2 lb [0.9 kg] oxalic acid, and 0.02 gal (U.S.) [0.016 gal (Imp.) or 0.008L] pyridene.

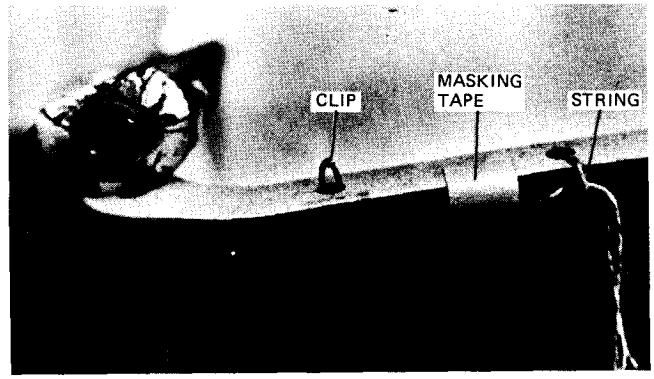


Fig. 13-4 Holding the gasket in place.

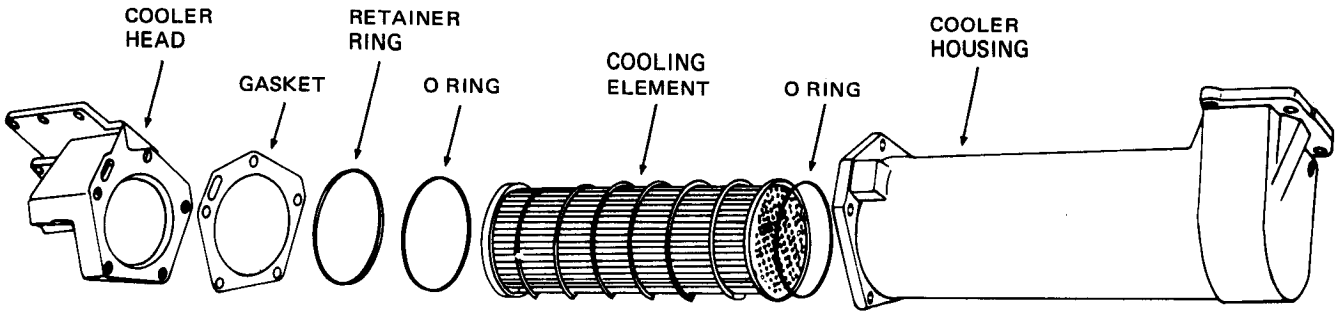


Fig. 13-5 Exploded view of a tube-type oil cooler. *(Cummins Engine Company, Inc.)*

Leave the oil cooler in the solution until the foaming and bubbling have stopped. Then remove the cooler and flush it with hot or warm water to remove the cleaning solution (Fig. 13-5).

NOTE: Because of the multitude of metals used, check with your service manual for the proper solution strength, as well as for the recommended cleaning procedure

To remove the cooler element, first remove the cover, the gasket retainer, and the O ring. Insert two stud bolts into the cooler element puller hole and secure a suitable puller bar to them. To prevent hardening of the residue, clean the oil side of the cooler as soon as the element is removed. Flush trichloroethylene or an oakite or alkaline solution (depending on the extent the cooler is clogged) around the cooler tubes or into the inlet of the cooler cores. Use hot water to flush the cleaning solution from the cooler. When there are metal particles from broken or worn engine components in the lubrication system of the core-type cooler, it must be replaced since it is impossible to check the cleaning effectiveness.

CAUTION Use rubber gloves and eye protection. Clean only in a well-ventilated room.

Inspecting and Testing Oil Cooler Dry the cooler with compressed air and flush the tubes with light engine oil. Check for damaged tubes or core. Check the flared ends of the tubes for corrosion and for welding or soldering cracks. Check the housing and connections for damaged threads and the flanges for nicks, gouges, or cracks. Check the bypass valve and spring for corrosion or a damaged surface, and if so deteriorated, replace them.

To check for cooler tube or core leakage, seal both ends of the tubes (or when testing a cooler core, seal the core with a plate,) and connect an air hose to the drilled and tapped hole. Using an air-pressure regulator for control, pressurize the core to the recommended pressure.

NOTE: In view of the variety of oil coolers, be sure to refer to your applied pressure specification. It varies from 15 to 80 psi [103.4 to 551.6 kPa].

Immerse the core in water heated to 180°F [82.2°C]. If air bubbles rise, mark their origin. In practice, a cooler which has a leak is either sent to a radiator shop for repair or replaced.

To repair damaged soldered cracks, resolder the flared ends of the tubes. Take care not to melt the solder on the adjacent tubes.

To repair damaged tubes, insert a smaller tube into the damaged tube, flare both ends, then solder the new and the old tube to the end plate.

Reassembling and Installing Oil Cooler Reassemble the oil cooler in a sequence precisely the reverse of disassembly. Make certain that the O rings are in their grooves and not twisted, that the gaskets are positioned properly, and that all hex bolts or nuts are torqued in sequence to the specified torque. Install the bypass valve in the correct sequence. When you mount the oil cooler onto the engine, make certain the mounting and sealing surfaces are clean and that the cooler faces in the correct direction in relation to the oil "in" and "out" and the coolant "in" and "out" connections.

When a multioil cooler is used, take care not to interchange the torque converter oil lines with the engine oil lines. Make sure the hex bolts and plugs are torqued to specification, and that the radiator and cylinder block hosè connections or tubes are positioned correctly and clamped securely.

Questions

1. What is the purpose of the lubrication pump?
2. What determines the maximum lubrication pressure?
3. What determines the minimum lubrication pressure?
4. Describe how you would measure the clearance from the oil-pump gears to the housing using a micrometer.
5. What is the purpose of measuring the backlash of the drive and driven oil-pump gears?
6. What is the purpose of the oil-pan baffles?
7. Why is the engine oil directed to the oil cooler before passing through the filter?
8. What precautions must you take when connecting the oil and coolant lines to an oil cooler?

UNIT 14 • CYLINDER HEAD AND VALVES

Cylinder-head Failure Service records indicate that cylinder-head and valve-train failures are often due to inadequate service, misadjustments, and poor maintenance.

Regarding misadjustments, a point which cannot be overstressed is the necessity to maintain correct sequence when torquing the cylinder-head bolts or nuts. Torquing them incorrectly, or out of sequence, may cause the head gasket to leak, the cylinder head to warp, or the valve train to be damaged. The valves, valve seats, and the injectors would be adversely, if not seriously, affected.

Improperly torqued cylinder-head bolts can distort the valves or cause the injector nozzle to stick, from which misfiring or timing change would result. In either situation, one side of the valve would seat earlier than the other and the contact side cool more quickly. The seating force would then be higher on the contact side and since the remainder of the seat area would then be open, hot combustion gases would escape, the valve fillet would expand, and the valve opening would increase. It follows that the valve would completely fail. However, before the complete valve failed, the escaped combustion gases would cause turbulence in the exhaust manifold, with the serious result of incomplete scavenging.

Cracks between the valve port and the injector, or between valve ports, are often due to overheating and/or overfueling, hot shutdown, and loss or reduction in coolant flow. Cracks also can result from defective casting, improper machining, improper installation, or the excessive use of ether for starting.

Damage to the cylinder head shown in Fig 14-1 is the result of foreign material entering the combustion chamber. The material may have come from a damaged valve, broken valve insert, broken piston, or broken ring land and/or piston ring. It is also possible that the foreign material originated elsewhere and was taken into the intake system.



Fig. 14-1 Cylinder-head damage due to foreign material. *(Cummins Engine Company, Inc.)*

Valve and Valve-insert Failure Excessive valve-face wear is caused by improper valve-spring tension, loose valve adjustment, high speed, or high engine temperature. When such wear is found only on the intake valves and inserts, it is the result of dirt being taken in on the intake stroke.

A warped valve is caused by improper setting, carbon and/or varnish accumulation, inadequate cooling, air-intake restriction, high exhaust temperature due to overloading the engine, overfueling, turbocharger failure, tight valve adjustment, or a weak valve spring.

Deposits of white ash or carbon on valve fillets are shown in Fig. 14-2. This usually results from burned engine oil residue. This oil could come from the crankcase because of a broken piston, worn oil-control ring, damaged sleeve, or simply because there was originally too much oil in the crankcase. It can also come from the rocker-arm side of the cylinder head resulting from excessive clearance of rocker-arm bushings, improper positioning of the rocker-arm shaft, or worn valve guides and/or valve stems.

The valve shown in Fig. 14-3 has a poor seat and varnish deposit on the fillet. These problems arise from improper valve adjustment, incomplete combustion, exhaust restriction, long low-idle period at low ambient temperature, extended time between oil and filter changes, or contaminated oil.

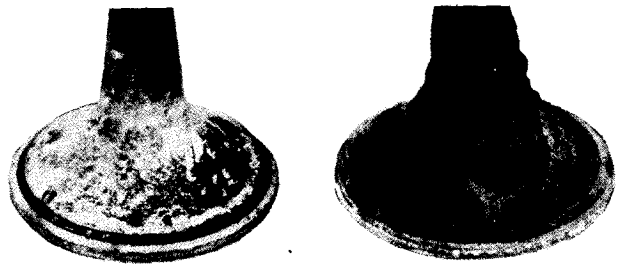


Fig. 14-2 Left, white ash deposit; right, carbon accumulation. *(Cummins Engine Company, Inc.)*

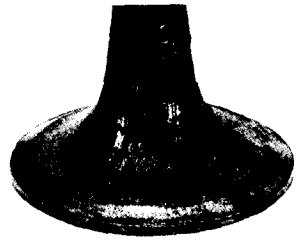


Fig. 14-3 Varnish accumulation. *(Cummins Engine Company, Inc.)*

Damage to the valve shown in Fig. 14-4 can be due to excessive heat, low coolant and/or reduced coolant flow, overfueling, improper injection timing, overloading the engine, air-intake restriction, or a damaged turbocharger. Continuous operation under any of these conditions can lead to overheating of valve inserts as well as valve burning or channeling. However, valve channeling can also be caused by a broken insert, bent valve, out-of-round valve or valve-seat insert, worn valve guide, damaged injector nozzle, deposits on valve seat, and/or misadjustment which prevents the valve from seating properly. When more than one valve insert is cracked, it is usually due to overheating. When only one insert is cracked the cause may be improper installation, an improperly machined insert bore, or an insert loose in its bore.

The defective valve shown in Fig. 14-5 contacted the piston. This does not happen often, but when it does, look for a broken valve spring, a valve sticking in the guide, the possibility of insufficient lubrication, a bent valve stem, a weak valve spring, or carbon deposits on the valve stem or guide. A valve can also come in contact with the piston from overspeeding the engine, a bent valve-bridge guide pin, improper installation, a worn valve keeper, or worn grooves.

Broken valve stems are uncommon. This defect can usually be traced to overspeeding the engine, improper valve adjustment, a valve seat not ground square to the valve guide, excessive engine temperature, or a weak or broken valve spring.

Abnormal valve-guide wear is caused by abrasives in the lubricant, inadequate lubrication, overheated engine, valve or valve insert being out-of-round, a bent valve spring, or an improperly ground rocker-arm arc contacting the valve-stem end at an angle. Inadequate valve-guide lubrication can originate from incorrect clearance between valve guide and valve stem, low oil level, low oil-pump pressure (worn pump), sticking pressure relief valve or contaminated lubricant.

Valve-bridge failure can be caused by a damaged adjusting screw. Side wear or excessive surface wear of the valve bridge usually is caused by an improperly adjusted or improperly torqued locknut, rocker arm and/or tappet adjustment failure, a bent bridge guide pin, a bent pushrod, or overspeeding the engine.

Rocker-arm breakage, though not common, is usually due to defective casting or careless handling during shipping. The rocker arm can also break because of failure of some other valve-train component.

Abnormal wear of the rocker-arm bushings or shaft can be caused by inadequate oil supply as a consequence of incorrect installation, contaminated oil, entrance of dirt during assembly or adjustment, low oil level, or low oil pressure.

The pushrod damage (Fig. 14-6) is infrequent. It is brought about by overspeeding the engine, a damaged follower, a damaged camshaft lobe, or an improperly adjusted rocker arm.

Abnormal socket or ball-end wear can be caused by insufficient lubricant, plugged oil passages, contaminated lubricant, or dirt left in the socket during assembly or service.

A broken valve spring, though a relatively uncommon defect, is one of the most damaging to the engine. The spring may originally have had a factory defect but most likely it broke because of flutter or fatigue when overspeeding the engine.

Cam follower failure does not usually occur until after other valve-train components have been damaged or have failed. A damaged camshaft lobe will cause uneven force on the follower roller and pin, which in turn increases stress and reduces lubrication. Improper installation, improper assembly, or overspeeding the engine can also bring about cam follower failure.



Fig. 14-4 Damage due to excessive heat. *(Cummins Engine Company, Inc.)*

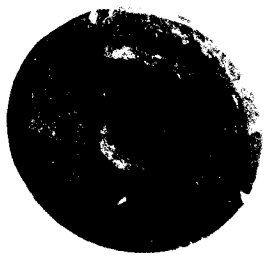


Fig. 14-5 Damage due to contact with the piston. *(Cummins Engine Company, Inc.)*

Cylinder-head Service After you remove the valves, plugs, cups, and cooling tubes (or nozzles, if used), steam-clean the cylinder head. You may first have to use a wire brush (Fig. 14-7) to remove carbon deposits. If steam-cleaning does not remove the lime

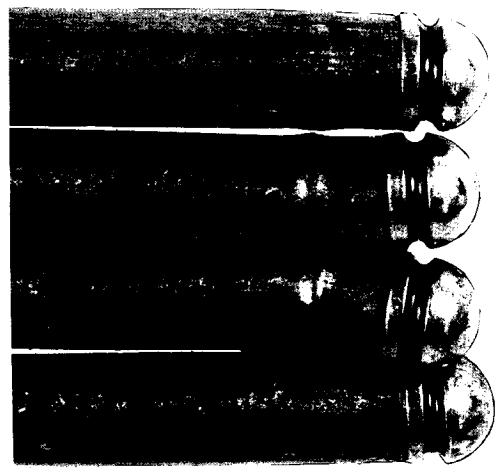


Fig. 14-6 Pushrod damage. *(Cummins Engine Company, Inc.)*

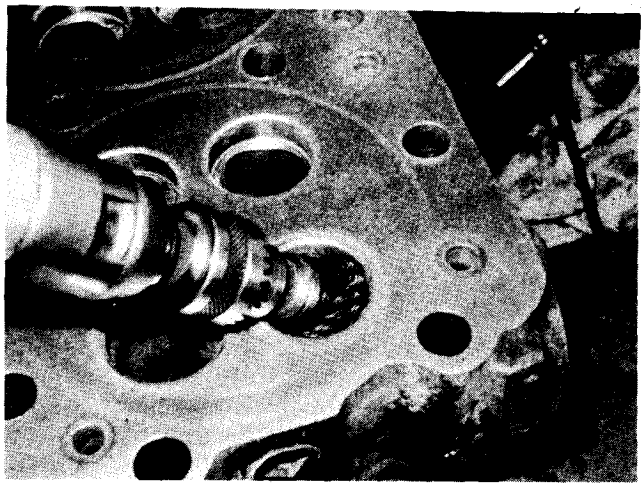


Fig. 14-7 Cleaning cylinder head.

or scale formation, the cylinder head must be cleaned by the hot tank method.

After you have thoroughly cleaned the cylinder head, visually inspect it for damage. Pay particular attention to the valve guides and the fuel and lubrication passages, and when necessary, clean them with a suitable wire brush. Also check the cylinder head for cracks, especially between the valves and injector tube, using the magnaflux method. Inspect the cylinder-head surface for scratches and corrosion. Measure the surface for flatness with an accurate straightedge and feeler gauge and compare these measurements with those in the service manual for maximum longitudinal- and transverse-allowable warpage. If the cylinder-head surface is within specification but the surface needs to be refinished, use a power tool to refinish it. Also check it for unevenness at the gasket sealing areas. If the cylinder-head surface cannot be cleaned adequately with a power sander, you can try restoring it with a surface grinder or a milling machine, in which case you must first measure the height of the cylinder head. (The service manual will tell you where to take the measurements.)

Check the injector tube (sleeve) for evidence of coolant leakage or a damaged nozzle seat. If the injector sleeve is damaged, do not replace it until the cylinder head has been air- or water-tested. After your inspections are complete, reinstall all the removed plugs and cups. When necessary, install a dummy injector (scrapped injector).

Seal all the coolant openings with suitable steel plates and gaskets. Drill and tap one plate to accommodate either an air- or a water-hose connection.

Air-testing Cylinder Head Connect an air hose to the tapped cover plate. Using an air regulator, pressurize the cylinder head to about 40 psi [275.8 kPa], then submerge the cylinder head in hot water. Check for air leakage, especially around valve seats and injector sleeve locations.

Water-testing Cylinder Head One method of water testing is to connect a water hose to the cylinder head and pressurize it to about 40 psi [275.8 kPa]. Steam-clean the cylinder head to raise the temperature of the head and water to approximately 180°F [127°C]. Blow-dry with compressed air. Check carefully around the valve seats and injector sleeve locations for cracks. As a rule, it is neither recommended nor worthwhile to repair a cracked cylinder head.

Injector Sleeve Service There are many types of injector sleeves (tubes) used to seal the cylinder-head coolant passage; however, some cylinder heads have the cylinder wells or bores integrally cast. Many sleeves require very little servicing and are simple to replace, except perhaps the Cummins and Detroit Diesel injector sleeves. *(NOTE: The Cummins K and Caterpillar 3500 Series engines have no sleeves. The injector sleeve is an integral part of the cylinder head.)*

To remove an injector sleeve (Fig. 14-8), tap a thread into it, screw a suitable eye bolt into its threads, and with a hammer puller, withdraw the sleeve. Clean the sleeve bore thoroughly. Steam-clean the cylinder head until its temperature is approximately 180°F [127°C]. Coat the new sleeve with an oil and water sealer then, with the appropriate driver, drive the sleeve into place. Most injector sleeves must be reamed after installation to ensure proper injector cooling and nozzle seating.

Servicing the injector sleeve of a Detroit Diesel two- or four-cycle engine or a Cummins engine is a little more complex and special tools are required. Even when the Detroit Diesel or Cummins injector sleeve shows no sign of damage or coolant leakage, the injector protrusion and the seating pattern must be checked. If the seating pattern is unsatisfactory, it can be refinished by using the correct reamer; however, the injector protrusion must then be rechecked. If the protrusion is more than specified, the sleeve must be replaced.

To check a Cummins injector-cup seat, lightly coat the injector cup with Prussian blue then install and torque the injector to the specified torque. Remove the injector and check the seat pattern. It must be within the specified limit, and the injector tip protrusion must also be as specified.

To replace a Cummins injector sleeve, install the injector sleeve puller and remove the sleeve. Clean

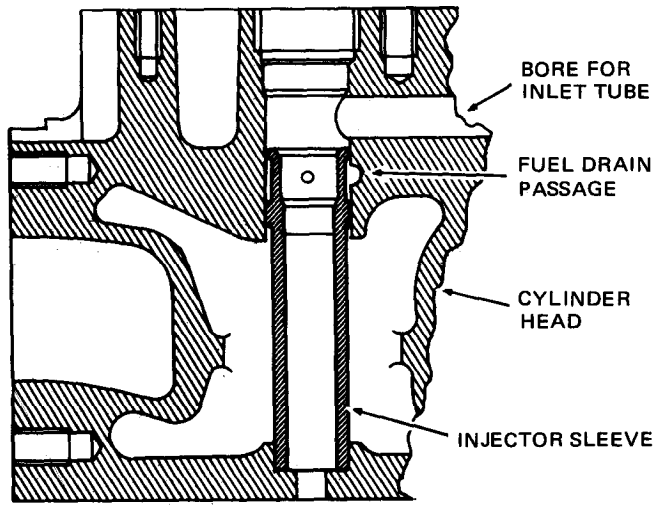


Fig. 14-8 Sectional view of cylinder head with injector sleeve. *(Mack Trucks Canada Limited.)*

the bore and O-ring groove, lubricate the O ring, install it in the cylinder-head sleeve bore, and then push the sleeve into the bore. Install and torque the sleeve holding-tool bolt to specification. Place the mandrel into the sleeve and strike the mandrel two moderate blows with a hammer to ensure sleeve seating. Remove the mandrel, install the expanding roller tool, and with an inch-pound torque wrench, turn the expanding tool until the wrench scale reads 75 in·lb [8.5 N·m]. (This expands the sleeve so that it seals between it and the O-ring.) See Fig. 14-9. Remove the tool, clamp the pilot of the sleeve cutter in a drill press, and position the cutter into the sleeve. Start the drill motor, apply a solid stream of cutting oil, and cut a new seat. Measure the injector protrusion repeatedly until the protrustion is within specification.

To replace a Detroit Diesel two- or four-cycle engine injector sleeve, place the installing tool (installer) into the sleeve (injector tube), insert the pilot through the small hole of the sleeve, and screw it into the installing tool. Tap the injector sleeve out and clean the injector sleeve bore and O-ring counterbore. The O-ring counterbore as well as the sleeve bore must be free of nicks and burrs.

To install the sleeve, slide a new sleeve over the installing tool and screw in the pilot tool. Insert a new O ring into the counterbore, lubricate it, and place the sleeve in the injector bore. Drive the sleeve into position (Fig. 14-10), replace the pilot tool with a flaring die (swaging die), and torque the die to 30 lb·ft [40.7 N·m]. See Fig. 14-11. This action causes the injector sleeve to flare out against the tapered shoulder of the cylinder head. *(NOTE: On the Fuel Pincher and 149 Series, the installation tool is bolted to the cylinder head during the flaring procedure, to prevent the sleeve from rotating.)*

Reaming Detroit Diesel Injector Tube to Fit Injector The injector sleeve must be hand-reamed. The two reamers shown in Fig. 14-12 are required for the two-cycle engines to ensure proper cooling, protrusion, seating, and sealing of the injector nut, whereas only one reamer is required for the Fuel Pincher cylinder head. Use the first reamer, as shown in Fig. 14-12*a*, to ream for correct clearance of the injector body, nut, and nozzle tip. Use the second reamer (Fig. 14-12*b*) to ream for correct injector-nut-to-sleeve-seat and injector protrusion.

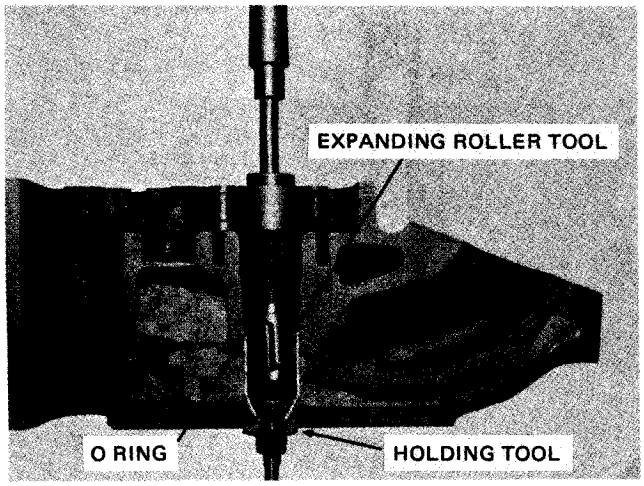


Fig. 14-9 Rolling upper injector sleeve. *(Cummins Engine Company, Inc.)*

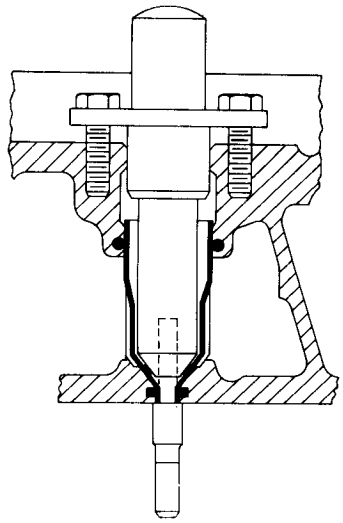


Fig. 14-10 Installing Fuel Pincher injector tube. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

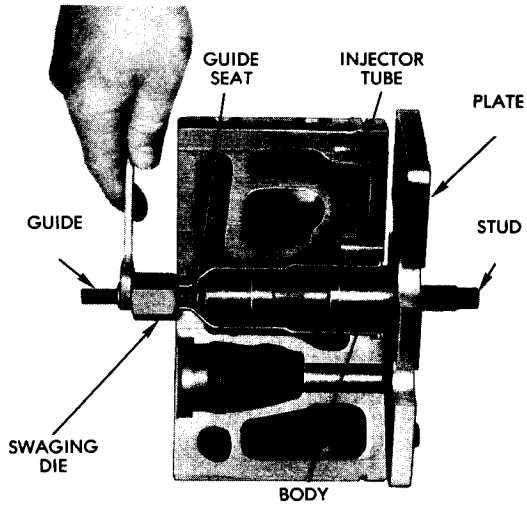
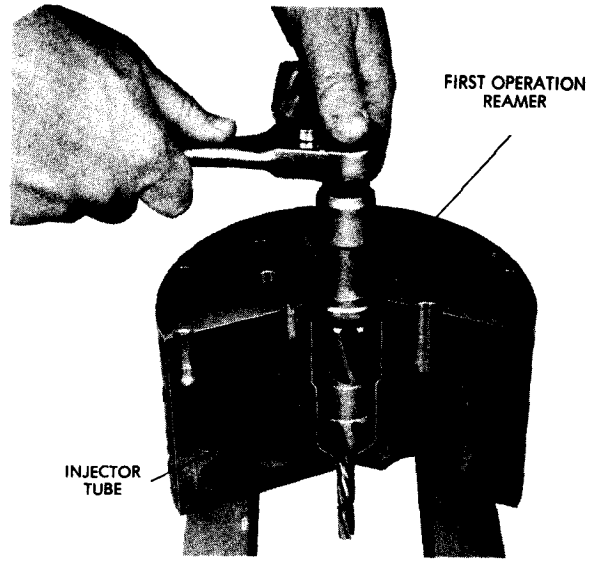


Fig. 14-11 Swaging (flaring) 71 Series injector tube. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

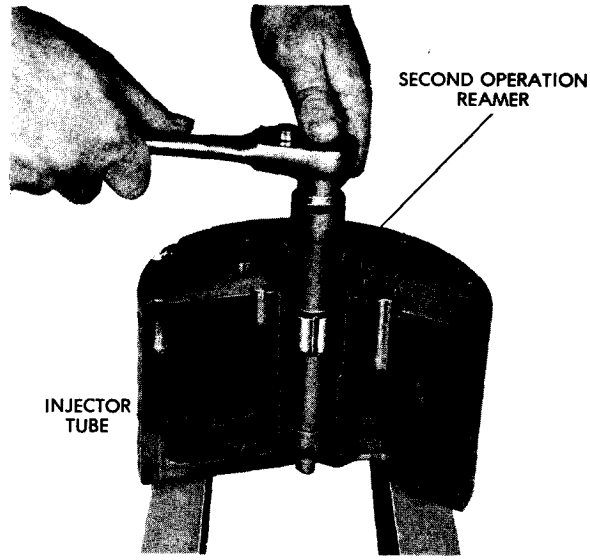
Start each reaming operation by applying cutting oil to the reamer flutes. Applying moderate force, turn the reamer in a clockwise direction to prevent breaking the cutting edges of the reamer and to produce a smooth bore. Throughout the reaming process, repeatedly withdraw the reamer in a clockwise rotation to remove the cutting chips. Be generous with the cutting oil to ensure a smooth surface.

When removing excessive material to achieve specified protrusion, take care not to ream out too much material or to cut a poor seat. Use a dial indicator to measure tip protrusion. Thoroughly clean the injector sleeve with fuel and compressed air. Install the gauge tool then hold the dial gauge to the cylinder-head surface. Zero the gauge dial and then hold the spindle on the gauge tool. Read the protrusion from the dial face (Fig. 14-13).

Valve Guides Replaceable valve guides are used on diesel engines. They are made of a cast-iron alloy which has superior wear and is more corrosion-resistant than the alloy used in the cylinder head. These



(a)



(b)

Fig. 14-12 *(a)* Reaming of injector tube for the 149 injector body and spray tip, *(b)* reaming an injector tube for the injector seat. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

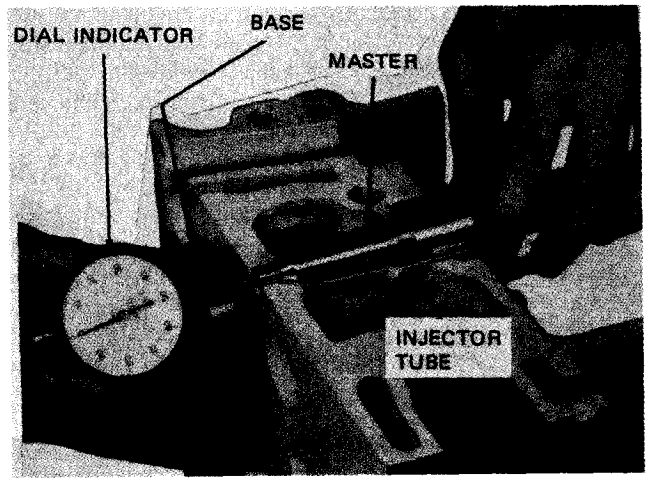


Fig. 14-13 Measuring injector protrusion. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

guides are usually half the length of the valves. When inserted into the cylinder head, they are flush with the ports (valve throat) to prevent turbulence of the incoming air or outgoing exhaust gases. The inner surface is often treated to increase its resistance to chemicals and corrosion. Some valve guides are grooved or knurled to reduce friction and to increase lubrication control. As a result, the service life of the guide, as well as the service life of the valve, is increased. Often the exhaust guides are counterbored to prevent carbon buildup and to reduce heat transfer which could damage the valve stem. The inside diameter is precision-honed or reamed to control lubrication and valve-stem movement.

Valve-guide Service After an engine has been operated for a considerable time its guides will show signs of wear. They must be measured for wear to determine if they can be serviced by knurling (to restore the inside diameter), or if they should be replaced.

Before you measure the guide using a small-bore gauge or a dial gauge, check it visually for chips, burrs, or cracks. When carbon is present remove it using a wire brush connected to a power tool. To check the guide for wear, adjust the bore gauge diameter to maximum allowable guide wear. Check at several points along the valve guide, especially at the valve head and stem end (Fig. 14-14). If the bore gauge is loose at any point in the guide, the guide must be knurled or replaced.

Bell mouthing at the valve head end usually is caused by carbon buildup on the valve stem. Bell mouthing at the stem end can be caused by a bent valve spring, worn rocker arm, or improper arcing of the rocker-arm-to-valve-stem surface.

Replacing Valve Guides To remove the valve guide, you should press or drive it out from the cylinder-head deck side. After removal check the valve-guide bore. If the bore is damaged, it must be reamed

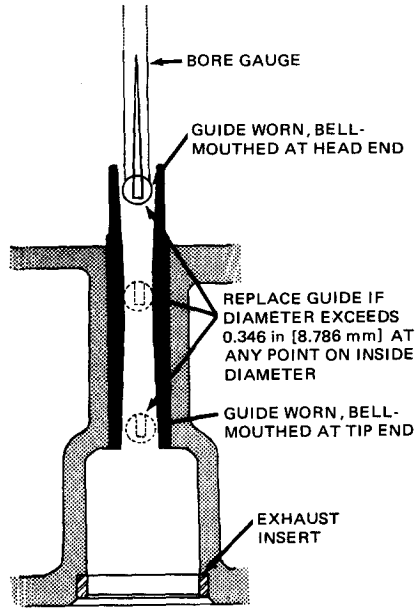


Fig. 14-14 Bell-mouthed valve guide. *[J.I. Case Agricultural Equipment Division. (TENNECO).]*

to accommodate a new oversize valve guide. To install a new guide, use a mandrel to press the guide into its bore to its specified height above the valve-spring seat surface. When no height specifications are given in the manual, the usual instructions call for pressing the guide flush with the valve port. Although honing or reaming the valve guide after installation is sometimes recommended, some manufacturers simply suggest checking the inside diameter.

When you hone or ream the valve guide, use lubricant, and ream from the valve-head side to achieve a satisfactory surface finish.

Valve Service Clean the valve with a buffer and polish the stem with crocus cloth. You may use a glass beader to remove heavy carbon deposits from the fillet, face, and valve head, but do not use it on the stem as this would accelerate wear on the valve guide. Check the valve to determine if it can be reused. If it is cupped (dished), cracked, pitted, or burned, it must be replaced. When the valve margin is smaller than specified, the valve cannot be reground; therefore it must be replaced. Magnaflux the valve, especially if it consists of two metals, to reveal hidden flaws. When the valve stem has nicks, pitting, or scuff marks, or the keeper (retainer) grooves are damaged, the valve must be replaced. If the valve stem tip is excessively worn, it must be replaced because the case hardening is no longer present (Fig. 14-15). *(NOTE: Worn keeper grooves will tip the spring retainer as well as the spring, causing the valve to tip, the valve seat to leak, and the valve to stick. It will also increase valve-stem and -guide wear. Be aware that refinishing the stem tip may restore its surface but may also remove the case hardening.)*

Measure with a micrometer the diameter of the valve stem at various points along the guide-bearing surface. The average allowable maximum wear is 0.001 in [0.025 mm].

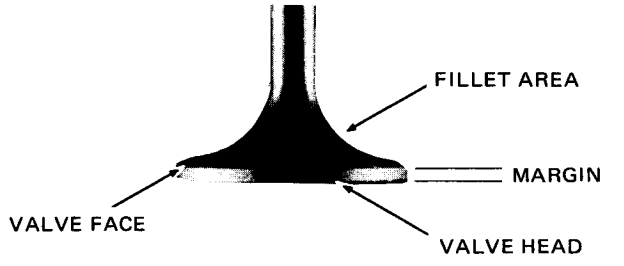
Measure the valve-stem straightness with a runout indicator, as shown in Fig. 14-16. The valve must be replaced if the runout exceeds 0.002 in [0.050 mm].

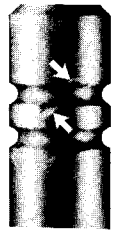
Grinding Valves Make a cursory check of the valve grinder by inspecting the drive belt tightness, the bearing's lubricant condition, and the coolant level. Make particularly sure that the chuck is clean.

Dressing Grinding Stone Select a grinding stone that is correct for the valve being refaced. Select the appropriate coolant and install the diamond dressing tool.

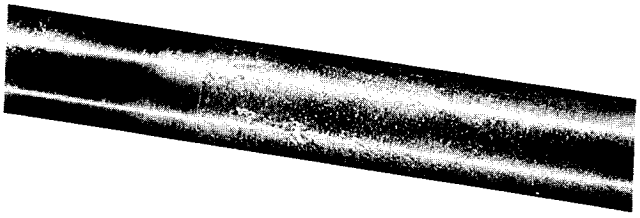
CAUTION Do not use water or a soluble oil when grinding sodium-filled valves. Use kerosene. Kerosene will not explode as a result of being mixed with sodium should the valve be damaged during grinding.

Start the motor and move the diamond toward the grinding stone, adjusting it so that it will take a fine cut. Turn on the coolant and slowly move the diamond back and forth across the stone. To prevent roughness, avoid cutting too deep or moving across the stone surface too fast.





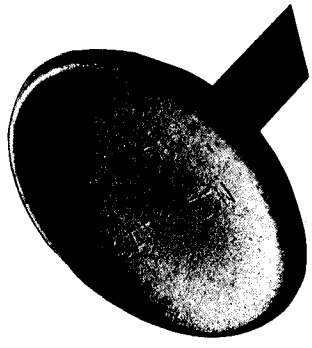
DAMAGED RETAINER GROOVES



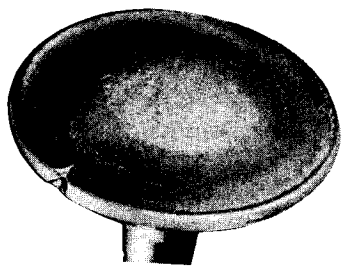
EROSION ON VALVE STEM



HORN STEM TIP



CUPPED (DISHED) VALVE HEAD



DAMAGED VALVE HEAD

Fig. 14-15 Major valve check points. *(Caterpillar Tractor Co.)*

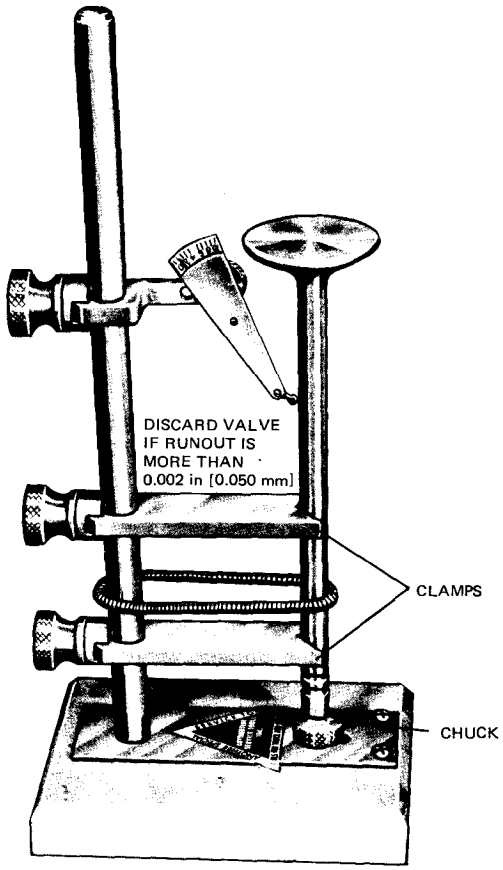


Fig. 14-16 Using a runout indicator to measure valve stem straightness. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

When you have finished dressing the stone, remove the diamond and adjust the chuck angle to the desired degree. Be very precise with your alignment. Insert the valve stem into the chuck as close as possible to the clamps to avoid valve vibration or bending during the grinding operation (Fig. 14-17). Adjust the carriage stop so that the valve stem cannot contact the grinding stone.

Start the chuck drive and check the valve runout. If the valve runout is greater than 0.001 in [0.025 mm], relocate the valve in the chuck and try again. If the valve cannot be centered within the limits of the runout, or if the valve head is warped, the stem is bent, or the stem wear exceeds specification (assuming the valve grinder is not worn), the valve must be discarded because the margin would be uneven after grinding. This would result in uneven temperature on the valve head and early valve failure.

Lightly cut across the valve face to determine if the valve can be ground. Grinding may remove too much surface and result in a margin less than half of the original width. This check will also indicate warpage of the valve head which did not show up previously.

Record the micrometer feed setting at the beginning of the grinding operation. To avoid valve overheating, take only light cuts, move the valve slowly across the full stone face, and apply cutting oil generously. Move the micrometer feed only 0.001 in [0.025 mm] at a time, and frequently stop the chuck drive to check the grinding progress. When the valve-face surface is smooth and free of pitting, check the micrometer feed dial and record the amount of metal removed. If the amount removed is greater than that anticipated, the margin will probably be too small and/or the valve head will be lower in the cylinder head than the specified maximum.

CAUTION Do not move the valve face beyond the stone during the grinding operation. This will cause the stone to ridge or groove and the grinding surface to become round. Also be careful not to damage the valve fillet area.

Sometimes it becomes necessary to redress the stone in order to maintain a smooth, even surface and a uniform valve-seat angle during the grinding of one valve. This need can arise because of the heat scale on the valve or because the grinding stone was not appropriate for the hardness of the valve.

NOTE: Make certain when reusing valves that each valve is placed in its original guide.

When you have ground all the valves, service the valve-stem end using an attachment (shown in Fig. 14-18) to support and hold the valve in position. Turn the micrometer feed until it contacts the stone. Record the micrometer setting. Back off a few thousandths of an inch [hundredths of a millimeter], start the grinding wheel motor, and position the cooling stream to the valve-stem end. Turn the micrometer feed slowly toward the stone to ensure a cleancut surface. Note the amount of metal removed so that you do not remove more surface than specified (about 0.015 in [0.38 mm]) and thereby eliminate the surface hardening and accelerate wear. *(NOTE: Do not neglect to dress the grinding stone as this would produce a rough surface.)*

When all stem ends are ground, it is sometimes necessary to grind a new chamfer. This is done in the following manner: Adjust the attachment to a 45° angle and lay the valve in the V block. Adjust the stops so that the valve cannot slide toward the stone. Start the grinding wheel and bring the stem end in contact

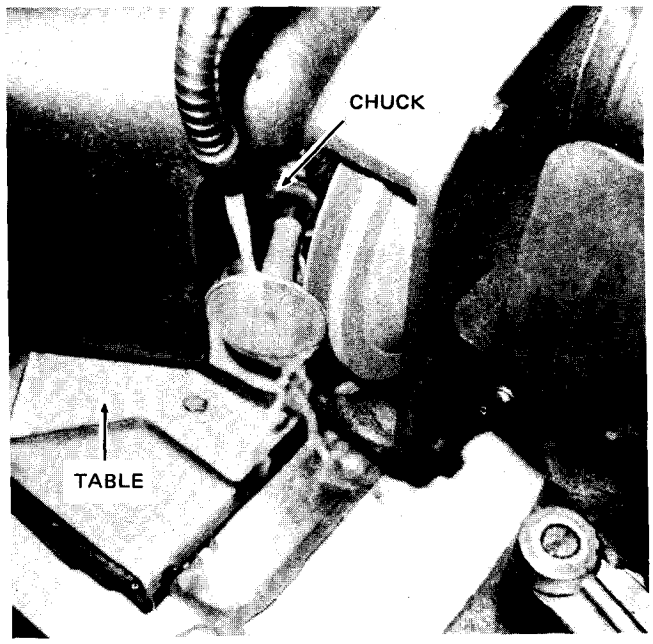


Fig. 14-17 Grinding the valve face.

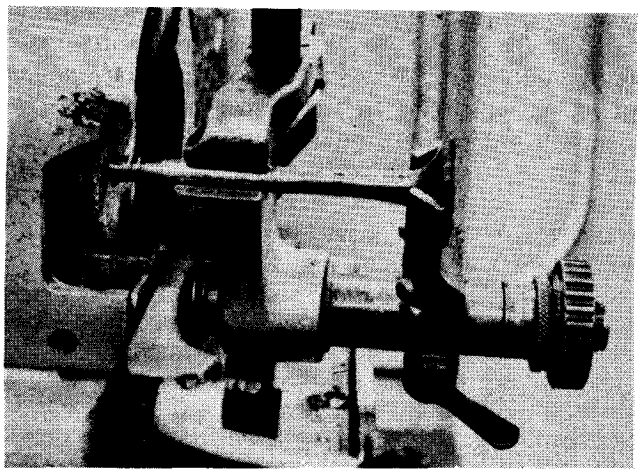


Fig. 14-18 Grinding valve stem.

with the stone and slowly turn the valve in its V block to grind the chamfer. Do not grind too large a chamfer as this will reduce the contact area of the stem end and may quickly deteriorate the rocker-arm surface.

Final Checks of Valves When you have refaced and cleaned all the valves, recheck the margin. Check the refaced valve on the runout indicator. The valve-face runout should not exceed 0.001 in [0.0025 mm]. If it does, check the general condition of the valve refacer; it may need to be cleaned or repaired. Check and remeasure the valve stem to determine if it is the cause of the high runout. Do not forget to measure the valve-head depth. This is often neglected, despite the fact that it can create untold trouble.

NOTE: New valves must also be checked, measured, and, at times, reground (resurfaced) if they have been damaged during shipping or handling.

Valve-seat Insert A valve-seat insert is a metallic ring which is lodged inside the cylinder head to increase the service life of the valve and valve seat. The cast-iron alloy from which the seat is manufactured will vary to suit various operational conditions. It may be of regular cast iron with the normal amount of carbon, silicon, phosphorus, and sulfur, or a cast-iron alloy with additional elements such as chromium, nickel, manganese, molybdenum, copper, cobalt, and tungsten. It is important for the insert to seat firmly in the counterbore to ensure good heat transfer and to prevent distortion (Fig. 14-19).

Valve-seat Insert Checks and Service Check the valve-seat insert for cracks or looseness by lightly tapping the cylinder head near the insert. Check the seat area width against that specified. The average valve seat width is between 0.060 to 0.120 in [1.52 to 3.04 mm]. If the width exceeds this specification and cannot be narrowed down by regrinding, the insert must be replaced. If grinding brings the valve head below the specified measurement, the insert must also be replaced. Carefully check the valve-head height or depth against the manual specification. When the valve head is too high, it may interfere with the piston which would cause valve and piston damage (Fig. 14-19). When the valve head is too low, a loss of compression is unavoidable. The valve and/or the valve insert must be replaced. If no insert is used and the valve seat is damaged beyond regrinding, a valve-seat insert must be installed.

To remove an insert, use a puller similar to that shown in Fig. 14-20. Do *not* use a prybar, punch, or chisel because the hardened material shatters like glass and serious face or eye injury could result. If you do not have a puller, run a couple of welding beads on the inside of the insert.

CAUTION Protect the valve guide and do not weld the cylinder head.

After the insert has cooled, it can easily be removed by hand or with pliers. Upon removal, check the counterbore for burrs, cracks, or rough edges. If these defects are present, remove them. Some manufacturers deplore replacement of the same size insert; rather they suggest boring the counterbore to accommodate an oversize insert.

NOTE: When using an insert cutting tool such as that shown in Fig. 14-21, make certain that the valve guide is not worn, that the insert cutter is the correct size, that it is sharp, and that it is installed properly. The

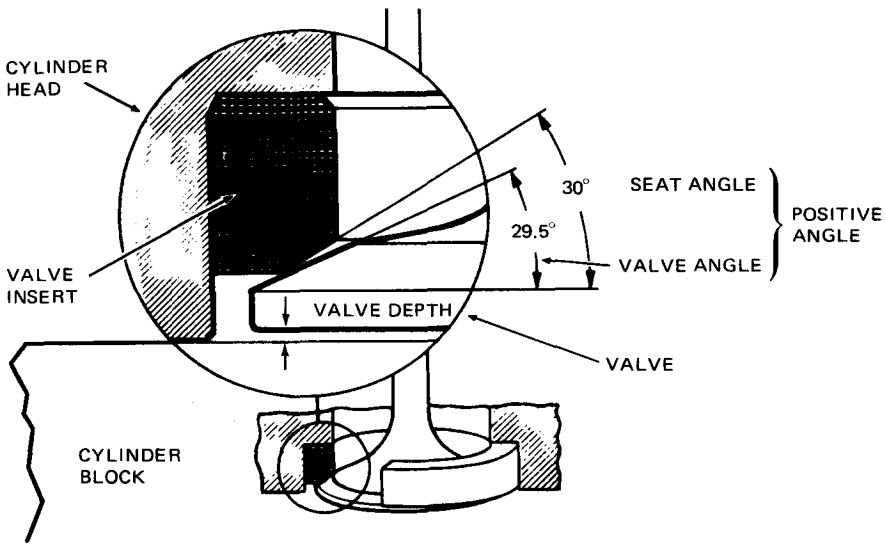


Fig. 14-19 Schematic view of valve and valve seat. *(Mack Trucks Canada Limited.)*

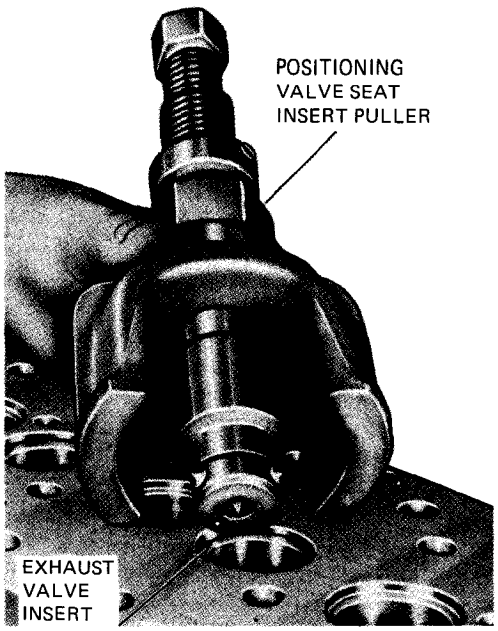


Fig. 14-20 Removing a valve-seat insert. *(Allis-Chalmers Corp. Engine Division.)*

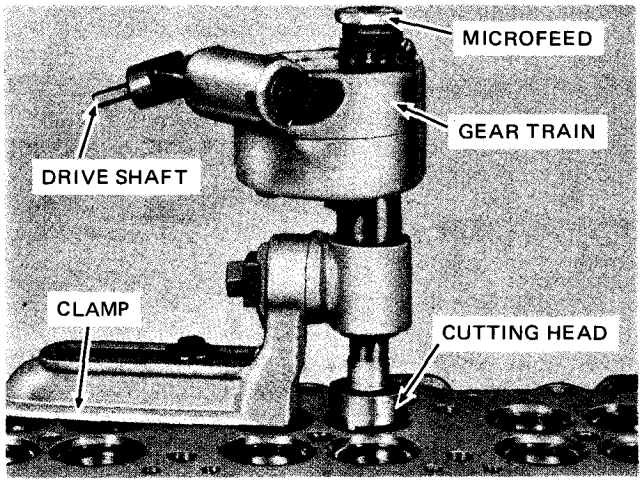


Fig. 14-21 View of valve insert boring tool installed.

insert cutting tool must be fastened tightly to the cylinder head.

When you install a new insert, place it in dry ice. When thoroughly chilled, quickly place the insert over the counterbore with the valve seat up.

CAUTION Take care when handling dry ice. Wear asbestos gloves.

Use a driver as shown in Fig. 14-22 to drive or press the insert down tightly into the counterbore. Some manufacturers recommend peening the insert with a special tool or a round-nose punch to force the metal around the outer insert chamfer edge.

Valve-seat Grinding Tools Defective valve-seat grinding tools should be repaired and wornout tools replaced. A valve seat, improperly ground, can cause compression losses, combustion changes, increased fuel consumption, burned valves, or valve-head breakage. A valve seat must be ground to a precise angle and be concentric with the valve guide. The seat area must be smooth and the width must be within specification.

Valve seats must be ground to a precise measurement. The tools required are: (1) a valve-seat grinder and stone dresser; (2) a pilot, the same size as the valve-stem diameter, to center the grinder; (3) a dial gauge to measure the concentricity of the valve seat; and (4) various grinding stones of different angles to grind the valve seat to a narrower width. The stones must also be of the correct width so that they do not interfere with the walls of the combustion chamber or cut a shoulder in the valve seat. They must be made of a material that will grind either the hardened insert or the cast-iron alloy of the cylinder head. The valve guide must not only be clean, it must conform to specified dimensions; otherwise the pilot will not be square to the valve seat. The valve seat and surrounding area must also be free of carbon and oil to ensure maximum cutting efficiency of the grinding stones.

STONE DRESSING After you select a stone of the correct width and texture, secure it to the drive. Then place the valve-seat grinder on the guide pin of the dressing tool. Back the diamond cutter away from the stone, adjust the diamond holder to the correct angle, and then lock it securely. Start the drive motor and adjust the diamond to the stone. Slide the diamond across the full stone face. Do not take too heavy a cut or slide the diamond too fast over the stone surface. To do so may ruin the diamond or shatter the stone. It would definitely leave the stone face rough.

Interference Angle Some manufacturers recommend grinding the valve seat ½ to 1½° larger, to achieve a narrow line of contact. Such an angle is known as an *interference angle*. The purpose of the interference angle is to permit a narrow leakfree valve seat when the engine is first started. As the valve gets hot, the valve head curls slightly and expands to a full seat contact (Fig. 14-19).

Valve-seat Grinding (Refacing) Before you grind a valve seat, make sure that the valve guide is clean. Then apply a light coat of engine oil to the pilot, and insert and secure it in the valve guide.

Clean the bore of the valve grinder and place the

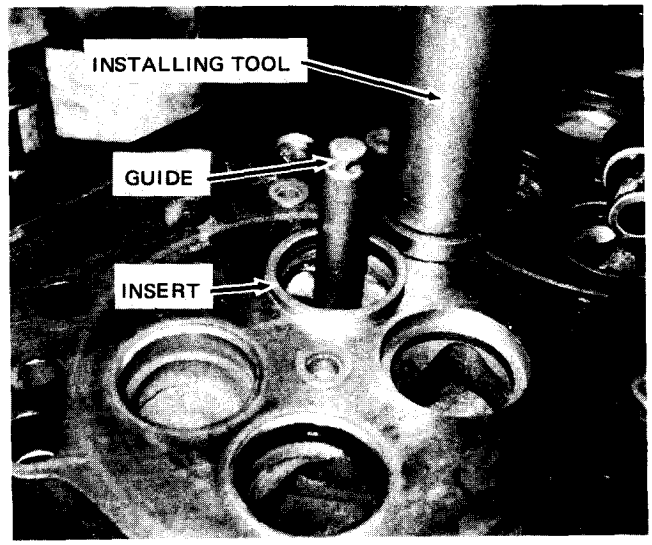


Fig. 14-22 Installing a valve-seat insert.

grinder over the pilot. Adjust the knurl micrometer knob so that the stone just contacts the valve seat. Support the valve-seat grinder and start the drive motor. Feed the stone gently to the seat using the micrometer knob. This will ensure a smooth seat surface. Too much force on the stone will produce a rough seat.

Record the dial number of the micrometer at the start of the grinding operation. Remove only enough surface metal to produce a pitfree continuous seat. Record the amount of valve-seat surface metal removed by checking the dial number of your micrometer feed when grinding is finished. You may have to dress the stone frequently before one valve seat is perfectly ground.

Before you narrow the seat in order to position the valve-face seat contact, you should measure the valve seat for concentricity. This can be done by using a dial gauge tool as shown in Fig. 14-23. When the gauge is installed and the dial stem adjusted, rotate the upper half of the tool to measure the valve-seat concentricity. The maximum runout should not exceed 0.002 in [0.050 mm]. If the valve-seat runout exceeds maximum allowable tolerance, recheck the valve guide, pilot, and valve-seat grinder for wear. If the excessive tolerance is not due to wear of any of these parts, you must regrind the valve seat.

Locating Valve-face and -seat Contact To check seat contact, wipe a thin film of Prussian blue on the valve seat and rest the valve momentarily on its seat. (Do not rotate the valve.) A thin, continuous line should be evident on the valve face. The contact area must be at the correct height and the valve seat must be the recommended width.

Another method of checking the concentricity and condition of the valve seat is to pencil-mark the valve face as shown in Fig. 14-24. Then place the valve against the valve seat and rotate it about 10°. Remove the valve and check your pencil marks. The seat and concentricity are satisfactory when all pencil marks are broken.

To locate the contact seat area on the valve face and at the same time to reduce it to the correct width, grind it with a 15° stone to lower the seat and to reduce its width, or use a 60° stone to raise the seat and reduce its width.

Measuring Valve-head Height The penultimate step before installing the valve is to measure and compare the height of the valve with the cylinder-head surface using a straightedge and feeler gauge as shown in Fig. 14-25, or by using a dial indicator. Check the measurement against the manufacturer's specification. If the valve head is too high, the seat or the valve must be reground to lower it. If the valve head is too low, the valve and/or insert must be replaced. The last step is the valve-seat test.

Valve-seat Testing Most manufacturers recommend testing the valve seat for leakage before installing the valves. A leaking valve can cause considerable damage if it is not detected prior to engine startup. The simplest valve-seat leakage test is to place a suction cup onto the cylinder-head surface over the valve and insert; then squeeze the bulb while positioning the suction cup. If the suction cup stays on the surface of the cylinder head for about 15 seconds after the bulb is released, the valve seat and the insert are airtight.

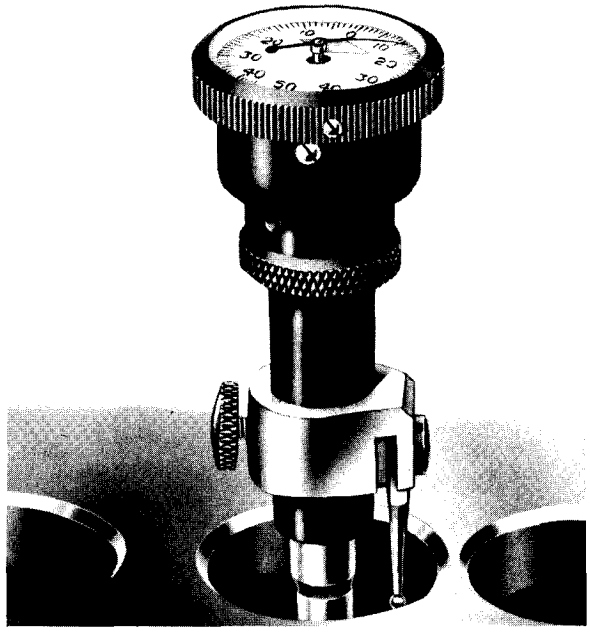


Fig. 14-23 Measuring valve-seat runout. *(International Harvester Company.)*

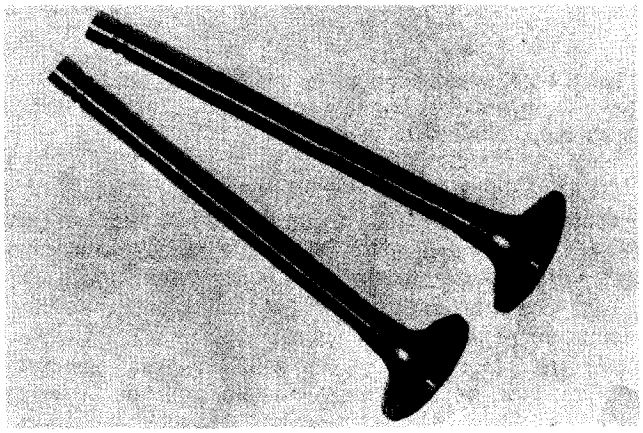


Fig. 14-24 Pencil marks on the valve face. *(Cummins Engine Company, Inc.)*

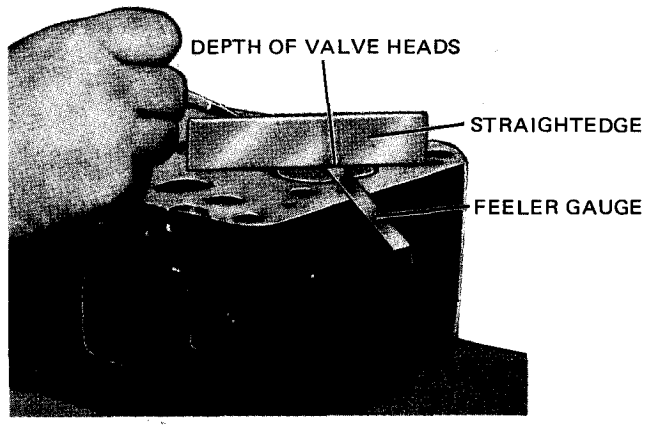


Fig. 14-25 Measuring valve-head height. *(Mack Trucks Canada Limited.)*

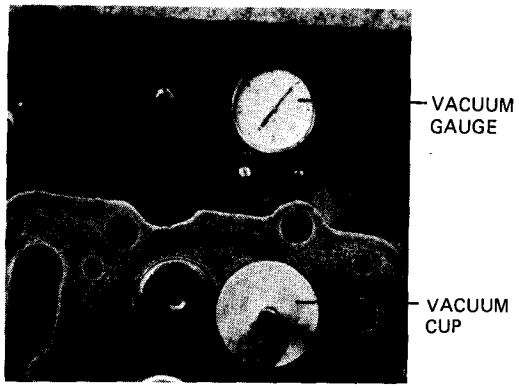


Fig. 14-26 Vacuum testing a valve for leaks.

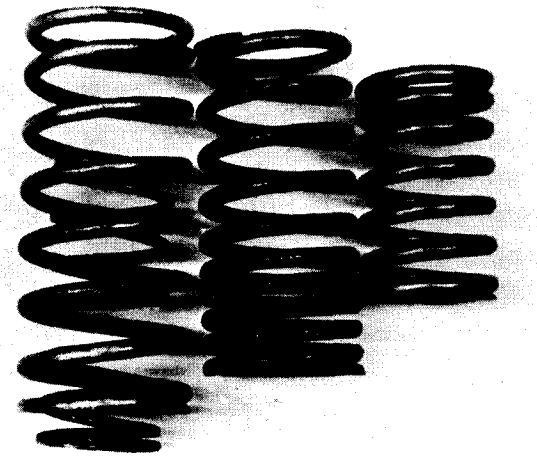


Fig. 14-27 Valve springs: *(a)* uniform coil spacing (one coil wound to the left, the other to the right), *(b)* variable coil spacing, *(c)* uniform coil spacing.

More reliable is the use of a tester consisting of a vacuum pump, a vacuum gauge, and a vacuum cup (Fig. 14-26). Here, also, place the vacuum cup onto the cylinder-head surface over the valve and valve insert. Start the vacuum pump and observe the vacuum gauge. When the gauge needle indicates 20 inHg [50.8 cmHg], close the shutoff valve. Begin timing as soon as the gauge needle reaches 18 inHg [45.72 cmHg]. After a lapse of 10 seconds, the gauge should read not less than 8 inHg [20.3 cmHg].

If the valve seat is unsatisfactory, tap the valve stem gently with a hammer handle or soft-faced hammer and repeat the test. If the seat is still unsatisfactory, check the test cup, the connecting lines, and the tester-shutoff valve. If it checks out satisfactorily, put grease on the insert groove and repeat the test.

If the valve seat is now satisfactory, then the leak was caused by the valve-seat inserts. To seal the inserts, stack or peen them and repeat the test.

Valve Springs, Spring Retainers, and Keepers The steel used for a valve spring usually is composed of carbon, manganese, phosphorus, sulfur, and silicon. It must be resistant to high temperature and corrosion and must maintain its strength throughout the compression and expansion cycles to control the sealing force. The valve spring is designed to ensure valve alignment with the spring retainer and valve keeper. Valve springs which have evenly spaced coils are designed in accordance with Hooke's law.

To control valve vibration or valve flutter at the time of closure and to reduce valve-seat and valve-seat-insert wear, variably spaced springs are used (Fig. 14-26*b*). Springs of this design, unlike those utilizing Hooke's law, have variable coil spacing.

NOTE: When variably spaced valve springs are used, the close-wound end (with less resistance) must be installed toward the cylinder head to give the valve spring stabilization.

When the valve lift and/or the engine speed is high, two springs are used to ensure adequate force and prevent valve vibration and flutter. The coils usually are wound in the opposite direction to prevent the valve springs from rotating (see Fig. 14-27*a*).

A spring retainer made of steel or cast-iron alloy stabilizes the valve spring and locks it to the valve stem through a set of keepers (Fig. 14-28). Valve keepers have internal grooves or recessed areas which match with the raised area or grooves on the valve stem. When the two keepers are placed on the valve stem, the outer surface forms a cone and matches with the contour of the valve-spring retainers. Sometimes a lower valve-spring seat (retainer) is

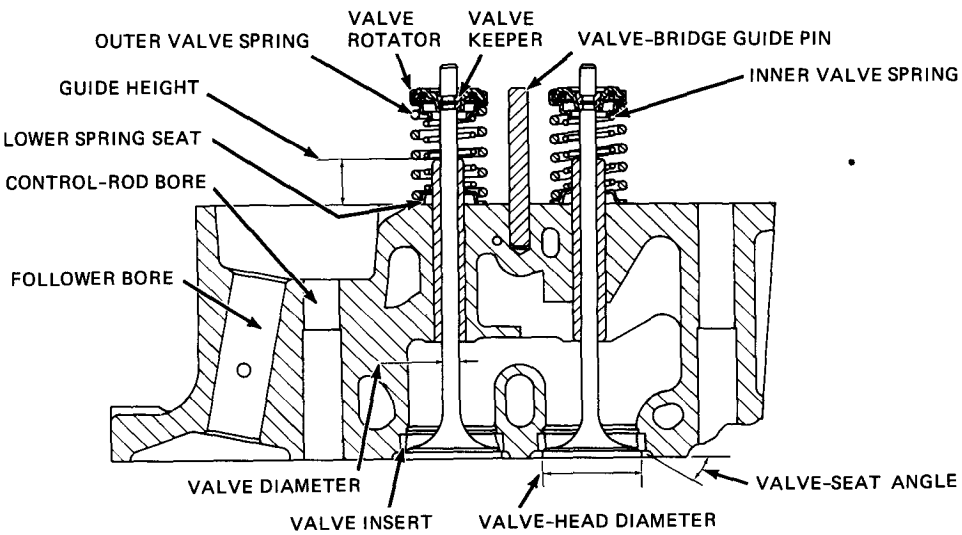


Fig. 14-28 Sectional view of a Caterpillar 3500 Series cylinder head.

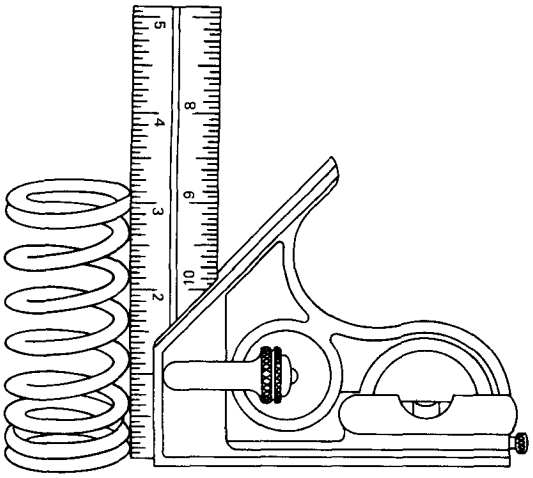


Fig. 14-29 Checking valve-spring alignment. *(Allis-Chalmers Corp. Engine Division.)*

used to act as a heat sink and as a wear washer preventing the spring from wearing into the cylinder head.

Valve-spring Service Clean with solvent any valve springs that have been coated for protection to maintain their resistance to corrosion. After properly cleaning and drying with compressed air, visually check them for rust, pitting, or fractured coils. Check both spring ends; they must be flat and must have a smooth, tapered surface. If any one of these defects is present the spring must be replaced. Check both ends for squareness by placing the spring on a flat surface. Slide a combination square close to the valve spring and then rotate the spring slowly (Fig. 14-29). The spring should remain parallel with the edge of the square. Place the other end of the spring on the flat surface and again rotate the spring against the combination square. If the rotating spring remains within 0.64 in [1.55 mm] of the edge of the square as you rotate it, you can assume that the spring is parallel and straight and can, therefore, be reused.

Measuring Spring Height and Force Position the spring between the two anvils of the valve-spring tester and let the movable anvil rest lightly on the spring end. From the tester scale, read the free length of the spring. If it is below specification, the spring must be replaced.

Compress the spring to the specified height. By doing this, force is put onto the lower anvil and recorded onto a dial calibrated in pounds [kilograms]. If the compressed valve-spring force is less than specified, the spring must be replaced. An average force variation of 5 percent is allowable. *(NOTE: When a total of more than 0.030 in [0.76 mm] is removed from the valve and the valve insert because of refacing, a valve spacer should be used to increase the spring height.)*

Valve Rotators To extend the valve and valve-seat life, the exhaust and/or intake valves of some engines are equipped with positive or nonpositive valve rotators. The nonpositive valve rotator has a Belleville spring (cone spring) between the two-piece valve-spring retainer, and a coil spring above the cone spring. As the rocker arm forces the valve down, the valve-spring force is momentarily removed from the valve. This gives the valve momentary freedom allowing it to rotate to a different position.

A positive rotator is similar in design to the nonpositive except that the cone spring is replaced by a number of small steel balls. They lie in a ramplike groove and are held there by small coil springs (Fig. 14-30). As the rocker arm moves the valve down, the

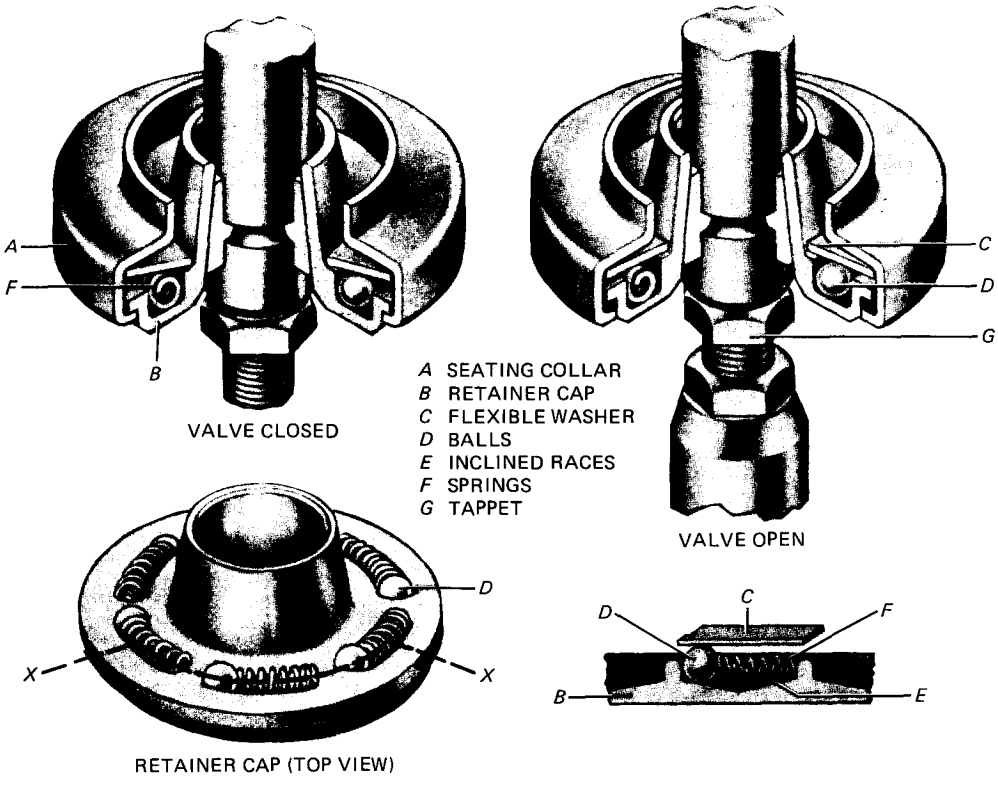


Fig. 14-30 Positive valve rotator.

cone spring is compressed. This forces the balls to move in their inclined ramps and the valve to rotate. As the rocker-arm force is removed, the cone-spring force is released. The balls are then forced by their coil springs to return to their starting position.

Valve-rotator Service It is not possible to check the function of a valve rotator when it has been removed. At this point your only alternative is to thoroughly clean and visually inspect the rotator for external damage. It can easily be checked when the engine is running by making a chalk mark on the rotor retainer and retainer body. When the valve rotator is operating, the retainer mark should wander (rotate) away from the spring retainer mark.

Valve-bridge Service (Crosshead) Visually check the surface of the rocker-arm lever and the valve-stem contact area for excessive wear or cracks. Check the adjusting screw and bridge threads for wear and distortion. With a small-bore gauge, measure the inside of the bore at several points for out-of-roundness and taper. When the contact surfaces are worn, the valve bridge must be replaced because of resurfacing problems. When the bridge bore is worn beyond specification, it can be reamed to accommodate an oversize valve-bridge guide pin (Fig. 14-31).

Replacing Valve-bridge Guide Pin With a micrometer, measure the outside diameter of the guide pin and compare the measurement to the manufacturer's specification. Using a square, check the guide pin for straightness. If the pin must be replaced, use an adapter attached to a slide hammer and pull the pin free from the cylinder head. Otherwise use a piece of metal pipe to bend it back and forth until it breaks. (It should be broken as close as possible to the cylinder head). Drill and tap a suitable size thread in the guide pin and use two pry bars to pull the pin from the cylinder head.

To install the guide pin, use a guide mandrel to press the pin into the bore, to the specified protrusion. After installation, recheck the guide pin for straightness.

Valve Seal Some engines utilize valve seals to prevent oil from passing into the combustion chamber through the intake or exhaust guides. These seals, made of Teflon, are placed either over the valve guide or on the valve stem below the valve keeper. The valve seals effectively control oil losses caused by vacuum, gravity, and inertia at the intake and exhaust valves.

Reassembling Cylinder Head After all the abrasives are removed, the head dried with compressed air, and all plugs reinstalled, swab the valve guides with an oil-saturated brush. Dip the valve stems into clean lubricant (oil) and place them in the valve guides. Make certain each valve is inserted in the valve guide in which it was tested. Place the lower spring seat over the valve guide onto the cylinder head, and the valve-stem seal over the stem and then over the valve guide. Next, place the valve spring

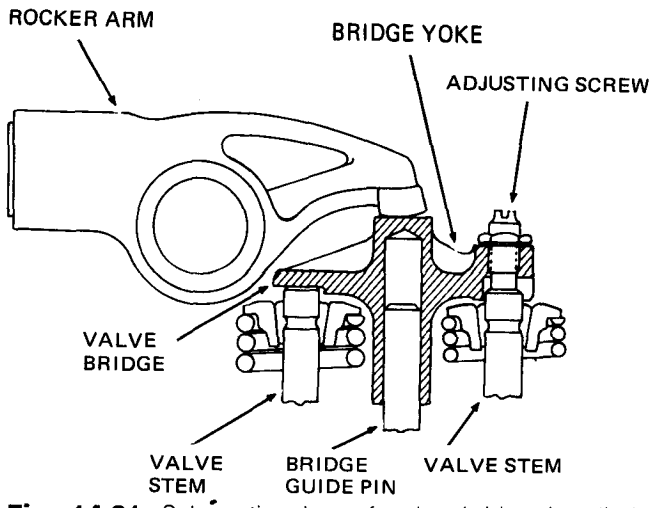


Fig. 14-31 Schematic view of valve bridge installed. *(Cummins Engine Company, Inc.)*

into position and the upper-valve spring retainer or valve rotator onto the valve spring. *(NOTE: Install the valve spring with the closed coil end toward the cylinder head.)*

Compress the assembly with a valve-spring compressor, or use the tool shown in Fig. 14-32. Place the two half-keepers onto the valve stems and then release the applied force. Tap the valve stems to determine if the keepers are correctly positioned.

NOTE: Some manufacturers recommend checking the force required to open the valves using a special spring tool.

Installing Cylinder Head Make certain that the machined surfaces of the cylinder head and cylinder block are clean. Do not forget to check the cylinder bores. Make sure there is no oil at the bottom of the cylinder head or threaded bolt holes. This could cause a hydrostatic lock when the cylinder head is in place or the head bolts are torqued.

Make sure that the water nozzle or cylinder-head cooling-jet tubes are in place and pointing in the correct direction. Install the necessary guide studs to position the cylinder-head gasket and to ensure troublefree head installation. Place the head gasket with

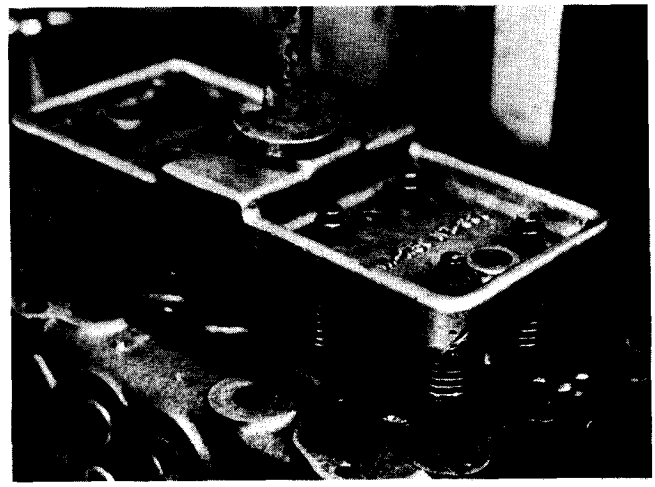


Fig. 14-32 Installing valve-stem keepers.

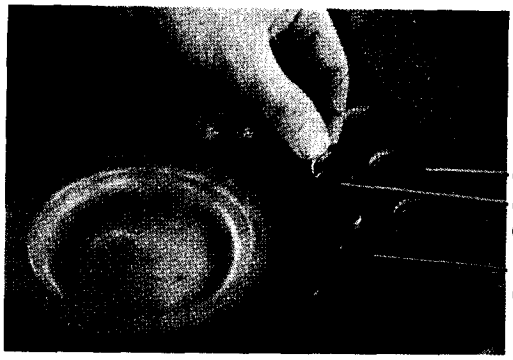
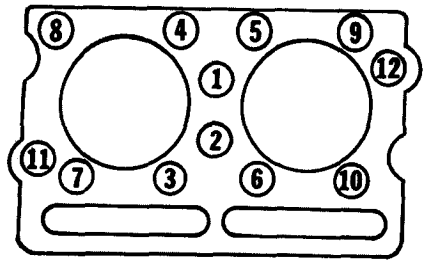


Fig. 14-33 Cylinder-head grommets. *(Cummins Engine Company, Inc.)*



CYLINDER-HEAD CAP SCREWS — 5½-in [139.7-mm] BORE ENGINES

Fig. 14-34 Typical torque sequence: (1) tighten to 50 lb·ft [67.7 N·m], (2) advance to 100 lb·ft [135.5 N·m], (3) advance to final torque of 280 lb·ft [379.4 N·m].

the side marked "top," facing up, on the cylinder block. If used, install the oil and coolant grommets (seal rings) and fire ring. (Fig. 14-33).

Hoist the cylinder head into position. Make certain that the cylinder head is parallel to the cylinder block when placing it in position and that the head gasket and grommets are correctly positioned. When multiheads are used, install all cylinder heads, then with a straightedge or special tool, align the cylinder head and/or manifold and/or water manifold mounting surfaces before tightening the head bolts.

Immerse the entire cylinder-head bolt in the recommended lubricant. Remove, and allow the excess oil to drip off. If thrust washers are used, place them on the cylinder-head bolts and insert the bolts, according to their length, into their respective bores. Tighten the head bolts in the recommended sequence and to the recommended torque in increments of 50 ft·lb [68 N·m] (see Fig. 14-34).

Installing Injector Refer to the appropriate units in Section 4, "Fuel-injection Systems," for recommended injector installation procedures.

Questions

1. What is the purpose of a cylinder head?
2. Why should you never remove the cylinder when the engine is hot?
3. List the checks and measurements you must make after the cylinder head has been cleaned.
4. Why should you air-test or water-test a cylinder head?
5. When the injector protrusion is below specification, but has not yet been corrected, how would this affect combustion?
6. How would you check the serviceability of a valve guide?
7. When pressing a new valve guide into place, why is it important to have the protrusion height at the precise specification?
8. What is the purpose of valve inserts?
9. What checks and preparations must be made prior to resurfacing the valve seats?
10. Describe how to locate the valve-seat contact?
11. What will result if the valve-head height is 0.020 in [0.508 mm] below specification?
12. Why should you not resurface a valve when the margin is below specification?
13. By what checks and measurements can you determine if a valve is resurfaceable.
14. What effect would a weak valve spring have on the valve action?
15. Why are valve rotators used?
16. What is the purpose of a valve bridge?
17. What checks must you make before placing of cylinder head in position?
18. Why is it important to torque the cylinder head in three, four, and five separate steps, for example, in the first torque sequence to 50 ft·lb [68 N·m], then to 100 ft·lb [136 N·m], and then to 150 ft·lb [204 N·m], and so on?

UNIT 15 • VALVE-TRAIN OPERATING MECHANISM

Servicing Rocker Arm Very little damage or wear will be found in the valve-train operating mechanism, especially if the engine is not abused or other parts of the engine have not failed. However, insufficient lubrication, contaminated oil, or incorrect installation of valve-train components could damage the bushings, shafts, or other valve-train components (Fig. 15-1).

Before disassembling the rocker-arm assembly, check each rocker arm and rocker-shaft bracket for identification. If not marked, identify each component in regard to its position on the shaft. Although some rocker arms look alike, their angle may be slightly different to give centralized contact on the valve stem or bridge. Disassemble one rocker-arm assembly at a time to prevent interchanging components.

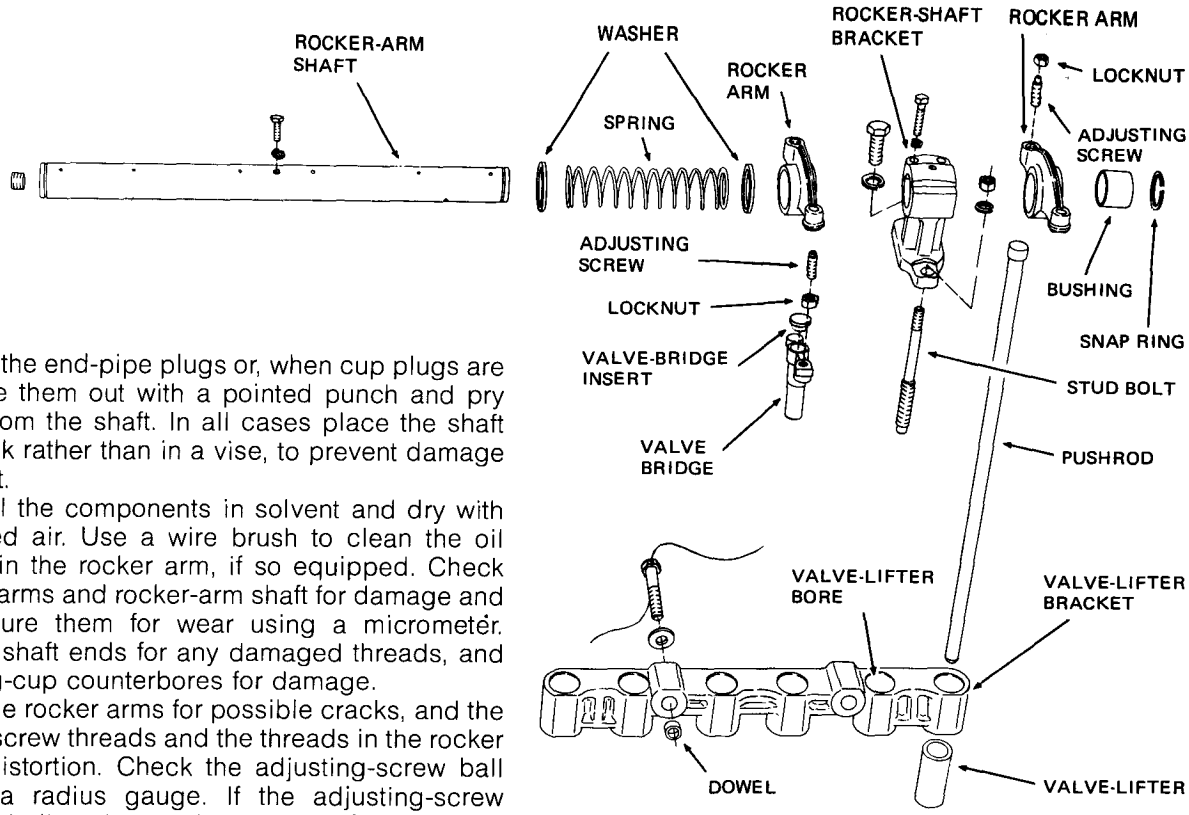


Fig. 15-1 Exploded view of a valve-operating mechanism. *(Allis-Chalmers Corp. Engine Division.)*

Remove the end-pipe plugs or, when cup plugs are used, drive them out with a pointed punch and pry the plug from the shaft. In all cases place the shaft in a V block rather than in a vise, to prevent damage to the shaft.

Clean all the components in solvent and dry with compressed air. Use a wire brush to clean the oil passages in the rocker arm, if so equipped. Check the rocker arms and rocker-arm shaft for damage and also measure them for wear using a micrometer. Check the shaft ends for any damaged threads, and the sealing-cup counterbores for damage.

Check the rocker arms for possible cracks, and the adjusting-screw threads and the threads in the rocker arms for distortion. Check the adjusting-screw ball end with a radius gauge. If the adjusting-screw threads or ball ends are damaged or flattened, replace them.

Check the rocker-arm surface where it contacts the valve stem or bridge. If it requires resurfacing, be sure to maintain the same contour radius so that the valve is forced straight downward. Do not remove more than 0.010 in [0.25 mm] from the surface, otherwise you may remove the surface hardening. Use the attachment tools of your valve refacer to resurface the rocker-arm (contact) surface (Fig. 15-2). *(NOTE: Some rocker arms have replaceable inserts to provide a self-aligning contact, thereby prolonging the life of the valve, guide, and rocker arm.)*

Measure the rocker-arm bushing for wear. When the rocker arm is new, the average running clearance is about 0.001 in [0.025 mm]. When the bushing exceeds specification, press it out, and then press a new one in. Carefully align the bushing oilholes with the rocker arm. Since some rocker-arm bushings have no oilholes, they must be drilled *after* installation.

To attain alignment and the correct inside diameter, the bushing may be honed or burnished with a burnishing tool. Burnishing is a procedure which seats the bushing and also sizes the bore diameter to specification. Check the rocker-arm-bracket mounting surface for flatness and cracks as well as for a smooth side-seat surface. Make sure that the oil supply holes are clean. The rocker arms of the Detroit Diesel 53, 71, and 92 Series engines have a clevis pinned to the rocker arm into which the pushrod is threaded. Check the threads and bores of the clevis for wear and distortion, and the clevis pin for wear.

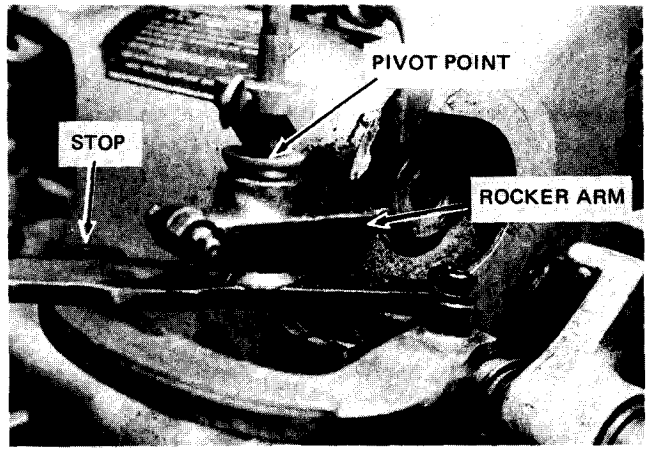


Fig. 15-2 Grinding rocker arm to valve-bridge contact surface.

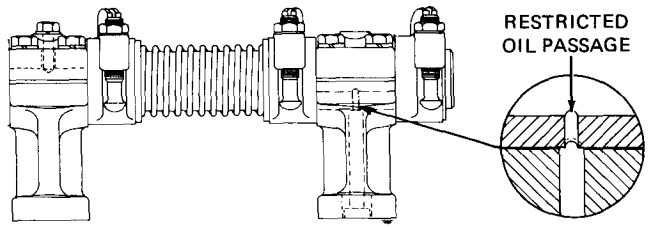


Fig. 15-3 Rocker-arm assembly. *(Allis-Chalmers Corp. Engine Division.)*

Assembling Rocker-arm Shaft Lubricate the rocker-arm bushing and shaft and assemble them onto the shaft in the sequence in which they were removed. Do not forget to install end plugs or cup plugs. Position the rocker-arm shaft so that the oilholes in the shaft align with the supply holes in the rocker-shaft bracket (Fig. 15-3), that is, with the rocker-shaft oilholes positioned toward the cylinder head rather than facing upward. Incorrect positioning

can allow too much oil to pass by the bushings. As a result, the valve guides cannot control the oil and it will find its way into the combustion chamber. When a special rocker-shaft bracket bolt(s) is (are) used as the oil supply link to the rocker shaft, take care to screw it (them) into its (their) correct location.

Pushrods or Push Tubes Pushrods or push tubes are made of special steel to withstand the great stress and force to which they are subjected. The advantage of using a push tube is that it has less inertia than the solid pushrod. There is usually a socket on one end of the pushrod and a ball on the other end to reduce friction and to maintain alignment. Consequently, when motion is transmitted to the rocker arm, it moves in a semicircle. The pushrods of the Detroit Diesel 53, 71, and 92 Series engines are threaded on one end and screwed into the clevis. The other end has a ball socket which rests in the cam follower. A pushrod spring ensures that the pushrod rests with a predetermined force on the cam roller (cam follower) to maintain it in constant contact with the camshaft lobe (Fig. 15-4).

Servicing Pushrods or Push Tubes Check the straightness of each pushrod by rolling it on a flat surface, or by placing the pushrod in V blocks and using a dial indicator to measure the out-of-roundness. Pushrods should not be out-of-round more than 0.020 in [0.508 mm]. Pushrods which are bent beyond specification must be replaced; those within specification should be straightened.

Check the ball ends for looseness, and check them for wear with a radius gauge. To check the socket-end wear, use a new rocker-arm adjusting screw, blue the ball surface, rotate the ball in the socket, and then check the contact surface.

Replace the pushrod when the contact area is less than 80 percent. Cummins push tubes should be checked to see if they contain any oil.

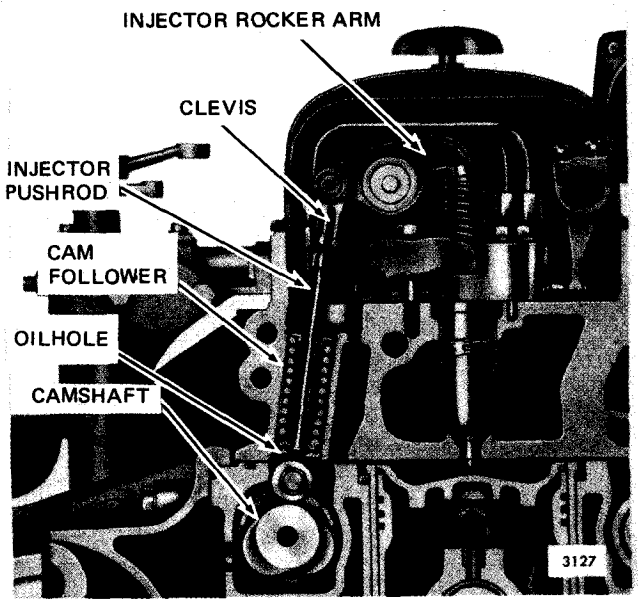


Fig. 15-4 Sectional view of Detroit Diesel 71 Series valve train. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

Cam Follower (Cam Roller) Cam followers and tappet rollers are made from cast iron or iron alloy which has a high resistance to wear and corrosion (Fig. 15-5). Although the external appearance varies with engine design, all cam followers or rollers reduce friction and evenly distribute onto the camshaft lobe the force placed on them during opening and closing of the valves or when operating the injector. The cam followers usually slide up and down in their bores as they follow the eccentricity of the camshaft lobes. Either a socket which accepts the pushrod ball end is machined into the follower or else a replacement socket is pushed into the follower. Some engines, because of the difference in camshaft location and action, have neither a pushrod nor the conventional cam follower.

The Detroit Diesel 149 Series engines have the cam roller pinned to the rocker arm which is in direct contact with the camshaft. On Caterpillar overhead-camshaft engines the rocker arms are located in the camshaft housing. The rocker arms with the valve-adjustment mechanism are placed directly over the valves, and the camshaft lobes act directly on the rollers to actuate the rocker arms (see Fig. 15-6).

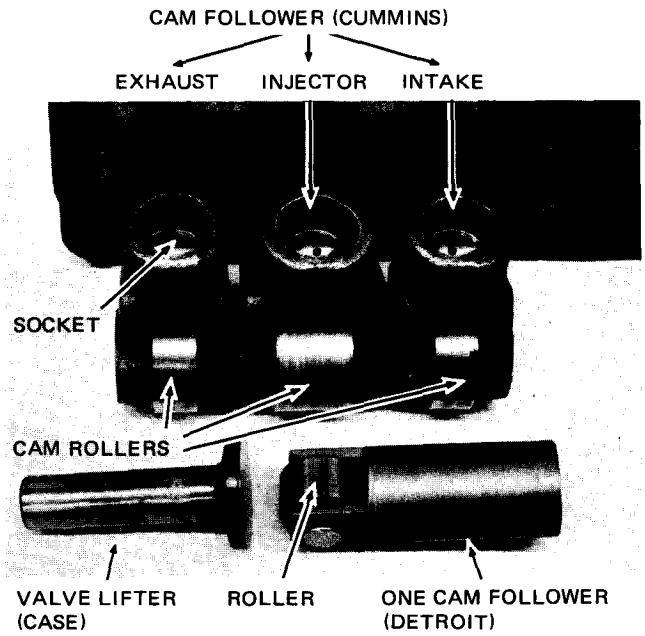


Fig. 15-5 Typical cam followers.

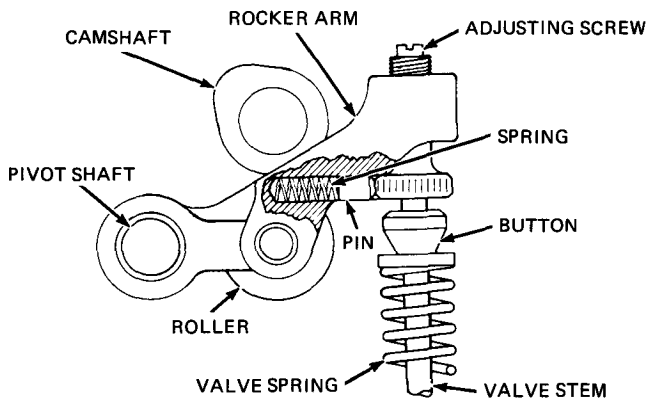


Fig. 15-6 Schematic view of an overhead valve train. *(Caterpillar Tractor Co.)*

Cummins in-line diesel engines have the cam rollers pinned to a lever which pivots on a shaft located in a separate cam follower housing. The pushrod rests in a replaceable socket.

Various types of cam followers, also known as *tappets* or *valve lifters,* are used on small diesel engines. Instead of cam rollers the valve lifters have enlarged wear surfaces which are in contact with the camshaft lobe. The cam followers (valve lifters) on engines of this type must be installed from the bottom and must be positioned before the camshaft is installed.

Servicing Cam Follower The wear limit of the cam-follower bushing, pin, roller, and bores must be checked very carefully. The cam follower's surface condition must be free of galling, pitting, or scoring. The rollers should be checked for flat spots since any slight defect will affect valve and/or injector timing.

Valve lifters having a flat surface instead of a roller should be checked for excessive wear and pitting. If the damage to the flat surface is not too severe, the lifter can be restored by using a valve refacer. The grinding procedure is the same as that used when refacing the valve-stem end. *(NOTE: To retain surface hardness, do not remove more than 0.010 in [0.25 mm].)*

Valve-bridge Adjustment To adjust the valve bridge, clamp the bridge in a vise, loosen the adjusting screw locknut, and turn the adjusting screw counterclockwise. Position the bridge on the valve-bridge guide pin (Fig. 14-31). With light finger pressure on the rocker-arm contact surface, hold the bridge in contact with the valve-stem end opposite to the stem end of the adjusting screw. Using a screwdriver, turn the adjusting screw until it contacts its mating valve-stem end. To compensate for thread looseness, advance the adjusting screw an additional one-eighth of a turn and finger-tighten the locknut. Remove the bridge and clamp it in a vise. Hold the screw in position and torque the locknut.

To check the adjusted valve bridge, place the bridge in position. Next check the valve-bridge contact, the clearance between the valve-spring retainer, and the bridge. For example, to check the adjustment of Detroit Diesel 71 and 92 Series, place a 0.001-in [0.025-mm] shim stock between each valve-stem tip and bridge. When forcing the valve bridge down, both shim stocks must be equally tight. If the adjustment is not correct, that is, if there is uneven force on the shim stock, remove the valve bridge and repeat the procedure previously outlined.

Installing Valve and Injector Mechanism Before you install the valve-train operating mechanism, turn all valve-adjusting screws to maximum clearance. This will prevent the valves from being forced against the piston as the rocker-arm shaft is torqued down. Generously lubricate the bores and cam followers before placing the cam followers into the bores.

When you install the cam follower assembly on Cummins N, NH, NT, and K diesel engines, use only one gasket between the housing and cylinder block. Use a soft-face hammer to force the assembly into position. Be sure that each housing fits flat against the cylinder block. Tighten bolts in the sequence specified. Install the push tubes. Make certain that each push tube is placed in its correct position, that the ball end fits into the socket, and that the larger-diameter push tube (injector) is in the center cam follower. Install a new rocker-housing gasket, back off all rocker-arm adjusting screws, and install the assembly. Align the push-tube sockets with mating rocker-arm adjustable ball ends. Install housing hex bolts and torque them in correct sequence to specification. Engine Timing is covered in Unit 33, "Cummins Fuel-injection System."

When assembling the pushrod assemblies of Detroit Diesel 53, 71, and 92, Series engines, place the lower spring seat, pushrod spring, and upper spring seat onto the pushrod. Screw the locknut to the full capacity of the threads onto the pushrod. Place the spring-seat retainer into its seat in the cylinder head, and slide the assembly from the bottom through the follower bore.

Screw the pushrod into the clevis until one pushrod thread is visible. Immerse the cam followers in clean Cindol 1705 oil heated to 100°F [73.3°C] for 1 hour to ensure initial lubrication before placing the cam follower into the bore (Fig. 15-7). Bolt the follower guide into place to hold the follower in position. *(NOTE: The oilholes in the bottom of the cam follower must be placed toward the trailing side of the camshaft.)*

Lubricate the rocker-arm bushing and shaft. Slide the rocker-arm shaft through the three rocker-arm bushings. Position a rocker-arm bracket to each end of the shaft, and if a valve bridge is used, install it on the guide pin, making certain that the ends rest squarely on the valve stems. Tilt the rocker-arm as-

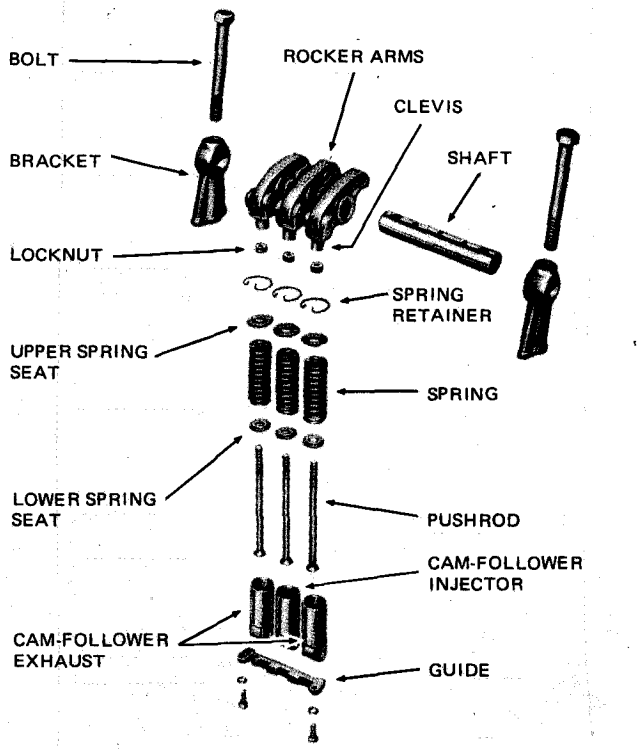


Fig. 15-7 Exploded view of Detroit Diesel 53, 71, and 92 Series valve train. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

sembly into position and insert the cap screws through the rocker-arm bracket and shaft. Start the cap screws into the cylinder head and torque them to specification.

Valve Adjustment Precise valve clearance, on any type of engine, is essential in regard to compression, combustion, scavenging, horsepower, fuel consumption, and running condition (firing) as well as to the service life of the valves and valve seats. A two-cycle diesel engine is more adversely affected by improper valve clearance than a four-cycle engine because its cycle is completed in one revolution and exhaust valve cooling is about 50 percent less. Remember too, that an increase or decrease in valve clearance will alter the time (in degrees) of the strokes.

CAUTION If servicing has disturbed the valve clearance, back off all tappet adjusting screws so that the valves cannot contact the piston when the engine is cranked over. Service manuals list valve clearance specifications for a cold engine and a hot engine; therefore, you must set the valve clearance twice: once before you start the engine and again when it has reached its operating temperature. Readjustment is necessary because the valve and valve-train components may expand at operating temperature. This can cause a change in the valve clearance.

Let us assume you have repaired a six-cylinder engine with a firing order of 1-5-3-6-2-4. Remember that the valves are closed when the piston is at TDC on compression stroke. When setting all valves with one crankshaft revolution, you should first record the firing order, that is, place the last three cylinder numbers under the first three, as follows:

1 - 5 - 3
6 - 2 - 4

In this example, No. 1 cylinder is on compression stroke at TDC, and therefore No. 6 cylinder is also at TDC but has completed its exhaust stroke, and the intake and exhaust valves are open (overlap).

At the same time, No. 5 cylinder is 120° BTDC and on compression stroke. No. 2 cylinder is also 120° BTDC but on the exhaust stroke. The No. 3 cylinder is 120° ATDC on its intake stroke, and No. 4 cylinder is also 120° ATDC but on its power stroke.

At this point you can set both intake and exhaust valve clearances of No. 1 cylinder, the intake valves of Nos. 2 and 4 cylinders, and the exhaust valves of Nos. 3 and 5 cylinders.

To adjust the valve clearance, insert a gauge of the correct thickness between (1) the valve bridge and rocker arm, (2) valve stem and rocker arm, and (3) camshaft and follower. Loosen the locknut and turn the adjusting screw downward (clockwise) to decrease the clearance or upward (counterclockwise) to increase the clearance between the two feeler-gauge contact points. The clearance is correctly set when the feeler gauge passes with a slight drag between the two surfaces. When you use a no-go feeler gauge, the no-go thickness will not pass through the two surfaces.

When the clearance is correctly set, hold the adjusting screw stationary and tighten the locknut. Recheck the adjustment to ensure that after tightening the locknut, the valve clearance has not changed. Each adjusted valve should be promptly identified so that none is overlooked.

Rotate the crankshaft 360° so that No. 6 cylinder is on TDC compression stroke. Adjust the valves of No. 6 cylinder, the intake valves of Nos. 3 and 5 cylinders, and the exhaust valve of Nos. 2 and 4 cylinders. (See Units 31 and 32 for procedures on adjusting injectors.)

To adjust the valves on the Caterpillar overhead-camshaft engine (Fig. 15-6), bring No. 1 piston to TDC on compression stroke. With a screwdriver turn the adjusting screw clockwise until you feel resistance, that is, when the button contacts the valve-stem end. Now turn the adjusting screw counterclockwise and note the click which is created by the plunger as it enters between the screw serrations. Each click is equal to 0.002 in [0.050 mm].

Decompressor (Compression Release) Many engines are equipped with a compression release mechanism which opens either all exhaust valves or all intake valves permitting the engine to be cranked more easily. This mechanism includes the necessary levers and linkage, and a decompression shaft with a pin or a shaft that is flattened on one side. (The adjusting screw of the release lever is in contact with the flat side of the shaft.) In either case, when the decompression shaft is rotated to its engaged lock or stop position, the rocker arms or the followers are forced down to open the intake or exhaust valves.

Servicing and Adjusting the Compression Release The compression linkage, levers, arms, or shafts require very little maintenance or service. However, when servicing, inspect for a possible bent or worn control linkage, a worn setscrew, or worn adjusting-screw threads. After replacing any of these parts, make certain the decompression mechanism cannot contact the rocker arm or follower and that the shaft either rests in its detent (trigger) or stops in the disengage position.

Questions

1. What are the major differences between the valve mechanisms shown in Fig. 15-3 and Fig. 15-6?
2. Why is the pivot point of the rocker arm closer to the pushrod than it is to the valve stem or valve bridge?
3. List the checks and measurements you must make to determine the serviceability of a rocker arm, a rocker-arm shaft, and a pushrod.
4. What is the purpose of a valve bridge?
5. Outline how to adjust a valve bridge.
6. List the checks you should usually make prior to and during installation of the valve-actuating mechanism.
7. When is a valve adjustment mandatory? List the reasons why a valve adjustment is essential?
8. What is the purpose of a compression release?
9. How can you prevent cylinder-head failure?
10. List several reasons (other than those mentioned in this text) why a rocker arm may break.

UNIT 16 - FLYWHEEL HOUSING, FLYWHEEL, AND TIMING COVER

Camshaft Rear Oil-seal Cover Because of the additional weight and/or the engine stand design, many service shops install the rear oil-seal cover, the flywheel housing, and the flywheel after the engine is removed from the engine stand.

The rear and front oil seals seal the crankshaft. The rear oil seal on most newer engines is pressed into a rear oil-seal cover which is made from steel, cast iron, or aluminum, and the cover is bolted to the flywheel housing or cylinder block. The front crankshaft seal is commonly pressed into the front cover or timing-gear cover. All engines use a one-piece cast flywheel housing; however, on those units where the timing gears are located at the rear, the flywheel housing is extended to also serve as a timing-gear housing. In the latter case the rear seal may be located in the bore of the housing. On engines where the rear seal cover is bolted to the cylinder block, it may also serve as the oil-pan mounting surface (see Fig. 16-1).

Inspecting and Servicing Flywheel Housing In order to inspect and service the flywheel housing, you must first remove the seals and gaskets. Next, clean the cover (or the flywheel housing), and dry it with compressed air. Check it for cracks and/or damaged mounting surfaces. Measure the bores, bushings, and shafts for wear and check them for pitting and grooving. Where necessary, remove nicks and burrs or replace components where warranted. Using a straightedge, measure all mounting flanges and sealing surfaces for straightness. Check all threaded holes, especially those of the rear engine mount.

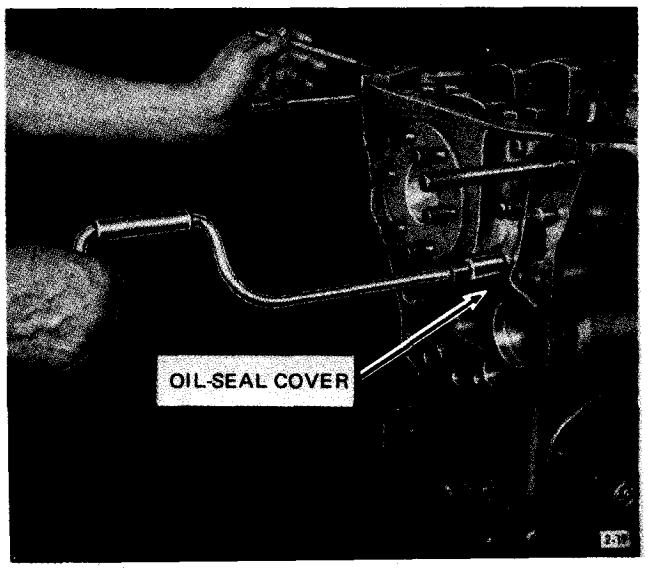


Fig. 16-1 View onto rear oil seal cover. *(Mack Trucks Canada Limited.)*

Installing Flywheel-housing Rear Cover Before you reinstall the same cover and/or flywheel housing, check all mounting surfaces and dowels for damage, nicks, and burrs. If present, remove them with a smooth file or oil stone. If the rear oil seal is located in the flywheel housing or cover, install it into its bore and install the auxiliary shaft seals, if used (see Unit 23, "Seals and Gaskets"). Lubricate the seal and the timing gears with clean engine oil. Install, when necessary, the O rings and/or gaskets which seal the cylinder block to the flywheel housing. If recommended by the manufacturer, apply a thin film of nonhardening sealant to both mounting surfaces. *(NOTE: A heavy flywheel housing should be lifted into position with a suitable hoist.)* To protect the rear seal as the flywheel housing is placed in position, push a seal sleeve over the crankshaft before installation. Install pilot stud bolts to the cylinder block to improve alignment and aid installation (Fig. 16-2).

Position the flywheel housing over the aligning bolts, onto the dowel pins, then onto the cylinder block. Some flywheel housings are secured with hex bolts of various sizes and lengths and may use flat washers, sealing washers, or lock washers under the

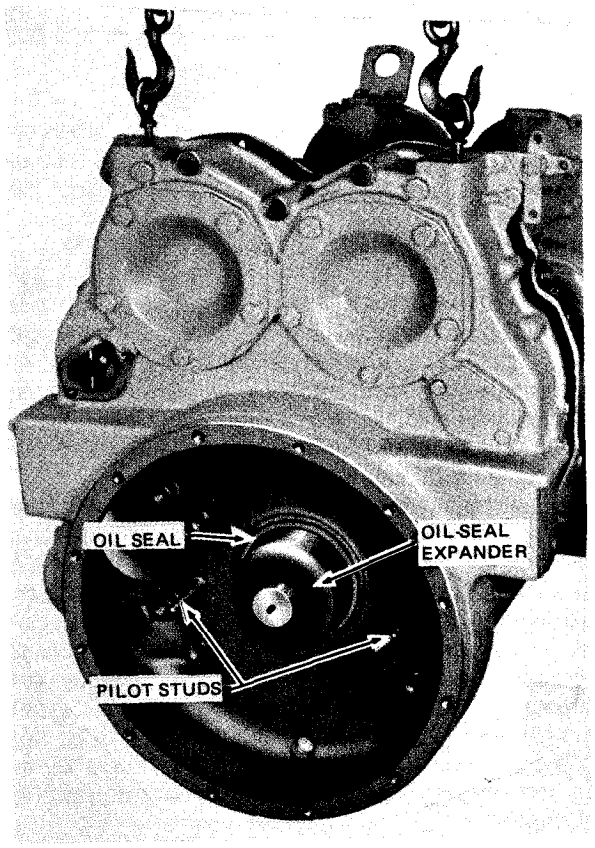


Fig. 16-2 Installing flywheel housing. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

bolts. Make certain that the flywheel-housing bolts and washers are not intermixed. Tighten the hex bolts in sequence and to the recommended torque.

When you install a new rear cover or flywheel housing, do not, at this point, install the rear oil seal, gasket, or dowels. Place the cover in position and merely hand-tighten the bolts because the cover or flywheel housing must first be aligned.

Aligning Rear Cover To align the rear cover, tap it gently until the lower flange is flush with the cylinder block. Then measure the cover bore alignment using a straightedge. When properly aligned, use an accurately ground drill to bore the recommended size holes, then use the correct size reamer to ensure dowel fit. Remove and clean the cover, then install the oil seal and gasket. Position the cover and install and finger-tighten all cover bolts. Drive the dowel pin into the reamed holes, and secure the oil-seal cover.

Aligning and Measuring Flywheel Housing When you install a new flywheel housing, you must position it to permit the axis of the crankshaft to be concentric with the flywheel-housing bore. To check the position of the flywheel housing, screw an indicator holder or place a magnetic base onto the crankshaft. Attach a dial gauge to it so that the pointer rests squarely on the surface of the bore (Fig. 16-3). Zero the dial, then turn the crankshaft one complete revolution. Record readings at 90° intervals. The reading at any point must not exceed an average concentricity (runout) tolerance of 0.005 in [0.12 mm]. Tap the housing into alignment and tighten the hex bolts.

Your next check should be the flywheel-housing face runout. To make this check, relocate the dial gauge so that the pointer rests against the flywheel-housing flange. Force the crankshaft forward to remove end play, then zero the dial. Turn the crankshaft one complete revolution, and record readings at 90° intervals. *(NOTE: Make sure the crankshaft is placed forward when taking the readings.)* The average allowable maximum face runout is about 0.010 in [0.25 mm].

When the face runout and the flywheel-housing bore concentricity are within specification, drill and ream new dowel pin holes. Remove and clean the flywheel housing. Install the rear oil seal, if applicable, and O rings (and gasket if used). Install the flywheel housing.

Inspecting and Servicing Flywheel Begin your inspection and service of the flywheel by checking all flywheel mounting surfaces for nicks, burrs, or scoring. Inspect all bores and threaded holes for damaged bores or pulled threads. Check the drive lugs of the intermediate clutch drive plates for wear and, using a square, check their alignment. Use a straightedge to check the clutch contact surface for straightness. Although score marks, grooves, and heat checks are always present to some extent, when the marks are too deep or the clutch surface is tapered beyond specification, the surface must be refaced.

To reface a flywheel, either special grinding machines are needed or a lathe and a special grinder

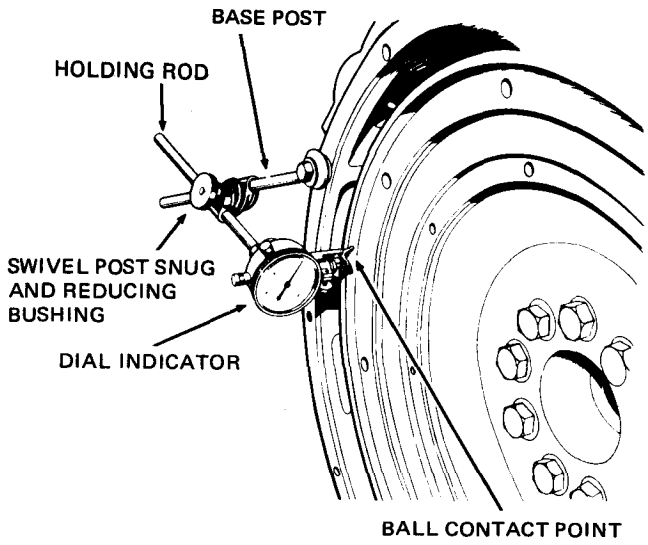


Fig. 16-3 Measuring flywheel housing bore runout. *(Caterpillar Tractor Co.)*

is required to maintain factory standards in regard to surface condition, dimension, and static balance.

Check the ring gear for worn, damaged, or broken teeth caused by incorrect starting procedure.

Replacing Ring Gear To replace a ring gear, use a blunt chisel to drive it evenly from the flywheel. Alternatively, heat the gear with a heating torch to expand it before driving it from the flywheel. Before you install a new ring gear, make certain that the gear and the cranking motor pinion correspond. Place the ring gear in an oven or use a heating torch to apply heat to its inner surface.

Check the applied heat with a special crayon (templet stick) that has a rating of 600°F [316°C]. This is done by touching the stick against the ring gear. When the applied heat reaches a temperature of 600°F [316°C], the crayon becomes soft and leaves a mark on the ring gear. At this point use two pairs of pliers and place the ring gear on the flywheel as quickly as possible. If necessary, tap the ring gear against the flywheel shoulder. *(NOTE: The chamfered edges should point toward the cranking motor.)*

Installing Flywheel Make sure that the flywheel and crankshaft flange are clean before installing the new dowels and two guide studs into the crankshaft flange. Lift the flywheel into position. Align the holes and place the flywheel on the guide stud. Place the lock plates (or wear plates, if used) into position and install the flywheel bolts. Tighten them in the correct sequence to the recommended torque. Crimp the lockplates to the bolt head or, when lockwire is used to secure the bolts, be sure to wire the bolts in pairs.

When a new crankshaft or a new flywheel is used, the flywheel pilot-bore runout must be checked and a measurement taken to determine if the flywheel housing and the flywheel face are parallel.

Measuring Flywheel Runout To check the flywheel face runout, place a magnetic base against the flywheel housing and position the dial gauge stem squarely against the flywheel face (Fig. 16-4). Force the crankshaft forward and zero the dial following the

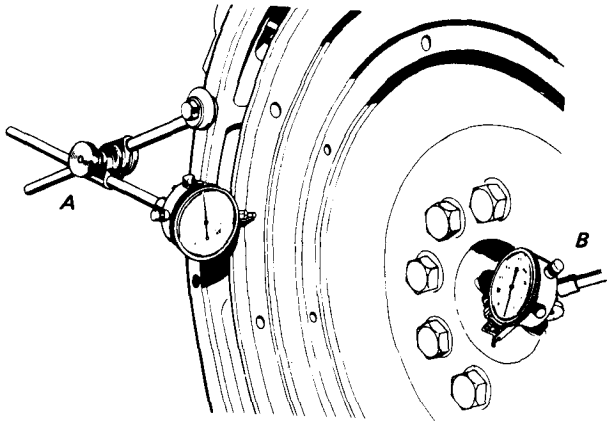


Fig. 16-4 Measuring flywheel face and bearing bore runout. *(Caterpillar Tractor Co.)*

measuring procedure previously outlined. The average maximum runout should not exceed 0.0005 in [0.0012 mm] for each 1-in [25.4-mm] radius. For example, when the pointer of the dial is 10 in [254 mm] from the center of the crankshaft, safe engine operation dictates that the maximum runout should not exceed more than 0.005 in [0.127 mm].

To check the pilot-bearing runout, relocate the dial gauge so that the stem rests squarely against the pilot-bearing bore. Check the runout, and if necessary force the flywheel into such a position that it will prevent the bore runout from exceeding 0.005 in [0.127 mm].

After the flywheel is aligned, drill and ream the flywheel and crankshaft flange. Do not fully ream the holes in the crankshaft flange; leave a small shoulder on which the dowels may rest.

Timing-gear Cover and Front Cover A timing-gear cover, or front cover, is one-piece cast iron, iron alloy, or aluminum casting, reinforced to withstand the stress placed on it. In addition to sealing the crankshaft, it covers the timing gears. It may become part of the oil-pan sealing and mounting surface, or it may also act as the front support or bearing for the engine mount. In addition it may serve as the mounting surface for the air compressor, air-conditioning pump, alternator, fuel-injection pump, hydraulic pump, or as the idler pulley for the fan-belt tensioner.

The correct time to install the front cover, front housing, or timing-gear cover is governed by the engine stand or the design of the cover itself. In any event, the cover should be installed as early as possible to prevent dust and dirt from accumulating on the exposed components.

Inspecting and Servicing Timing-gear Cover Clean the cover, remove the auxiliary seals, and scrape off all old gasket material from the sealing surfaces. You can then inspect the cover for cracks, damaged bolt holes, pulled threads, nicks, or burrs. Use a smooth cut file to restore the mounting surfaces and a bearing scraper or emery cloth to restore the bores. See the sections on installation procedure in Unit 23, "Seals and Gaskets."

Some manufacturers recommend installing crankshaft seals after the timing-gear cover has been installed and after the bore runout has been dialed in order to ensure proper bore concentricity.

Installing Timing-gear Cover From Fig. 16-5*a* you can see that the gear housing is an extension of the cylinder block and is attached thereto by bolts. The gear housing must be positioned, aligned, and bolted to the cylinder block before the camshaft, idler, and fuel pump gears, and the oil pump are installed. After the gears are installed and the backlash checked, lubricate the gears with engine oil, then install the gear cover (Fig. 16-5*b*). Install two or more guide studs, then place a seal protection sleeve over the crankshaft. Position the oil slinger, if one is used. Apply a nonhardening sealant to the front plate or to the side of the gasket facing the front plate.

When you position the gasket on the gear housing, make sure that the oil passages are not covered. Install shims if they are needed to adjust camshaft end clearance, or install the gear cover, then the shims and thrust plate, onto the cover. Measure the camshaft end play, remove or add shims to achieve the specified crankshaft end play, and then bolt the thrust plate to the gear cover.

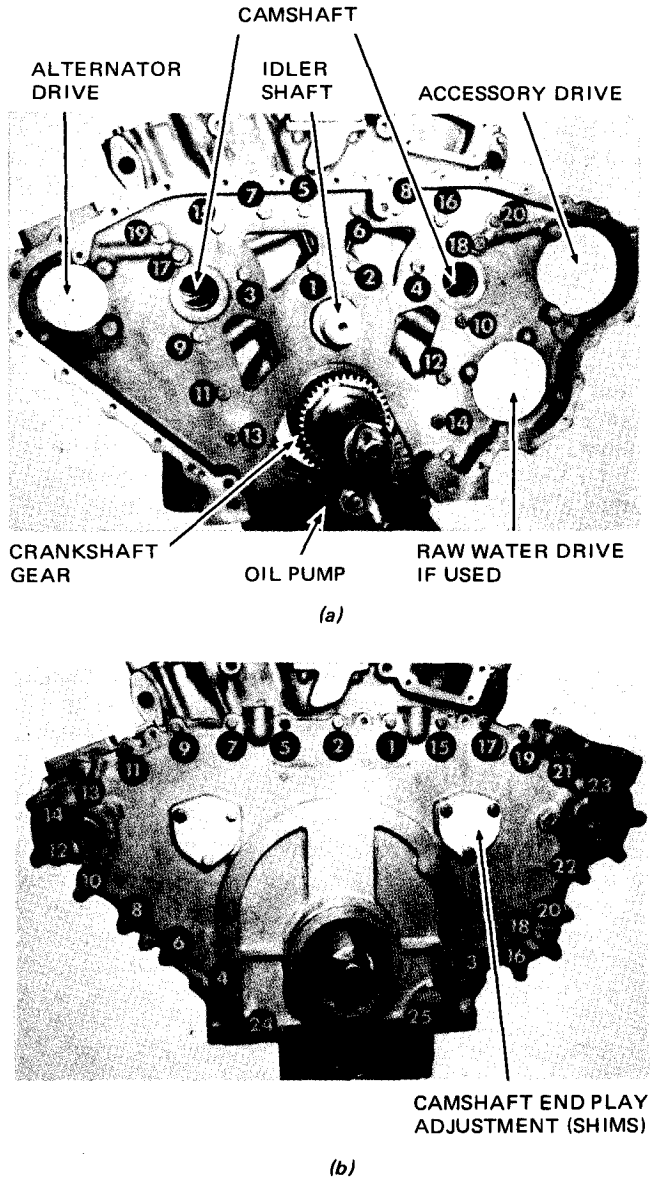


Fig. 16-5 *(a)* and *(b)* Views of gear housing and torque sequence. *(Cummins Engine Company, Inc.)*

Lift the gear cover into position, place it on the guide studs, and then place it on the dowels. Tap the cover into place, then install and tighten the cover bolts. If applicable, trim off any excess gasket material at the oil-pan mounting surface. The bottom surface of the cover must be flush with the cylinder block or within the specified limits, that is, within 0.004 in [0.101 mm].

When a new cover is installed, the dowels must be removed, the front seal bore must be aligned with the crankshaft, and the mounting surface of the oil pan and the cylinder block must be within specification. You may have to compromise alignment to achieve proper bore runout and to achieve tolerance between the cover surface and the cylinder-block surface. After the cover is aligned, the dowel holes must be drilled and reamed to retain cover position.

NOTE: Never enlarge dowel bores or file the dowels in order to force the cover to fit. After such modification, the cover bolts will not hold the cover in alignment. Oil will then leak at the joint where the oil pan and cover meet. It may also leak out of the front crankshaft seal.

After installation, do not forget to tighten the bolts in correct sequence to the torque specified.

Crankshaft Pulley and Hub A crankshaft pulley is one-piece cast iron or cast-iron alloy, cast with one or more pulley grooves, and has either a machined-tapered bore or a straight bore. Pulleys with a straight bore rest against the shoulder on the crankshaft or against the oil slinger and crankshaft timing gear. Keyways in the pulley bore and crankshaft accommodate keys which position the pulley to the crankshaft. Other designs have a straight or tapered pulley hub keyed to the crankshaft, to which the pulley and/or vibration damper is bolted. The machined outer surface on the crankshaft pulley or pulley hub provides the sealing surface of the front crankshaft oil seal when its hub extends into the front cover. In the latter case most of the pulleys or pulley hubs have a wear sleeve to prolong the pulley's service life. The vibration damper is bolted against a machined surface at the front or rear of the crankshaft pulley (Fig. 16-6).

Inspecting and Servicing Crankshaft Pulley Crankshaft pulleys rarely need to be replaced because of wear although they are often damaged because of improper installation, removal, or storage, or because of worn sheaves. Nevertheless, check the pulley bore and keyway for wear and burrs. Check the oil-seal contact area if applicable. Check the belt grooves very thoroughly. Be sure the side walls are straight and the surfaces are smooth.

To check the V-belt groove (sheave) for wear, place a new drive belt in the groove. There should be adequate clearance between the belt and the smaller diameter of the V groove (Fig. 16-6). If the new drive belt bottoms out, if the clearance is less than ⅛ in [3.175 mm], or if the sides are rough or dished out, the pulley must be replaced. Any of these defects will reduce friction and cause the drive belt to lose its driving power and also wear excessivley.

When the crankshaft pulley has a vibration damper bolted to it, check the flange surface and the threaded bolt holes. If the pulley or hub has a tapered bore, check the taper for sufficient contact, particularly if the pulley, hub, or crankshaft is new.

To check the pulley or hub fit, remove the oil from the crankshaft and the pulley bore. Remove any nicks and burrs and spread a light even coat of Prussian blue on the crankshaft taper. Push the pulley or hub straight onto the tapered crankshaft, rotate the pulley 45°, and then pull it straight off. The contact area, defined by a transfer of the Prussian blue, must be a full 360° and more than three-quarters of the tapered length.

Should there be insufficient contact, the pulley or hub must be lapped to the crankshaft. To do this, clean the shaft and pulley bore and apply a 300-grit lapping compound to the crankshaft taper.

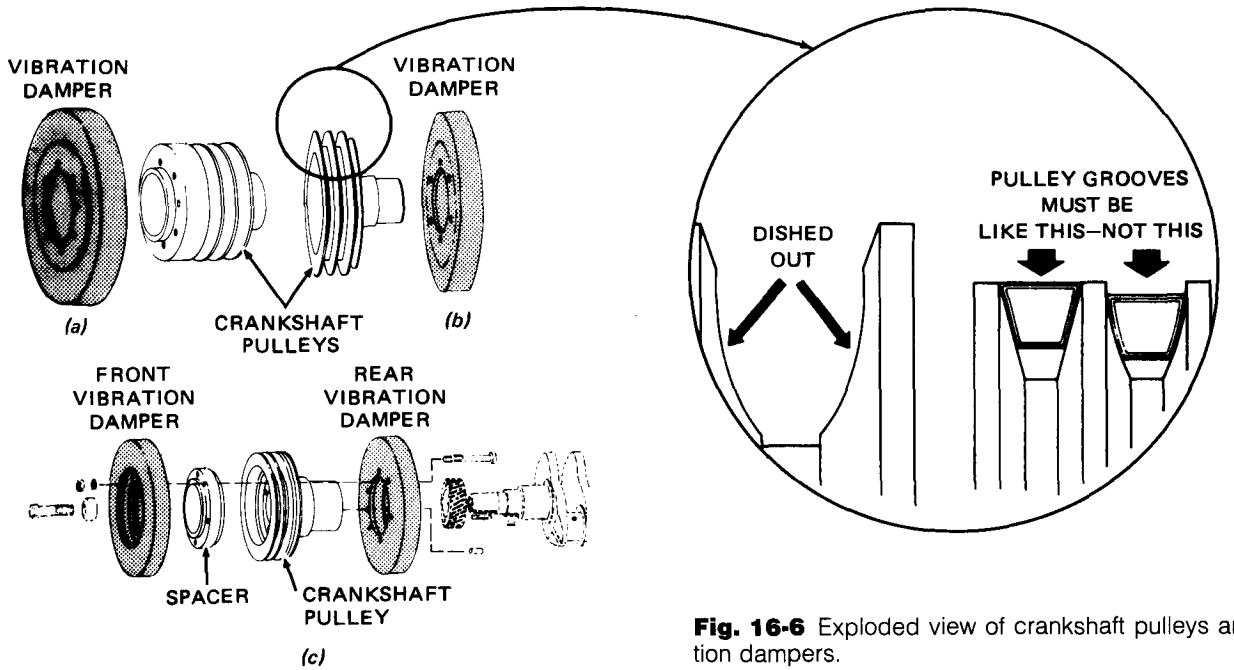


Fig. 16-6 Exploded view of crankshaft pulleys and vibration dampers.

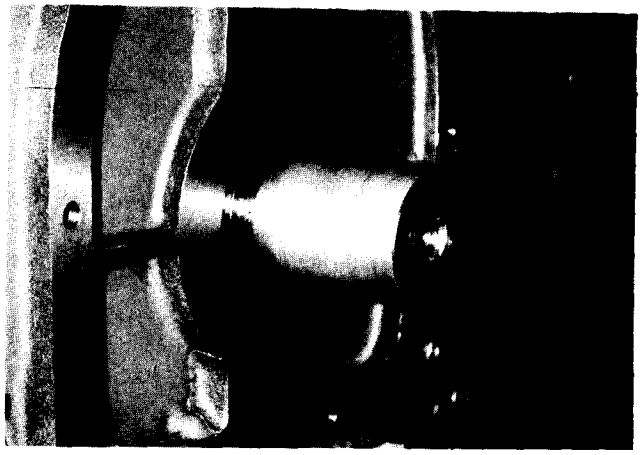


Fig. 16-7 Crankshaft-pulley seating surface after lapping. *(Cummins Engine Company, Inc.)*

CAUTION Do not allow the compound to come into contact with the lip of the oil seal.

Slide the pulley, or hub, onto the crankshaft taper so that it can be rotated about 90° each way. Although rough at the beginning, the lapping motion will smooth out after a few turns. To check lapping effectiveness, wipe off the compound; the surface finish should appear similar to that shown in Fig. 16-7. Whether or not it looks satisfactory, you should recheck the contact area by the Prussian-blue method.

Installing Crankshaft Pulley Remove evidence of lapping and bluing. Install a new key into the crankshaft keyway and slide the pulley onto the tapered end of the crankshaft. Use a soft-face hammer to guarantee seating. Place a heavy washer over the hex bolts and lubricate the threads before installing, then tighten the bolt to the recommended torque. *(NOTE: Some pulley retainer bolts have a self-locking device.)*

Pulleys with straight bores must be pressed rather than driven onto the shaft to prevent damage to the pulley and crankshaft thrust bearing.

To install the pulley shown in Fig. 16-6*a*, lubricate the crankshaft end, and then install the key and pulley. Position the retainer on the bolt and thread it into the front of the crankshaft. Torque the bolt to specification.

Inspecting Vibration Damper Before inspecting any damper, first remove dirt, grease, and corrosive residue. A rubber-element damper should be cleaned with ordinary household detergent and a viscous vibration damper should be cleaned with a suitable solvent cleaner.

When inspecting the rubber-element vibration damper, check the rubber element for deterioration. If it contains cracks deeper than 0.375 in [9.52 mm], it must be replaced. Check that the index mark on the mounting flange and the inertia weight are in alignment. If they are out of alignment more than 0.064 in [1.6 mm] this indicates that the rubber has lost its elasticity or has loosened from its bond. The damper must then be replaced. Check the mounting flanges and the bolt holes for cracks and elongation. Check the surface for straightness.

When you check a viscous damper, inspect it thoroughly for evidence of external damage. Even small indents make the damper unusable since they prevent the inertia mass from rotating. Check the mounting flanges as well as the bores. Check for pinholes, broken welds, or cracks by heating the damper in an oven 200°F [93.3°C]. When removed from the oven, no evidence of oil should be visible. *(NOTE: It is usual practice to replace a viscous damper whenever a major engine overhaul is performed.)*

Installing and Testing Vibration Damper Before you mount the vibration damper to the pulley flange, or to the hub, use a dial gauge to check the flange concentricity and runout (wobble). The average allowable runout is about 0.003 in [0.08 mm] and the eccentricity is about 0.004 in [0.10 mm]. The measurement should be taken at the outside radius and the outside diameter of the flange.

Before you install the damper, make sure that the mounting surfaces of the crankshaft and damper are clean. Then position the damper, install the hex bolts, and tighten them in three phases, in sequence, to the recommended torque. Then with a dial gauge, check the concentricity and runout (wobble) as shown in Fig. 16-8. *(NOTE: Keep the crankshaft at the front or rear against the crankshaft thrust bearing while making both checks.)*

When installing an assembly as shown in Fig. 16-8, bolt the vibration damper to the hub and torque the bolts to specification. Lubricate the oil seal and crankshaft. Slide the inner cone over the large diameter side of the crankshaft, snuggly against the oil slinger. Next, place the hub assembly onto the cone and the outer cone onto the smaller-diameter side of the crankshaft. Install the two keys, align the pulley keyways with the keys, and position them on the crankshaft. Pull the pulley onto the crankshaft and then remove the puller. Install the crankshaft bolt and

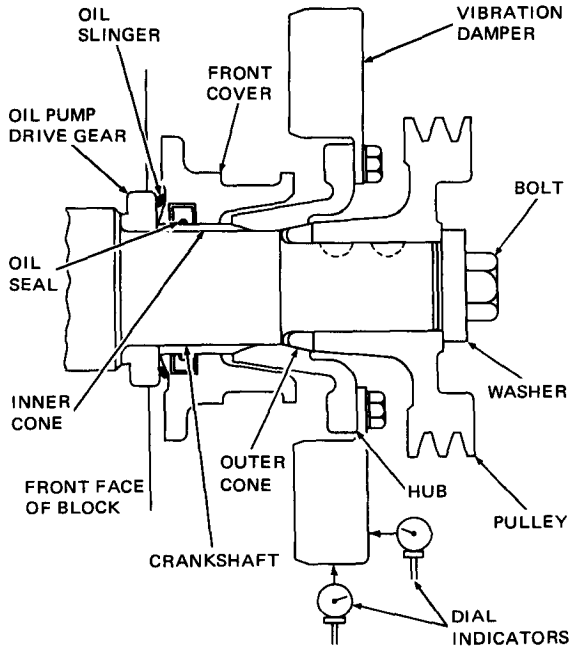


Fig. 16-8 Schematic view of crankshaft pulley, vibration damper, and dial indicator installed. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

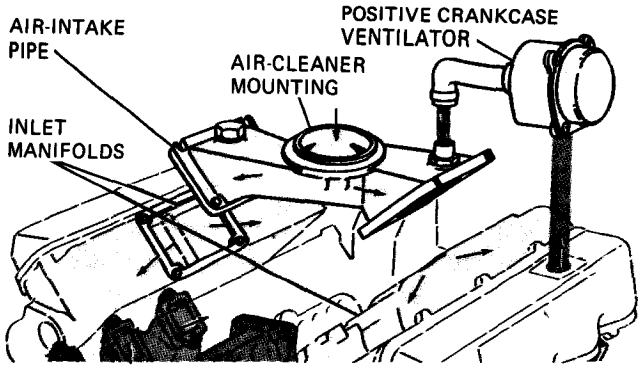


Fig. 16-9 Positive crankshaft ventilation. *(Caterpillar Tractor Co.)*

torque it to 180 ft·lb [224 N·m], or as specified, then strike the bolt with a 2-lb hammer and torque it to 300 ft·lb [407 N·m].

Crankcase Ventilation Diesel engines must (breathe) circulate air in a precise direction around the lubricated components in order to remove the harmful vapors. An inadequate ventilation system will reduce the service life of an engine as surely as will an inadequate air-intake system. An inadequate ventilation system will not permit the acid, the condensation, or the pressure to escape. This causes the oil to become slushy and lowers its quality. The oil temperature will then rise, and the seals and gaskets will leak.

Most diesel engines rely on air motion created by the fan blades (and/or the movement of the vehicle) to lower the pressure at the breather pipe. This causes atmospheric pressure to force air through a filter into the engine. The air circulates within the engine and leaves through the breather pipe.

V-type engines may use two ventilation systems, two breather pipes, and two filters. The typical locations for the air breathers (filters) are on the valve cover, on the timing-gear cover, and on the cylinder block.

Positive Crankcase Ventilation Because of the lower efficiency of the former system and the enforcement of pollution control, engine manufacturers have been persuaded to change the ventilation system to a positive crankcase system (Fig. 16-9). With this system, fumes from the engine are filtered before being drawn into the intake manifold. V-type engines have either two filters, or they use a crossover pipe.

NOTE: No control valve of any kind is required on a diesel engine because the diesel engine inhales air only, whereas a gas engine inhales a mixture of air and fuel.

Questions

1. What is the purpose of the rear oil-seal cover?
2. Why must the flywheel-housing bore and the face runout be within specified tolerance?
3. List the factors which determine the size and weight of a flywheel.
4. Describe how to install a new ring gear.
5. List the checks required to determine the serviceability of a flywheel.
6. What checks must be made after a new crankshaft or flywheel has been installed?
7. Give two reasons why a timing-gear cover or gearcase cover must be aligned with the center of the crankshaft and the cylinder block.
8. List the areas of damage (or wear) on a crankshaft pulley which will necessitate its replacement.
9. List the precautions you must take when installing a vibration damper.
10. What is the effective difference between a road draft (ventilation through vehicle movement) and a positive crankcase ventilation?

UNIT 17 • BEARINGS

Everything that turns requires a bearing (or bearings) to reduce friction between the moving and stationary parts, to reduce power loss, and to decrease wear. Many types of bearings have been designed in an effort to overcome friction and frictional heat.

Friction *Friction* is defined as the resistance to movement between any two surfaces which are in contact with each other. Friction is classified into three types: sliding friction, rolling friction, and fluid friction (see Fig. 17-1).

Bearing Types Bearings may be divided into two main types: friction bearings and antifriction bearings. Both types are used on diesel engines.

Friction bearings can be found in the engine or in its components. They are used to support the crankshaft, the connecting rod, the engine camshaft, or the fuel-injection pump camshaft, the rocker arms, and in some applications also the rocker-arm shaft, the idler gears or pulleys, the turbocharger shaft, the alternator rotor shaft, the starter armature shaft, and the oil-pump gears.

The use of antifriction bearings is limited. You may find them in such applications as the coolant fan and the belt tightener, in coolant pumps, fuel-injection pumps, governors, the flywheel pilot bearing, and in alternators.

FRICTION BEARINGS

The simplest type of friction bearing is a hole drilled into a support plate to guide the shaft. Friction bear-

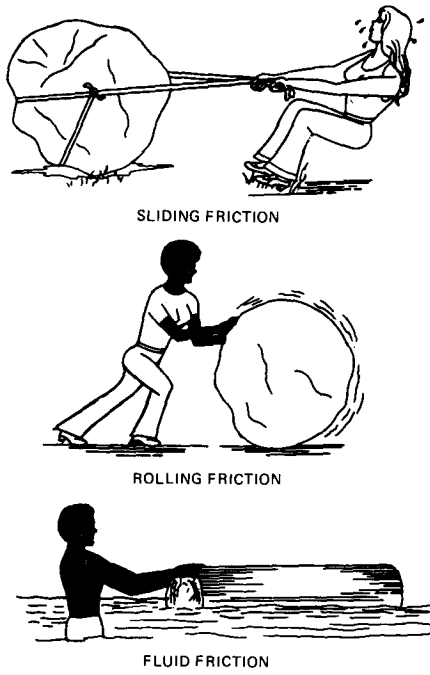


Fig. 17-1 Types of friction.

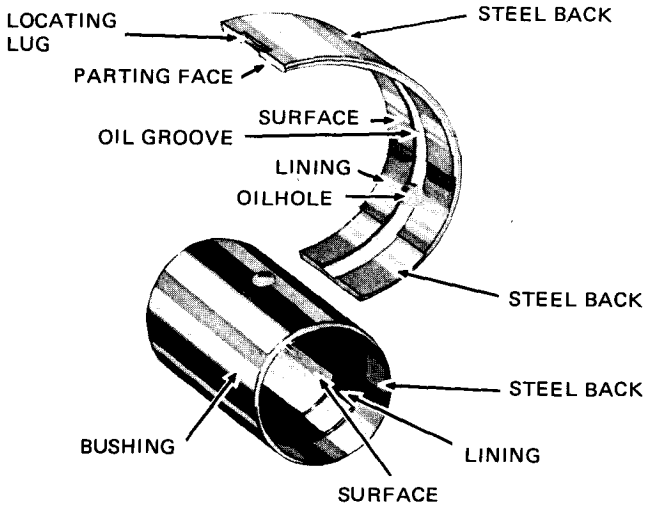


Fig. 17-2 Insert bearing. *(Cummins Engine Company, Inc.)*

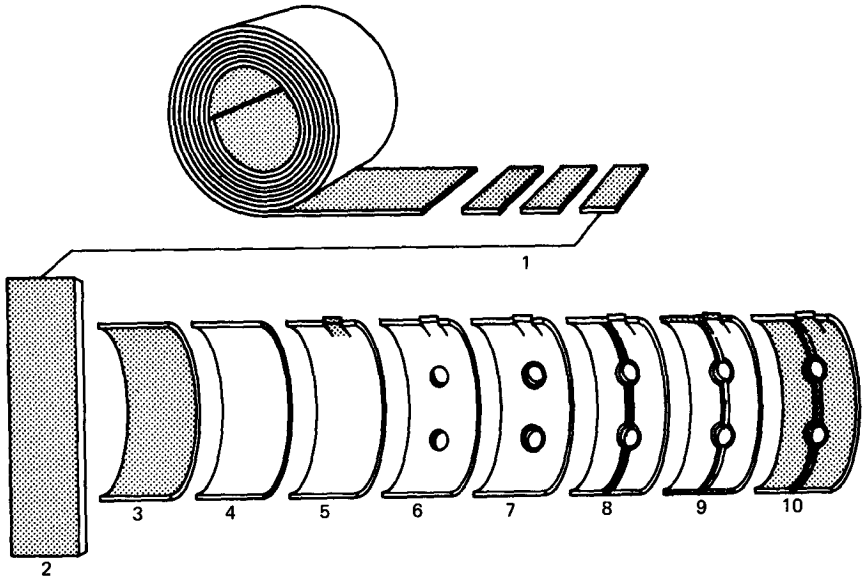


Fig. 17-3 Manufacturing steps of an insert bearing. *(Federal-Mogul Worldwide Marketing Group.)*

ings used on diesel engines and for the supporting components are called *insert bearings* (Fig. 17-2).

Friction Bearing Design and Construction

Bearing construction originates with a strip of steel to supply the strength for the bearing back. A softer lining is bonded to this steel strip. The softer metal is necessary to improve conformability and embeddability of the bearing. Figure 17-3 illustrates the manufacturing steps of a typical engine bearing:

1. Blanks cut
2. Facing attached to length (width)
3. Blank pressed into semicircular shape
4. Overplate added
5. Locking lip formed
6. Oilholes punched or drilled
7. Oilholes chamfered
8. Blank grooved and broached to height
9. Inside surface broached and overplated
10. Inside surface overplated

The most popular types of bearings produced are: (1) steel back with a bronze inner layer, and lead- or tin-based or indium overlay; (2) steel back and multiple copper-lead inner layers and thin lead-tin overlay; (3) steel back with a sintered copper-nickel inner layer and lead-alloy overlay; (4) steel back with a sintered copper-alloy inner layer, a barrier plate, a lead-alloy overplate, and overlay tin over the entire bearing; (5) steel back with a cast copper-alloy inner layer, a barrier plate, a lead-alloy overplate and lead alloy overlay over the entire bearing; (6) steel back with an aluminum-alloy lining, a lead-alloy overplate, and a tin overlay over the entire bearing; (7) steel back with a solid aluminum alloy and a flash tin plate over the entire bearing. *(NOTE: Most bearings use a thin layer of copper or nickel as the bonding agent between the overlay and inner layer.)*

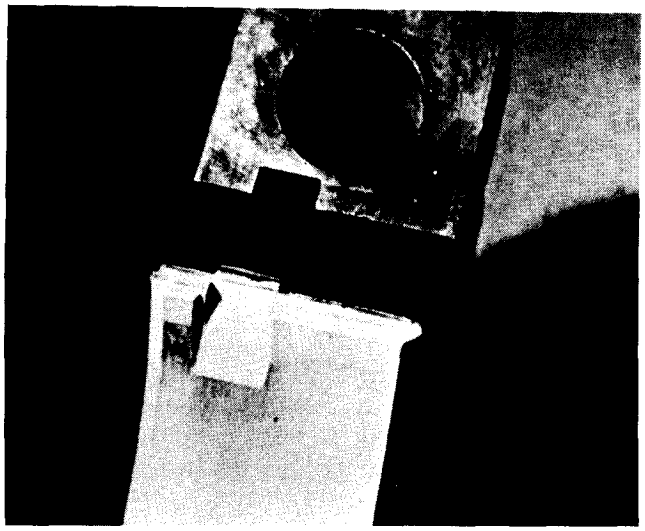


Fig. 17-4 Locating lug and slot.

Function of Friction Bearings To do its job properly, a friction bearing must be held firmly in place and in full contact with the supporting bore. It must hold and protect the shaft, withstand extreme pressure and heat, and absorb harmful grit. It must also have the ability to maintain a film of lubricant between moving and stationary parts.

The simplest and most common method of holding a bushing in position is to press it into its supporting bore. A locating lug (Fig. 17-4) or dowel is used to hold a half-bearing in place during the assembly. The lug fits tightly into the support slot and thus assures proper alignment and prevents the half-bearing from moving. A half-bearing is manufactured with a spread and is slightly larger than the bearing bore. This is to ensure a precise fit and full contact with the bore surface when the connecting-rod or main-bearing cap screws are torqued. The bearing spread by which the dimension is larger than its bore varies between 0.005 and 0.030 in [0.125 and 0.75 mm] depending on bearing design and size. The bearing crush may be as little as 0.00025 in [0.006 mm].

An insufficient crush or spread allows the bearing to move within its bore, reducing heat dissipation and causing excessive wear.

Bearing Requirements No metal by itself has the strength to withstand all the demands placed on bearings.

A bearing should have a *fatigue strength* (load-carrying capacity) to withstand loads without the metal flaking away or cracking on the surface or at the bond line.

A bearing should have *conformability* since no journal or bore is perfectly round or straight. The bearing must mold itself to this imperfection so that the load is evenly distributed over the total bearing surface. A soft metal overplate and/or tin overlay increases the conformability of the bearing.

A bearing should have *embedability,* that is, the bearing surface must be soft enough to absorb minute particles. This is an important feature since no filter is effective forever, and no service and maintenance procedure can completely guarantee that dirt particles can not enter the oil to score the journal and bearing.

A bearing should have *resistance to corrosion* because chemicals and water from combustion (or from other sources) enter the crankcase. The chemicals and water in the oil will attack the bearing metal if it is not resistant to them.

A bearing should have *resistance to seizure* because, under certain conditions, there is a metal-to-metal contact between the journal and the bearing. Materials used to prevent this type of failure are shown in Table 17-1.

A bearing should *conduct heat* to a high degree so that most of the heat will be conducted to the connecting rod or cylinder block. (A good bearing fit increases conductivity.)

A bearing should have a relatively high *high-temperature strength;* that is, its construction and composition must not weaken from heat.

A bearing must have *oil clearance* in order to lubricate properly, to cool, and to form a wedge to center the journal during rotation (see Fig. 17-5).

Bearing Action When the engine is stopped, the journal rests against the lower bearing shelf (Fig. 17-6). As the crankshaft is rotated (and oil is present in the oil clearance), the journal climbs the bearing and oil slides under the load area. The journal is

TABLE 17-1

BEARING MATERIALS AND PROPERTIES

Property	Back 100% steel	Lining 75% copper 25% lead	Overlay 90% lead 10% tin	Aluminum bearings 100% aluminum
Fatigue strength	High	Medium	Low	High
Conformability	Low	Medium	High	Medium
Embedability	Low	Medium	High	Low
Corrosion resistance	High	Medium	High	High
Friction reduction	Low	Medium	High	Low
Heat resistance	High	Medium	Low	High

SOURCE: Cummins Engine Co., Inc.

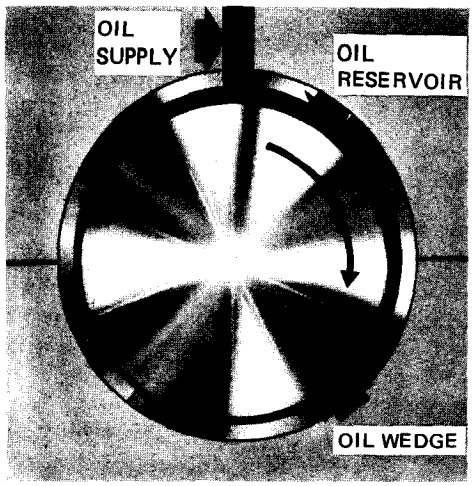


Fig. 17-5 Shaft rotation plus a load forms an oil wedge. *(Federal-Mogul Worldwide Marketing Group.)*

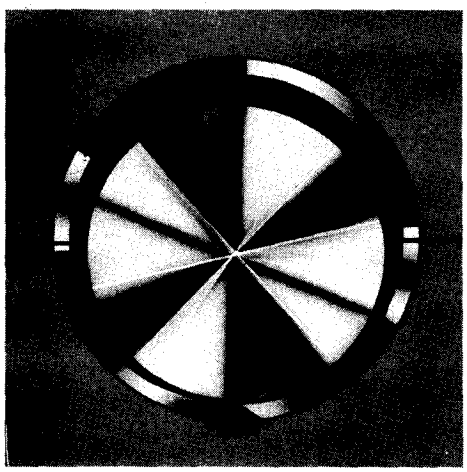


Fig. 17-6 Stationary shaft rests on the bearing. *(Federal-Mogul Worldwide Marketing Group.)*

lifted, or the connecting-rod bearing is moved away from the journal, by the wedge formed from the oil molecules. Some oil molecules tend to stick to the journal and bearings. The oil molecules attached to the journal rotate with it while those on the bearing are somewhat stationary.

The slippage of the oil molecules past each other is known as *fluid friction*. However, the oil film thickness between the journal and the bearing is not always the same. The bearing load during the four strokes, the speed, and the load changes vary the film thickness. Under extreme load conditions only the oil that sticks to the journals and bearing area remains, permitting a metal-to-metal contact which could lead to seizure.

Oil Grooves and Oilholes Oilholes are not required in all bearings. Oil grooves are usually only in the lower half of the bearing. They are used to distribute oil over the total journal and bearing area. In some applications an additional oil groove is used to direct oil to other bearings or to supply oil to other components within the engine.

Main and Connecting-rod Bearing Evaluation

Very reliable evidence can be gained from examining the main bearings, the connecting-rod bearings, and the journals. The extent of their deterioration gives evidence of the engine condition as a whole.

The cause of excessive bearing wear may be divided into four major groups: dirt failure (45 percent), lubricant and allied failures (25 percent), operation and installation failures (15 percent), and surface-reaction failures (15 percent).

Normal Bearing Wear Before you can diagnose abnormal wear, you must first understand what is considered to be normal wear. Most bearing wear that occurs during the first few hours of operation is minimal and accepted as "normal." The bearing shown in Fig. 17-7 was taken from a truck engine which was operated for 4500 hours. It shows normal wear. Under normal usage some of the thin lead-tin overlay surface wears off, exposing the lining (copper, nickel, or aluminum). The pattern of wear is concentrated toward the center of the bearing because of its larger bearing diameter compared to the diameter of the journal. When motortruck or crawler engine bearings show this wear within less than 2000 hours or 100,000 miles (mi) [160,930 km] of operation, the wear is considered to be abnormal, suggesting that abrasives have entered the oil. Check for the following: poor air filtration, intake manifold leakage, poor lubrication filtration, overfueling, or restricted engine breathing. Fine abrasives may also enter the oil during the engine rebuilding period or through carelessness while making oil and filter changes.

As previously mentioned, most bearing failures are due to foreign matter (plain old dirt) passing between the journals and bearings. This also applies, of course, to other operating components. Depending on the type of foreign matter in the lubricant, the journals, bearings, and components may become scratched, pitted, or discolored, etc.

How to Prevent Dirt From Contaminating Lubricant

1. To begin with, your work area and tools must be clean.

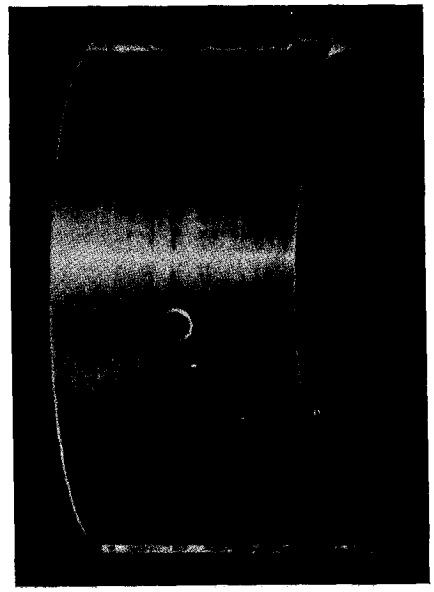


Fig. 17-7 Normal friction-bearing wear after long use. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

2. Before assembling the engine, make sure that all components and bores are immaculately clean. When the engine is not being worked on, cover it with plastic sheets to keep out any fine dust.
3. Keep all oil storage containers and measuring equipment clean.
4. Follow the manufacturer's recommended procedure when making oil and filter changes.
5. Avoid excessive delay between oil filter changes because this may cause the filter to become plugged and cause the bypass valve to open.
6. When adding oil, wipe the area around the dipstick clean before reinserting.
7. Service the air breather regularly.
8. Remember that the entry of even a small amount of dirt into the lubricant will create extensive damage at a later date.

Bearing Failure due to Coarse Particles in Oil
Coarse particles may originate as residue from moving engine components, from improper handling of lubricant or oil filters, or from incomplete removal of honing or boring abrasives.

The bearing shell shown in Fig. 17-8 will fail completely because of the long deep scratches which decrease the efficiency of lubricant and heat dissipation. The visible particles have displaced metal (aluminum) and have added to the abrasion, causing heat to build up and melt the lead surface. However, if the bearings show fine scratches and the consequence of embedded particles, but nevertheless the bearing surface is smooth and reformed, it can be reused.

Bearing Failure due to Improper Contact between Bearing Shell and Bore Particles, whether large or small, left between the back of the bearing shell and the bore during assembly will prevent the bearing from seating properly (see Fig. 17-9). This causes decreased clearance, localized heating, and excessive wear of those parts of the bearings and journals which are above the embedded particles. Excessively large embedded particles will destroy the bearings and journals altogether. This is especially true when the embedded particles are in the load area.

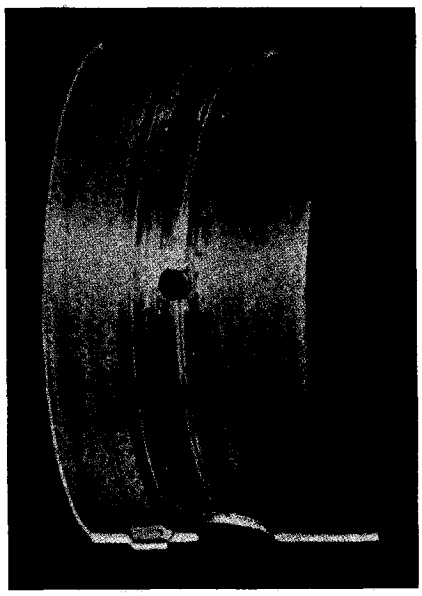


Fig. 17-8 Damage caused by coarse particles. *(Cummins Engine Company, Inc.)*



Fig. 17-9 Damage caused by immobile dirt particles. *(Cummins Engine Company, Inc.)*

The improperly positioned bearing shell shown in Fig. 17-10 was only in operation for 2 hours. It will fail because of the misaligned oil-supply hole. It could also cause the bearing shells to seize and rotate in the crankpin bore.

Bearing shells which are loose because of improper torque are inadequately crushed and cause the bearings to become out-of-round. This increases friction and does not allow sufficient heat dissipation. The affected bearing and journal often are destroyed whereas the other bearings show normal wear (Fig. 17-11).

The back of a bearing which is loose in its bore has a shiny appearance or shows fretting and sometimes also shows wear at the mating surface of the shells. Fretting is a transfer of metal from the steel back to the bearing bore. When the shells are extremely loose, a metal transfer from the shell back to the bore surface may take place. Looseness of bearing shells may also result in an out-of-round or enlarged main or connecting-rod bore, or bores distorted from engine overloading.

A misassembled connecting rod is shown in Fig. 17-12. Once again this bearing may not have the proper crush and may also misalign. As a result, the bearing could break at the oilhole, damaging the

locating tang area. In extreme cases, the shell assembly spins in the crankpin bore.

Bearing Failure due to Overspeeding and Long Idle Period The diesel engine mechanic has no control over bearing failure caused by overspeeding and long idle periods. The mechanic does, however, have control of overspeeding when the governor is misadjusted, the fuel cutoff is set too high, or when the fuel-injection pump is improperly adjusted (overfueling).

The bearing shell shown in Fig. 17-13 was damaged by overspeeding. The increased bearing load decreased the oil film and allowed a metal-to-metal contact between the shell and the journal. You will also find, when confronted with an overspeed bearing failure, that the lower half of the connecting rod and the upper half of the main bearing are more noticeably worn.

Bearing failure because of prolonged engine idle period is now uncommon because today's operators are careful to keep the engine rpm above idle speed. Nevertheless, it is possible for the bearings to fail when the engine temperature drops below operating temperature and when unburned fuel has diluted the lubricant, thereby reducing its viscosity.

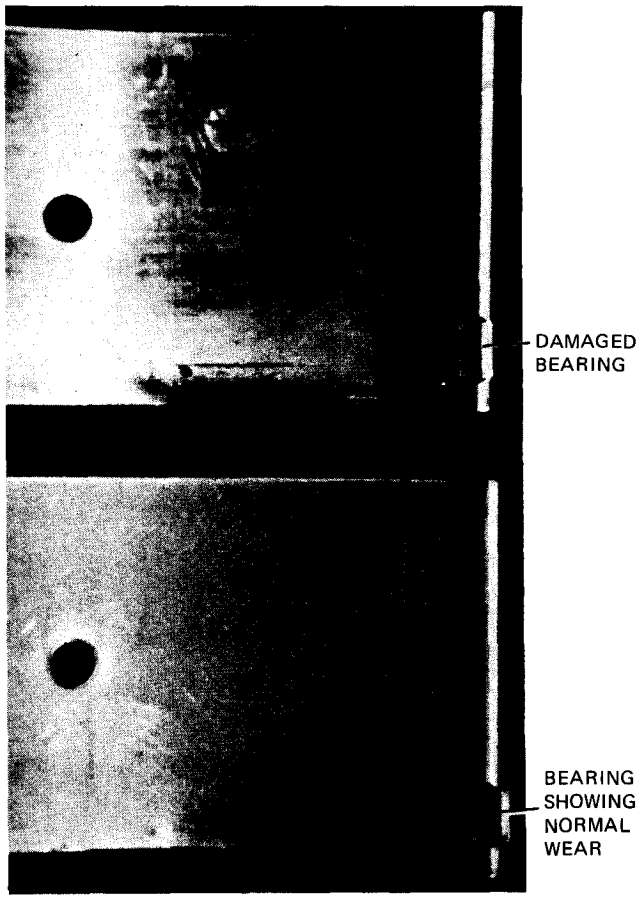


Fig. 17-10 Damage caused by improper installation. *(Cummins Engine Company, Inc.)*

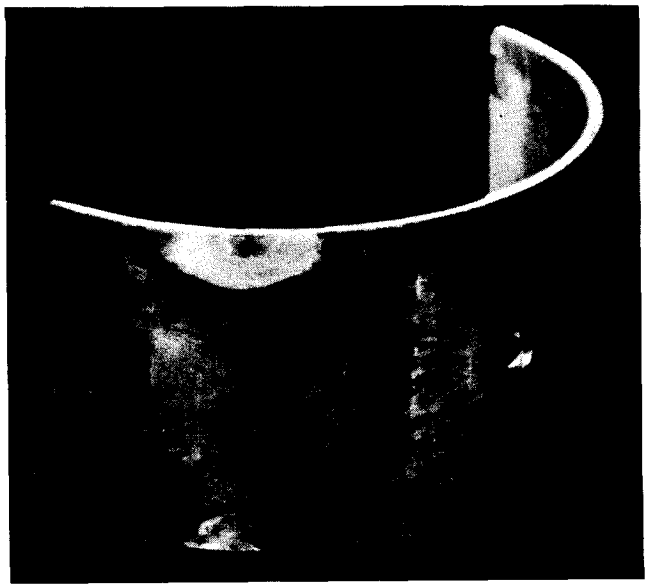


Fig. 17-11 Damage caused by improper torque. *(Cummins Engine Company, Inc.)*

Bearing Failure due to Improper Starting Normally, sufficient residual lubrication is retained in the bearings during a short period of cranking and during idling speeds. It takes about 15 to 30 seconds after starting the engine, before the oil flow causes pressure in the lubrication system to rise to main pressure. If, during this interval, the engine speed is increased above 1000 rpm, the bearings may be without lubrication. This high surface speed, lack of lubrication, and load on the bearings wipe away the bearing overlay and gradually scratches become noticeable. If this starting procedure is continued, the connecting-rod bearing will deteriorate and fail.

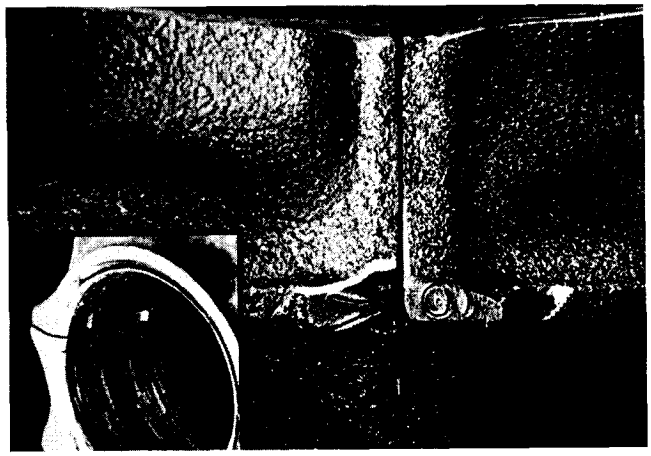


Fig. 17-12 Misassembled connecting rod. *(Cummins Engine Company, Inc.)*

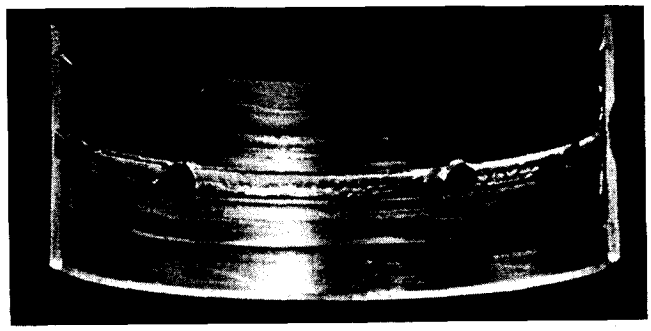


Fig. 17-13 Damage caused by overspeeding. *(Cummins Engine Company, Inc.)*

(NOTE: If the engine has not operated for several days, be sure to crank the engine with the injection pump in the shutoff position, until oil pressure is indicated on the gauge.)

Bearing Failure due to Cold Starting This type of bearing failure usually is restricted to areas where the ambient temperature goes below 20°F [6.6°C]. Low ambient temperature reduces the amount of residual lubricant and oil supplied to the bearings at engine start-up. The bearing furthest away from the oil supply will deteriorate radically whereas the one closest to the oil supply may have little or no wear. Consequently, when the ambient temperature is low, the engine should not be run at full speed or under full load, until the engine temperature has reached operating temperature; otherwise, the bearings will be damaged (see Fig. 17-14). During cold weather it is imperative to follow the manufacturer's recommendations as to the oil viscosity and the starting procedure.

Bearing Failure due to Lack of Lubrication Many conditions can lead to oil starvation of the bearings or running components. The damage caused can vary from light wear to total destruction of all bearings (Fig. 17-15). Some bearing failures which are due to insufficient lubrication can be prevented by a good maintenance program such as: maintaining the oil level, repairing excessive oil leaks, changing oil filters, reducing the period between oil and filter changes, and shutting the engine down only after it has cooled.

Bearing failure due to poor maintenance is rare today because of the extensive training programs attended by both diesel mechanics and operators. Nevertheless, there are some causes of bearing failure which are not easily discernible before the bearings are irreparably damaged. These are: plugged oil pump screens, excessively worn or damaged oil pump or relief valve, and a broken or loose oil-supply line.

If it appears that only one bearing is damaged, check the supply hole or the line; either one can become plugged or restricted. To make a complete analysis of the damage, however, you should examine all bearings and journals and compare their wear, and the wear rate of the lower and upper shells.

When starting the engine initially, do not forget to pressurize the lubrication system before testing the engine on the dynanometer. This also applies to factory-new engines. Neglecting to take this step can lead to early bearing failure if the lubricant from the bearing drains into the oil pan.

Bearing Failure due to Coolant in Lubricant The source of a coolant leak into the oil is sometimes hard to locate since the leakage can come from damaged head gaskets, seal failure at the cylinder sleeves, oil cooler damage, improperly installed injector tubes, improper torque, or damaged gasket and seat of the precombustion chamber. Of a more serious nature is the coolant leakage into the lubrication system through cracked cylinder heads or a cracked cylinder block.

The bearing shown in Fig. 17-16 failed because the

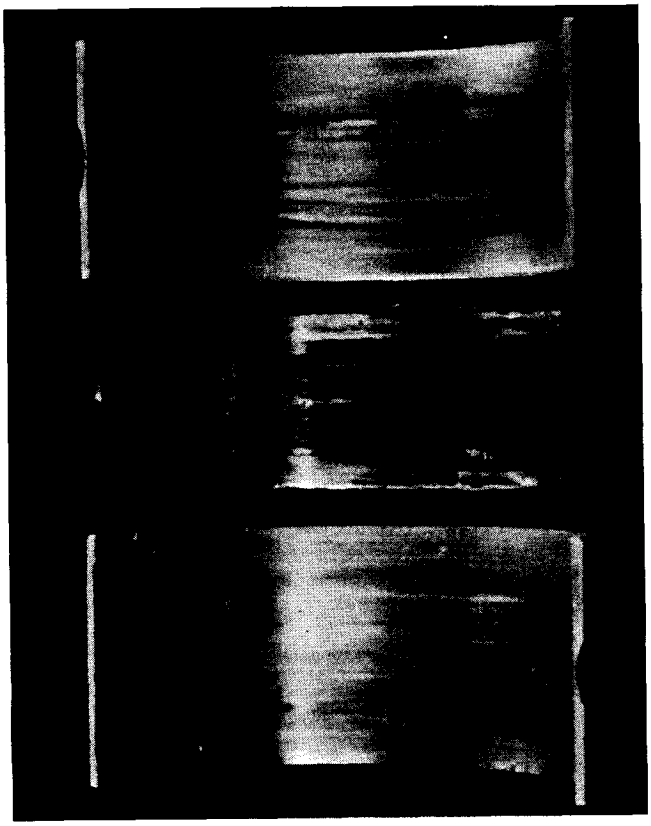


Fig. 17-14 Damage caused by a cold start. *(Cummins Engine Company, Inc.)*

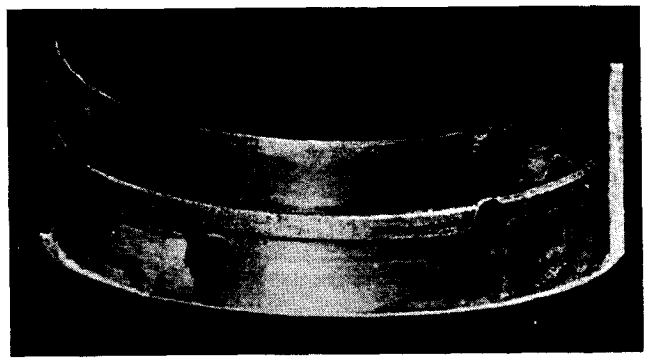


Fig. 17-15 Damage caused by a lack of lubrication. *(Cummins Engine Company, Inc.)*

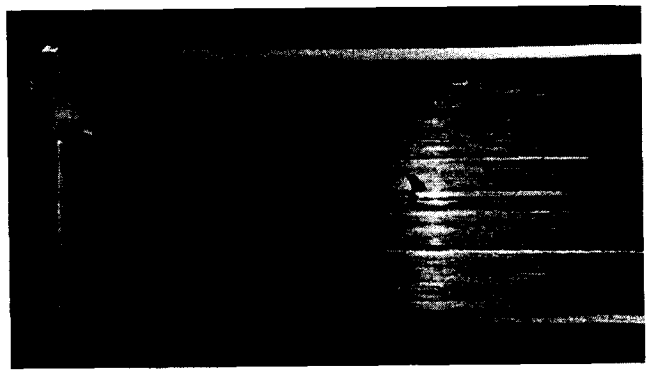


Fig. 17-16 Damage caused by coolant in the lubricant. *(Cummins Engine Company, Inc.)*

coolant entered the lubrication system and mixed with the lubricant. As a result, some of the surface was destroyed and the remaining overlay surface became discolored. Whether the discoloration is black or brown depends on the type of corrosion resistor used. When the lubricant is extremely diluted, the bearing shells become flaked or pitted.

When lubricant becomes grey or milky colored, it could be contaminated with coolant. Ethylene glycol or antifreeze in the lubricant forms a gummy substance. If, after checking the coolant level, you suspect that there is coolant in the oil, do *not* start the engine. Remove the oil plug and check for its presence. Do not judge too hastily! What may first appear to be coolant in the lubricating oil may be water condensation due to temperature changes of the oil and the engine or due to the engine being operated at an excessively low temperature.

Bearing Failure due to Fuel-Diluting Lubricant Some engines because of their fuel-injection systems are more vulnerable to fuel leakage than others. Generally speaking, fuel in the lubrication system is not common. However, it may enter the lubrication system through a worn seal in the fuel-transfer pump or fuel-injection pump, or through a leaking nozzle, or damaged injector O-ring seal (Cummins) or fuel-supply line (GM).

Incomplete combustion caused by worn rings, leaking valves, restricted air intake, worn turbocharger, or worn blower is the most common cause of fuel entering and diluting the lubricating oil. Incomplete combustion (overfueling) can also be due to incorrect adjustment of the injection pump, a damaged or incorrectly adjusted aneroid control or fuel ratio control, or to prolonged idling at low ambient and engine temperatures.

A bearing shell damaged because fuel was in the lubrication system is shown in Fig. 17-17. You can see the surface wear in the illustration, and when you find a bearing shell with this type of damage, you will notice a dark green hue where pitting is evident. Pitting becomes even more pronounced when combustion byproducts of high-sulfur-content fuel have passed by the piston ring into the lubricant.

Bearing Failure due to Off-side Wear When one side of a bearing is excessively worn, it is wise to examine the entire bearing set. The other bearings in the set may be damaged or may have metal embedded in their shells since the abraded material will circulate through the lubrication system.

Figure 17-18 shows a bearing worn on the off-side. This may be the result of a bent connecting rod, and out-of-round journal, a misaligned bearing cap, an improperly installed bearing shell, or a loose bearing cap. If, however, it is only the rear main-bearing shell that is worn and none of the other bearings, then the problem is likely to be an out-of-balance flywheel, or the engine lugging down at low speed and causing low-speed bucking.

When the whole set of main bearings, and perhaps also the connecting-rod bearings show off-side wear (Fig. 17-19), the problem is obviously more serious and more expensive to repair. Such wear could result from a sagging (warped) cylinder block, excessive engine vibration, (loose engine) mounts misfiring, vibration from the power train, or a damaged or inadequate viscous damper or rubber vibration damper.

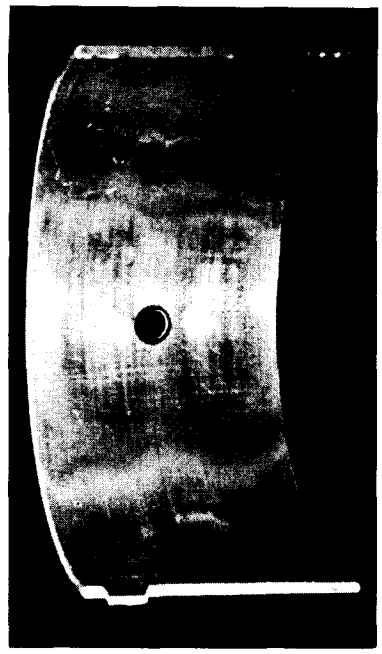


Fig. 17-17 Damage caused by fuel in the lubrication system. *(Cummins Engine Company, Inc.)*



Fig. 17-18 Damage caused by off-side wear. *(Cummins Engine Company, Inc.)*

Surface-reaction Failures

ELECTRIC CURRENT Bearing damage caused by electric current (electrolysis) will show small pits in a defined pattern and/or surface fluting (Fig. 17-20). The pattern or the fluting (when present) may vary

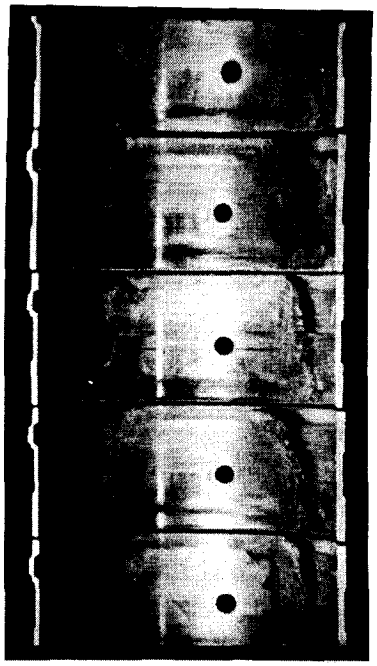


Fig. 17-19 Damage to whole set caused by off-side wear. *(Cummins Engine Company, Inc.)*

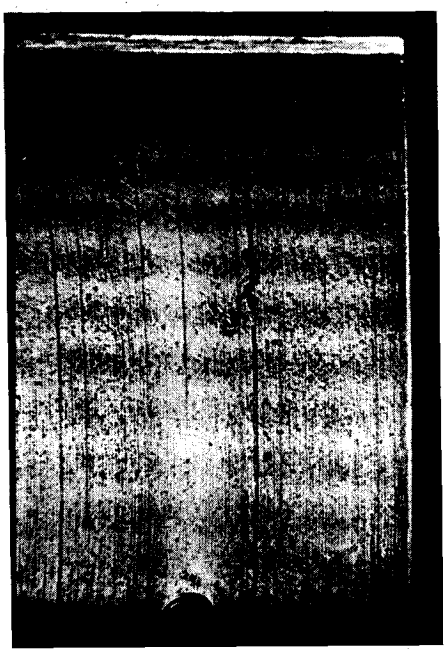


Fig. 17-20 Damage caused by electric current (electrolysis). *(Cummins Engine Company, Inc.)*

from engine to engine because of the differences in the current sources and the attacked metal.

Damage to bearings due to electric current may originate from the electrically actuated components such as motors, switches, relays, etc. Inadequate grounding of the engine to the frame or static current from rotating parts may also damage the bearings.

To prevent bearing damage from electric current, make certain that all the electrical components and the engine are grounded properly to the frame.

Bearing failures have occurred when large areas of the bearing surfaces have disintegrated as a result of static current because the engine was not used over the cold winter months and was not winterized.

CHEMICAL CORROSION Another type of surface reaction is chemical corrosion (Fig. 17-21). The pitting, discoloration, surface roughness, and fatigue cracks are caused by gaseous chemicals in the air. This problem can be solved by using special air cleaners. Standard air cleaners do not filter out chemicals.

CAVITATION CORROSION Cavitation in the oil film causes localized spalling or erosion of the unloaded bearing shell (the upper main and lowering connecting-rod bearing) (Fig. 17-22). Cavitation damage occurs only on the surface layer and it does not affect the copper, bronze, or aluminum lining. Since this type of failure is caused by aeration of the lubricating oil, check the inlet side of the lubrication pump for loose connections through which air could enter.

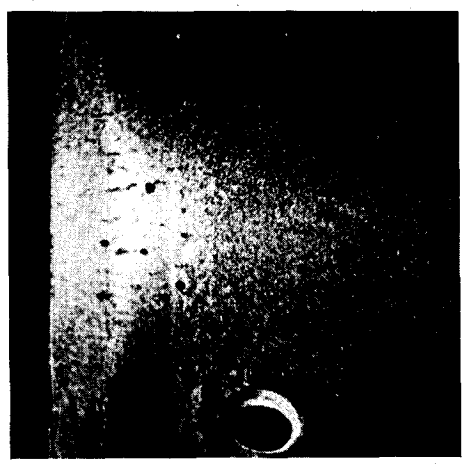


Fig. 17-21 Damage caused by chemical corrosion. *(Cummins Engine Company, Inc.)*

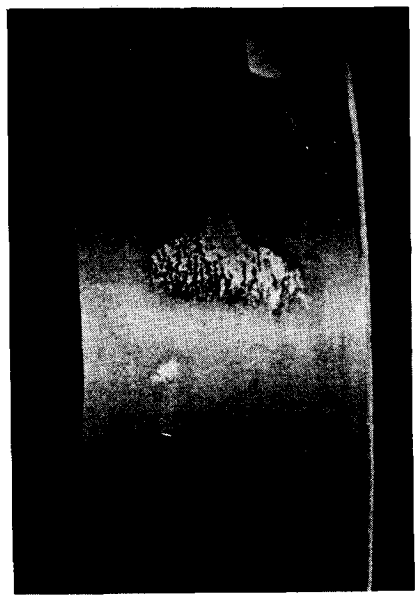


Fig. 17-22 Damage caused by cavitation or corrosion. *(Cummins Engine Company, Inc.)*

Working on the side of a hill when the oil pan is not specifically designed for this terrain can also cause cavitation corrosion.

Thrust-Bearing Failure The crankshaft thrust bearings have the same overlay and are made from the same material as the other engine bearings. As a general rule, thrust bearings, thrust washers, or the thrust surface of the crankshaft are not serious failure areas. Only when the end play is incorrect, when the operator rides the clutch, or the air or hydraulically actuated clutch is not adjusted properly will difficulties arise.

ANTIFRICTION BEARINGS

All antifriction bearings use a rolling element (balls, rollers, or needles) between the inner and outer rings (races) to convert sliding friction into rolling motion. Either the inner or the outer ring remains stationary.

Because of the small contact area between the rolling elements and the inner and outer rings (races) and in order to withstand the high compression stress, the material used for ball bearings is usually of heat-treated chromium-alloy steel and the material for most roller bearings is usually carbonized steel alloy.

The load placed on the bearing can be perpendicular to the shaft and axis of the bearing (radial load), parallel with the axis of the shaft and bearing (thrust load), or a combination of radial and thrust loads (Fig. 17-23).

The radial load is carried by only half of the rolling elements by compressing the inner ring against the rolling element, to the outer ring or vice versa. However, the thrust load is carried equally by all of the rolling elements.

Types of Antifriction Bearings Antifriction bearings may be classified into six types: (1) ball bearings, (2) cylindrical roller bearings, (3) needle bearings, (4) tapered roller bearings, (5) self-aligning roller bearings, and (6) thrust bearings. However, each type is coded further according to its individual application.

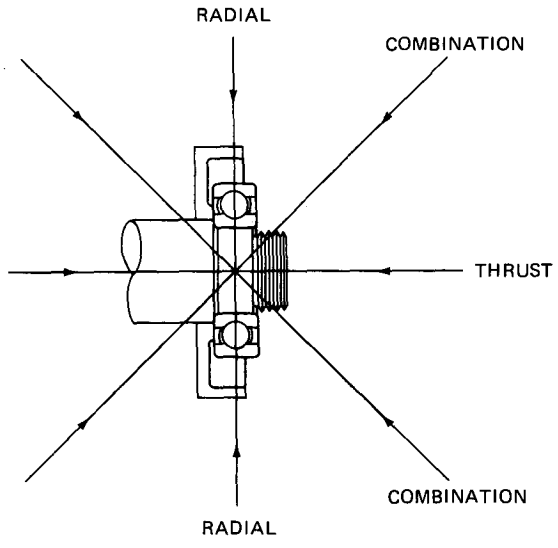


Fig. 17-23 Schematic view of an antifriction bearing showing types of loads.

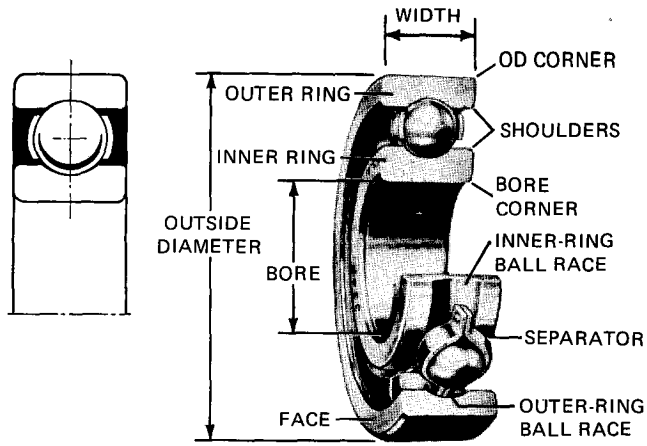


Fig. 17-24 Single-row deep-groove ball bearing. *(International Harvester Company.)*

Bearing Identification Code Ball bearings and roller bearings are identified by a numerical code which indicates the bore in millimeters or in sixteenths of an inch. Letter codes indicate the type of bearing, the outside diameter (OD), the width, the cage, the seal or shield, the modification, and the required lubricant. The internal fit, the tolerance, and any special characteristics are coded by number.

Ball Bearings A single-row deep-groove (no-loading) ball bearing is shown in Fig. 17-24. Each race has a single, deep, high supporting groove in which the balls are located. The high support and the close fit allow the bearing to take a very high radial load. Because the load is through the axis of the balls, it can also withstand a substantial thrust load.

NOTE: Since little or no movement exists between the inner and outer races, careful installation and alignment between the shaft and the housing is necessary.

A single-row loading-groove ball bearing is shown in Fig. 17-25. It is so named because the balls are inserted through a filling groove or loading groove. This type of bearing has a higher radial load capacity than the bearing shown in Fig. 17-24 because more balls can be inserted.

NOTE: Where thrust load may be a factor, this type of bearing should be installed with the loading groove facing toward the thrust side.

SNAP-RING BEARINGS A snap ring placed in the groove of the outer ring is used to provide a shoulder for the axial location of the bearing in the bore.

SHIELD BEARINGS A shield or plate on one or both sides of this type of bearing (Fig. 17-26*a*) limits the entrance of small particles between races and balls and at the same time reduces the pressure and flow of oil through the balls.

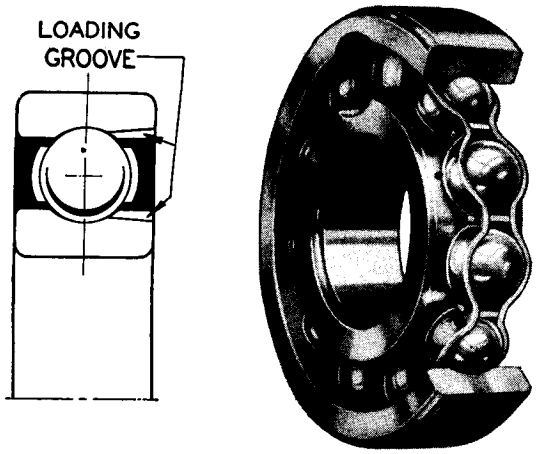


Fig. 17-25 Single-row loading-groove ball bearing. *(International Harvester Company.)*

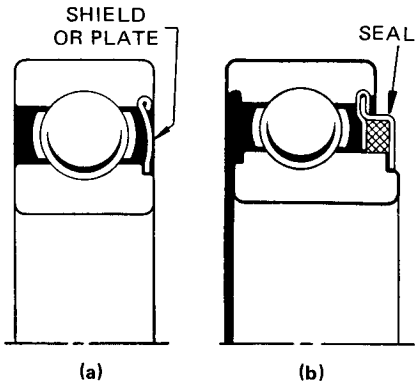


Fig. 17-26 *(a)* Shield bearing and *(b)* sealed bearing. *(International Harvester Company.)*

NOTE: Extreme care and cleanliness must be exercised during the handling and cleaning of this type of bearing. Do not damage the shield during removal or installation; it may contact the bearing separator and cause wear or increased friction.

SEALED BEARINGS These bearings have a permanent seal either on one side or on both sides (Fig. 17-26*b*). Bearings having a seal on both sides are prelubricated and cannot be cleaned. When their seals are damaged or the bearing feels rough during rotation, they must be replaced.

NOTE: When you install or remove these bearings, be extremely careful not to damage the seals.

Where only one seal is used, take care that no dirt enters the bearings during installation. It is difficult to remove dirt once it has worked its way between the balls, separator, and races and has reached the seal.

SINGLE-ROW ANGULAR-CONTACT BEARINGS Single-row angular-contact bearings are used in injection pumps where radial load and thrust load are combined. However, the thrust can only be applied in one direction. Single-row angular-contact bearings usually are used in pairs, with one bearing on each side of the shaft.

NOTE: When you install these bearings in pairs, make certain that the thrust faces point in opposite directions to each other. When they are used for a one-sided heavy thrust load, install them as shown in Fig. 17-27.

DOUBLE-ROW DEEP-GROOVE BEARINGS The design of these bearings does not differ from that of the single-row deep-groove ball bearings but, of course, the load capacity in any application is higher because of the two rows of balls.

DOUBLE-ROW ANGULAR-CONTACT BEARINGS These bearings are designed similarly to the single-row angular-contact bearings. However, they usually are constructed with a predetermined internal preload. They are used where a shaft must be held tightly, radially as well as axially.

Cylindrical (Straight) Roller Bearings These bearings use straight rollers as their rolling elements and have a very high radial capacity since the roller axis and the inner and outer races (or the contact surface) are parallel (see Fig. 17-28). They are manufactured in single or double rows and vary in design.

Needle Bearings Initially, needle bearings were considered cageless roller bearings because they

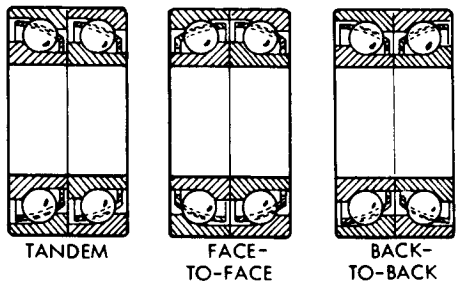


Fig. 17-27 Installing single-row angular-contact bearing. *(International Harvester Company.)*

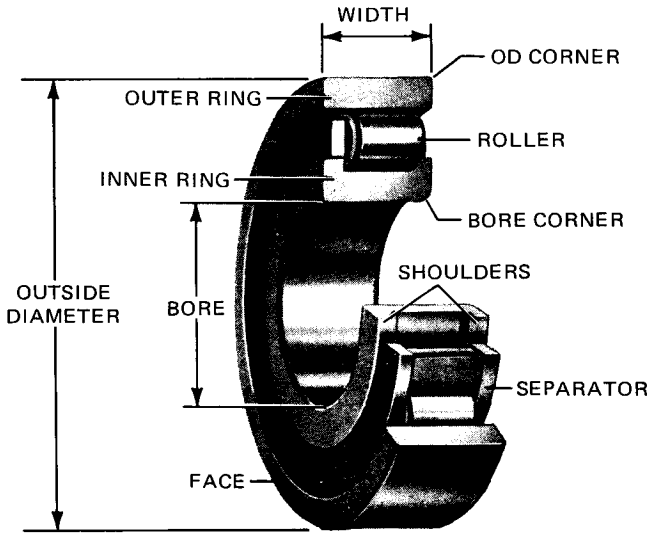
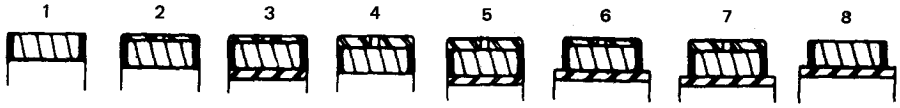


Fig. 17-28 Cylindrical (straight) roller bearing. *(International Harvester Company.)*



1. Roller only
2. Roller assembly with outer ring
3. Roller assembly with outer and inner rings
4. Roller assembly with outer ring and separator
5. Roller assembly with outer and inner rings and separator
6. Roller assembly with outer ring and wide inner ring
7. Roller assembly with outer ring, wide inner ring, and separator
8. Roller assembly with wide inner ring

Fig. 17-29 Needle-bearing designs. *(International Harvester Company.)*

use rollers as their rolling element. They are classified as needle bearings when their length is at least six times that of the diameter of the rollers. This type has high radial capacity but no thrust-carrying capacity.

A needle bearing may be any one of the designs shown in Fig. 17-29, that is, with or without a separator, without inner ring or outer ring or cage, or without an outer ring or cage.

NOTE: When you install a needle bearing with an outer cage, press it on the side with the bearing identification mark.

Self-aligning Roller Bearings One type of self-aligning roller bearing has single- or double-row spherical rollers and has an *outer* spherical raceway (Fig. 17-30*a*). The contour of the *inner* raceway has the shape of the roller. The second type of self-aligning roller bearing has an *inner* spherical raceway and the rollers have an hourglass shape (Fig. 17-30*b*). The contour of the *outer* raceway has the shape of the rollers.

Tapered Roller Bearings These bearings have tapered rollers as the rolling element between the cone and the cup (Fig. 17-31). The lines of contact between the rollers, cones, and cup, when extended, intersect in the center of the shaft. The cage and the high shoulder on the cone keep the roller in alignment. These bearings are designed to carry high combined radial and thrust loads. As a general rule, tapered bearings are used in pairs with one bearing on each side of the shaft.

NOTE: Tapered roller bearings need periodic adjustment to take up any looseness which may have developed because of wear or stress.

Thrust Bearings Thrust bearings are designed for axial thrust load application only; their radial load-carrying capacity is only incidental. They use balls, tapered rollers, or cylindrical rollers as their rolling element (see Fig. 17-32). The tapered or cylindrical thrust bearings generally use short rollers to compensate for the variation in speed between the outer and the inner diameters of the rollers.

Removing Antifriction Bearings The greatest enemies of any bearing are dirt and improper installation. Cleanliness of the tools and the work area where the bearing is to be removed cannot be overemphasized. Careless handling will most assuredly promote early bearing failure.

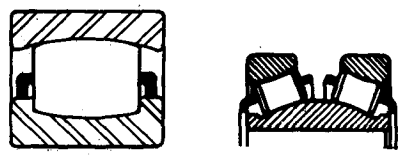


Fig. 17-30 Self-aligning roller bearings: *(a)* single-row spherical roller with outer spherical raceway, *(b)* double-row hourglass roller with inner spherical raceway. *(International Harvester Company.)*

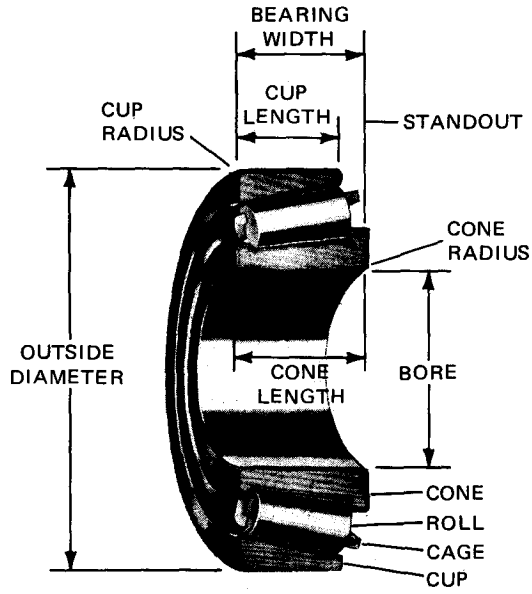
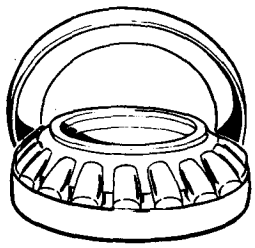


Fig. 17-31 Tapered roller bearing. *(International Harvester Company.)*





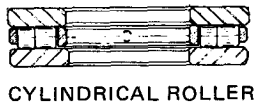


Fig. 17-32 Types of thrust bearings.

Following are a number of rules applicable when you are removing or installing bearings, whether or not the bearing is to be discarded or reused:

1. Never use a hammer, a hammer and punch, or an impact wrench in conjunction with a puller arrangement when removing bearings. These tools will damage the races and the contact surfaces of the rolling elements and lead to spalling and premature failure.
2. Never heat a bearing with a cutting torch. Use a heating tip and a temperature stick to determine the temperature.
3. When possible, press or pull the bearing or the race from the shaft or housing. Use the correct pullers and attachments, as shown in Fig. 17-33, or drive them off the shaft, as illustrated in Fig. 17-34.
4. When using a press to remove a bearing or race, support the bearing or the housing correctly, as shown in Fig. 17-35.
5. When using a tube-type tool, be careful not to cock the bearing. Drive it alternately on one side and then on the other.
6. When using heat to remove an inner ring which is equal to the diameter of the shaft, use an asbestos glove to prevent your hands from being burned. Alternatively, heat only one part of the ring or cut off part of the ring, and then remove it. You can also use a hammer and cold chisel on the heated area to crack the ring open.

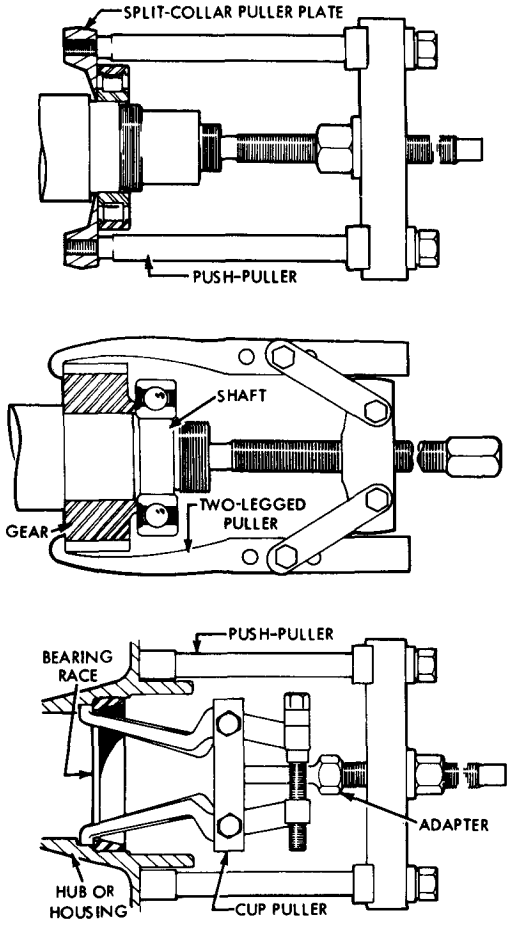


Fig. 17-33 Typical puller arrangements. *(International Harvester Company.)*

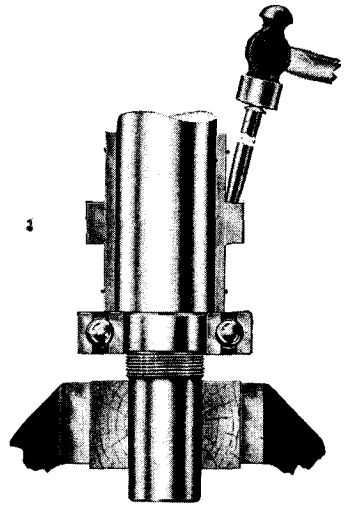


Fig. 17-34 Driving a bearing off the shaft (partial cutaway view). *(International Harvester Company.)*

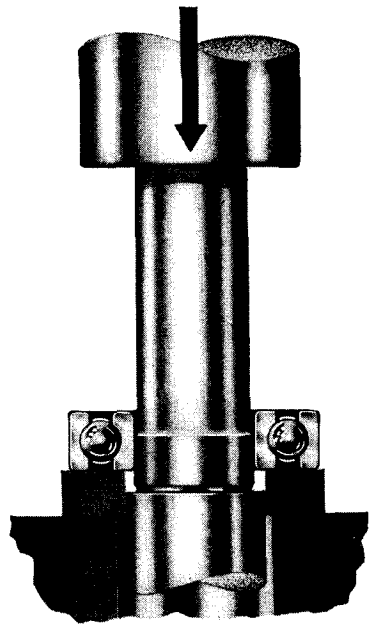


Fig. 17-35 Supporting a bearing when pressing it from the shaft (partial cutaway view). *(International Harvester Company.)*

7. After bearings have been removed, handle them with as much care as if they were new. Wrap them in clean paper or promptly place them in a basket and immerse the assembly in clean solvent.

CAUTION Never "rotate" a removed bearing. It can be damaged by such practice.

8. To prevent shield damage, do not place shielded bearings in a basket with other components.
9. Do not place a bearing with both sides sealed in solvent for cleaning. Wipe the surface clean and wrap it in clean paper for later inspection.
10. Do not place too many bearings in one basket for cleaning. You will reduce the cleaning effectiveness because dirt from one bearing will wash into another.

Cleaning Antifriction Bearings Let the bearings soak in a basket for some time in a recommended cleaning solution, in diesel fuel, or in Varsol.

CAUTION All solvents are highly inflammable. Handle them with care to prevent a fire.

After a period of time, agitate the basket several times. Air can also be used to agitate the cleaning fluid. This will remove the particles (contaminants) from the bearings.

Remove and inspect one bearing at a time. If further cleaning is necessary, use a durable brush (the bristles must not come out or break off during cleaning) to loosen the remaining dirt particles, etc.

After stubborn dirt has been loosened, complete the cleaning by moving the bearings back and forth in the solvent and then repeat this procedure in a clean solvent bath. Use forced air to remove any remaining particles and to remove the solvent; however, hold both races. Never allow a race to spin by the force of the air; the ring may explode. Always use caution when employing forced air.

When you clean bearings which have removable shields, dismantle the shields and then clean the bearings and the shields separately. When you clean bearings with fixed single- or double-sided shields or with a single seal, use only an oil spray cleaner. Otherwise continuously rinse them with clean solvent to wash out the particles. If compressed air is used, take care not to damage the seal or the shields. Never attempt to clean cage needle bearings because it is impossible to clean them adequately.

Inspecting Antifriction Bearings After the bearings are clean, dip them in light engine oil, gently rotate them a few times, and place them on clean paper to drain off the excess oil.

To determine the serviceability of a bearing, hold it as shown in Fig. 17-36, then check it for discoloration; for cracked or damaged races; damaged shield (or shields) or damaged seals; damaged separator; broken or damaged balls or rollers; brinelled, flaked, or spalled areas on balls, rollers, or races. Indication of any of the above will necessitate bearing replacement.

If, on inspection, the bearing appears satisfactory and during inspection does not feel rough or have a tendency to stick, the bearing should be dipped in clean oil and stored in greaseproof paper until it is to be reinstalled.

If bearings are to be stored for a longer period, coat them thoroughly with grease so that no air can come in contact with their surfaces and then wrap them in greaseproof paper. Identify the wrapping with the bearing part number or indicate the location from which it was removed.

Installing Antifriction Bearings A bearing is installed by doing precisely the reverse of what you did to remove it. However, before you can press, push, or drive the bearing in place, the shaft and the bore must be cleaned and then checked for nicks and burrs. If any are present, remove them. Make certain there is no dirt on the shaft.



Fig. 17-36 Holding a bearing for inspection. *(International Harvester Company.)*

Apply a moderate amount of oil to the bearing seat and bore and at this time remove the bearing from its package. Needless to mention, your hands and tools must be spotlessly clean.

Align the bearing on the press bed, and align the shaft with the bore. Then press or pull the bearing until it seats firmly against the shoulder (Fig. 17-37).

If it is necessary to install the bearing with the shaft in place or if no puller or press is available, tap the bearing lightly with a tool similar to that shown in Fig. 17-38. This will start it square onto the shaft. Be certain it is not cocked; otherwise, the shaft and/or bore will be scraped or burred. To prevent the balls or rollers from being damaged while driving a bearing against the seat, you should place a lintfree cloth around the assembly.

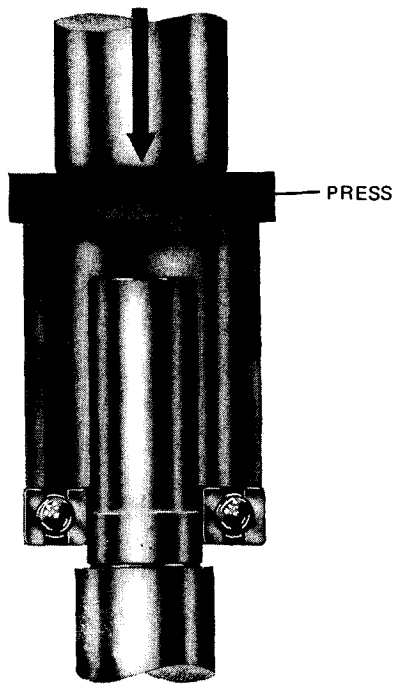


Fig. 17-37 Installing a bearing using a press (partial cutaway view). *(International Harvester Company.)*

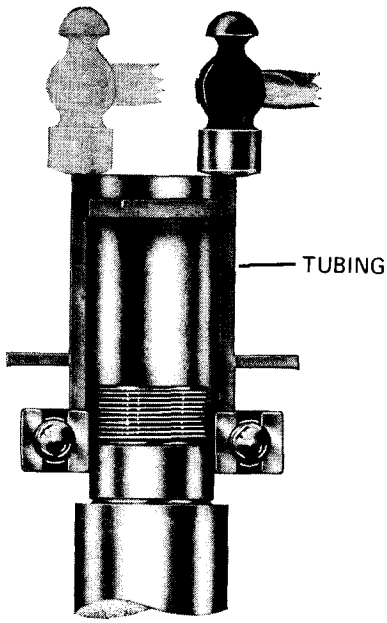


Fig. 17-38 Installing a bearing using a piece of tubing and a hammer (partial cutaway view). *(International Harvester Company.)*

CAUTION Under no circumstances should you use an impact wrench to turn the puller spindle, the puller nut, or the shaft nut to pull the bearing in place. Any of these procedures could damage the rolling elements and the races.

The safest way to install a bearing to a shaft is to heat the bearing to 250°F [121°C]. This may be done in an oven, on a hot plate, or by the method shown in Fig. 17-39. Heating the bearing will expand it so that the inner race slides freely onto the shaft. *(NOTE: Work as quickly as possible when positioning the bearing.)*

An alternative method, which is also a safe one, is to cool the shaft or the bearing, depending on bearing installation, using dry ice to shrink the shaft or the bearing.

CAUTION Take care when using dry ice or heat. Always wear asbestos gloves for protection.

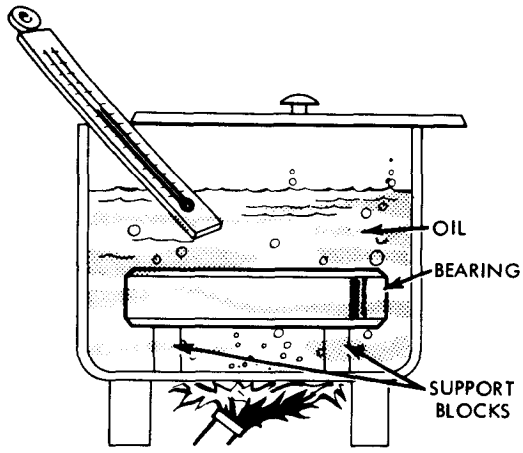


Fig. 17-39 Heating a bearing for assembly on the shaft. *(International Harvester Company.)*

Questions

1. Name the two types of friction bearings that are used on diesel engines.
2. What type of materials are used for the bearing backs?
3. Why are half-bearings manufactured with a spread? Why do bearings require a crush?
4. Why are oil grooves usually only in the lower half of connecting-rod bearings and in the upper half of main bearings?
5. List the four most common causes of friction bearing failure.
6. What is the main difference between a friction bearing and an antifriction bearing?
7. Why has a roller-type bearing a greater load-carrying capacity than a ball bearing of the same size?
8. For what purposes are single- or double-row angular-contact bearings designed?
9. List the three main causes of antifriction bearing failure.
10. List the checks you must make before installing a bearing.

SECTION 3
INTAKE, EXHAUST, AND COOLING SYSTEMS
UNIT 18 • AIR-INTAKE SYSTEM

Much of a diesel engine's successful performance depends on its supporting systems, that is, the intake system, exhaust system, cooling system, and their components such as the connecting lines and fittings, filters, and gaskets. Too often, these systems receive insufficient priority in maintenance and service, simply because the problems they create do not immediately affect engine performance. Nevertheless, a reduction in efficiency of any of the supporting systems causes unnecessary wear and strain on the engine components.

Purpose of Air-intake System The purpose of the air-intake system is: (1) to supply clean and cool air to each cylinder as required for complete combustion, (2) to supply air for scavenging, (3) to reduce (silence) the airflow noise, and (4) to cool the air going to the cylinders.

Air-intake System Components The air-intake system of a four-cycle engine consists of: an air cleaner, connecting elbows, tubes, hoses, and the intake manifold. When a turbocharger is used, the compressor side of the turbocharger becomes part of the intake system.

If, in addition, an aftercooler (intercooler) is used to cool the air and thereby improve engine efficiency, it then becomes part of the intake system (Fig. 18-1).

Four-cycle V-type engines have either two intake systems with two air cleaners and two turbochargers, or else a single intake system with a crossover intake manifold.

The air-intake system of a two-cycle engine consists of an air cleaner, connecting elbows, tubes, hoses, and the blowers. The air box, which is part of the engine block, is the manifold. When a turbocharger is used, the compressor side of the turbocharger becomes part of the intake system. If, in addition, an aftercooler is used, it also becomes part of the intake system (Fig. 18-2). Two-cycle V-type engines may have two turbochargers and an aftercooler.

The required amount of air intake is directly related

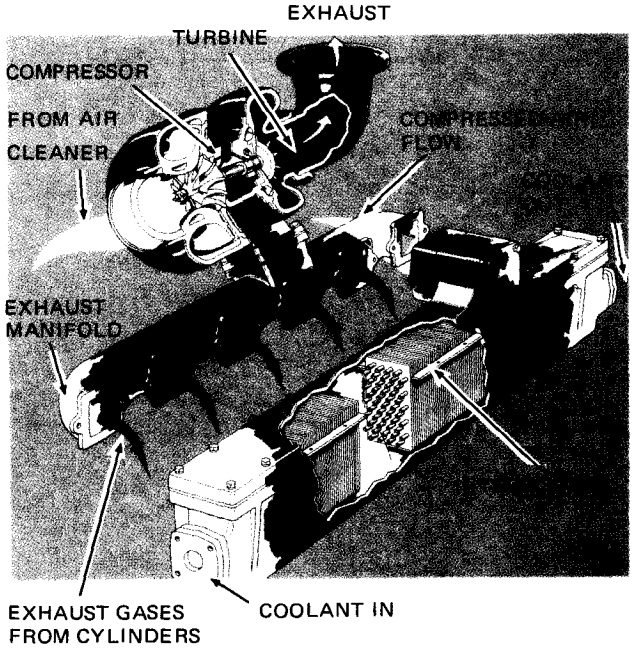


Fig. 18-1 Illustration of a four-cycle air-intake system. The intake manifold on this engine is an integral part of the cylinder. *(Caterpillar Tractor Co.)*

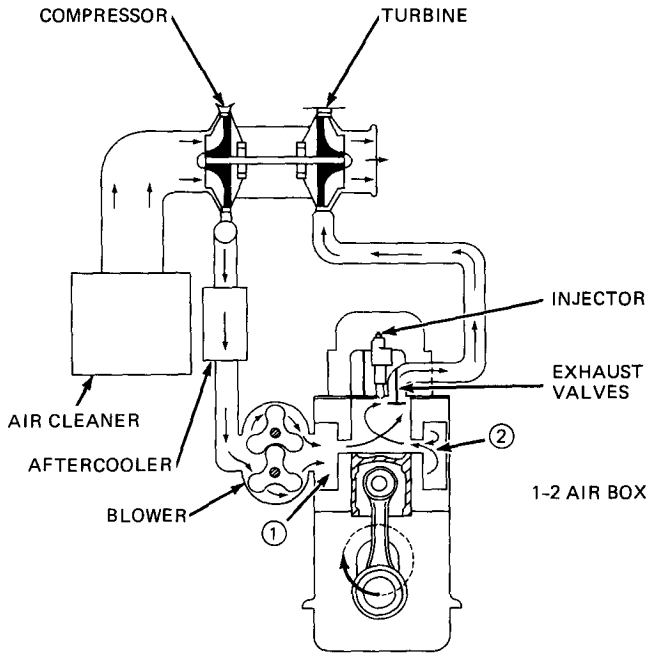


Fig. 18-2 Schematic view of a two-stroke-engine air-intake system having a turbocharger, blower, and aftercooler.

to the bhp, atmospheric pressure, and temperature. It ranges from 2.0 to 6 cubic feet per minute (ft^3/min) per bhp [56.6 to 169.9 liters per min (L/min)], 2.0 to 2.8 ft^3/bhp for naturally aspirated four-cycle engines, 2.3 to 4.0 ft^3/bhp for turbocharged four-cycle engines, and 3.5 to 6 ft^3/bhp for turbocharged two-cycle engines.

Intake Manifold The intake manifold is a one-piece or multipiece cast-iron alloy or cast-aluminum alloy casting which connects the intake ports of a row of cylinders and distributes the air equally to each cylinder, or the intake manifold is an integral part of the cylinder head. The inlet port of the manifold is connected to the air cleaner, the aftercooler, or the compressor side of the turbocharger.

Inspecting Intake Manifold After you clean the manifold, recheck its internal passages. If any foreign obstructive material still remains, remove it. Inspect the manifold for cracks, and the mounting surfaces for corrosion, straightness, or warping. If any of these defects are sufficient to prevent proper sealing, the flanges must be machined or the manifold replaced.

Installing Intake Manifold Be sure the mounting surface of the manifold and the cylinder head are clean before placing a new manifold gasket between them. Follow the correct sequence and tighten the manifold bolts to their recommended torque. Cover the inlet opening if the turbocharger is not to be immediately installed.

Air Cleaner and Silencer The efficiency and service life of an engine depend to a large extent on adequate maintenance and servicing of the air cleaner along with the other components of the air-intake system. There is a wide range of air cleaners available to meet any air demand of a given engine and to provide ample clean cool air to the combustion chamber. Insufficient air, because of air-cleaner restriction, will limit the amount of fuel the engine can burn. This will result in a loss in power output as well as excessive exhaust smoke and high fuel consumption. A damaged or leaking air cleaner, flanges, or hoses can lead to excessive engine-component wear, shorter engine life, and higher oil consumption.

The air cleaners used on diesel engines can be classified into two groups: the oil-bath cleaner and the dry-type air cleaner.

Oil-bath Cleaner Oil-bath cleaners, because of their lower cleaning capacity, are more prevalent where dust conditions are not severe. Their efficiency is about 97 percent compared to a dry-type cleaner which is 99.9 percent.

A typical oil-bath cleaner with a silencer is shown in Fig. 18-3. Air enters through a screen in the hood and passes downward through the stand-up tube toward the oil bath. The stand-up tube ends about ½ in [12.7 mm] below the oil level. The air enters the oil bath, is purified, and then changes direction. Gravity and inertia cause the larger dirt particles to settle at the bottom of the oil cup. As the oil and air mix and cause a vapor, the smaller dirt particles are

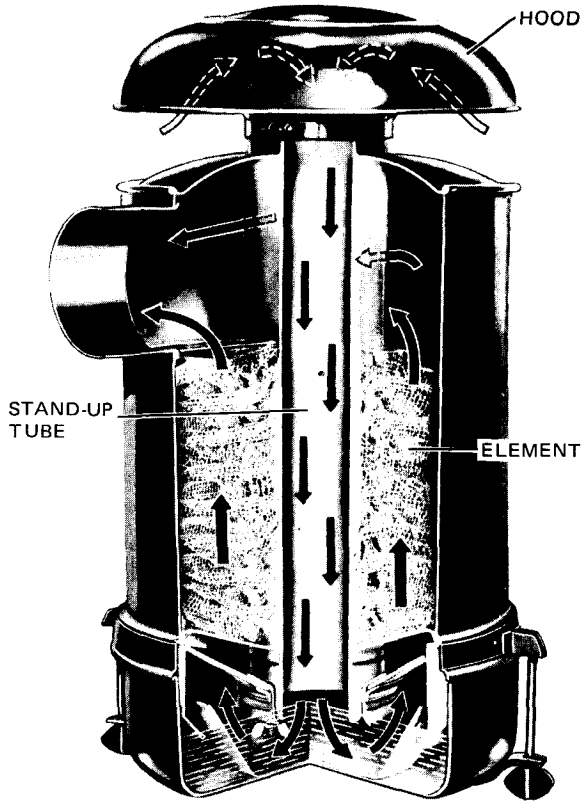


Fig. 18-3 Sectional view of oil bath cleaner. (The arrows show the oil flow.) *(Detroit Diesel Allison, Division of General Motors Corporation.)*

carried with the oil mist (vapor) upward through the wire-type filter element or elements. When the oil mist enters the filter, the heavier particles (oil mixed with dust) cling to the wire mesh and the oil mist is reduced continuously until clean oil-free air leaves the filter.

Servicing Oil-bath Cleaner A formidable weakness of an oil-bath cleaner is the impossibility of installing in it a warning device to signal when there is little or no oil in the bowl, when the bowl is loose or has come off, or when the bowl is full of dirt.

There are warning devices or gauges which will indicate airflow restriction [see Air-intake Restriction and Poor Compression (Unit 53)]. The average permissible restriction for an oil-bath cleaner is about 5 in [12.7 cm] (H_2O) on the water manometer gauge. The only way to be sure if the oil-bath cleaner is functioning properly is to check, daily, the general condition of the oil level and the amount of accumulated dirt.

A precleaner cap should be used when operating an engine in an area where sawdust, leaves, and chaff are in the air (Fig. 18-4).

In order to service the oil-bath cleaner, remove the oil bowl, pour out the old oil, and remove the sludge. Wipe the bowl clean and refill it to the "level" mark with the same grade and weight of oil as that used in the engine. Proper oil viscosity is very important to the washing action since oil which is too light (of low viscosity) can cause oil to be drawn out of the bowl. Oil which is too heavy (of high viscosity) can increase restriction to an unacceptable level. In either case, oil may be drawn into the cylinders. Furthermore, the cleaning action may have been lost.

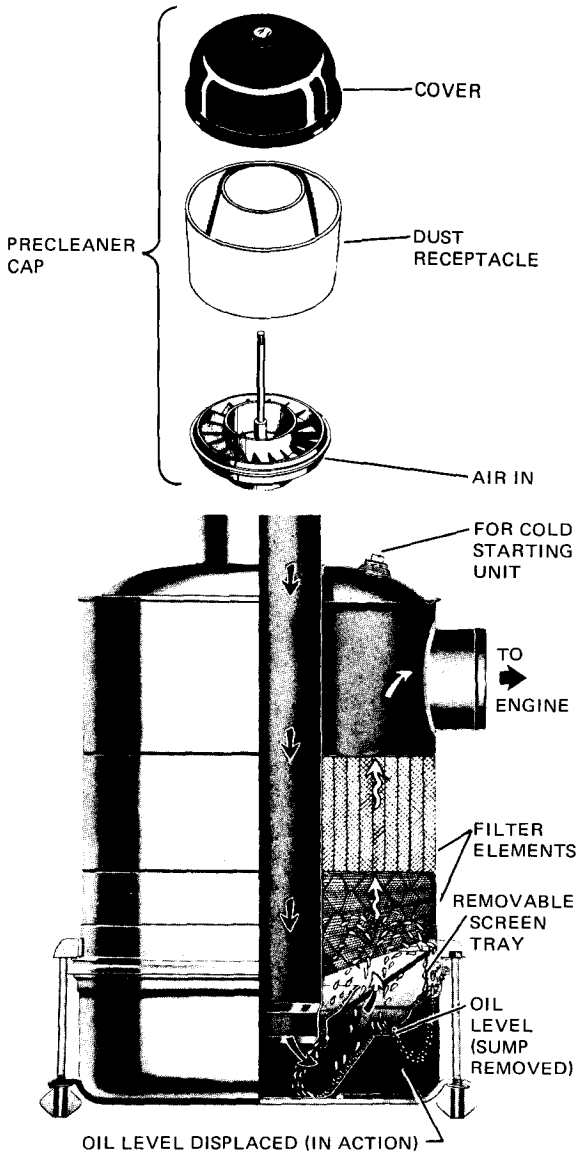


Fig. 18-4 Sectional view of oil bath cleaner with precleaner cap. (The arrows show the oil flow.) *(Mack Trucks Canada Limited.)*

Be sure to check the center tubes, the precleaner cap, and the lower filter element. The filter elements of a light-duty oil-bath cleaner are removable, whereas the filter elements of a heavy-duty oil-bath cleaner are not. Therefore, when the filter elements of a heavy-duty oil-bath cleaner are dirty, the filler assembly must be removed and cleaned in a cleaning tank.

Do not use an air pressure higher than 5 psi [34.4 kPa]. After washing an air cleaner in solvent, make certain to remove all traces of the solvent either by using a steam cleaner or by blowing it dry with compressed air. If this step is not taken, the engine may speed beyond governor control since it will use the solvent as fuel.

Dry-type Air Cleaner Most (on- and off-highway) engines use dry-type air cleaners since they have an efficiency of 99.8 to 99.9 percent regardless of airflow. Furthermore, the cleaning efficiency is not affected by climatic conditions or the type or size of dust particles. In addition, the operator is instantly

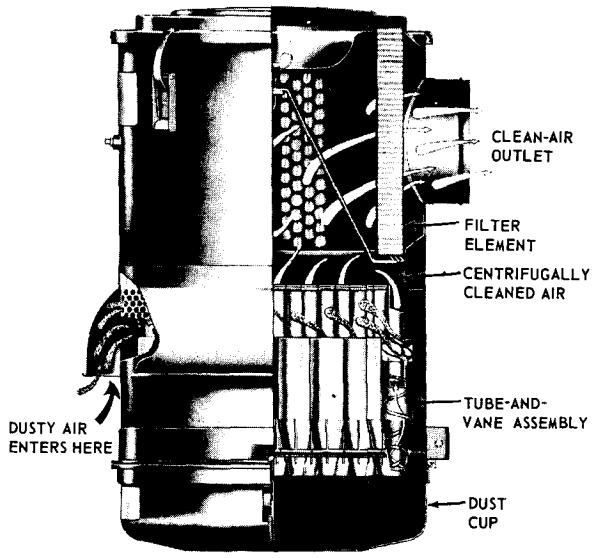


Fig. 18-5 Sectional view of a Donaclone single-element air cleaner. (The arrows show the airflow.) *(Mack Trucks Canada Limited.)*

alerted to air restriction by means of built-in warning devices. The only drawback to the dry-type air cleaner is that carbon or oil vapor can reduce the service life of the filters.

A great variety of dry-type air cleaners are used. They range from a simple single element (Fig. 18-5) to a large two-stage element which may have some type of mechanical cleaning device (Fig. 18-6).

Air-cleaning Action of a Donaclone Air Cleaner The Donaclone is a dry-type cleaner which combines a centrifugal-stage cartridge and a paper-filter cartridge, the latter being protected by a perforated steel shell. The centrifugal-stage cartridge has many tube assemblies. Each tube assembly has a larger outer tube which tapers off at the bottom. The smaller tubes, to which vanes are fastened, protrude into the larger tubes approximately one-quarter of the length of the smaller tubes. The small tubes are fastened to the upper sealing ring and the large outer tubes are fastened to the lower sealing ring.

As the engine is cranked over, a lower pressure is present around the inlet skirt of the air cleaner. Atmospheric pressure forces the air through a large screen into the centrifugal cartridge and around the smaller tubes. The air passes into the larger tubes where the vanes force the air to rotate (cyclonic mo-

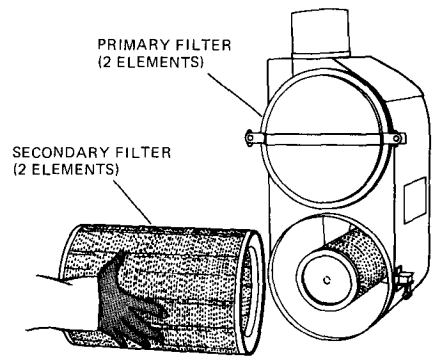


Fig. 18-6 Schematic view of a two-stage air cleaner. *(Caterpillar Tractor Co.)*

tion). The heavier foreign particles are thrown outward against the walls of the larger tubes and then drop downward into the dust cap. The partly cleaned air (that is, the center of the rotating air motion) passes upward through the smaller tubes into the paper-element cartridge where particles of the lower micrometer range are removed. Engines which must operate in heavily polluted atmospheric conditions may use a two-stage (dry-type) air cleaner as shown in Fig. 18-7. The dirt in the dust bin is continuously drawn out by the exhaust gas pressure which creates a low pressure at the bin.

Operation Air is drawn past the deflector vanes which impart a swirling motion to the air and centrifuge the dust particles against the walls of the tubes. Bleedoff air (approximately 10 percent) forces the particles into the dust bin. The air at the end of the primary chamber reverses direction and spirals back along the discharge tubes and again heavier particles are thrown against the wall. The airflow reverses again and enters the discharge tubes, passing through the paper-filter element where the final cleaning stage takes place.

Servicing Dry-type Air Cleaner When the dust cup is about two-thirds full of foreign particles, say to within ½ in [12.5 mm] from the bottom of the tapered tubes, the dust cup must be cleaned.

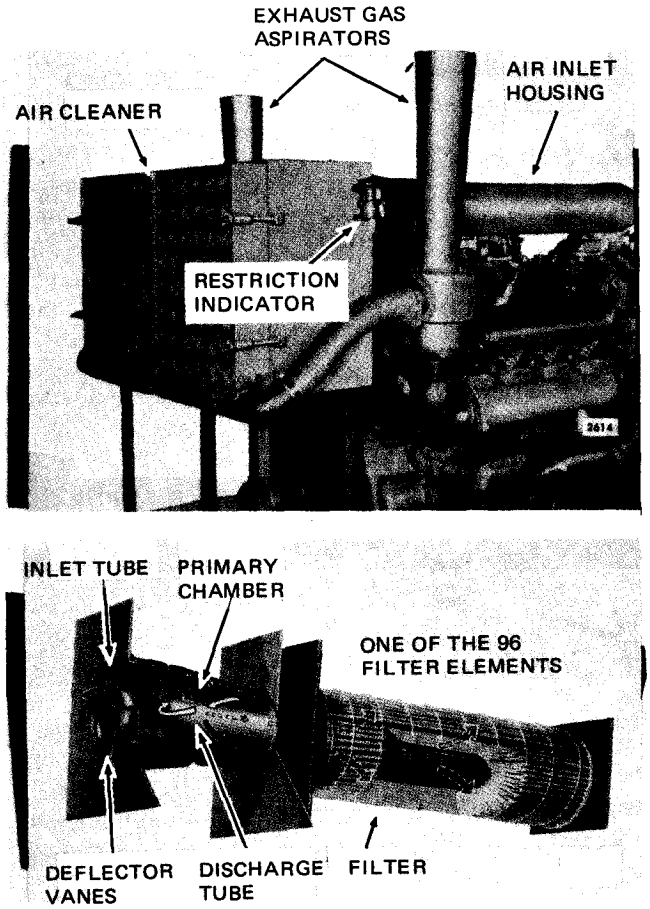


Fig. 18-7 Schematic view of a two-stage dry-type air cleaner. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

To clean the filter, remove the clamp which holds the cup. Dump out the particles. Clean the bowl and the gasket. Do *not* use a solvent, gasoline, or other fuels. Use only a dry rag or ordinary laundry detergent and warm water.

When the restriction indicator shows that the maximum allowable restriction has been reached, both cartridges must be cleaned or the filter element replaced. To service the filter element, remove both cartridges. Wash the elements or clean them with compressed air. When you use the compressed-air method, direct the air through the cartridges opposite to the normal airflow. Hold the air nozzle about 1 in [25.4 mm] from the surface of the paper element and move it up and down while rotating the cartridge.

When oil or carbon residue is present, the cartridge must be washed. Soak the cartridge about 10 minutes in a solution of warm water and laundry detergent or air-cleaner detergent, then flush it gently with a low-pressure water stream until clean water leaves the filter. Air-dry or use a warm airflow to dry the cartridge before reusing it.

Check the paper cartridge to be sure it is clean and free of damage by placing a light on the inside and rotating the element. If an even bright light is visible throughout, the cartridge is clean. If there are holes in the cartridge or if it is ruptured, it must be replaced (see Fig. 18-8).

NOTE: Do not use compressed air to dry the element. Do not allow the hot air with which you are drying the filter element to exceed 160°F [71°C]. Either will destroy the paper cartridge. Do not use solvent, fuel, or gasoline for cleaning the elements as they would destroy the elements.

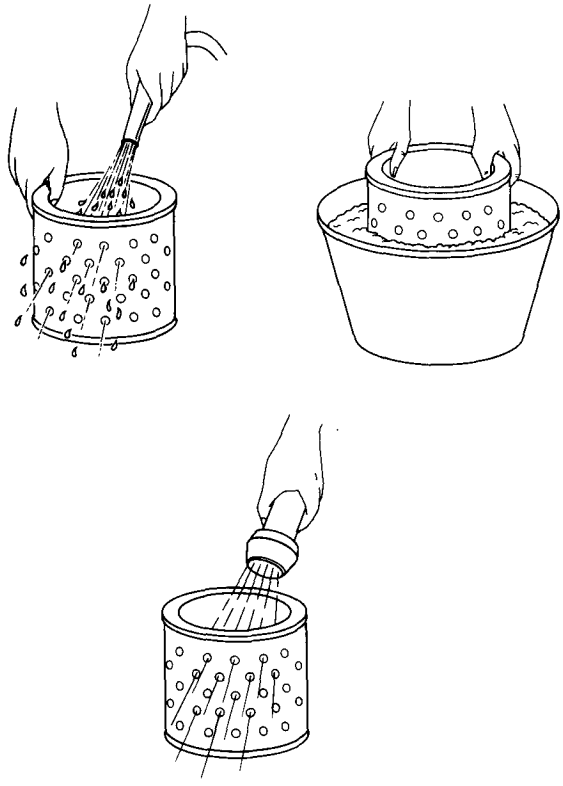


Fig. 18-8 Cleaning an oil-bath filter element.

The body assembly can now be cleaned. Wipe off or blow out any loose dirt. Check the sealing flanges and gaskets for damage. Reassemble. Make certain when you reassemble the air cleaner that the cover fits into position smoothly, without being forced, and that the gasket seal is 100 percent effective.

Aftercooler Most engines which are turbocharged employ an *aftercooler* to further improve the brake mean effective pressure (bmep). Aftercoolers (also called *intercoolers* or *heat exchangers*) are small radiators positioned between the compressor housing and the inlet manifold. The aftercooler and intake manifold may be one unit, or the aftercooler may be bolted to the cylinder head or to the intake manifold (Fig. 18-1).

Aftercooler Coolant and Airflow Coolant enters the aftercooler and passes through the core tubes and back into the cylinder block or cylinder head. Air from the compressor flows around the tubes and is cooled before it enters the inlet manifold. This increases the power output by about 10 to 20 percent because the incoming air is cooled to within 40°F [22°C] of the engine coolant temperature and, therefore, more air enters the cylinders. The result is lower cylinder pressure, more effective cooling of the cylinder components, and a lower exhaust gas temperature which brings about a higher bmep. Without the aftercooler the air temperature entering the intake manifold increases sharply because of the compression of the air and heat from the turbocharger. This results in a loss in air density and power, and a higher temperature within the cylinder and exhaust gases.

Note that with a 1°F [0.56°C] increase in air-intake temperature the exhaust temperature increases by 3°F [1.67°C]. For example, when the engine is operating at torque speed with a manifold pressure of 35 inHg [88.9 cmHg] and the ambient temperature is 70°F [21°C], compressed air entering the intake manifold would be around 248°F [120°C], which would result in an exhaust temperature of about 1150°F [621.1°C].

If the same engine were aftercooled (by coolant) and were operated under the same conditions, the compressed air entering the intake manifold would be 190°F [87.7°C] and the exhaust temperature around 1000°F [537.7°C].

Air-to-air Aftercooler The air-to-air aftercooler consists of the components shown in Figs. 18-9 and 18-10. The intercooler manifold is bolted to the front

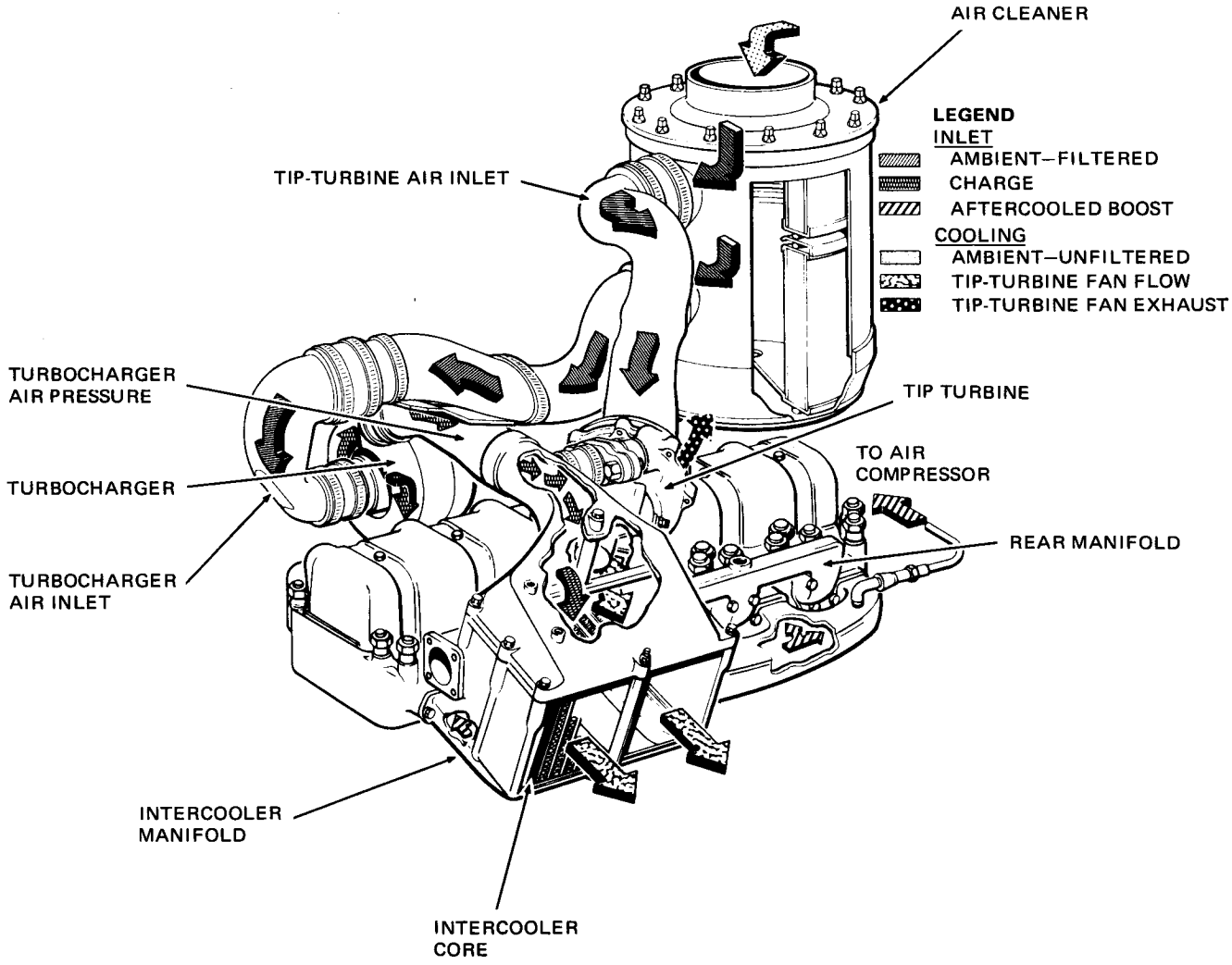


Fig. 18-9 Schematic view of an air-to-air intercooler. *(Mack Trucks Canada Limited.)*

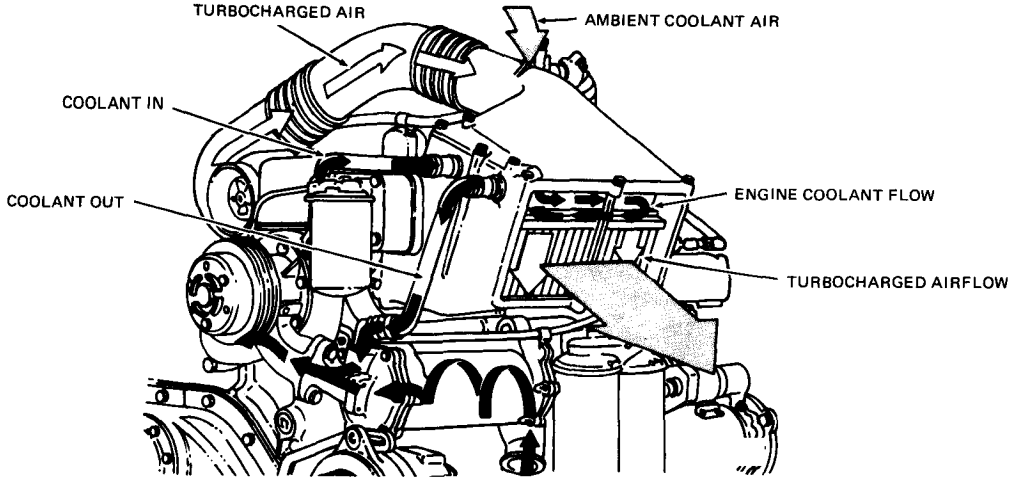


Fig. 18-10 Schematic view of two stage (or Series) intercooler. *(Mack Trucks Canada Limited.)*

cylinder head. The rear inlet manifold is bolted to the rear cylinder head and is connected with a hose to the intercooler manifold. A separate intercooler air cleaner protects the tip turbine from contaminants. The intercooler cooler cores have wide fins whereas the (charged) compressed-air airflow cores have narrow fins.

When the engine is operating at maximum torque speed, compressed air from the turbocharger (compressor) enters the intercooler header (see Figs. 18-9 and 18-10), where it is forced downward through the intercooler core into the intercooler manifold and the rear manifold. At the same time bleed air (60 ft^3/min [283.2 L/s]) from the turbocharger (turbine) enters the tip turbine and forces the tip turbine and fan to rotate at 2200 rpm. The fan draws air from its air cleaner at the rate of 775 ft^3/min [365.8 L/s] and forces it in a horizontal direction through the intercooler core out into the atmosphere. *(NOTE: The compressed air from the turbocharger compressor is cooled by the cooler ambient air to about 120°F [48.8°C] above ambient air temperature.)*

The air-to-air cooler has been redesigned to further reduce the intake temperature (Fig. 18-10). A coolant-to-air core is placed onto the top of the air-to-air core. The left-hand side of the coolant-to-air core is connected to the coolant pump. The right-hand side of the core is connected, via the air cooler, to the cooling system. This two-stage coolant-to-air and air-to-air intercooler arrangement reduces the air temperature from the compressor by about 180°F [82.2°C], which is about 10 percent greater than the air-to-air intercooler.

Another type of air-to-air intercooler is shown in Fig. 18-11. You will notice a large radiator-type cooler in front of the radiator. The compressor is connected

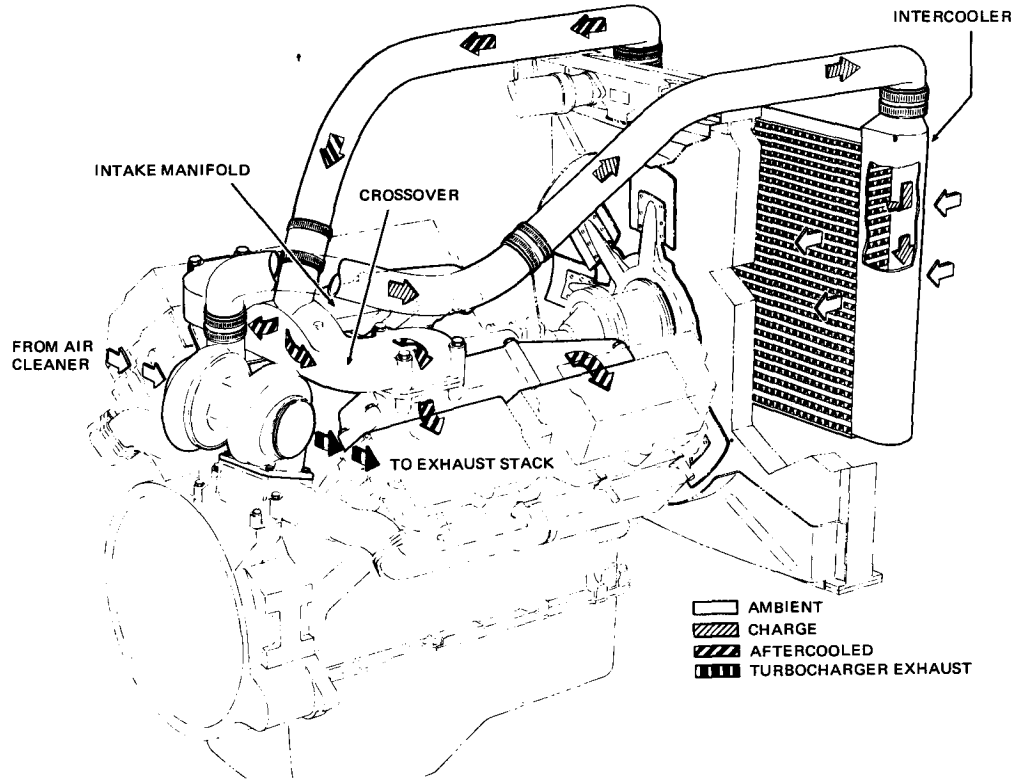


Fig. 18-11 Schematic view of an air-to-air intercooler. *(Mack Trucks Canada Limited.)*

to the intercooler (right-hand side) through pipes and hoses, and from the left-hand side through pipes and hoses to the crossover, and from there to the inlet manifolds. Cooling air is drawn through the intercooler and radiator by the fan and the forward motion of the motortruck. Intercooling efficiency is slightly higher than that of the turbine air-to-air intercooler.

Inspecting and Servicing Aftercooler After you have cleaned and disassembled the aftercooler, make the checks and tests outlined under Inspecting and Testing Oil Cooler (Unit 13). However, when making a leakage test (pressure test) do not pressurize the cooler tubes by more than 15 psi [103.4 kPa] of air. When the coolant tubes show a buildup of scale or any other type of residue, clean it with a solution the same as that for cleaning the coolant side of the oil cooler.

Roots-type Blower A two-cycle diesel engine requires an air pump (blower) capable of pumping air into the engine cylinders at a pressure of about 2 to 7 psi [13.8 to 48.3 kPa] to replace exhaust gases with fresh air (scavenging). The air volume needed to perform scavenging is about 40 times greater than the cylinder volume. A positive displacement Roots-type blower is commonly used as the air pump. It is bolted to the air-box opening flange (see Fig. 18-2) and is driven by the engine.

NOTE: On in-line engines the air-box opening is either on the left- or right-hand side of the engine, whereas on V engines it is in the V between the cylinder heads.

The Roots-type blower has two hollow, three-lobe rotors which revolve with very close clearances within the housing. To achieve efficient sealing and a uniform airflow (volume), one rotor lobe is twisted to the right and one is twisted to the left. The two rotors are timed by two drive (timing) gears which space the rotor lobes to a close clearance. Since the lobes do not come in actual contact with each other or with the housing, the rotor needs no lubricant. Should the drive gears exceed the backlash clearance, the rotors will then come in contact with each other. The resultant wear will cause a reduction in volume and pressure. The rotor shafts rotate on double roller bearings in the drive (rear) end plate and on roller bearings in the (front) end plate. Lip-type seals seal the rotor shaft. *(NOTE: The rotor drive side may be on the left or right, depending on engine model.)*

The upper rotor is driven by the camshaft through the rotor drive gear. The ratio between rotor and engine rpm varies between engine series and models and also depends on whether a turbocharger and/or aftercooler is used. For example: A V-8 71 Series turbocharged engine has a ratio 1.95:1, a V-8 92 Series turbocharged is 2.05:01, and the same engine (aftercooled) has a ratio of 1.95:1. On in-line engines the governor is splined to the top rotor, and on V engines the fuel pump is splined to its left-hand rotor. The fuel pump is coupled to the lower rotor (rear) and the coolant pump is coupled to the front. On V engines the governor weight assembly is splined to the right-hand rear blower rotor. A flexible coupling is used on both blowers to reduce the transfer of torque fluctuation to the blower (see Fig. 18-12).

Lubricating Blower on a V-type Engine The timing (rotor), gears, governor, and fuel pump drive are pressure-lubricated from the main oil gallery. The main oil gallery leads to an oil passage in each blower end plate and oil returns to the crankcase via an oil passage in the cylinder block. On in-line engines, oil from the valve mechanism drains into camshaft or balance-shaft pockets (depending on engine model) and from there through passages into the end plates. A slinger attached to the lower rotor (water pump side) throws oil onto the bearings and governor assembly. At a certain oil level it drains through passages back into the oil pan.

Inspecting Blower When inspecting the blower on an engine which is in running condition, you should first check the effectiveness of the blower pressure, air-intake restriction, and compression (see Unit 53, "Troubleshooting and Tuneup").

To inspect the condition of the rotors, housing, end plates, bearings, and seals, you must remove the air shutdown housing. The housing should then be thoroughly cleaned. Next, check the screen for damage, and make certain the valve rotates freely and that it is positioned flat on its seat. If it is not flat on its seat, the airflow will not stop when the engine is in shutdown position.

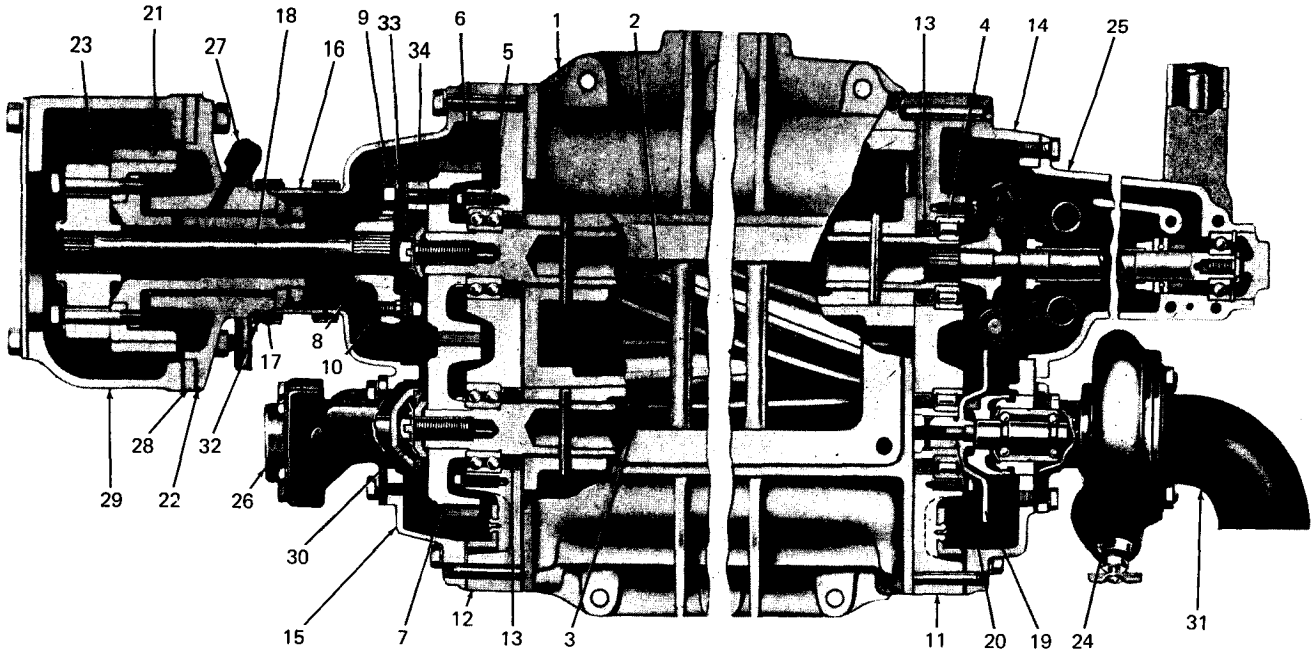
Check the ability of the latch to hold the valve securely open when in the "run" position. Check the springs for erosion and broken ends. Examine the rotor and housing for scratches, burrs, and grooves. If these defects are present, it is an indication that foreign matter has entered through the air-intake system. If the damage cannot be corrected with emery cloth, the blower must be serviced.

Check the leading edges of the lower rotor and the trailing edges of the upper rotor for evidence of contact or wear. Check the backlash of the timing gears; if it exceeds 0.004 in [0.101 mm], the gears must be replaced. If the rotor crowns and the mating rotor roots show a contact pattern or if there is extensive wear on either the inner housing or end plates, then one or more bearings are worn or else the rotor shaft is loose.

Engine oil on the rotors near the end plates or housing indicates leaking oil seals. This leakage could be the result of a worn bearing, a high air-intake restriction, a plugged crankcase breather, or a damaged seal.

To check the flexible drive coupling, force the top rotor to rotate. A springing movement of about 3/8 to 5/8 in [9.525 to 15.87 mm] (measured at the lobe crown) should be present. When the rotor is released, it should spring back to within 1/4 in [6.35 mm] of its previous position. If the rotor does not spring back, or alternatively, if it springs back further than specified, the flexible drive coupling must be replaced.

Removing Blower When you remove and disassemble a blower, follow the steps outlined in the ap-



1. Blower housing
2. Blower rotor (upper R.H. helix)
3. Blower rotor (lower L.H. helix)
4. Front roller bearing
5. Rear ball bearing (double-row thrust)
6. Rotor gear (upper R.H. helix)
7. Rotor gear (lower L.H. helix)
8. Rotor drive-gear hub
9. Plate-to-gear bolt
10. Plate-to-hub bolt
11. Front end plate
12. Rear end plate
13. End-plate oil seal
14. Front-end-plate cover
15. Rear-end-plate cover
16. Blower drive-shaft cover
17. Drive-shaft-cover seal
18. Blower drive shaft
19. Water-pump-drive-coupling assembly
20. Allen-head-bolt coupling
21. Blower drive gear
22. Blower drive-gear-hub support
23. Blower drive-coupling assembly
24. Freshwater pump
25. Governor
26. Fuel pump
27. Oil-line-to-blower-drive elbow (90°)
28. Rear cylinder-block end plate
29. Flywheel housing
30. Fuel-pump-drive fork
31. Water-pump-inlet cover
32. Drive-cover-seal clamp
33. Blower-rotor drive-hub plate
34. Plate-to-gear spacer

Fig. 18-12 Sectional view of the blower, drive assembly, and accessories, including mechanical governor attached to standard blower or small-diameter rotor blower (71 Series engines). *(Detroit Diesel Allison, Division of General Motors Corporation.)*

propriate service manual. This is essential since the number and location of blowers differ among engine series and models.

Inspecting the Disassembled Blower Components Refer again to Fig. 18-12. The picture shows the location of components and parts of a six-cylinder 71T blower. Begin your inspection of this blower by scrutinizing the inside walls of the blower housing for burrs and scoring. Using a straightedge, check the side surface and the mounting surface for flatness. Check the bolt holes for elongation and the threaded holes for damaged threads. Remove burrs, nicks, and scratches with emery cloth.

Check the end-plate surface and the bearing bores and seals for grooving or for evidence that the bearings have rotated in their bores. Whenever the engine is placed in the shop for a major overhaul, all seals and bearings should be replaced. Alternatively, if a major overhaul is not being done, the bearings and seal surfaces should be checked for wear (see Unit 17, "Bearings").

Check the splines of the rotor shaft for wear (shaft serration) and, at the same time, check the splines of the timing gears. When the gears are loose on the blower shaft, the gears and/or the rotors must be replaced. Otherwise the backlash will exceed specification. Check the gear teeth for wear or damage.

NOTE: Never replace only one gear, always replace both. These replacements reduce noise and also prevent excessive wear of the timing gears. The excessive wear will eventually damage the rotor.

When the seal surface is damaged, the problem can be overcome by using an oversized seal and a seal spacer. When the splines or bearing surfaces are worn, the rotor must be replaced.

Inspect the sealing ribs of the rotors. They must be flawless if they are to maintain sealing and ensure proper air volume and pressure.

Check the spring packs of the blower drive coupling and the cams for wear.

Assembling Blower Before assembling the blower, check the blower housing and end-plates'

mating surfaces. They must be perfectly flat and smooth since no gasket is used between them. Next, check the dowel pins; they must project the specified height from the inner and outer faces. Install the oil seals in the end plates as shown in Fig. 18-13. Make certain they start straight in their bores and are pressed into place to the specified protrusion.

Place the blower housing on a clean work bench so that the top (identified by the engine letters E.T.P.) faces upward and the front end-plate's side faces toward you. If the blower is used in conjunction with a turbocharger, apply a rubber sealant over the total surface of the front end plate and blower face. On naturally aspirated engines, use the sealant as required to avoid air leakage. Place the front end plate, as shown in Fig. 18-14, onto the dowel pin and gently tap it straight onto the housing. Install, then tighten, the two fillister head screws to the specified torque. Place an oil-seal protector on each nonsplined rotor shaft. Next, place the rotors in mesh with the right-hand helix rotor at the top and the omitted serrations (one on each shaft) facing upward. In this position, guide them into the housing, through the shafts, and through the end-plate bores. Turn the assembly 180° so that you can install the rear end plate. Place the lip-seal protection sleeves over the shaft ends then install the rear end plate following the procedure used to install the front end plates. Place the semi-assembled unit in a vertical (rear end up) position on two blocks (Fig. 18-15).

Remove the two ball bearings from their packing and lubricate them well. With the identification numbers facing you, place one ball bearing over each rotor shaft and onto its bore. Use a bearing installer to drive the bearings into place. (The bearing-retainer plates secure the bearing to the rear end plate.)

Position the coolant-pump drive coupling on the (lower) left-hand rotor shaft, then, with the drive-coupling retainer bolt, draw the oil slinger and coupling against the end of the shaft. Tighten the hex bolt to the recommended torque. Place a new gasket over the dowel pins and install the end-plate cover and bolts, then tighten the hex bolts to recommended torque.

Turn the blower 180°. Place it on wooden blocks and install the ball bearings and the bearing retainers.

NOTE: Check your service manual to determine if the blowers require shims between the end of the shaft and the bearings.

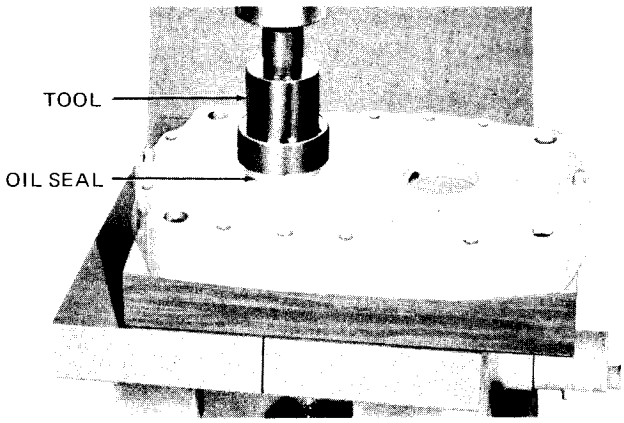


Fig. 18-13 Installing the oil seal (seal-ring carrier) in the blower end plate. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

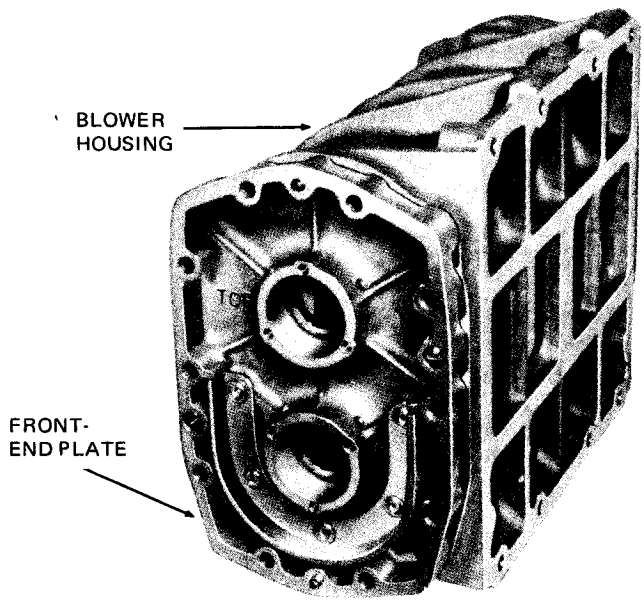


Fig. 18-14 Position of blower front end plate on housing. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

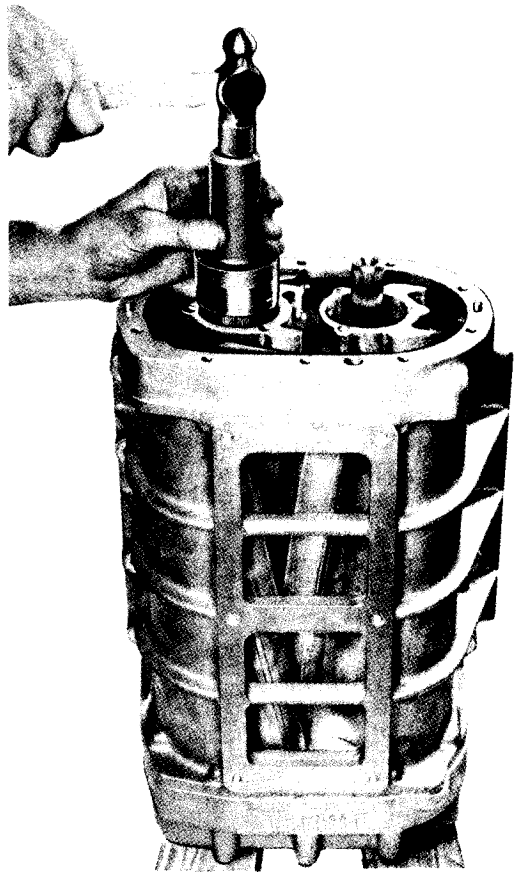


Fig. 18-15 Installing ball bearing onto rotor shaft and rear end plate. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

At this point, measure the end clearance between each rotor lobe and end plate. This will require 12 separate measurements (Fig. 18-16). Should the clearance exceed specification, you must disassemble the blower and replace the two rotors. Check the clearance at *E* and *D*. Should the clearances exceed specification, the blower housing and/or rotor must be replaced.

Installing Timing Gears When reusing the rotors and timing gears, replace the same number of shims as were removed on each rotor shaft. However, when new timing gears and/or new rotors are used, pull the timing gears onto the rotor shaft without using any shims.

To do this, lay the blower housing on the work bench with the air inlet facing upward and with the timing-gear ends over the edge of your workbench. Turn the rotor to bring the omitted shaft serrations upward, and lubricate the splines of the shaft and the timing gears. Locate the timing gears so that the one with the left-hand helical twist is on the left-hand helical rotor and the one with the right-hand helical twist is on the right-hand helical rotor. Install your pullers. Place a clean shop towel between the rotors and another one between the rotor and housing. This prevents the rotors from turning as you evenly pull the gears into position (Fig. 18-17).

NOTE: Both gears must be pulled onto the shaft at the same time and care must be taken when coming to the end of the gear position not to damage the rotor lobes.

Timing Blower Rotors With the timing gears in position, use a dial gauge to measure the timing-gear backlash. It should not exceed 0.004 in [0.101 mm]. With a feeler gauge inserted at *C* and *CC* (Fig. 18-16), measure the clearance at several intervals

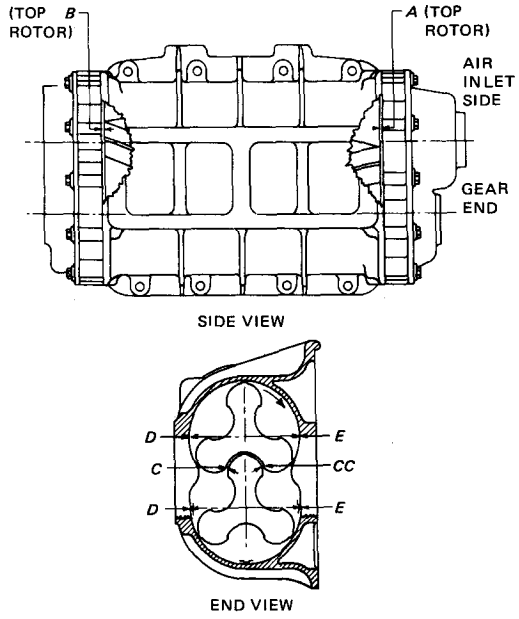


Fig. 18-16 Rotor-to-rotor and rotor-to-housing measuring points. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

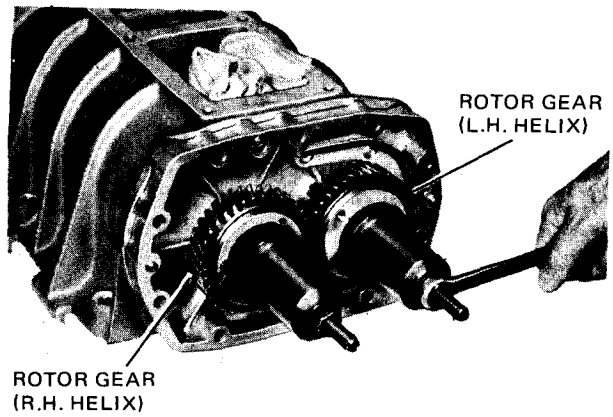


Fig. 18-17 Installing rotor gears on rotor shafts for preliminary clearance check. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

along the total length of the rotors. Compare your measurement with that specified in the service manual. Note example below:

		A	B	C	CC	D	E
4-71	Min.	0.007	0.009	0.012	0.002	0.015	0.004
	Max.				0.006		
6-71E and T	Min.	0.007	0.014	0.012	0.002	0.015	0.004
	Max.				0.006		

Time Rotors to Dimensions Above

To increase the clearance at *CC*, pull the top timing gear out; to reduce the clearance, pull the timing gear in. To increase clearance at *C*, pull the bottom timing gear out; to reduce clearance, pull the gear in. *(NOTE: A 0.003-in [0.076-mm] shim revolves the rotor 0.001 in [0.025 mm].)* When you have the clearance properly adjusted, use a feeler gauge to measure between the gear and bearing inner race to determine the required thickness of the shims. Pull both gears evenly from the rotor shafts. Place the selected shims on the shafts against the inner race bearing and install the gears.

NOTE: Be sure to recheck the clearance at CC and C, and remeasure at points A and B. Place a lock-plate washer and gear-retaining washer on one gear-retaining bolt and screw in the right-hand helix shaft. At the same time guide the tangs in the seats of the timing gear. Place a lock-plate washer and fuel-pump drive-coupling disk over the other gear-retaining bolt and screw it into the left-hand helix rotor shaft. Guide the lugs into the gear slots. Torque the bolts to specification and bend one lug onto each retainer bolt head. Next, remove the shop towel from the blower rotors and bolt the rotor drive hub to the top rotor, the fuel pump drive to the lower rotor, and then bolt the rear-cover end plate to the rear end plate.

Installing Fuel-transfer Pump Place a new gasket on the fuel-transfer-pump mounting surface. Place the pump-drive-coupling fork on the square of the drive shaft and align it with the slot in the drive

disk. Place the pump-drive-coupling fork in position and tighten the transfer pump to the rear-cover end plate.

Installing Governor and Coolant Pump Place a new gasket on the mounting surface of the governor housing and slide the governor shaft splines into the splines of the upper rotor. Use new copper gaskets on the hex bolts which secure the governor to the front-cover end plate.

To install the coolant pump, place a new gasket on the mounted surface of the front-cover end plate. Align the locks of the coolant-pump drive coupling with the locks of the intermediate coupling and position the pump on the cover. Secure the pump to the end cover using new seal washers on the three hex bolts.

Installing Blower to Engine Since blower locations vary, only the most common procedures are listed below.

Use nonhardening gasket sealant on all gaskets. Hand-tighten all hex bolts, particularly those of the governor which are screwed into the cylinder head, *before* tightening them to the recommended torque.

Connect and secure the fuel lines, coolant-pump outlet hoses, and clamps to the cylinder block. Connect the oil cooler. Install the air shutdown and connect, if applicable, the turbocharger (compressor) with the blower air inlet.

Testing Air-intake System for Leakage When there is evidence of dirt around the connections, in the hoses and pipes, in the compressor housing, on the compressor wheel, or in the connecting link to the intake manifold, this indicates an air leak. Therefore, you must pressure-test the intake system to locate it. This test should also be made after servicing the intake system, or when dirt is found on the inside of the air-filter housing.

To test for air leaks you need a pressure gauge which registers about 20 psi [137.9 kPa], a shutoff valve, a pressure regulator or tire pump, and either an inner tube or a rubberized plastic material which will withstand a pressure of 5 psi [34.5 kPa] (Fig. 18-18). Cover the air-cleaner intake with the inner tube or rubberized plastic material to make it airtight, and connect the air hose to the intake system. Position one piston so that the valves do not overlap and so that no air can escape through the exhaust valves. The valves do not overlap when the piston is ATDC and the exhaust valve of that cylinder has just closed and the intake valve is open.

Now pressurize the intake system to 5 psi [34.5 kPa], shut off the airflow, and observe the pressure gauge. If the pressure drops back to zero immediately, recheck the piston position. It may be that the exhaust valves are not closed or there may be a serious leak in the air-intake system. Apply the soap solution method to all connections and hoses to locate the leaks. Repair as necessary and then repeat the test. If pressure again drops quickly back to zero, make a thorough check of the air-cleaner housing and the aftercooler. When no leak can be found in the entire intake system, but specified air pressure still cannot be obtained, the cause is due to either a leaking valve or valves, or worn piston rings [see Air-Intake Restriction and Poor Compression (Unit 53, "Troubleshooting and Tuneup")].

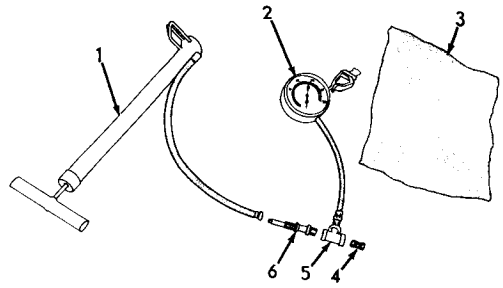


Fig. 18-18 Equipment required to pressure-test the air-intake system: (1) tire pump, (2) pressure gauge, (3) airtight rubberized or plastic material, (4) ¼-in [6.35-mm] pipe nipple, (5) ¼-in [6.35-mm] pipe tee, (6) valve stem with ¼-in [6.35-mm] pipe plug. *(Allis-Chalmers Corp. Engine Division.)*

Questions

1. List the inspections and checks to be made prior to installing a manifold.
2. What is the major difference between an oil-bath air cleaner and a dry-type air cleaner?
3. What would result (to engine performance) if the oil level in the bowl was, say, 1 in higher than specified?
4. Why does a dry air cleaner have a higher efficiency than an oil-bath cleaner and why is it not affected by climatic conditions?
5. Explain how you would check a dry-type filter element for damage and for cleanliness.
6. What is the purpose of an aftercooler?
7. List the advantages of an air-to-air cooler over an aftercooler.
8. List the areas you should check when an air-intake leak is suspected. How would you locate this suspected air leak?
9. Why does a Roots-type blower require no lubrication?
10. List the areas or check points which should be inspected to determine the operating condition of the blower.
11. Explain how you would increase, to specification, the running clearance of a blower at CC (Fig. 18-16).
12. Why must the timing gear be evenly removed from, or evenly installed to, the rotor shaft? (See Fig. 18-17).

UNIT 19 • EXHAUST SYSTEM

Purpose of Exhaust System The purpose of the exhaust system is to direct the exhaust gases into the atmosphere and to silence the noise by dampening the exhaust pressure waves. However, the back pressure imposed by the piping and the silencer must not exceed 3 inHg [7.62 cmHg].

Exhaust System Components The exhaust system consists of one or two one-piece exhaust manifolds or of multisectional exhaust manifolds, exhaust pipes, and a silencer (muffler). When a turbocharger is used, the turbine side of the turbocharger becomes part of the exhaust system (Fig. 19-1).

Removing Exhaust Manifold If a turbocharger is used, remove the air-cleaner or aftercooler connection from the compressor flange, and the exhaust pipe from the turbine flange. Remove the turbocharger. (Use masking tape to cover all openings.) Next, bend the locks from the manifold nuts or bolt heads, if applicable (Fig. 19-2). Remove the nuts or bolts and lift the manifold from the cylinder head.

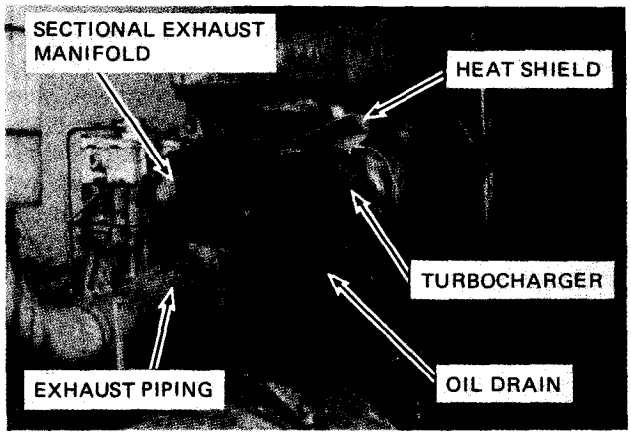


Fig. 19-1 View of exhaust system.

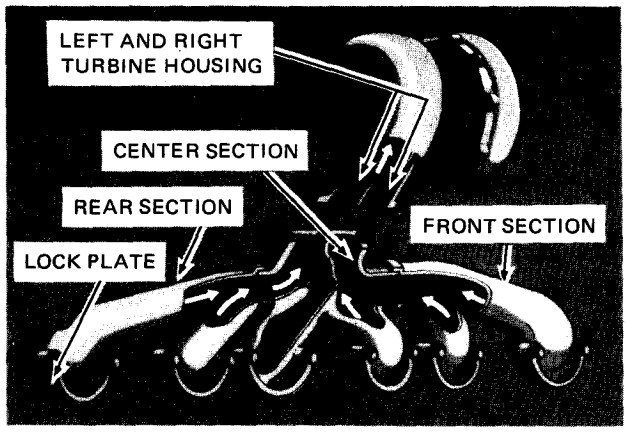


Fig. 19-2 View of pulse-type exhaust manifold and turbocharger. *(Cummins Engine Company, Inc.)*

Inspecting and Servicing Exhaust Manifold In most cases the manifold can be steam-cleaned; however, when carbon deposits or scale are present, the manifold must be cleaned with a sand or glass-bead cleaner. This is especially important with a turbocharged engine to prevent loose scale from entering and therefore damaging the turbine.

Check the manifold for cracks. Using a straightedge, check the mounting surface for warpage. If warpage is sufficient to prevent effective sealing, the mounting surfaces must be machined or the manifold replaced. Check the threaded bores for damaged threads or broken studs. If you have not previously checked the stud bolts in the cylinder head for thread damage, do so now. When installing new stud bolts, use an antiseize lubricant to prevent thread corrosion and seizure.

Installing Exhaust Manifold To prevent damage to the engine, make sure that all loose deposits and cleaner dust (residue) are removed from the manifold, particularly when a turbocharger is used.

After you have checked the cylinder-head surface, place new manifold gaskets over the stud bolts or install temporary stud bolts. *(NOTE: The beveled side of the gasket should face you.)*

When a multisectional manifold is used, install the center section first but do not tighten the bolts. Then slide each end section into place or assemble the manifold on the workbench and install it as a unit. Apply an antiseize lubricant to the threads of the studs or manifold bolts, and tighten the manifold bolts to the specified torque and in the recommended sequence. Check the service manual in the event special washers are required on the manifold bolts.

Install the exhaust elbow or the connecting link to the turbine. If the turbocharger is not to be installed immediately, cover the exhaust opening.

Turbochargers Since the dependable and relatively efficient diesel engine cannot easily be replaced with another type of engine, extensive and costly research programs have been undertaken to modify its emissions for environmental protection and to improve its energy efficiency. *Supercharging* may be defined as the precompression of part or the whole of the charge (air) outside the working cycle.

Supercharging, using a turbocharger, employs the normally wasted exhaust energy to drive the (air pump) impeller and therefore most effectively increases power (mean effective pressure) without increasing the engine speed, the number or displacement of the cylinders, the stroke, or the mean piston velocity. The mean effective pressure of today's diesel engines using a turbocharger is between 160 and 230 psi [1103.2 and 1585.8 kPa], which is a power gain of 75 to 100 percent for the same engine when not turbocharged. Turbocharging requires, among other things, a very strong engine to carry the in-

creased gas force. The birth of the turbocharger has come about after many engineering refinements, improved metallurgy, more efficient fuel-injection systems, and better-quality engine oils. The power-to-weight ratio, however, which was previously 10:1, is now close to 6:1.

The modern diesel is highly economical on fuel and the exhaust emission is relatively clean. However, to achieve the optimum power output, the volumetric efficiency and the scavenging flow must be increased. To accomplish this, the valve overlap is increased and the compression ratio is slightly reduced. On four-cycle engines the exhaust valves open between 40 and 70° BBDC to avoid negative piston displacement, and to obtain a sufficiently large airflow during scavenging the exhaust valves close as much as 40 to 60° ATDC.

Turbocharger Design Basically there are two types of turbochargers, the constant pressure and the pulse turbocharger. On a constant-pressure turbocharger the exhaust gas of all cylinders is piped into a common exhaust manifold so that the pressure pulses are smoothed out, resulting in an almost constant pressure in the intake manifold. On a pulse turbocharger, pressure and air velocity fluctuate in the intake manifold because individual exhaust manifolds are used in which flow the exhaust gas of a number of cylinders (see Fig. 19-2). The exhaust energy of each manifold is placed on the turbine wheels in the form of pressure energy so that there is a back pressure of varying magnitude in the exhaust manifolds which affects the exhaust work done by the pistons. The objective when using a pulse turbocharger is to have a pressure higher than the boost pressure in the exhaust manifolds at the time the exhaust valves open which then drops below boost pressure toward the end of the exhaust stroke during the scavenging. *(NOTE: The pressure rise in the cylinders during scavenging is caused by the inflow of charged boost air.)* To achieve this pressure fluctuation, a four-cylinder or six-cylinder engine requires two exhaust manifolds, whereas eight-cylinder engines require four exhaust manifolds in order to provide a pressure interval of 240°. This also necessitates a turbine housing division into two or four entry volutes.

A pulse turbocharger in comparison with a constant-pressure turbocharger has the following advantages: It has (1) no backflow of exhaust gases to the cylinder(s) which are on the intake stroke at part or full load, (2) a higher scavenging gradient even at full load, (3) a greater acceleration potential because of its pulse, and (4) superior scavenging, which results in a lower exhaust temperature and reduced emission during acceleration.

On the whole, all turbochargers are similar in design. They consist of three basic systems (see Figs. 19-3 and 5-2), that is, the turbine and turbine housing, the bearing housing assembly, and the compressor housing and impeller. The differences which exist are the manner in which they arrive at the various desired boost pressures and airflow (volume). The turbine housing, turbine wheel design, and volute or nozzle opening size determine the velocity of exhaust gas flow and the shaft power. The compressor housing (including inlet diameter), scroll, diffuser, and impeller design (blade angle and diameter) must match the shaft power to achieve the desired airflow and pressure. The diffuser's purpose is to convert the air velocity (kinetic energy) into pressure. The heat shield, with its insulating material, minimizes heat transfer to the bearing assembly. The bearing housing assembly supports the turbine and compressor housing and the bearing (bushing) assembly. The bearing supports the common turbine and impeller wheel shaft. It may be a one-piece unit or consist of two pieces, one pressed into the left- and the other into

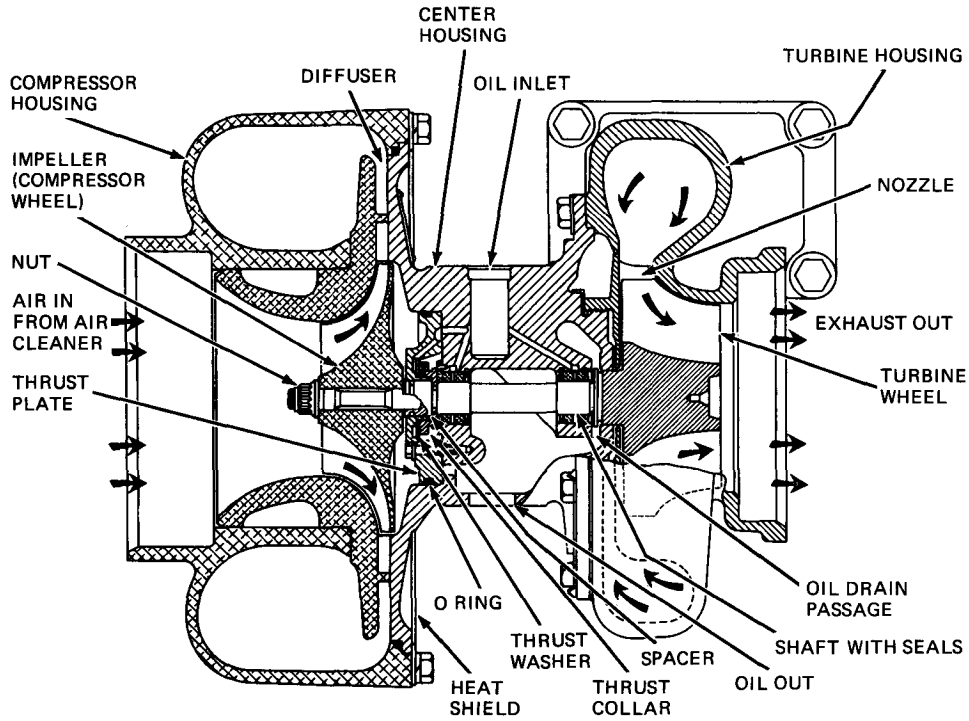


Fig. 19-3 Schematic view of a turbocharger.

the right-hand side of the bearing housing. If a one-piece bearing is used, its flange serves as a thrust bearing. When two bearings are used, a separate thrust bearing and thrust collar are employed to absorb the thrust placed on the compressor wheel during operation. The bearing assembly receives oil from the engine lubrication system. Pressurized oil enters the bearing housing and is distributed through oil passages to the bearing(s) and shaft, and drains through gravity into the lower bearing housing, and then through a drain hose into an oil pan.

The average exhaust temperature at lower engine load is about 500°F [260°C], and the boost pressure is about 5 inHg [12.7 cmHg]. At maximum engine load (maximum torque), the exhaust temperature may reach 1000 to 1200°F [537.7 to 648.8°C] with a boost pressure of about 35 inHg [88.9 cmHg]. *(NOTE: The exhaust temperature varies because of the displacement variation, the boost pressure variations, and whether or not the engine is aftercooled.)*

Action in Turbocharger The turbocharger, through its turbine housing, is bolted to the outlet of the exhaust manifold. Either the compressor housing or the compressor extension is connected to the inlet manifold or aftercooler.

Refer to Fig. 19-3 as you read the following description of the action in the turbocharger. After the engine is started, the exhaust gases leave the exhaust manifold and enter the turbine housing. The exhaust gases flow under pressure, and with relatively high velocity, into the volute-shaped turbine housing. The snail-shaped housing gradually decreases in area, causing a further increase in velocity. The high-velocity air is directed through the nozzle onto the turbine wheel and from there discharges through the exhaust pipes to the atmosphere.

The exhaust gases force the turbine wheel and the compressor wheel to rotate, which in turn creates a low pressure at the compressor housing inlet. Atmospheric pressure forces air at high velocity into the inlet opening of the compressor housing or compressor extension. The continued increasing rotational speed of the impeller increases the air velocity. As the air is forced through the diffuser and then into the compressor housing, it gradually slows down, converting the kinetic energy into pressure. The diffuser may be in the form of an open passage with a cross-sectional area which gradually increases toward the outer circumference, or it may be in the form of blades. The diffuser, compressor housing, and the inlet manifold convert the air velocity to pressure. When the engine operates at its maximum torque rpm, the turbocharger operates at its maximum designed efficiency, that is, it operates at its maximum designed rpm and within its designed boost pressure. Any variation in engine torque reduces the rpm and boost pressure; however, rpm and boost pressure will not reduce proportionately.

To balance the quantity of fuel being injected with the boost pressure, various control devices are used. These control devices are designed to prevent excessive turbocharger rpm and boost pressure, and/or to reduce emissions during acceleration and deceleration.

Two-stage Turbocharging To increase the torque range and to increase the mep to an even higher value, some V and in-line engines use two or four turbochargers and aftercoolers (one for each exhaust manifold), or they use two turbochargers in series and an aftercooler (see Fig. 19-4).

OPERATION The air flows from the air cleaner into the first-stage compressor housing (low-pressure turbocharger), from the housing outlet into the second-stage compressor, and from the second-stage outlet into and through the aftercooler into the intake manifold. At this point the airflow temperature is reduced to 223°F [106°C] and has a pressure of 60.4 inHg [204.5 kPa].

The exhaust gas from combustion enters the pulse-type exhaust manifold and then enters into the second-stage pulse turbine housing. The exhaust gas leaving the turbine housing is routed to the first-stage turbine housing, where it drives the turbine wheel with

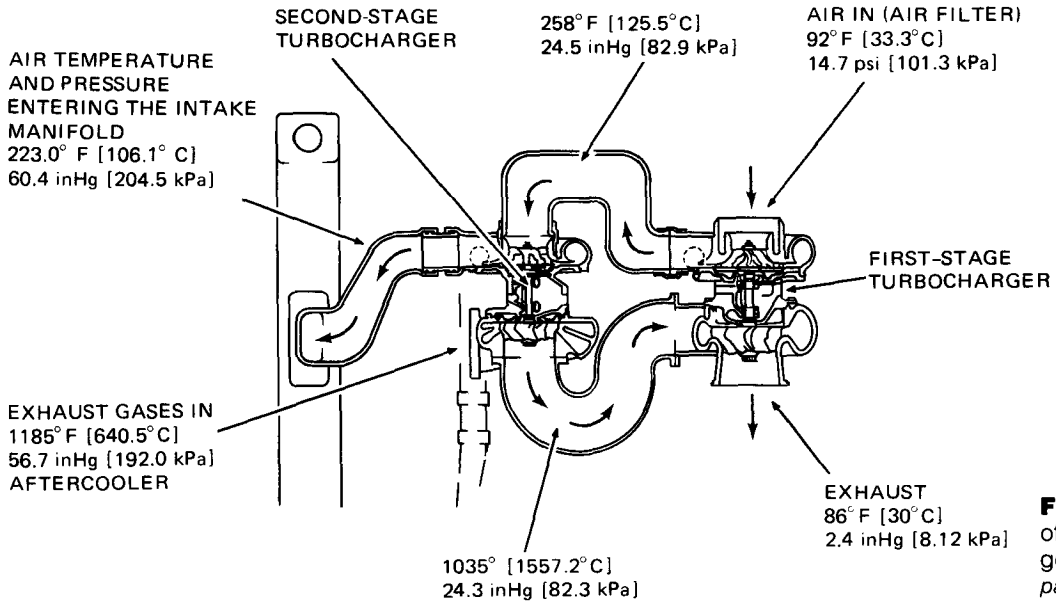


Fig. 19-4 Schematic view of a two-stage turbocharger. *(Cummins Engine Company, Inc.)*

its remaining energy. It then exhausts into the exhaust pipe system and then into the atmosphere. Through this design the engine gains 75 hp [55.93 kW] and increases its torque range to 700 rpm.

Compound Turbocharging Another turbocharging approach soon to be seen on engines is shown in Fig. 19-5. An experimental engine of this design has a proven efficiency of 46.5 percent. The system includes a power turbine wheel and its shaft, connected to a fluid coupling. The turbine of the fluid coupling is connected to a reduction gear train and its output shaft is connected to the crankshaft. It uses the standard turbocharger.

OPERATION Exhaust gas drives the power turbine wheel, which in turn drives the fluid coupling. The turbine drives the reduction-gear input shaft, and the output shaft helps to rotate the crankshaft. The exhaust gas leaving the power turbine housing is routed to the turbocharger turbine housing, driving the turbine and impeller wheel. The remaining airflow and exhaust gas flow are the same as that of a standard turbocharged engine.

Turbocharger Failure The most prevalent causes of turbocharger failure are: extreme temperature caused by hot shutdown, a restricted air cleaner, air leaks in the intake system, leaks in the exhaust system, overfueling, higher altitude without compensatory fuel-pump adjustment, or a dirty compressor wheel due to a leak in the air-intake system.

Secondary causes of turbocharger failure are the failure to prelubricate the turbocharger after completion of servicing, after an oil filter change, or after a long shutdown period. A malfunction in the lubrication system or the oil supply will also cause the turbocharger to fail.

Improper maintenance is another contributor to turbocharger failure. Dirty air cleaners, oil leakage into the air-intake system, leaking oil lines, air leaks, exhaust leaks, and loose or overtorqued mounting bolts or clamps also can reduce the efficiency of the turbocharger.

It is seldom that a compressor or turbine wheel is damaged by foreign material entering the turbocharger or that a turbocharger fails because of improper assembly or component damage during assembly, although both have been known to happen.

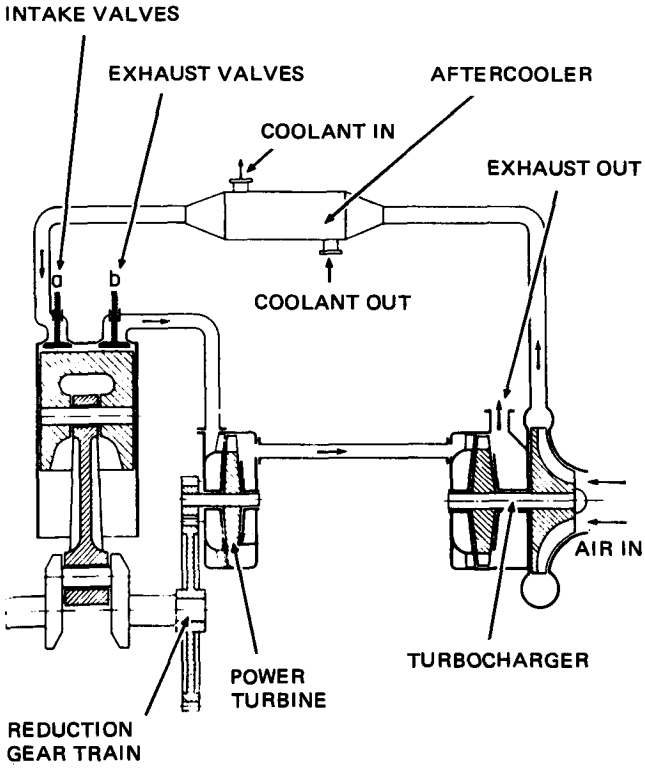


Fig. 19-5 Schematic view of a compound engine with power turbine. (Note that fluid coupling is not shown.)

Inspecting and Maintaining Turbocharger Turbochargers (depending on the engine design and torque) are exposed to temperatures of 800 to 1300°F [427 to 704°C] or more, and they may be driven at speeds of 60,000 to 150,000 rpm. Therefore, weekly inspection of a turbocharger is advisable if it is to be kept in good running condition.

Begin your inspection with the air-intake system's air cleaner because a faulty or dirty air cleaner restricts the airflow. A loss in power is then unavoidable since boost pressure is lowered. The restriction also can cause an otherwise serviceable seal to leak because of the vacuum the restriction creates.

Remove the connecting link to the intake manifold and check the compressor housing and connecting link for the presence of oil.

NOTE: The compressor housing (and sometimes the connecting link) of all operating turbochargers contains a small but harmless amount of engine oil. This is usually due to the lower pressure behind the compressor under running conditions. However, it can also come from an overfilled oil-bath air cleaner, although if this were the case, the vanes would also show evidence of oil. If you find "heavy" deposits or wet oil in the compressor housing and connecting link, they are an indication of seal leakage. The turbocharger should then be serviced immediately, otherwise extensive damage will result.

Check to be sure that all intake piping and components are aligned, that they fit without stress, that they are properly torqued, and that no evidence of leakage is present.

Check the crankcase breather and the turbocharger oil-return line for restriction. If either is restricted, the oil pressure will build up and cause the turbine end seal to leak.

Check, and when necessary, correct the position of the oil-return line. It must allow the oil from the bearing housing to return through gravity flow to the oil pan. If there is oil on the external surface of the turbocharger, check for a leaking oil cooler. Check the oil inlet and return line connection and/or the condition of the oil hoses. If either is defective, it is possible that the oil has been blown onto the turbocharger through air circulation.

Check the turbine housing for hairpin cracks which occur on its outer surface and near the mounting flange. (See Fig. 19-6.)

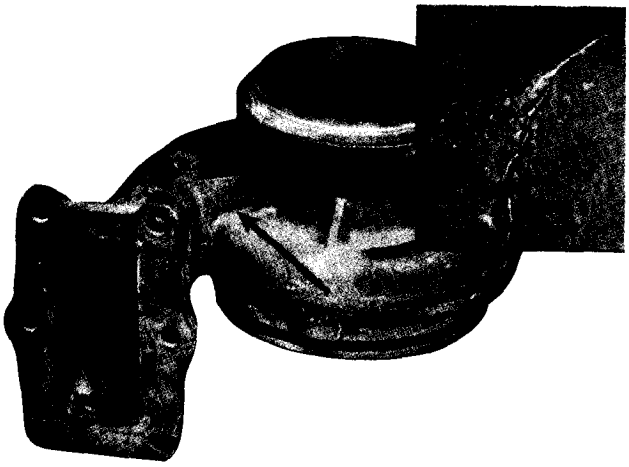


Fig. 19-6 Cracked turbine housing due to excessive heat. *(Cummins Engine Company, Inc.)*

Check the exhaust manifold for gas leakage and the exhaust piping for restriction.

Cleaning Compressor Housing and Compressor Wheel If there is an oil deposit or dirt on the compressor wheel, housing, or connecting link, the components should be cleaned, otherwise maximum performance (boost pressure) cannot be maintained. Some manufacturers suggest cleaning these components after 50,000 mi (miles) [80,450 km (kilometers)] or 1000 hours of operation.

When servicing the components you should, at the same time, check the compressor wheel for nicks and burrs. If the compressor components are only lightly covered with dirt or oil, remove only the compressor housing. Take care not to damage the compressor wheel or the diffuser when removing the housing. Use only a recommended metal-cleaner solvent and a bristle or nylon brush to wash the components. Never use a caustic solution, wire brush, sharp object, or glassbead cleaner because all of these will damage the components. This is particularly true of the compressor wheel which may lose its balance.

CAUTION Never permit cleaning fluid to contact the bearing housing.

Tolerance Checks In order to determine the condition of the bearing(s) and/or turbine shaft, several checks have to be made. To check the end play of the turbine shaft, install a dial gauge so that the dial pointer rests on the compressor end of the shaft (see Fig. 19-7). When moving the shaft back and forth against the dial indicator pointer, the total indicated dial movement is the total end play. It should be within 0.004 to 0.006 in [0.101 to 0.152 mm].

If the end play is less than 0.004 in, it is an indication of carbon or oil residue buildup. If the end play is more than 0.006 in, the bearings or the thrust bearing are worn, In either case the turbocharger should be serviced immediately.

To check bearing and shaft wear (radial clearance), remove the oil-return line, and in its place install a dial gauge with an extension through the opening created by the removal of the oil-return line (see Fig. 19-8). The extension must pass through the bearing hole and rest on the turboshaft. Exerting equal force on both ends of the shaft, move it against and away

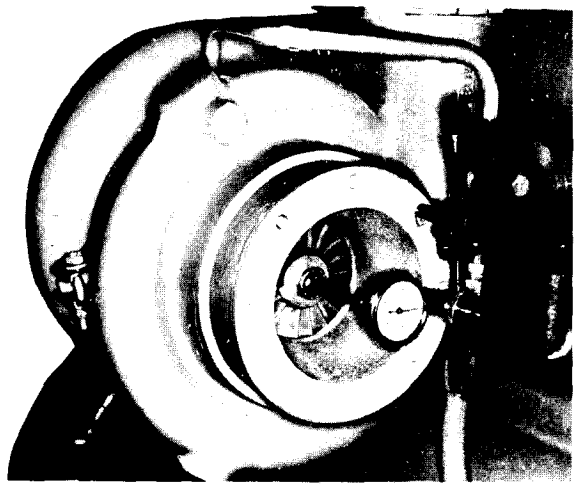


Fig. 19-7 Checking turbine-shaft end play with a dial indicator. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

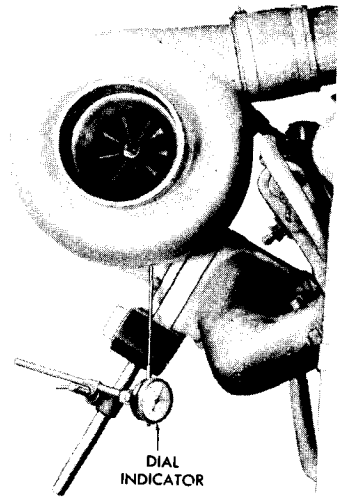


Fig. 19-8 Checking radial clearance. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

from the dial indicator pointer. When moving the shaft back and forth against the dial indicator pointer, the total indicated dial movement is the total bearing clearance. If the total indicated clearance exceeds 0.003 in [0.076 mm], the turbocharger should be serviced. Servicing a turbocharger requires special tools. Furthermore, servicing is not usually done by a diesel mechanic, and hence it is not covered in this text.

Installing Turbocharger Before you install a turbocharger, check the intake and exhaust manifolds for loose foreign materials such as bolts, lock washers, etc. Make sure before placing the turbocharger onto its mountings that all the manifold bolts are torqued to specification, that the mounting flanges are clean, and that the gaskets are in the correct positions.

Install all hex bolts fingertight using an antiseizing lubricant on the turbocharger mounting bolts. Loosen the V clamps that fasten the turbine housing and compressor housing to the center housing in order to align the compressor and turbine housing outlets; then tighten the mounting bolts and V clamps to the recommended torque.

Connect the turbocharger to the inlet manifold (or aftercooler), the oil inlet, and the oil-return line. When you install the oil-return line, avoid sharp bends and avoid an angle of more than 30° from the vertical. Keep the air-intake cover on to prevent foreign material from entering the turbocharger.

Questions

1. Which areas of exhaust manifold and cylinder head must be checked before the exhaust manifold can be installed?
2. What are the main differences between a turbocharger and a Roots-type blower?
3. Explain the airflow when the engine is operating at full torque rpm.
4. List the advantages of a pulse turbocharger over a constant-pressure turbocharger.
5. List the parts or components in a turbocharger that are used to vary the airflow.
6. List six causes of turbocharger failure.
7. List the periodic checks that should be made on a turbocharger.
8. Outline how to check the end play of the turbocharger shaft.
9. How can turbocharger failure be prevented?
10. What checks must be made after a turbocharger or blower has been installed to the engine?
11. A turbocharged diesel engine should be idled down before shutdown, to prevent (*a*) air pressure in the cylinders, (*b*) oil from going into the engine, (*c*) turbocharger from running out of oil, (*d*) oil from boiling in the turbocharger.
12. When hauling a turbocharged diesel engine on a low bed you should (*a*) fill the turbocharger with oil, (*b*) plug the exhaust pipe opening, or (*c*) plug the air-filter opening.
13. An aftercooler unit is used on a turbocharged engine (*a*) to cool the exhaust gas, (*b*) to cool the inlet air before it enters the engine, (*c*) to cool the inlet air before it enters the turbocharger, or (*d*) to cool the exhaust manifold.

UNIT 20 • COOLING SYSTEM

Purpose of Cooling System The purpose of the cooling system is to circulate the coolant in order to absorb, dissipate, and control the heat emanating from combustion. About 28 percent of the heat must be removed in order to retain the engine's efficiency and to reduce component wear. About 20 percent is removed by the cooling system and the other 8 percent through convection and radiation. The flow volume which the coolant pump must move through the coolant system, as well as the overall coolant volume, are specifically related to engine horsepower. For example, a 600-hp [447-kW] engine at its maximum power output must reject heat at the rate of 15,600 Btu per minute (Btu/min) [275 kW]. To meet this requirement the engine needs a coolant capacity of 8 gal (30.2 L) with a coolant flow of 220 gallons per minute (gal/min) [13.87 L/s) at an internal coolant pressure of 35 psi [241.3 kPa]. The airflow through the radiator must be 1400 ft^3/min (660.8 L/s).

Under the conditions outlined above, coolant in the top radiator tank would have a temperature of 180°F [82.2°C] when the thermostat range is 180 to 200°F [82.2 to 93.3°C].

Combustion heat is dissipated in three different ways: (1) convection, by means of air currents, (2) radiation, by waves sent out from the vibrating molecules, (3) conduction, by traveling through the metal into the cooling passages (where the coolant picks up the heat and carries it into the radiator). Heat absorbed by the engine oil is partly removed by conduction. The remainder is removed in the oil cooler and the oil pan by a combination of the methods just described.

The dissipation of heat, in itself, would be relatively simple if it were not essential that the cooling system maintain an even temperature at any torque range, at any engine-speed range, and at varying ambient temperatures, for example, from −30 to +110°F [−34.4 to +43.3°C].

At maximum engine torque and high ambient temperature the system is forced to dissipate heat at its maximum capacity in order to maintain the top tank temperature around 180°F [82°C]. When the engine torque and the ambient temperature are low, the system must nevertheless maintain the engine at approximately the same temperature.

Cooling-system Components Beginning at the front of the engine, the components which make up an average cooling system are: the radiator, fan, coolant pump, engine oil cooler, aftercooler, and the connecting pipes and hoses (Fig. 20-1). The cylinder block and cylinder head are, of course, also part of the system.

Some engines have additional components, such as a torque-converter oil cooler, a radiator shutter system, a coolant filter, a surge tank, and a second coolant pump.

It is the engine and equipment manufacturers who select the cooling-system components to be used on a given engine. They choose the radiator size, the shroud and fan size, the fan design, its rotating speed, and the coolant capacity and flow. Together, these components ensure that: (1) the cooling temperature in the top tank of the radiator does not exceed maximum prescribed temperature, that is, about 200°F [93.3°C]; (2) the horsepower required to drive the fans does not exceed 6 percent of the engine

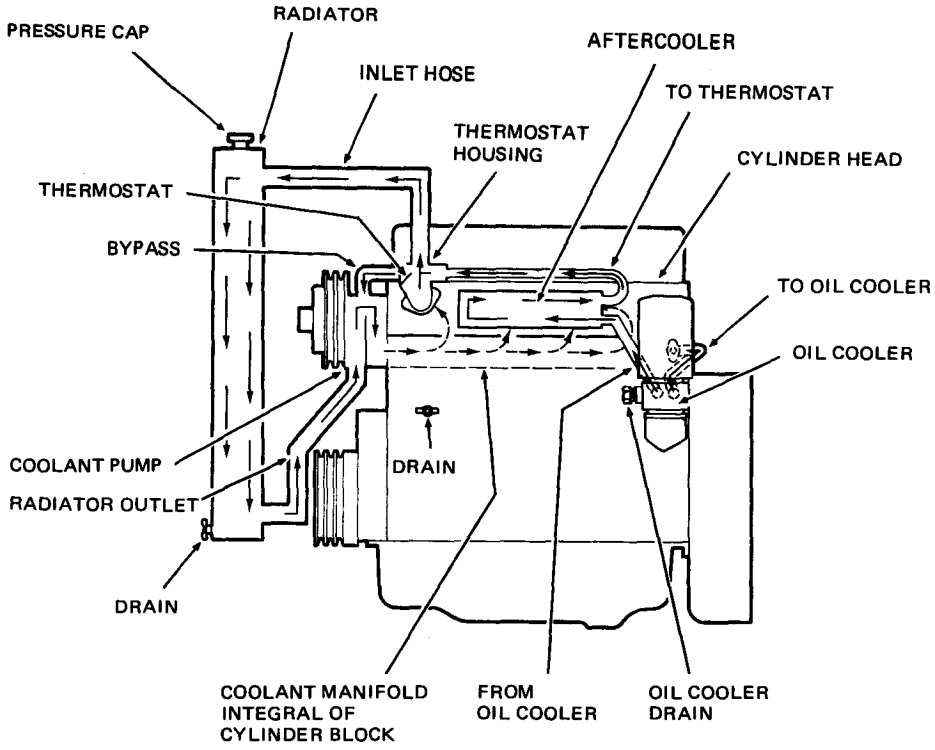


Fig. 20-1 Schematic view of a coolant system. *(Allis-Chalmers Corp. Engine Division.)*

horsepower; (3) the speed of the tip of the fan is not greater than 18,000 ft/min [6000 m/min] and therefore keeps the fan noise to an acceptable level; (4) the airflow does not exceed 1600 ft^3/min [755.12 L/s], and (5) there is no dead area (unswept core area) on the surface fo the radiator.

Maintaining Cooling System Quite often, operators and mechanics restrict their checks of the cooling system to the coolant level, coolant leaks, and perhaps to the drive belts. Sometimes the cooling liquid is not inspected or changed, and the coolant filter, thermostat, shutter system, and internal radiator, cylinder block, and cylinder-head passages also are neglected. Inefficiency in any of these components can cause the coolant temperature to increase above 200°F [93.3°C] or recede to about 150°F [66°C], allowing the oil to become sludge. Coolant deposits then form within the engine where the coolant meets hot metal. These deposits reduce the cooling flow to the cylinder sleeve, piston, and valves and thereby accelerate wear.

Coolant deposits fall into four categories: scale from waterborne minerals, products of corrosion, products of chemical incompatibility, and petroleum contaminants.

Coolant-system Requirements The coolant temperature in the top tank of the radiator should never exceed 200°F [93.3°C] regardless of ambient temperature or engine torque.

The coolant system must be capable of: (1) raising the coolant temperature quickly to keep engine-component wear to a minimum, (2) providing for coolant expansion and an outlet for the coolant to escape, (3) maintaining a greater than atmospheric pressure at the inlet side of the coolant pump, (4) providing a means for venting itself during the filling operation, (5) providing for de-aeration.

Air-cooled Engines The cooling system of an air-cooled engine includes an engine-driven blower to cool the cylinder fins and metal shields. The cooling fins on the cylinder and cylinder head are precisely calculated and designed according to the required heat dissipation of the area. They are enlarged to increase dissipation of heat and reduced to dissipate less heat. Metal shields direct the air around the fins in a predetermined flow and at a predetermined velocity to help achieve an even temperature.

Advantages of an air-cooled engine are:

1. It is of lighter and simpler construction compared to a liquid-cooled engine of the same horsepower.
2. The cooling system is easily maintained, that is, by simply checking the condition and position of the shields and the fins for breakage, dust, or oil accumulation, and by checking the blower drive belt and bearings for wear and general condition.

Radiators Two types of radiator designs are common to diesel engines: where the core, bottom and top tank, and side members are bolted together to form an assembly (Fig. 20-2) or where the core, top and bottom tank, and side members are soldered together to make up an assembly (Fig. 20-3). The core of either type could be built in two styles, that is, vertical or crossflow. *(NOTE: The crossflow (horizontal) type radiator was designed for low-profile installation.)* As its name indicates, the coolant in the crossflow type flows in a horizontal direction. Core construction may be any one of the three types shown in Fig. 20-4.

Factors which determine the radiator design are airflow, size, and cost.

Radiators should be as nearly square as possible if they are to provide the most effective fan performance, since this shape has the least unswept core area. The radiator fins are spaced with 8 to 10 fins

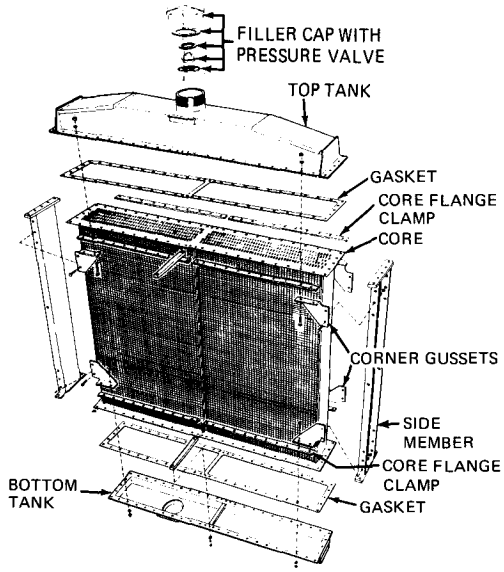


Fig. 20-2 Detailed view of typical radiator. *(Allis-Chalmers Corp. Engine Division.)*

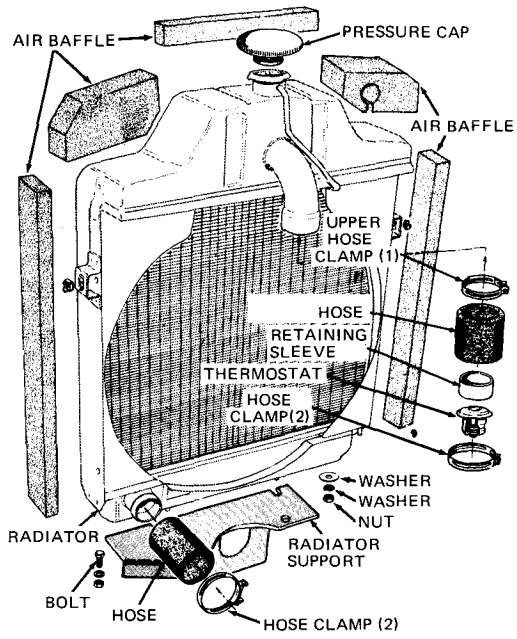


Fig. 20-3 Detailed view of one-unit radiator. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

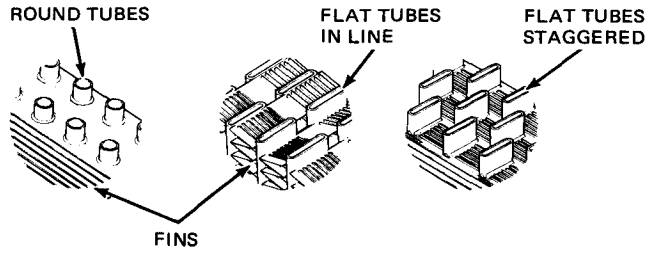


Fig. 20-4 Schematics of radiator core design.

per square inch [1.2 to 1.5 fins per square centimeter]. When heat dissipation is of prime concern, the number of fins per square inch is increased, but this can lead to faster core obstruction from insects, road dirt, etc. Furthermore, since additional fins restrict the airflow, more horsepower is needed to drive the fan.

Engine horsepower predetermines the radiator size (front square area). An average of 3 to 4 in^2 [19.35 to 25.80 cm^2] is needed for each engine horsepower and the airflow required is between 1000 and 1600 ft^3/min [471.9 to 755.1 L/s].

To improve airflow and fan efficiency and to direct the air around the engine, one of the three types of fan shrouds is used. They are bolted to the radiator and allow the fan blades to protrude about two-thirds past the corner of the shroud (Fig. 20-5). Airflow efficiency is greatest when the tip clearance does not exceed 1.5 percent of the fan diameter.

All radiators have a drain valve located at the lowest point of the radiator, one outlet connection in the bottom tank, an inlet connection in the top tank, and a radiator filler opening (filler neck) which is sealed by a radiator cap.

Some radiators have a solid baffle which divides the top tank into an upper and lower section to reduce aeration. Coolant enters the lower section from the cylinder head and the upper section from a standpipe. This latter design helps combat the cooling system's biggest enemy—air! Air in the coolant reduces heat dissipation, reduces heat transfer to the coolant, and can cause the coolant pump to lose its prime. It is also the principal cause of corrosive action in the coolant passages.

NOTE: The top tank area space serves as a reserve volume space to compensate for minute coolant losses and at the same time provides space for thermal expansion.

Coolant-system Piping Two coolant systems are schematically illustrated in Figs. 20-6 and 20-7. The system shown in Fig. 20-7 is designed with a separate top tank and a makeup line (supply line) which connects the top radiator tank and the lower radiator tank. The vent line (deaeration line) connects the cylinder head or cooling manifold to the top radiator tank. Because of these lines, problems associated with filling the radiator because of air locks are prevented. This system uses a pressure cap on the radiator.

The bypass line is the link between the thermostat and the cylinder block. Its purpose is to reduce warm-up time and to prevent overheating of the cylinder head. When the engine is shut down, the coolant pump stops but coolant continues to circulate from the hotter cylinder head into the cylinder block via the bypass line.

The system shown in Fig. 20-7 uses an additional reservoir (auxiliary tank) which is mounted higher than the (downflow) radiator. The auxiliary tank may be one as simple as that shown in Fig. 20-7, or it may be a tank similar in design to the top tank of a radiator. In this case the auxiliary tank has a pressure cap, and the radiator a solid cap.

The main function of the system design shown in Fig. 20-7 is to remove and/or prevent air from entering the system. It also provides additional coolant fluid to the system and reduces the possibility of coolant losses should the system become overpressurized.

Radiator Inspection and Testing As soon as it becomes apparent that there is a coolant leak, the

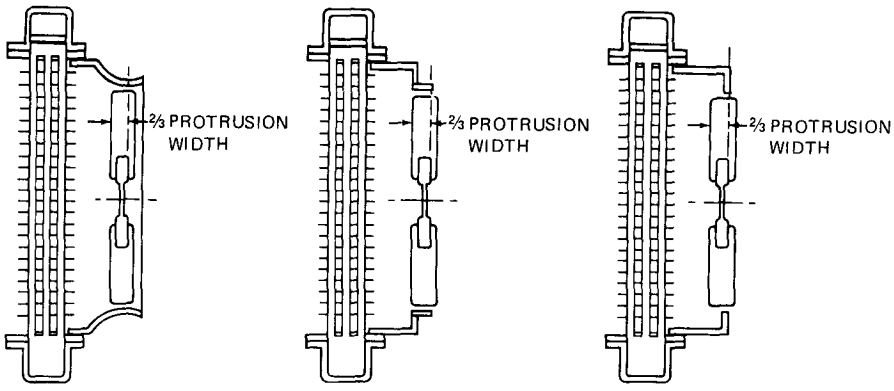


Fig. 20-5 Types of fan shrouds. *(Cummins Engine Company, Inc.)*

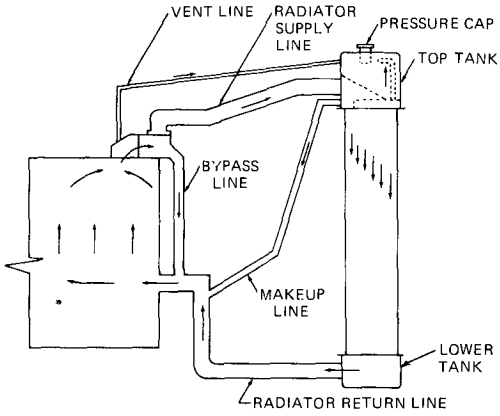


Fig. 20-6 Deaerating-top-tank piping. (The arrows show the coolant flow.) *(Cummins Engine Company, Inc.)*

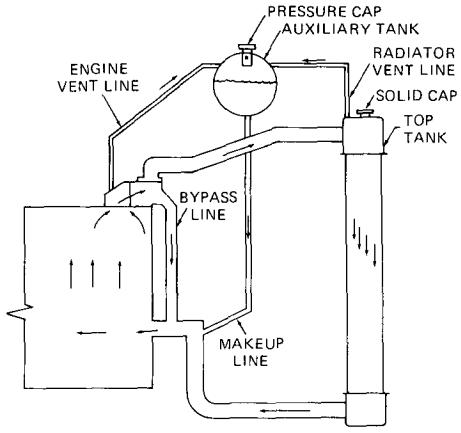


Fig. 20-7 Auxiliary-tank piping. (The arrows show the coolant flow.) *(Cummins Engine Company, Inc.)*

faulty component should immediately be repaired to prevent damage to the other components which also rely on the coolant. Radiator damage or leakage may be the result of undue force from external objects, a rough road or engine vibration, a loose radiator mounting, a broken engine mounting, or stiff radiator hoses. Occasionally, corrosion may cause the radiator to leak.

Examine the radiator carefully for white or rust-colored leak stains. Mark the stained area and then thoroughly clean the radiator. Before you remove the radiator for repair, it may be expedient to pressure-test the cooling system so as to expose any leaks which were not previously visible.

To pressure-test the coolant system, install a coolant-system pressure tester as shown in Fig. 20-8. Pressurize the system about 10 percent over the normal operating pressure. Check the total coolant system, particularly the coolant manifold and casting-core hole plugs. (Take care not to overpressurize the system. Excessive pressure can swell the radiator core tubes, which would restrict airflow and consequently damage the tank and/or the coolant pump seal.)

Removing Radiator Some radiators can be removed with relative ease; others require a more time-consuming effort. The simplest procedure is to first drain the coolant from the cylinder block and radiator. Then remove upper and lower radiator hoses. Remove the shroud and lay it over the fan. Finally, remove the mounting bolts. The radiator is now ready to lift up from its mounting.

CAUTION Use a lifting device that you know is safe.

Servicing Radiator Radiators should be inspected daily and cleaned regularly when operating conditions expose them to dust, leaves, insects, or other matter being trapped between the cooling fins. If these foreign particles are not removed, they will restrict the airflow through the cores and prevent heat transfer.

To dislodge alien matter, remove the shroud and,

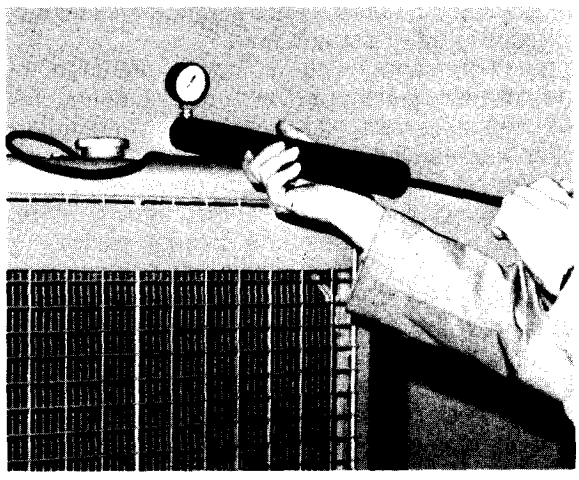


Fig. 20-8 Pressurizing the cooling system. *(Caterpillar Tractor Co.)*

with the air hose, direct the compressed air over the total area of the radiator surface in a reverse direction to the normal airflow. It is sometimes necessary to first flush water through the fin area to loosen the foreign matter. When a film of oil or grease causes dust to adhere to the fins of the core, a steam cleaner or spray-cleaning gun carrying cleaning solvent may be required. Never use a wire, screwdriver, or brush to clean debris from the fins because they will damage the tubes and bend the fins.

Most radiator core repair should be done by a recognized radiator shop since it has the appropriate equipment to make the required tests and repairs. However, if the leak is caused by a damaged gasket, you should be able to service it.

To replace leaking gaskets of the radiator shown in Fig. 20-2, hold the radiator by its side members. Never lay the core against an object because this will bend the cooling fins. Use an impact wrench to remove the top-tank bolts, but take care that your wrench holds the nut without slipping and damaging the core.

After you have removed the top tank, clean the tank and its flanges. Remove the old gaskets and when necessary straighten the core flanges. Check the core top surface and tubes for corrosion, scale, or sludge. If the radiator tubes are restricted, the bottom tank must be removed and the core cleaned in a hot cleaning tank.

CAUTION Use only the cleaning solution recommended by the manufacturer. Finally flush with clean water to remove any remaining solution.

When reassembling the radiator, apply a nonhardening sealant to both sides of the gasket. Tighten the hex bolts by using an even cross-tightening pattern to ensure a good gasket seal.

Before you install the radiator, straighten all fins. Bent fins restrict the airflow and reduce heat dissipation.

Cleaning Cooling System Do not procrastinate in cleaning the cooling system until such time as physical and chemical changes in the cooling system have caused insufficient heat transfer or have restricted the coolant flow. With a chemical cleaner, remove any accumulated deposits since they reduce heat transfer into the coolant fluid.

Two types of cooling-system cleaners are used: the alkaline cleaner and the inhibitor acid cleaner. The alkaline cleaner is most effective for removing sludge and silicon scale. The inhibitor acid cleaner is most effective for removing rust and carbonate scale.

Your cleaning procedure should include three steps: cleaning with an alkaline cleaner, recleaning with an acid cleaner, and flushing the system with a neutralizing fluid. Follow the cleaner manufacturers' instructions regarding the use of their products. Do not hesitate to seek advice on cleaning problems from your local supplier.

Simply stated, the cooling-system cleaning procedure is as follows:

1. Drain and, if necessary, flush the system with water to remove as much contamination as possible.
2. Remove the thermostat.
3. When the system has a bypass line (Figs. 20-6 and 20-7), this line must be plugged in order to allow concurrent cleaning of the radiator and to prevent overheating of the cylinder block.
4. Fill the cooling system with your ready-mixed alkaline solution and run the engine for the recommended length of time. (You may have to use the shutters or cover the radiator to raise the coolant temperature to that recommended by the supplier.)
5. After the recommended running time, cool the engine down by reducing the speed and removing the cover from the radiator.
6. Drain the system, flush it with clean water, and refill it with the acid solution.

CAUTION Do not fill or flush the system with cold water when the engine is hot because rapid cooling distorts the engine casting.

7. When the acid solution is drained from the cooling system, neutralize the system by flushing it with water and refilling it with a neutralizing solution. Another method is to reverse-flow flush first the radiator and then the cylinder block, in separate steps.

REVERSE-FLOW FLUSHING RADIATOR For reverse-flow flushing you need a flushing gun with an air and water connection and an air and pressure regulator. Connect a return hose to the radiator top tank so that the water does not go over the engine. Connect the flushing gun to the lower tank, as shown in Fig. 20-9. Open the water supply to fill the radiator, then regulate the air pressure to that recommended by the engine manufacturer. With the water running out of the top tank, intermittently apply air pressure for about 2 to 3 seconds at a time until clean water runs out of the top-tank hose.

REVERSE-FLOW FLUSHING CYLINDER BLOCK It is time-consuming to reverse-flow flush the cylinder block because the coolant pump must be removed, but it is recompensed in the long run. (You must also remove the thermostat and plug the bypass if this has not yet been done.)

Your first step is to install the flushing gun to the top coolant inlet, as shown in Fig. 20-10. Open the

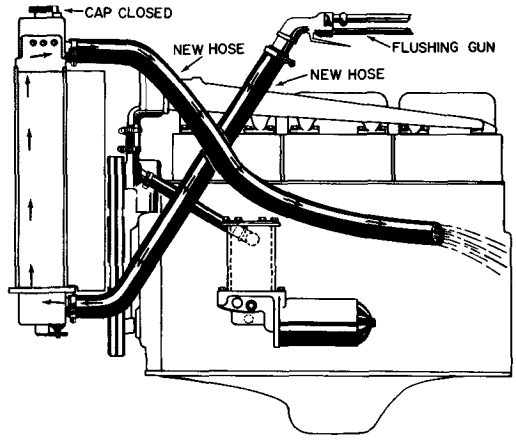


Fig. 20-9 Reverse-flow flushing the radiator. (The arrows show the water flow.) *[J.I. Case Agricultural Equipment Division (TENNECO).]*

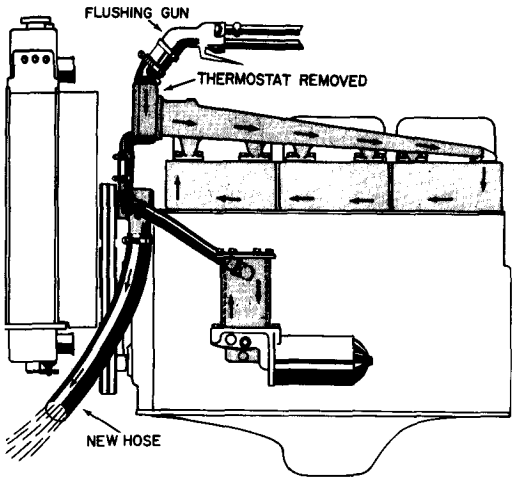


Fig. 20-10 Reverse-flow flushing the engine block. (The arrows show the water flow.) *[J.I. Case Agricultural Equipment Division (TENNECO).]*

water valve to let water flow through the cylinder block. Adjust the air-pressure regulator to the recommended pressure and blow the water out of the cylinder block. Repeat this procedure until clean water runs out of the opening.

Install the coolant pump and thermostat. Connect the bypass line. Fill the coolant system with an antifreeze concentration which is not less than 30 percent, otherwise the cooling system will not be protected sufficiently from corrosion.

Radiator Filler (Pressure) Cap The radiator or the surge tank (expansion tank) is equipped with a filler cap (Fig. 20-11) having a pressure and vacuum valve. The purpose of the pressure valve is to maintain a fixed coolant-system pressure during engine operation, and the purpose of the vacuum valve is to equalize pressure (coolant and atmospheric) when the engine is cooled off.

When the pressure in the system shown in Fig. 20-6 rises higher than the valve-spring tension, coolant leaves through the overflow, thereby reducing the coolant-system pressure. However, in the system shown in Fig. 20-7, when the pressure rises above the spring tension, air alone, and not the coolant fluid, leaves the system thus reducing pressure.

It is very important to the entire cooling system that the pressure value and vacuum valve seal properly and that the valve springs have the proper tension. When the pressure valve has a weak spring or a faulty seal, the boiling point of the cooling system will be lowered because the faulty valve lowers the system pressure.

For each 1 psi [6.89 kPa] above atmospheric pressure within the cooling system, the boiling point is raised by about 3°F [1.66°C]. The average cooling system operating pressure is about 25 psi [172.37 kPa]. This allows the engine to operate at a higher temperature since the water then boils at 287°F [141°C]. The boiling point is higher when antifreeze is added. For example, when the antifreeze concentration is about 40 percent at atmospheric pressure, this mixture will boil at about 223°F [109°C]. With a 25 psi [172.37 kPa] pressure cap, the boiling temperature will be higher: 298°F [147.7°C].

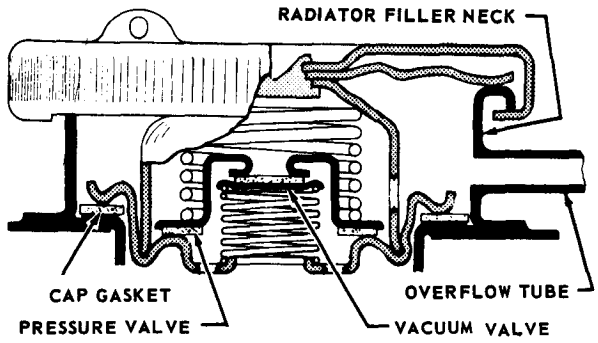


Fig. 20-11 Radiator filler cap. *(Mack Trucks Canada Limited.)*

Testing the Radiator Filler Cap and Filler Neck Check the top and lower cap seats on the expansion tank or radiator filler neck. A filler cap cannot hold the cooling-system pressure if the seat is damaged. The seat must be smooth; when it becomes rough, the filler neck must be replaced.

Check the general condition of the filler cap, the synthetic rubber seals, the gaskets, the pressure, and the vacuum springs. If any of these components are damaged, the cap must be replaced. When the cap is in good condition, use a filler-cap tester to check the effectiveness of the seals and the release pressure of the valve. The pressure should be within 1 psi [6.89 kPa] of specification. When checking the sealing effectiveness of a nonpressure cap (solid cap), pressurize the tester about 10 percent above normal system pressure. The pressure on the gauge should not vary at all.

Cooling Fans There are two types of fans—the pusher fan and the suction fan. They have varying airflow capacities and are of contrasting design. A suction fan draws the air through the radiator and then over the engine, whereas a pusher fan draws the air from around the engine and pushes it through the radiator.

Whether a pusher or suction fan will be used depends on the engine application. Loaders and wheel or track machines commonly use a pusher fan since it is less likely to draw as much dirt, sand, and small stones into the radiator as the suction fan. Fast-moving vehicles, however, use suction fans since the airflow through the radiator at their normal motor vehicle speed acts against the pusher fan. On smaller diesel engines the fan is bolted to the coolant pump whereas on larger engines the fan is bolted to the fan-hub assembly (Fig. 20-12). The coolant pump and the fan-hub assembly are driven by one or more V belts, a poly V belt, or are gear-driven.

The manufacturers also consider the weight of the fan as it affects the horsepower requirement, the life of the drive belts, and the bearings. Weight, however, is only one of the factors that have influenced many companies to use fiber-glass fans instead of steel fans. The flex of certain fiber-glass fan blades provides maximum cooling at any speed. Their fan-blade pitch changes automatically reducing or increasing with the change in engine speed. Furthermore, fiber-glass fans require less power than is needed to drive a fixed steel-bladed fan running at the same speed.

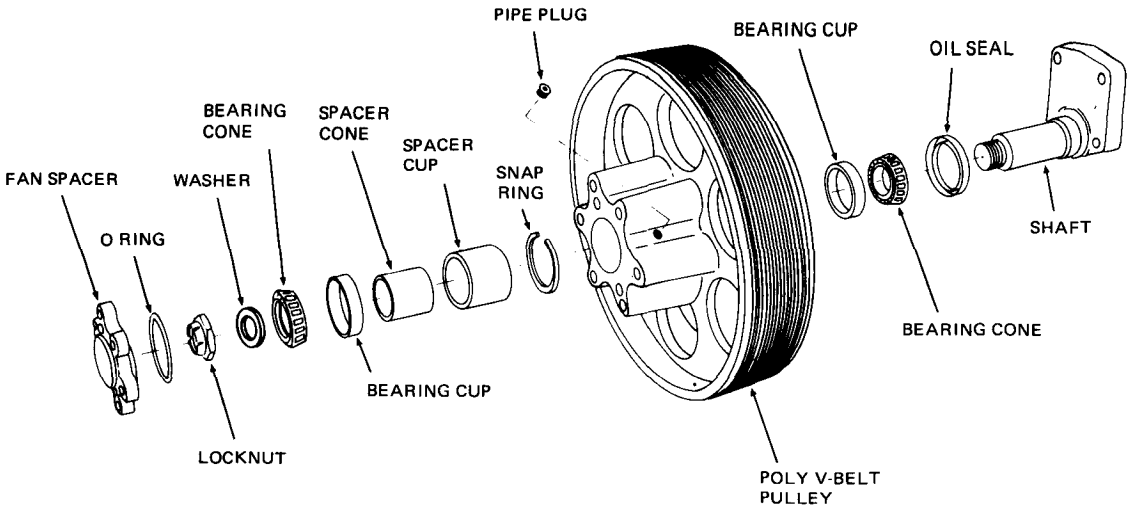


Fig. 20-12 Exploded view of a fan hub assembly. *(Cummins Engine Company, Inc.)*

Bearing and drive-belt life are increased and noise reduced.

Fan Inspection Fans should be inspected periodically for loose rivets, cracks, or bent blades. Remove any oil or dirt from the fan blades since contamination causes an unbalanced condition which can lead to blade breakage and bearing wear. Do not attempt to weld a cracked fan. Welding will destroy the fan's balance as well as the tensile strength of the steel. Slight bends may be straightened, but if the blade is sharply bent, the fan must be replaced.

Thermomodulated and Viscous Fans Inherent in the thermomodulated and viscous designed fans is their capacity to drive the fan only as required. For instance, to provide a fast engine warm-up the fan is not driven. They also require less horsepower to drive than the standard-design fan because the drive only commences when the coolant temperature approaches maximum. This not only increases drive-belt service life but lowers the fan noise level.

The thermomodulated fan is an integral unit with no controlling device or piping (see Fig. 20-13). The drive assembly consists of a sealed clutch housing filled with a silicone fluid. The drive plates are connected to the input drive and the driven plates to the fan-drive-housing assembly. The silicone-fluid film between the drive plates transmits the torque from one member to another, depending on engine temperature. Changes in air temperature, to which the temperature-control unit is exposed, vary the viscosity of the silicone fluid. Variations in viscosity reduce or increase friction and alter fan speed.

Maintenance and service of the thermomodulated and viscous fans is restricted to a periodic check of the fluid level, the condition of the bearings, and the cleanness of the temperature-control assembly.

Viscous Fan Drive The viscous fan drive is a sealed unit. It operates by changing the amount of fluid between the input and output member, which results in a controlled fan-speed drive. A leaf-type bimetal sensing unit is located on the front cover. It senses the temperature coming through the radiator core. The sensing unit is coupled to an internal valve. As the bimetal sensing unit reacts to temperature, it opens or closes the valve and regulates the flow of viscous fluid from the reservoir area into the drive area. The driving torque is transmitted by the shearing of a thin film of fluid between the surface of the housing, the input drive disk, and the front cover (to which the fan is bolted). {*NOTE: At no time while the engine is operating will the fan rotate at a one-to-one speed in relation to the drive input speed when the coolant temperature is at or above 180°F [82.2°C], nor will the fan completely stop at engine start-up (Fig. 20-14).*}

To check fan performance, remove the bimetallic strip and piston, make a chalk mark on the vibration damper, and then start the engine. Operate it at the recommended speed, say for instance, 1400 rpm. Check and adjust the engine rpm using a stroboscope. If the engine rpm is correct, hold the stroboscope to the fan and make the necessary adjustments

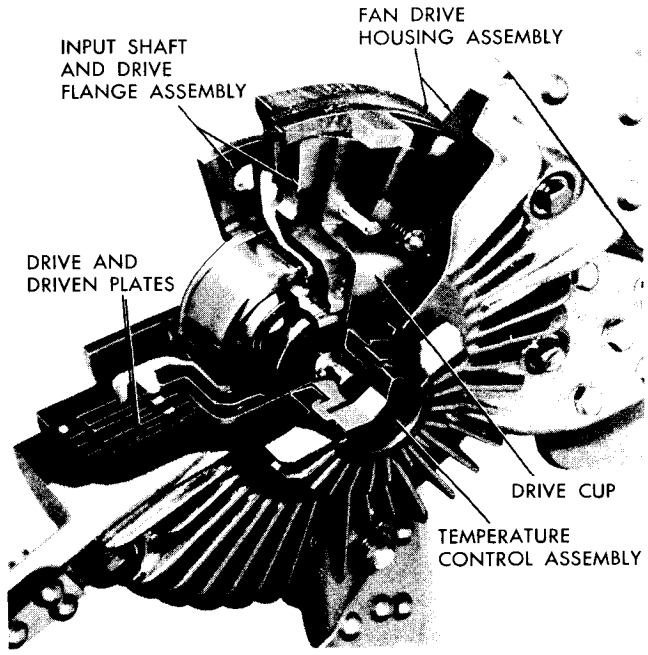


Fig. 20-13 Sectional view of a thermomodulated fan. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

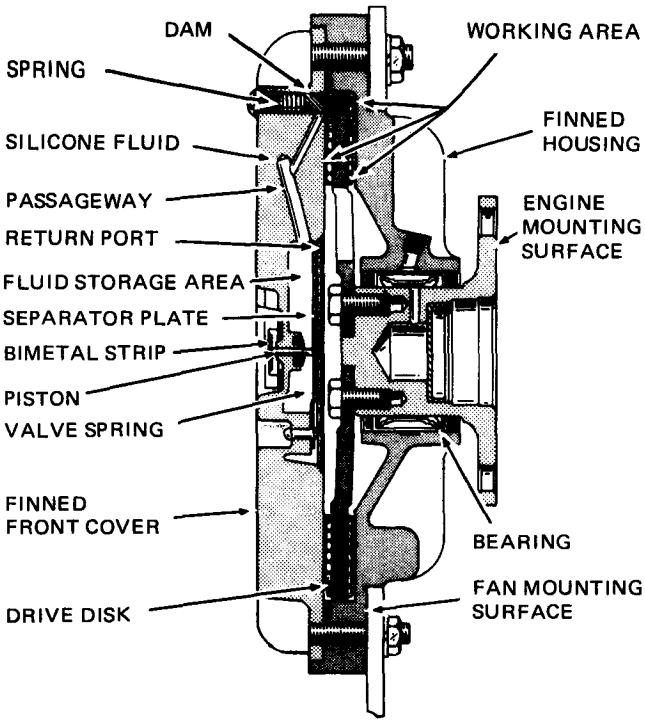


Fig. 20-14 Sectional view of a viscous fan drive. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

to regulate the flashes until the fan appears to have stopped. Read the dial. It should, in this instance, read 1890 to 1960 rpm if the viscous fan drive is in good operating condition.

Thermatic Fan Drive and Horton Fan Clutch The thermatic fan drive and the Horton fan clutch (Figs. 20-15 and 20-16) use a single-plate clutch which is disengaged by spring force and engaged by air pressure. As the coolant-system temperature approaches 184°F [84.6°C], the sensing switch closes the electric circuit and the solenoid opens the air valve. Reservoir pressure of 90 to 110 psi [620.5 to 758.4 kPa] is directed to the fan-clutch piston which then forces the clutch plate against the friction lining and connects the fan with the pulley. As the coolant-system temperature drops below the sensing switch temperature, the switch opens the electric circuit. The solenoid then closes off the air from the reservoir and opens the exhaust valve. Air is released from the piston and the spring force disengages the clutch, causing the fan to stop.

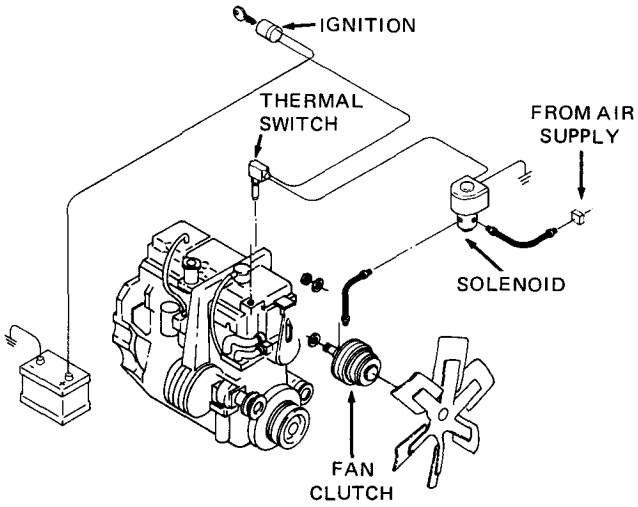


Fig. 20-15 Components of a Horton fan clutch. *(Horton Industries, Inc.)*

Servicing Fan Clutch, Sensing Switch, and Solenoid To check the operation and adjustment of the sensing switch, immerse the lower part of the switch in water. Connect an ohmmeter to the leads (see Unit 38, "Electric Circuits and Test Instruments"). Immerse a thermostat in the water and heat the water. When the ohmmeter indicates circuit continuity, take the thermometer reading. If the thermometer reading does not correspond with the recommended opening temperature, adjust the switch to allow it to open and close at the specific temperature.

NOTE: If a shutter system is used, the sensing switch of the fan must be adjusted about 5 to 10°F [2.8 to 5°C] higher than the sensing switch of the shutterstat.

To check the solenoid for an open, short, or grounded circuit, connect an ohmmeter to the electrical leads. Measure the resistance of the solenoid coil. Compare this measurement with your specification.

Check and inspect the air valves and seat. Make certain that the rubber is not damaged and that the seat is not rough and has no grooves.

To service the fan-clutch assembly (bearings, piston seals, O rings, friction clutch or pulley), clamp the assembly in a vise and remove the eight socket-head cap screws which hold the air chamber to the bearing cage (see Fig. 20-16). Remove the air chamber, slide the key out of the adjusting nut, and remove the nut. The spindle, spacer, and piston assembly can now be removed from the spindle (journal).

Replace all seals and gaskets. Repack bearings with the recommended grease. Check the pulley

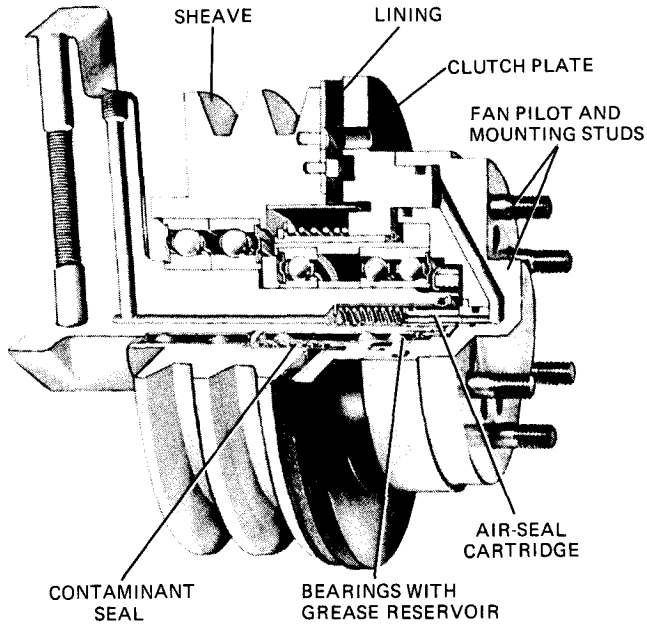


Fig. 20-16 Cutaway view of a Horton fan clutch. *(Horton Industries, Inc.)*

grooves, the friction disks, and the spline hub for wear. Replace the air-seal cartridge. Reassemble the components.

NOTE: When you lubricate the seals and O rings, check that they are not twisted. Tighten the adjusting nut, the stud bolts, and the cap screws to their recommended torque.

K-temperature Sensing Fan Drive This type of fan drive is used on Cummins engines only (see Fig. 20-17). The fan drive is bolted to the timing-gear cover with the drive gear in mesh with the camshaft gear. The drive gear and shaft, as well as the fan hub and shaft, are a one-piece unit. Each shaft is supported by one set of tapered roller bearings. The clutch drive hub is splined to the drive-gear shaft and the clutch-driven hub is splined to the fan hub shaft. The external tangs of the steel clutch drive plates are positioned in the slots of the drive hub, and the internal splines of the fiber-face driven plates are splined to the external splines of the clutch-driven hub. The thrust bearing is positioned between the rotating pressure plate and the stationary thrust washer. Two large Belleville springs are positioned behind the thrust plate to provide force on the clutch pack for engagement; therefore, the clutch is engaged whenever the air pressure is removed from the piston cavity. An air piston is located within the cylinder and is fastened to the front cover. The cylinder is positioned over the front cover; however, it can move to the left or the right. A thermo air valve and the energy of compressed air are the control unit to engage and disengage the clutch. The thermo air valve is screwed into the thermostat housing and the air line from the primary reservoir is connected to the front inlet fitting. Another hose is connected from the end-outlet fitting to the front-cover inlet fitting.

Engine oil pressure lubricates the fan drive, the bearings, and the clutch pack, then drains back into the timing-gear cover. An orifice at the inlet port reduces the oil pressure entering the oil passages.

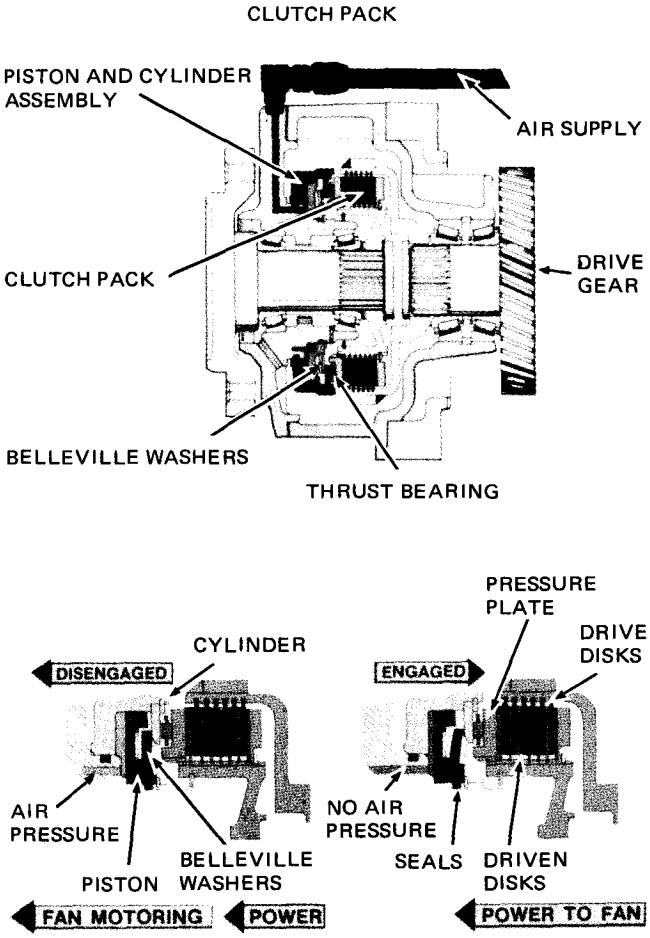


Fig. 20-17 Schematics of K-temperature sensing fan drive. *(Cummins Engine Company, Inc.)*

FAN DRIVE OPERATION When the air reservoirs are without air, the coolant is at atmospheric temperature, and the engine is started, the Belleville springs' force engages the fan clutch, thus driving the fan. As the air pressure increases and overcomes the Belleville springs' force, the cylinder moves to the left and with it, through the thrust plate, the ends of the Belleville springs also move to the left. This releases the force on the pressure plate, releases the clutch pack, and disconnects the fan from the drive shaft. However, since there is oil between the clutch plates, the fan may rotate. As the coolant temperature rises, the thermo air valve senses it and regulates (reduces) the air pressure and the cylinder moves to the right, allowing the Belleville springs to start engagement of the clutch pack and drive the fan. *(NOTE: The air pressure is in direct proportion to the slip ratio of the clutch. When the coolant reaches the specified temperature, the clutch becomes fully engaged because the thermo air valve then cuts off the air supply to the piston cavity.)*

Testing Fan Drive If you suspect that the fan drive is not operating properly, remove the air line from the front cover and connect the shop air supply to it. Supply an air pressure of 110 to 125 psi [758.4 to 861.8 kPa] to the clutch cylinder and the fan should free-wheel. Disconnect the air supply line. The fan should then lock rather than rotate even when you try to rotate it.

To check the thermo air valve, connect a pressure gauge to the outlet, and the shop air supply to the inlet. Immerse the valve and a thermometer in water. Readings on the shop air gauge and pressure gauge should coincide, and no air bubbles should appear in the water. Now heat the water and notice the pressure reduction at the pressure gauge connected to the thermo air valve. If the thermo air valve is working properly, the pressure gauge will read zero when the water reaches the specified temperature.

Fan Hub and Fan-belt Tighteners Although many types of fan hubs, idlers, or fan-belt tighteners are used, they all have much in common. (See Figs. 20-18 and 20-12.) Each has external V grooves or poly V grooves and internal machine bores to accommodate its bearings and seals. The shaft (spindle) is part of the adjustable or fixed mounting bracket or is bolted to the bracket. Tapered roller bearings, ball bearings, or bushings support the pulley.

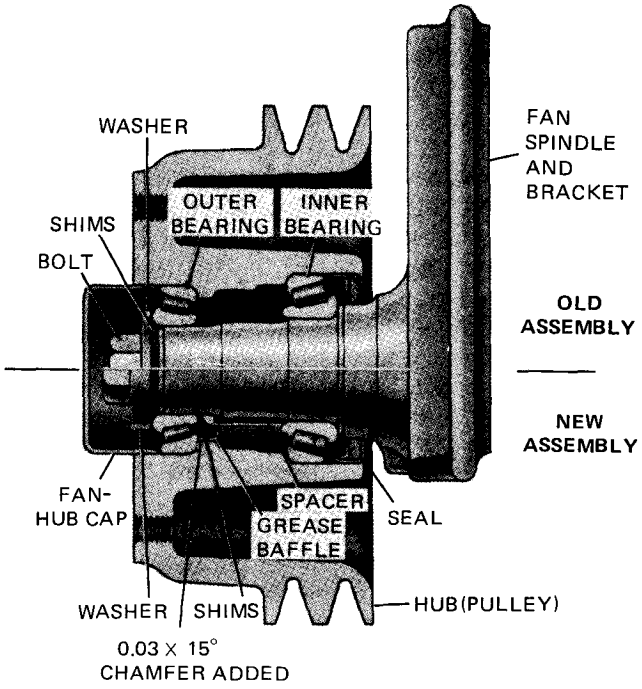


Fig. 20-18 Typical fan hub assembly. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

Inspecting and Servicing Fan Hub and Fanbelt Tighteners Begin servicing by cleaning all parts thoroughly, and then dry them with compressed air. Check the pulley grooves for wear and remove any corrosion or rough spots. If the pulley grooves are damaged, or if the sides are rough, the pulley must be replaced. Check the bearings and seal surface on the spindle. Although the latter is seldom found to be defective, still it must be checked. When new bearings are required, press the old cups out and the new ones in, using the correct bearing pusher. Support the pulley only by its bore surface and not by the groove surface. Do not hammer the seals into place, use a press to place them in position.

When you press the bearing cones onto the spindle, rest the cones squarely on the bore and then press them tightly against the bore shoulder. Do not forget to pack the bearings or lubricate the seal(s) before placing the pulley on the spindle.

Support the spindle in a press or in a vise and press or drive on the outer bearing cone. Install the washer and nut. Tighten the nut to seat the bearings, then back off and tighten the nut until a slight drag is felt when the pulley is rotated. (Back off only enough to allow the cotter pin to fit.)

When your service manual recommends an end play, then you must install a dial gauge on the spindle so that the pointer of the gauge rests against the pulleys. Tighten the nut to accomplish the required end play. (The preload or end play of some pulleys is adjusted by shims.)

Radiator Shutter System The radiator shutter system helps to maintain engine temperature by closing off the airflow through the radiator (Fig. 20-19). This system consists of the shutter, shutter operating bar, shutter cylinder, shutterstat, and in some cases an air filter.

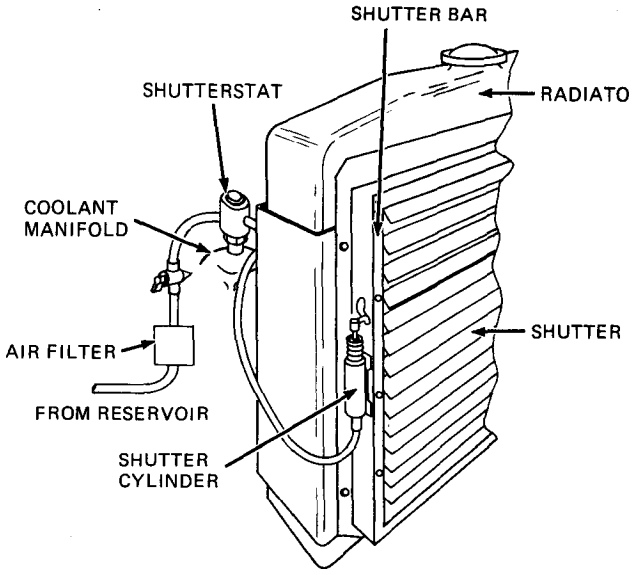


Fig. 20-19 Schematic view of a radiator shutter system.

The shutter is bolted to the front of the radiator and each individual shutter blade is connected to the shutter bar. The shutter return spring on the shutter bar keeps the shutter open, whereas the shutter cylinder allows it to close. The shutterstat, located in the radiator inlet or radiator outlet connection, is a temperature-sensing air valve (Fig. 20-20).

SHUTTER OPERATION When the engine is stopped and there is no air pressure in the reservoir, the air is

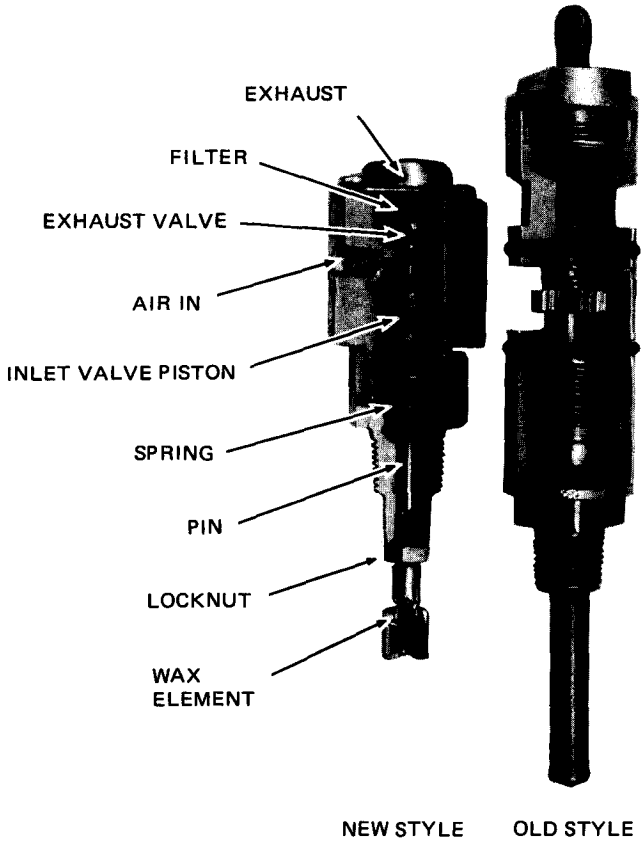


Fig. 20-20 Sectional view of shutterstat.

exhausted from the shutter cylinder through the shutterstat, the air inlet valve of the shutterstat is open, and the shutter is opened by the shutter spring. When the engine is started, air passes through the air filter, by the open inlet valve, and into the shutter cylinder. As soon as the air pressure is high enough to overcome the shutter return spring, the air pressure forces the piston to move and causes the linkage to rotate. This rotation pulls the shutter bar and brings the shutter blades into the closed position. The coolant temperature then rises quickly because air cannot be drawn through the radiator. As the coolant temperature reaches the shutterstat adjustment setting, the thermostatic material expands so that it moves the pushpin piston against the needle valve, closing the air-inlet valve and opening the exhaust valve. The air exhaust from the shutter cylinder and the shutter spring opens the shutter blades.

An air filter should be used when there is no other valve in the air system to remove the accumulated water and sludge. Other shutter systems use a Vernatherm element (actuator) which serves as the sensing unit and the actuator (Figs. 20-21 and 20-23). It is screwed into the actuating mechanism. This element is a sealed unit, made of a thermostatic material which is a special mixture of hydrocarbon that expands with increases in temperature until it is fully expanded at 185°F [85°C]. The expanding hydrocarbon forces the diaphragm to the right and moves the piston. This causes the actuating lever to rotate and the shutter operating bar to open the shutter. As the coolant temperature is reduced to 177°F [80.5°C], the hydrocarbon retracts into the cup and the shutter return spring closes the shutter.

To have a precise coolant temperature, all three sensing units (thermostat, shutter system, and thermostatic-fan sensing unit) must operate in precise order, that is, the thermostat must open first, then the shutter, to finally start the fan rotating. Service manuals show the precise degree at which each sensing unit (element) should start to open, actuate, or close the electric circuit.

Inspecting, Testing, and Adjusting Shutter System First check all linkages for wear. With solvent, remove accumulated dirt from the assembly. When possible, use a graphite powder on all movable joints, rather than a 10-weight engine oil since oil will, at a later date, cause dirt to stick to the linkages.

When necessary, adjust the yoke so that the cylinder stop nut rests against its stop when the shutter is closed.

To check the shutter-blade fit, start the engine and run it at about 800 rpm. Hold a large piece of paper against the shutter. If the paper slides off, the shutter blades are closed properly. If the paper stays in place, any one of the following malfunctions may be present: the shutter blades may not be sealing properly; the relation between the shutter bar and cylinder may be out of adjustment; the shutter cylinder may be leaking; the linkage may be binding; or the shutter frame may be bent. Whatever the problem, it should be corrected before any other tests are made.

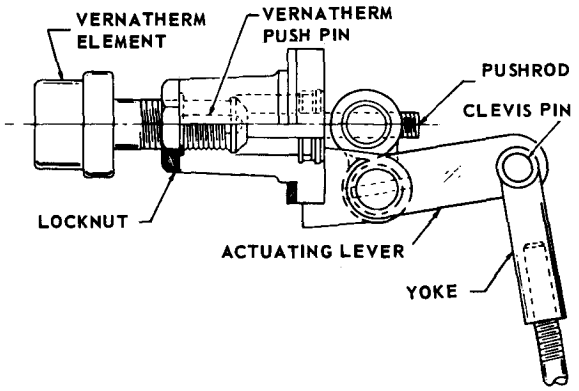


Fig. 20-21 Vernatherm shutter control. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

Testing and Adjusting Shutterstat To test and adjust the shutterstat, immerse the bulb of an accurate thermometer into the top tank of the radiator. Start the engine. The shutterstat should start to open at 170°F [77°C]. When the temperature reaches about 185°F [85°C], the shutter should be fully open. Reduce the engine speed and within 7°F [3.90°C], that is, at a temperature of 177°F [80.5°C], the shutter should close.

To delay the shutter opening (and increase coolant temperature), increase the spring tension against the piston by loosening the locknut and turning the wax element in a right-hand direction. To open the shutter earlier, turn the wax element in left-hand rotation. *(NOTE: One revolution is about 2°F [1.1°C].)* If a Vernatherm element is used, the shutter opening can be altered by replacing the element with one that has a 5°F [2.8°C] higher or lower setting.

Testing and Adjusting Fan-clutch Sensing Unit To check the fan-clutch sensing unit, disconnect the air line from the shutter cylinder so that the coolant temperature can be raised. Run the engine at high idle. As the coolant temperature approaches 190°F [88°C], the fan clutch should be fully engaged. At this point, open the shutter by hand and observe the coolant temperature. At about 182°F [83.5°C] the air should exhaust from the fan-clutch piston to release the fan clutch.

Thermostat The thermostat is a valve located between the cylinder head and the top tank of the radiator which reacts to temperature changes. Its exact location varies with engine application. It is usually in the end of the cooling manifold or in a separate thermostat housing bolted to the cylinder head or cooling manifold.

Because of the higher coolant flow (U.S. gallons per minute or liters per minute) [gal (U.S.)/min or L/min], larger engines utilize two or even four thermostats to allow an unrestricted coolant flow.

The coolant valve is connected to a heat-sensing element which may be either a wax pellet, or a hydrocarbon-mixture pellet (see Figs. 20-22 and 20-23). A pressure spring, placed between the heat-sensing element and the thermostat frame, opposes the expanding force of the heat-sensing element.

Depending on the design of the thermostat and its

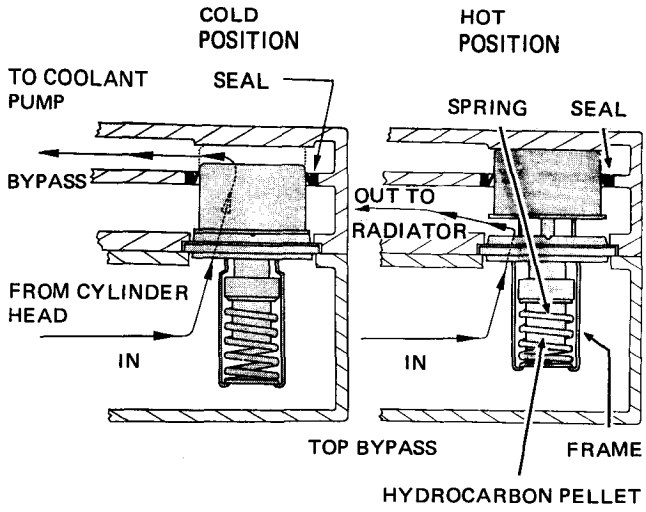


Fig. 20-22 Schematic view of a hydrocarbon thermostat.

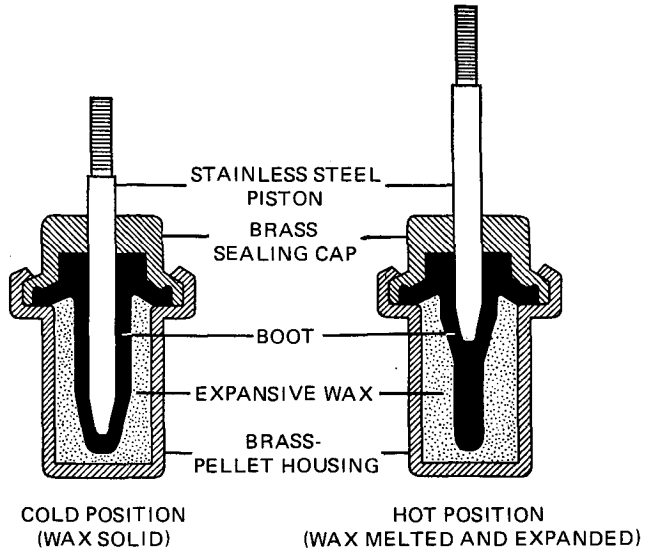


Fig. 20-23 Wax pellet thermostat.

housing, the coolant flow within the system varies. Two types of thermostat and housing arrangements are used, the full-blocking and the partially blocking flow arrangements. With the full-blocking flow arrangement, the thermostat blocks the coolant flow to the radiator when the valve is closed, and the coolant flows from the coolant pump through the cylinder block and cylinder head and is redirected by the thermostat back to the inlet side of the coolant pump. The return or makeup lines allow coolant and air to flow to the radiator. As the coolant approaches the thermostat temperature setting, the valve gradually opens and directs coolant to the radiator and when fully open it blocks the flow into the bypass line.

A partially blocking thermostat system allows a small amount of coolant to flow to the top tank of the radiator at all times, whether the thermostat is open or closed.

NOTE: The radiator shutter system controls the coolant temperature after the thermostat has brought the coolant to operating temperature.

Inspecting and Testing Thermostat When you have removed the thermostat, check the valve seat. Check the heat-sensing element for external damage or rupture. If the valve is bent, distorted, or easily pushed off its seat, it must be replaced.

It is imperative to test the thermostat to determine whether its valve opens and closes at the proper temperature and whether it fully opens and fully closes when immersed in heated water. The thermostat is designed to allow the valve to open at a predetermined temperature in the range of 150 to 200°F [66 to 93.3°C]. The temperature range (or part number) 150 to 155, 160 to 165, etc., is marked on the valve. The valve should reach the fully open position when the temperature increases by approximately 15°F [8.33°C] above opening temperature.

Let us now assume thay you have just removed a thermostat. It has the part number stamped on its flange or it is stamped to identify its opening temperature at 170 to 175°F [77 to 79°C].

NOTE: Do not clean the thermostat before you test it if you suspect the coolant-system trouble was caused by the thermostat valve or thermostat action.

Immerse the thermostat and a thermometer in a container of water and heat the water until the valves open. Remove the thermostat from the water, and insert a long strip of paper between the valve and the seat. Let the water cool (or add cold water to reduce the temperature) to below that indicated as the thermostat opening temperature. Again, immerse the thermostat in the water, holding it by the paper strip. Gradually heat and stir the water. The paper will be released when the thermostat valve opens. At this point in the test, the temperature of the water should be within specification, in this instance, 170 to 175°F [77 to 79°C]. If the valve does not open until a higher temperature is reached, the accumulated sludge or corrosion must be removed from the thermostat and the test must be repeated.

Should the thermostat continue to open earlier or later than specified, it must be replaced. When the valve starts to open at its specified temperature, heat the water to a higher temperature to determine at which temperature the valve is fully open. *Never assume the valve is fully open. Always check it!*

If a thermostat fails to open to its maximum or does not close, the thermostat must be replaced.

NOTE: When making this test, do not let the thermostat or the thermometer rest against the container walls as this will give you a false reading.

Testing for Combustion Leakage into Cooling System To determine if air or combustion gases are leaking into the cooling system, run the engine until it reaches normal temperature 180°F [82°C]. Then drain out sufficient coolant to allow removal of the upper radiator hose and thermostat. Remove the thermostat, upper radiator hose, and drive belt(s).

Supply the sytem with coolant until it reaches the level of the thermostat-housing neck. Start the engine and accelerate five to six times while watching the outlet opening for bubbles or a rise of liquid. Appearance of bubbles or a rise of liquid indicates that combustion gases are entering the cooling system.

CAUTION Perform the test as quickly as possible; otherwise the coolant will boil and steam, and bubbles will rise from the thermostat neck resulting in misleading test results.

Testing for Air Leaks in Cooling System Two methods are used to determine if air is circulating within the cooling system. One method is to pressure-test the cooling system as previously outlined, the other is as follows:

1. Drain as much coolant from the system as is necessary to place a short transparent plastic tube between the thermostat housing and radiator top tank.
2. Refill the engine and run it until it reaches normal temperature.
3. Observe the coolant flow. Air in the coolant will be visible as white round spots passing out of the cylinder head into the radiator through the plastic hose.

Coolant Pump A coolant pump is the heart of the cooling system and is of the nonpositive centrifugal design. Coolant pumps are driven directly or indirectly by V belts, by a poly V belt from the crankshaft pulley, or by a gear from the timing gears. A typical coolant pump is shown in Fig. 20-24.

OPERATION AND DESIGN The pump shaft rotates on single- or double-row sealed ball bearings or bushings located in the spiral or volute housing or as shown in Fig. 20-24. The impeller is pressed to one end of the shaft or keyed to the shaft. The other end may attach to a drive gear or a pulley, or to a pulley and viscous fan drive and fan. The bearings may be lubricated by engine oil or packed with grease.

When the engine operates, the impeller is rotated and creates a low pressure at the center. Coolant enters at or near the center of the impeller, the impeller vanes start the fluid revolving, and centrifugal force accelerates the fluid onto the inner wall of the housing. Because of the snail-shaped housing, the velocity head is converted into a pressure head.

The size and design of the impeller, and the rotating speed at which the impeller is driven, depend on the amount of coolant flow required to cool the engine components. The coolant flow can vary between 10 and 300 gal (U.S.)/min [37.85 and 1135.62 L/min]. As the pump capacity increases, so does the size of its internal components, that is, the shaft, bearings, housing, seals, and impeller.

Coolant-pump Failures A coolant pump is said to have failed when it has lost its pumping capacity. Loss of the pumping capacity can be the result of bearing failure since bearing failure increases clearance between the impeller and the housing and causes increased slippage within the pump.

The cause of bearing failure can sometimes be traced to a damaged seal assembly which has allowed coolant to pass into the bearings. It also may be the result of any one or more of the following: overtightened drive belts, misalignment, vibration of the pump shaft, or overheating of the coolant (hot shutdown).

A damaged seal assembly can be the result of bearing failure, overheating, contaminated coolant corrosion, scale buildup, excessive wear of carbon face or ceramic face, excessive wear of seat, or damaged bellows.

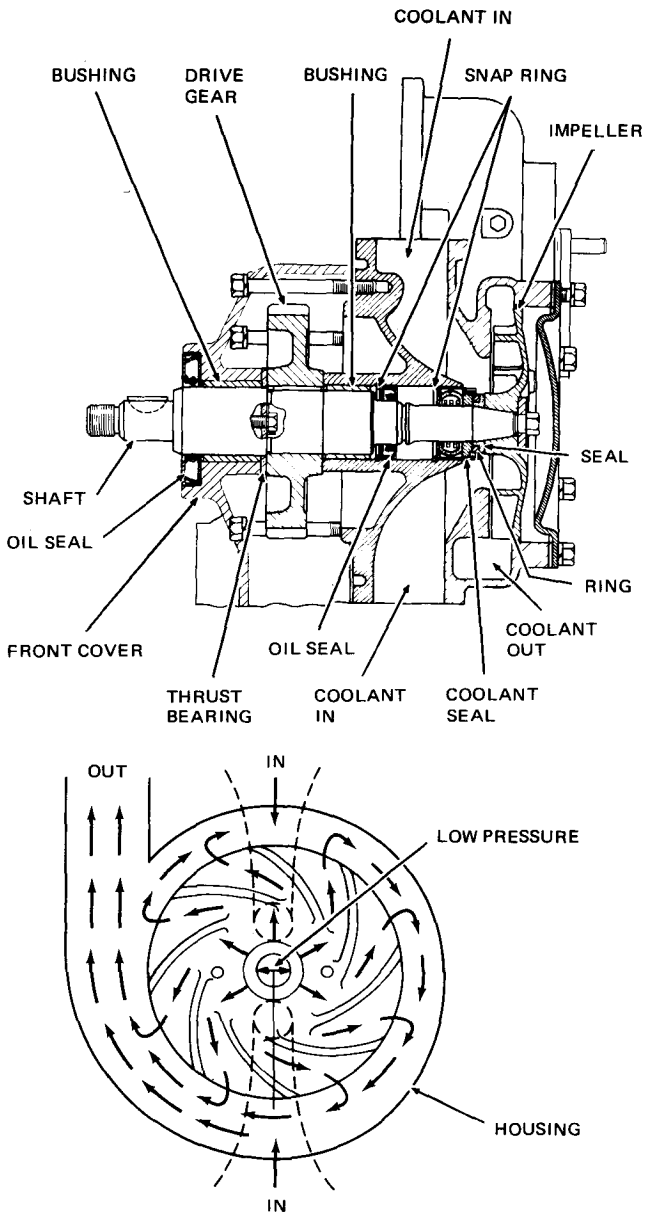


Fig. 20-24 Sectional view of a coolant pump. *(Caterpillar Tractor Co.)*

Loose bearings in the housing or on the shaft can also cause early pump failure because they allow the impeller to come in contact with the housing. Also, when there is scale buildup on the internal housing and on the impeller or when they have become corroded, the resultant rough surfaces will reduce coolant flow.

Servicing Coolant Pump Let us assume you have to service a coolant pump similar to the one shown in Fig. 20-25. Clean the coolant pump externally and remove the fan-hub-retainer nut and impeller-retainer nut. With a suitable puller, pull the impeller and fan hub off the shaft and remove the keys. You may have to tap the impeller holes to install the puller bolts.

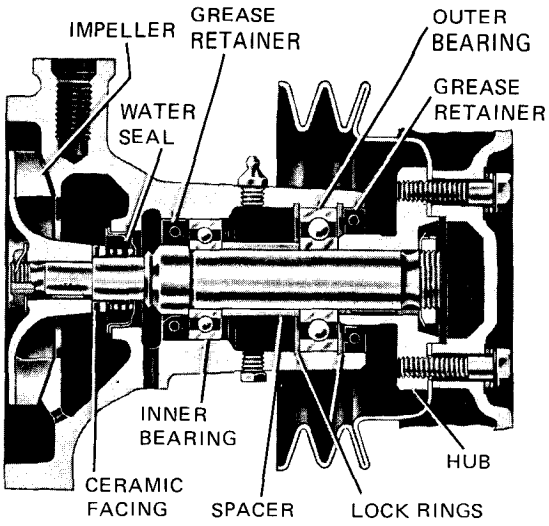


Fig. 20-25 Cutaway view of a typical coolant pump.

NOTE: Use a shaft protector to protect the pump shaft when pulling the hub and impeller off the shaft. If a ceramic seal is bonded to the impeller, take care not to damage it.

Use a hammer puller to remove the front lip-type seal, then remove the bearing retainer (snap ring). Place the coolant pump on a press, supported by the bearing bore, and press out the shaft and bearings from the impeller side.

Remove the other front bearing retainer. Remove the rear lip-type seal and press the coolant seal out. If the pump shaft is reusable, press the bearings from the shaft.

Inspecting Coolant-pump Components Clean all components thoroughly and dry them with compressed air. Check the impeller's ceramic-seal face. If it is scored or damaged, you must replace the impeller. If the impeller is damaged externally, or if the vanes are worn, damaged, or cracked, the impeller must be replaced.

Check the pump shaft for wear where it contacts the lip-type seal, the bearings, and the coolant seal. Replace the shaft when necessary.

Check the pump housing for cracks or other damage caused by worn bearings. Replace all seals and bearings to reduce the possibility of early bearing failure or coolant leakage.

Reassembling Coolant Pump Reassemble the coolant-pump components in precisely the reverse order in which they were disassembled. When pressing the bearings and seals into place, use the correct adapters and sleeves. If specified in your service manual, pack the bearings and the space between the bearings with applicable grease before you press the assembly into the pump housing. Apply a thin coat of water-sealing compound to the outside diameter of the bearings before installation.

NOTE: New impellers sometimes have a waxlike coating over the surface. Remove this coating before you install the impeller, but take care not to damage the impeller seal surface.

When pressing the impeller onto the shaft, make certain that the coolant seal and the impeller surface

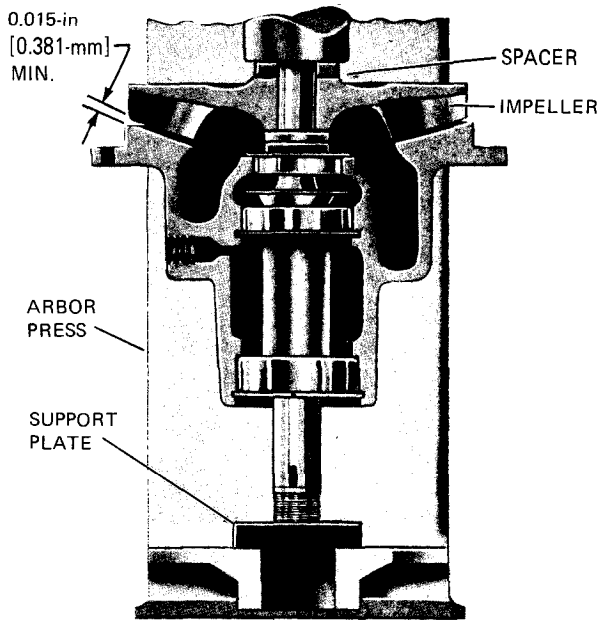


Fig. 20-26 Pressing the impeller onto the pump shaft (sectional view). *(Mack Trucks Canada Limited.)*

are clean. Do not apply any kind of liquid to their surfaces. Support the pump shaft, then press on the impeller until the specified clearance between the pump housing and impeller is achieved (Fig. 20-26).

Coolant Liquid Any water, whether of drinking purity or not, will produce a corrosive environment in the cooling system. Only water with an acceptable mineral content should be used in the cooling system of an engine. Water that is within the limits specified in Table 20-1 is satisfactory; nevertheless, proper inhibitors must be added to protect the cooling system against corrosion and sludge.

Filters and Conditioners The coolant filters and conditioners are spin-on-, canister-, or clamp-on-type elements. Each is connected in parallel (bypass) to the coolant flow. The filter removes any particles such as sand, rust, etc., thus prolonging the coolant and pump service life and ensuring proper operation of the thermostat. The corrosion inhibitors are placed into the elements and are dissolved in the cooling system during operation.

Most diesel engines use an ethylene-glycol antifreeze solution consisting of 50 percent ethylene-glycol and 50 percent water, since it requires no additional inhibitors. However, this solution must not decrease below 30 percent ethylene-glycol in volume, otherwise the inhibitors are no longer strong enough to protect the system against corrosion and sludge.

TABLE 20-1

SUITABLE WATER

	Parts per million
Total hardness (max.)	170
Chlorides (max.)	40
Sulfates (max.)	100
Total dissolved solids (max.)	340

Drive-belt Failure and Preventive Maintenance Drive-belt failure can often be traced to improper alignment of the pulleys, or the belt(s) insufficiently tightened, or oil, grease, etc., on the pulleys and belts. Perhaps the belts were not tightened because they were inaccessible or difficult to adjust or were inadvertently overlooked. In any event, haphazard maintenance has too often necessitated many expensive repairs to the cylinder sleeve, pistons and cylinder head.

When you replace a worn or damaged drive belt, replace it with a belt from the manufacturer who supplied the original. Replace dual belts with a matched belt set; *never* replace only one belt.

Do not pry off the belt from the sheaves. This will damage the pulley as well as the side wall (fabric) of the belt. Slack off the idler or tightener so that the belt can be put onto the sheaves by hand. Make certain the shafts are parallel so that the sheaves are aligned.

Before you replace the drive belts, check the sheaves for oil, grease, corrosion, rough spots, or rough sides. Thoroughly clean the sheaves and smooth out any rough spots. If this is not possible, the pulley must be replaced. Be sure to correct the cause of oil or grease leaks.

Follow the engine manufacturer's recommendation about belt tension and the use of a drive-belt tension gauge. A common rule of thumb is to measure the belt length from the center of each pulley and measure the belt width. When pressing down on the belt centrally, between pulleys, the belt should flex one width at each foot length.

When new drive belts are installed, run the engine at least 20 minutes and then retighten all belts. Retighten them again after the first trip is completed or at the end of the first working day. This is essential because new belts stretch and seat themselves in the sheaves.

Indications of V-belt Malfunction When a drive belt squeals, it is loose, worn, or has lost its friction. Belts will also squeal when the sheaves are worn or the belt is contaminated. When the drive belt has been operated beyond its capacity, it will stretch. It should be replaced with a stronger belt.

If a drive belt runs crooked, it has been stretched on one side as it was forced over the pulley, or else it has run misaligned. When a drive belt whips and flaps, it may be because it is too loose, because one or both pulleys are loose on the shaft, because the pulley shaft is bent, or because the idler tightener, fan hub, or generator, etc., is not rigidly supported.

Cracks on the outside of the belt indicate that the diameter of the pulley is too small or that there is severe reverse bend from the idler pulley. However, it may have been damaged from an external force.

When the drive belt, the side fabric, or the rubber is cracked, either the belt is running too loose or an oil or grease condition has caused it to lose its friction and it has burned.

A drive belt which has turned over completely either has broken cords, worn sheave grooves, or excessive belt vibration or the pulleys are misaligned.

Marine Engine Cooling Systems Two types of cooling systems are used on marine engines—the heat-exchanger cooling system and the keel cooling system. Both use a water-cooled exhaust manifold.

The heat-exchanger cooling system combines two separate cooling systems, that is, a conventional engine cooling system and the raw-water cooling system. The components which comprise the engine cooling system are: a water-cooled exhaust manifold, an engine coolant pump, one side of the heat exchanger, and the expansion tank.

The raw-water cooling system consists of a raw-water coolant pump and the other side of the heat exchanger, along with pipe and hose accessories. The raw-water pump is a positive displacement pump which uses a synthetic vane-type rubber impeller (see Fig. 20-27). It is direct-driven by the engine.

HEAT-EXCHANGER COOLING-SYSTEM OPERATION When the engine is operating and is at the operating temperature, coolant from the expansion tank flows downward through the fresh-water core of the heat exchanger, around the oil cooler, around the reverse-gear oil cooler, through the engine, and then to the inlet side of the engine coolant pump. It is then pumped through the engine cooling passages, through the exhaust-manifold cooling passages, onto the thermostat housing, and a portion then flows to the expansion tank. When the thermostat is closed, the coolant flow to the heat exchanger is blocked by the thermostat, and is redirected to the inlet side of the engine coolant pump (see Fig. 20-28). *(NOTE: There is a continuous flow of coolant through the exhaust manifold.)*

Whenever the engine is operating, the raw-water pump impeller is rotating, and as the impeller vanes pass the raw-water pump inlet, a low pressure is created. Water from the inlet, below the vessel's water line, is forced into the pump and carried around the pockets formed by the vanes and housing. As the vanes pass by the outlet port, the water is forced out of the pump and directed through the heat-exchanger raw-water core (in a horizontal direction) back into the sea. This continuous raw-water circulation main-

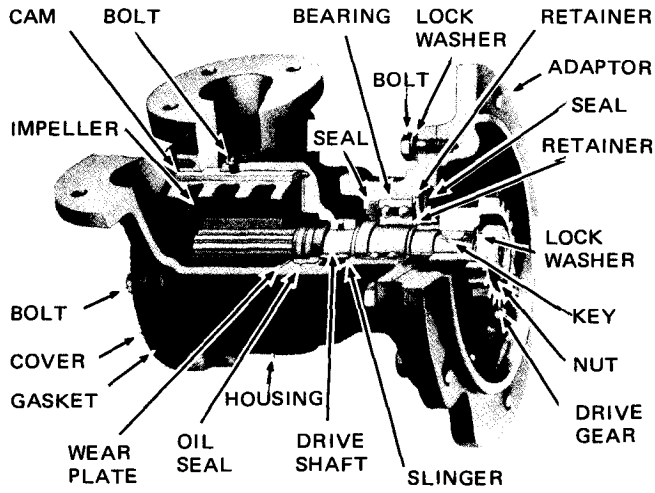


Fig. 20-27 Sectional view of a raw water pump. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

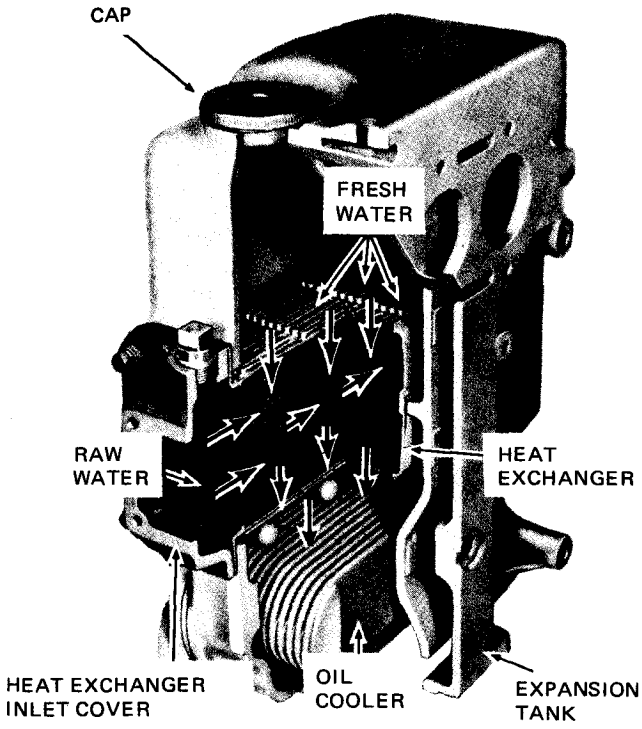


Fig. 20-28 Sectional view of a heat exchanger. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

tains cool engine coolant. However, the thermostat controls the engine coolant flow and, therefore, also the temperature. *(NOTE: Zinc electrodes within the system are used to reduce electrolytic action.)*

A similar heat-exchanger cooling system is shown in Fig. 20-29; however, in this system the oil cooler is not located within the heat exchanger.

Keel Water Cooling The keel cooling system is a closed system. It consists of the water-cooled exhaust manifold, a high-capacity engine-cooling pump, an expansion tank, and the keel cooling coil which is fastened to the hull of the vessel (Fig. 20-30).

KEEL COOLING-SYSTEM OPERATION When the engine is operating, coolant flows from the expansion tank into the cooling pump, then through the engine oil cooler, marine-gear oil cooler, cylinder block and cylinder head, and through the exhaust manifold passages. Part of the coolant flows directly back to the expansion tank and the remainder flows back to the inlet side of the coolant pump. As the thermostat starts to open, the coolant is directed to (and through) the keel cooling coil, then back to the inlet side of the coolant pump. *(NOTE: There is a continuous coolant flow through the exhaust manifold.)*

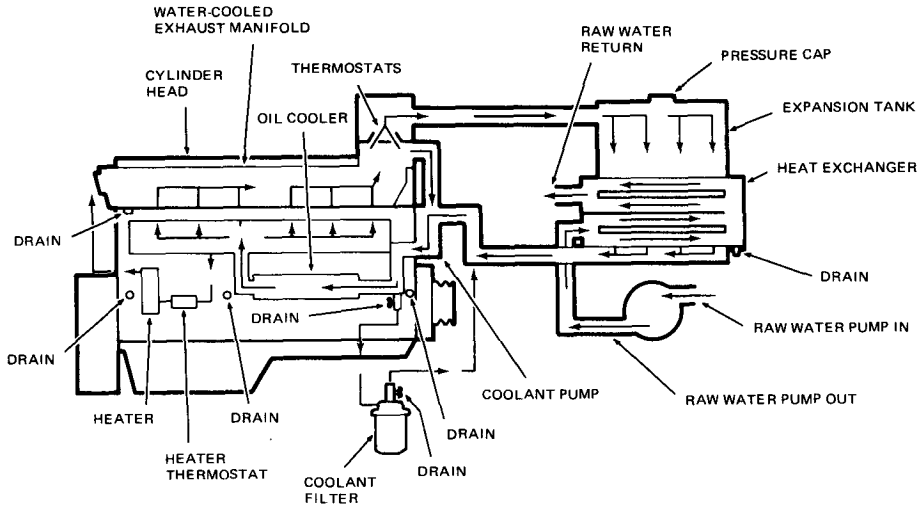


Fig. 20-29 Schematic view of a heat-exchanger cooling system. *(Allis-Chalmers Corp. Engine Division.)*

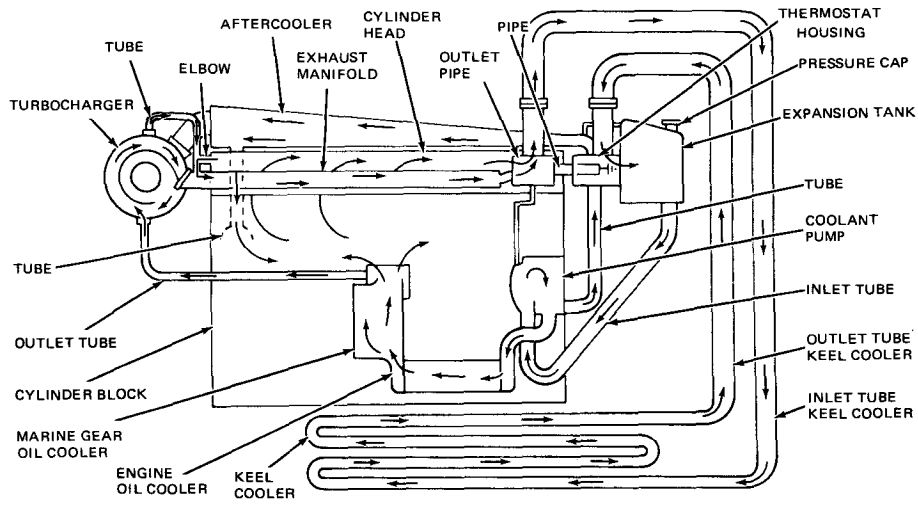


Fig. 20-30 Schematic view of a typical keel cooling system. *(Caterpillar Tractor Co.)*

Questions

1. Why does an air-cooled engine maintain a uniform temperature throughout the cylinder block and cylinder head more so than a liquid cooled engine?
2. What maintenance checks of the cooling system should be made daily?
3. List the ways in which the radiator can dissipate heat.
4. List each step to be taken when testing a radiator for leaks.
5. Why must a radiator or cylinder block be flushed in reverse flow?
6. What would happen to the radiator and coolant hoses if the vacuum valve seized in the open position? What could happen if the vacuum valve seized in the closed position?
7. During the cooling system checkup, what checks would you make to the cooling fan?
8. List the main purposes of a thermomodulated drive and fan-clutch drive.
9. Why is it so important that the opening of the thermostat precede the opening of the shutter and the engagement of the fan drive follow the opening of the shutter?
10. How would you test thermostat operation?
11. What test would you make to determine whether the cooling system has an air leak or combustion leak?
12. Give several reasons why coolant pumps are of the nonpositive displacement design rather than the positive displacement design.
13. Why do all coolant pumps use a mechanical seal instead of a lip-type seal or an O ring?
14. Why is ethylene-glycol antifreeze used to protect the coolant from freezing, rather than alcohol or some other synthetic substance?
15. What is the purpose of a coolant filter?
16. Correct procedure is essential when installing a drive belt if failure is to be prevented. List several don'ts (precautions) when installing the drive belt.
17. What are the main differences between a heat-exchanger cooling system and a keel cooling system?
18. Explain the coolant flow of a keel cooling system: (*a*) when the thermostat is closed, and (*b*) when the thermostat is open.

UNIT 21 - HYDRAULIC LINES AND FITTINGS

Need for Hydraulic Lines and Fittings The hydraulic lines and fittings are as important as any component in the hydraulic system. In transporting the fluid they become an integral part of the system. Poor or inadequate piping, regardless of the type of hydraulic line used, will not only reduce the efficiency of the system but will also reduce the service life. A variety of hydraulic lines and fittings are available to fit specific needs. It is essential for the mechanic to know about the various attributes and shortcomings of each type.

Types of Hydraulic Lines The three most common types of hydraulic lines used are: pipes, tubings, and hoses. When selecting the appropriate hydraulic line, a mechanic should know where and how the line is to be located, at what temperature and pressure the line will operate, what volume of liquid the line will carry, and what type of liquid will be used.

The location, temperature, and pressure will determine the type of material used for the hydraulic line. The volume of the fluid flow will determine the size of the line. Note that manufacturers recommend a maximum velocity of 15 ft/s (feet per second) [4.572 m/s (meters per second)] on pressure lines and 5 ft/s [1.524 m/s] on inlet lines. Supply charts and data tables, obtainable from most manufacturers, can be used as a further aid in selecting the most suitable line.

The number of bends and the length of the line must be kept to a minimum regardless of the type of hydraulic line used, and the radii of the bends must not exceed specification as any of these will reduce the flow, cause turbulence, and increase the fluid heat. Every section of the line must be fastened securely to keep vibration to a minimum and to remove the weight from the fittings or joints.

When making your selection, remember that bends are preferable to elbows because they reduce friction and turbulence. The bend radius of the pipe, tube, or hose should not be less than 2½ to 3 times the inside diameter. When hoses are used instead of pipes or tubing, you must consider the applied pressure and the movement of the hose as well as the reduced bend radius due to the actuator. *(NOTE: Pressure can cause the hose to expand, which would reduce the overall length and decrease the bend radius. You should also avoid a bend radius which is too sharp as this causes friction which will increase turbulence.)*

Pipes Many manufacturers classify pipes and tubing indiscriminately. But actually there are a number of differences between them. When ordering or selecting supplies, you should first check the individual manufacturer's terminology in order to avoid misinterpretation.

To the mechanic, the terms *pipe* and *tubing* have many meanings. Distinctions lie not in the material or the design but in the dimensions, that is, the outside

diameter (OD), the inside diameter (ID), and the wall thickness. Nominal dimensions are used to simplify the standardization of pipe fittings. The wall thickness is identified by a schedule number.

Although manufacturer classifications of pipes and tubing overlap, you should know when to use one as opposed to the other. Tubing is used much more frequently for hydraulic lines because of the difficulty in bending and sealing pipes. The sealing problem, however, has been improved as a result of the cooperation between industry and the Society of Automotive Engineers in setting up improved standards for pipe thread. The result has been the dry-seal pipe thread. Dry-seal threads form a tighter and safer seal because they can be tightened to make a leakproof joint without excessive torque.

Threading Pipe The actual threading of pipe is not a common occurrence for a diesel mechanic, but if it should become necessary the following procedure should be followed:

1. Hold the pipe in a chain vise in order to prevent internal and external damage.
2. Remove any burrs from the pipe since they reduce flow and increase turbulence.
3. Use a sharp die and cutting oil to achieve a clean thread. Damage to the threads can result in leakage.
4. Cut the pipe to the appropriate length and, whenever possible, use a pipe cutter instead of a hacksaw. The pipe cutter will leave no residue which may enter the pipe and damage the hydraulic system.
5. Use pipe dope or pipe tape to improve the sealing and prevent corrosion and seizure. This is placed on the male fitting only, leaving the first two or three threads completely clean. If the sealing compound enters the system, it may cause serious damage.

Pipe Fittings A great variety of pipe fittings (connectors) are manufactured. Most common are the threaded pipe fittings of the tapered and straight (dry-seal) designs (Figs. 21-1 and 21-2). Flange-type and welded-type fittings are used on large hydraulic systems. Standard fittings are adequate to accommodate an operating pressure up to 3000 psi [20,685 kPa] and have a proof-test rating of 15,000 psi [103,425 kPa]. This makes the threaded design most suitable for the diesel engine.

All tapered pipe threads should be tightened to a minimum of 2½ full turns past handtight. The straight-pipe thread fittings, on the other hand, can be positioned and then the nut tightened since the O-ring seals the fitting.

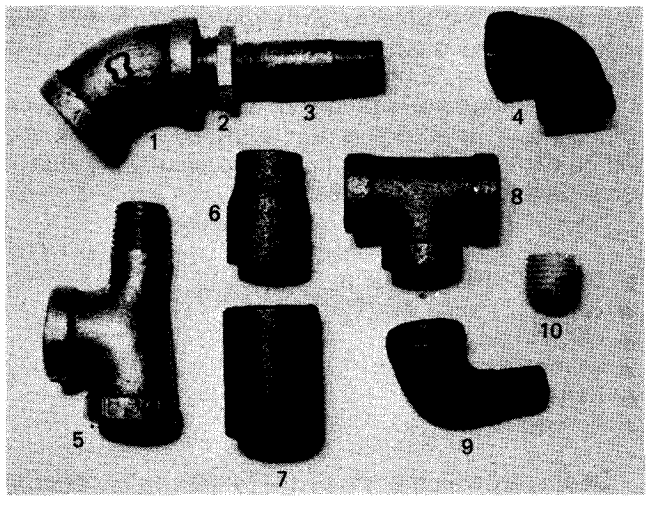


Fig. 21-1 Tapered pipe fittings: (1) 45° elbow, (2) bushing, (3) nipple, (4) 90° elbow, (5) street tee, (6) reducer, (7) coupling, (8) tee, (9) street elbow, (10) slotted plug.

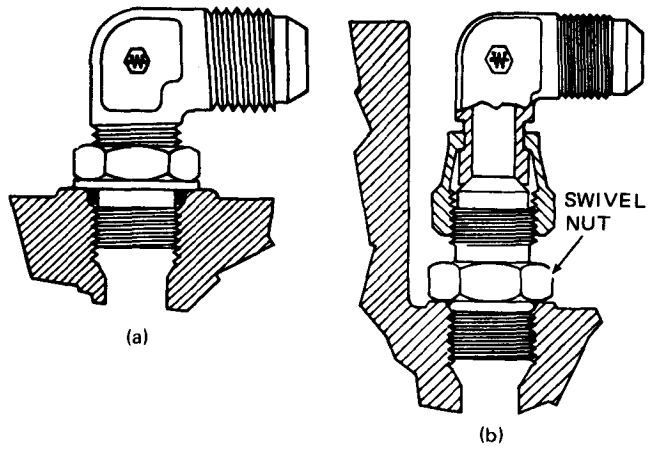


Fig. 21-2 Straight pipe fittings. *(The Weatherhead Co. of Canada, Ltd.)*

Tubing Tubing made from steel, copper, nylon, polyethelene, or other synthetic materials are the most common hydraulic lines used in diesel engine applications.

A tubular product is called a *tube* if its nominal size is the actual measurement of the outside dimension. Standard tubings vary in size from ⅛ to 3 in [3.18 to 76.2 mm]. When examining the tube-size designation chart in Table 21-1, note that the tube sizes increase in 1/16-in increments to ⅜ in and then in ⅛-in increments to ¾ in. Within each tube size there is a selection of wall thicknesses to fill the various pressure demands.

To identify a standard rigid tube size, a dash number system is used. This dash number system relates to the outside diameter of the tube size in 1/16 in.

Table 21-2 lists standard tube size increments and corresponding dash numbers.

Cutting Tubes Tube cutting should never be considered so routine that it is done carelessly. Avoid, under all conditions, bending a tube more than is necessary.

1. Hold the tube roll in an upright position on a clean and straight surface. The tube end is held firmly against the surface while the tube coil is rolled out to the desired length. Never pull the tube end from the tube roll. Remember to keep the open end closed off to avoid the entry of foreign material.
2. In cutting the tube, use a tube cutter to assure a clean, square cut on the edges. Do not force the cutting wheel into the tube. Instead, let the wheel cut into the tube by rotating the tube cutter 360° and gently increasing wheel pressure after each revolution.

TABLE 21-1

STANDARD-SIZE HYDRAULIC TUBING

Tube OD, in*	Tube ID, in	Wall, in
1/8	0.055	0.035
0.125	0.061	0.032
	0.065	0.030
	0.069	0.028
3/16	0.117	0.035
0.1875	0.123	0.032
	0.127	0.030
1/4	0.120	0.065
0.250	0.134	0.058
	0.152	0.049
	0.166	0.042
	0.180	0.035
	0.190	0.030
5/16	0.182	0.065
0.3125	0.196	0.058
	0.214	0.049
	0.228	0.042
	0.242	0.035
	0.248	0.032
3/8	0.245	0.065
0.375	0.259	0.058
	0.277	0.049
	0.291	0.042
	0.305	0.035
	0.311	0.032
1/2	0.310	0.095
0.500	0.334	0.083
	0.358	0.072
	0.370	0.065
	0.384	0.058
	0.402	0.049
	0.416	0.042
	0.430	0.035
	0.436	0.032
5/8	0.435	0.095
0.625	0.459	0.083
	0.481	0.072
	0.495	0.065
	0.509	0.058
	0.527	0.049
	0.541	0.042
	0.555	0.035
3/4	0.532	0.109
0.750	0.560	0.095

*Refer to Conversion Tables for metric equivalents of English tube OD sizes.

3. While cutting, support the heavy section of the tube so that its weight does not interfere with the rest of the cutting procedure.
4. Do not let your cut become too harsh because it will burr both the inside and outside of the tube. Should this occur, however, use a reamer blade to remove the inside burrs. (The reamer blade is mounted on the tube cutter and can be folded away when not in use.) The outside burrs can be removed with a file or an outside-burr remover. In all cases, try to achieve smooth, square edges. Above all, make sure that all debris from the cutting operation is removed from the tube.

Bending Tubes A small steel or copper tube which has thin walls is easy to bend with a spring tube bender. After you have selected the appropriate spring bender, slide it over the tube which is to be bent and gently shape it to the desired bend radius. A slight overbending will facilitate bender removal.

Larger tube sizes and tubes having thicker walls are bent much more easily with a mechanical tube bender. Here also, select the proper size mechanical tube bender to avoid impairing the tube. It is recommended that the bend be made prior to the flaring or cutting to the final length.

Pointers for Bending Tubes

1. Mark the start of the bend on the tube. (For example, you might be bending a ½-in [12.7-mm] steel tube to a 90° angle. Note that if the bend must be located immediately after the flare or compression nut, the bend should be started a distance from the nut of two to three times the length of the nut. This ensures easy installation.
2. Position the tube so that your mark coincides with the centerline mark of the tube bender. Then, hook the hold-down foot over the tube.
3. Gently move the handles together until the desired angle is reached (for example, 90°). Always overbend a little. This is to compensate for the tube's tendency to straighten out slightly after the bend is accomplished.

Tube Fittings and Adapters A tube may be connected to a component, hose, pipe, or to another tube by one of several types of tube connectors. Quite often, a welding-type tube connector is used. The most common tube connectors, however, are those of the threaded-type design and these, therefore, are the ones you should become most familiar with.

In general, threaded tube fittings and adapters are divided into two types: the flare-type fitting and the compression-type fitting.

With the flare-type fittings and adapters, connection and sealing is achieved by spreading (flaring) the ends of the tube to an angle of 37 or 45°. The fitting nut and adapter, when properly torqued, will make a secure, leakproof seal.

Connecting and sealing of the compression-type fittings and adapters is achieved by screwing the fitting nut to the adapter, thus compressing the sleeve or sleeve nut onto the tube.

The six threaded-type connectors are:

- SAE 37° JIC flare twin
- SAE 45° flare
- 45° inverted flare
- Compression fitting
- Self-aligning
- Threaded sleeve

Because of the many types of fittings and adapters, various thread sizes are used. A tube fitting thread-size comparison chart of the six threaded fittings (in each classification of tube size) is given in Table 21-3. By examining Table 21-3 you will recognize the

TABLE 21-2

TUBE SIZES AND DASH NUMBERS

Actual OD, in*	3/16	1/4	5/16	3/8	13/32	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4
Standard dash nos.	−3	−4	−5	−6	−7	−8	−10	−12	−14	−16	−18	−20

* Refer to Conversion Tables for metric equivalents of English tube OD sizes.

TABLE 21-3

THREAD-SIZE COMPARISON CHART

Tube		SAE 37° JIC flare twin		SAE 45° flare		45° inverted flare		Compression self-align		Threaded sleeve	
Size, in*	Dash no.	Size, in	Thread per inch	Size, in	Thread per inch	Size, in	Thread per inch	Size, in	Thread per inch	Size, in	Thread per inch
1/8	−2	5/16	24	5/16	24	5/16	28	5/16	24	5/16	24
3/16	−3	3/8	24	3/8	24	3/8	24	3/8	24	3/8	24
1/4	−4	7/16	20	7/16	20	7/16	24	7/16	24	7/16	24
5/16	−5	1/2	20	1/2	20	1/2	20	1/2	24	1/2	20
3/8	−6	9/16	18	5/8	18	5/8	18	9/16	24	9/16	20
7/16	−7	. . .	. . .	11/16	16	11/16	18	5/8	24	5/8	18
1/2	−8	3/4	16	3/4	16	3/4	18	11/16	20	11/16	16
5/8	−10	7/18	14	7/8	14	7/8	18	13/16	18		
3/4	−12	1 1/16	12	1/16	14	1 1/16	16	1	18		
7/8	−14	1 3/16	12								
1	−16	1 5/16	12	. . .	. . .	. . .	. . .	1 1/4	18		

* Refer to Conversion Tables for metric equivalents of English tube OD sizes.

ambiguities arising from the countless number of fittings, adapters, and thread designs. Good connection sealing is usually accredited to good flaring, the tube being properly installed, and the nut being correctly torqued. Good sealing, however, also depends a great deal on the correct selection of adapters and fittings.

Inverted Flare Inverted flare fittings, although found on fuel and lubrication lines, are uncommon on diesel engines because the short nut is unable to support the hydraulic line. More suitable to diesel application are the SAE 45° and the SAE 37° JIC flare-twin fittings, which will be discussed later.

Forming Double Flare To form a good double flare, you must keep the tube end straight. Also, the pointers for cutting tubes, outlined previously, should be strictly adhered to. Further rules for forming a good flare are:

1. Select the proper adapter and hole size in your tube-holding fixture.
2. Slide the nut on the tube.
3. Insert the tube. Clamp it securely so that the tube extends to the height of the adapter.
4. Lubricate the tube slightly and insert the adapter.
5. Locate the cone of the yoke over the center of the adapter and run it down until it bottoms against the tube-holding fixture. This action causes the tube to bell out or flare. It is the first step in forming a double flare (Fig. 21-3*a*).
6. Remove the adapter and run the cone tightly against the belled tube to form the finished flare (Fig. 21-3*b*).
7. Remove the tube and check the flare diameter. Also, examine the flare for excessive thinning out of material (see Fig. 21-4).

Correct Method of Installing Fittings Before you begin the installation, be sure that all foreign materials have been removed from the nut, the adapter, and the inside of the tube. Lubricate the threads before aligning the tube with the adapter. Excessive force should not be used in alignment; this can cause a cross-threaded fitting and stress on the tubing. Hand-tighten the tube nut and then tighten it with a flare wrench by carefully turning the wrench until it feels snug; thereafter apply a sixth of a turn.

SAE 45° Flare A single SAE 45° flare (using a long nut) is shown in Fig. 21-5. Various adapters are shown

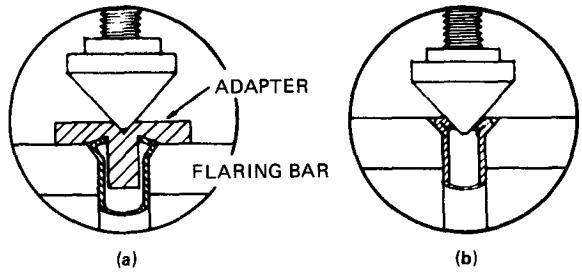
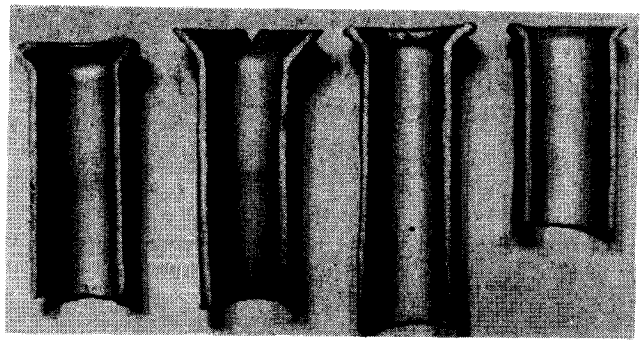


Fig. 21-3 *(a)* First step in making a double flare, *(b)* finishing the flare. *(The Weatherhead Co. of Canada, Ltd.)*



(a) (b) (c) (d)

Fig. 21-4 Improper flares and their causes.

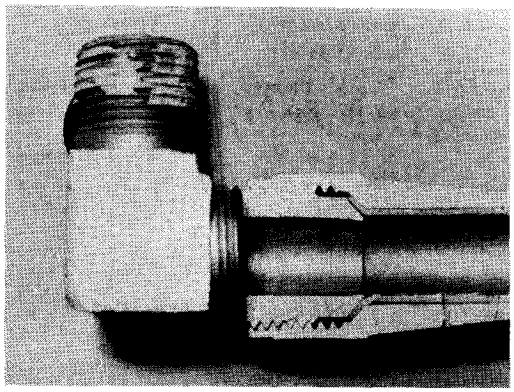


Fig. 21-5 Cutaway view of an SAE 45° flare fitting.

in Fig. 21-6. When connecting diesel engine components, it is advisable to use only long nuts and a double flare so as to reduce connection failure.

Flaring and installation procedures are the same as those outlined for a double flare fitting.

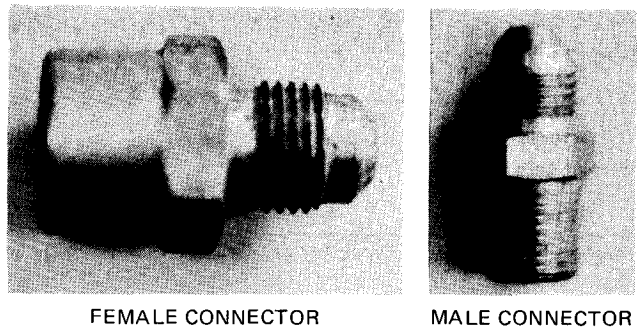
SAE 37° JIC Flare Twin Two- and three-piece SAE 37° JIC flare-twin fitting assemblies are shown in Fig. 21-7. Various adapters are shown in Fig. 21-8. From the illustrations you will recognize how these types of fittings give greater tube support and why they are recommended for diesel applications.

Flaring and installation procedures for the SAE 37° JIC flare twin are the same as those outlined for the double flare and the SAE 45° flare. The flaring angle for the JIC flare twin is 37° instead of 45°.

Flareless Connectors Threaded sleeve, self-aligning, and compression fittings are not recommended for use on diesel engines because the connectors cannot withstand vibration. By using a long nut on self-aligning and compression fittings, improved vibration resistance is achieved. A correctly assembled threaded sleeve is shown in Fig. 21-9.

NOTE: When you install a tube with this type of fitting, the tube must rest against the adapter shoulder not flush with the nut. After the nut is hand-tightened, an additional 1½ turns with a wrench is recommended.

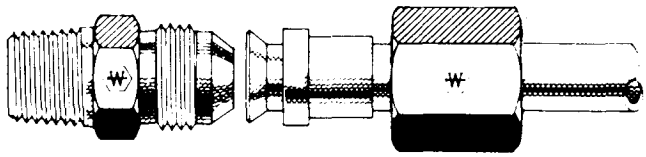
A self-aligning fitting is shown schematically in Fig. 21-10. A compression fitting is shown in Fig. 21-11. The assembly and torque procedure is identical to that outlined above for a threaded sleeve.



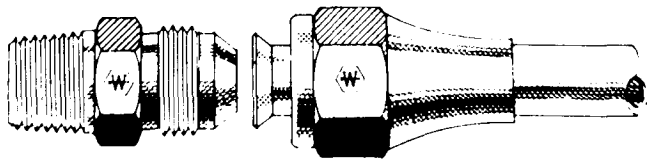
FEMALE CONNECTOR MALE CONNECTOR

MALE ELBOW UNION

Fig. 21-6 SAE 45° flare fitting adapters.

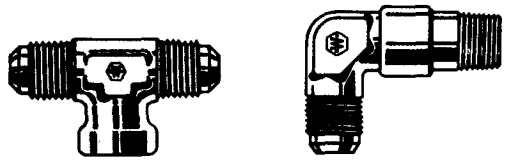


THREE-PIECE TYPE



TWO-PIECE TYPE

Fig. 21-7 SAE 37° JIC flare-twin fitting assemblies. *(The Weatherhead Co. of Canada, Ltd.)*



FEMALE BRANCH TEE MALE ELBOW (LONG)



90° FEMALE ELBOW BULKHEAD UNION

Fig. 21-8 Hydraulic tube fitting adapters. *(The Weatherhead Co. of Canada, Ltd.)*

Flexible Tubing Tubes made from nylon, neoprene, or other synthetic materials are used in indus-

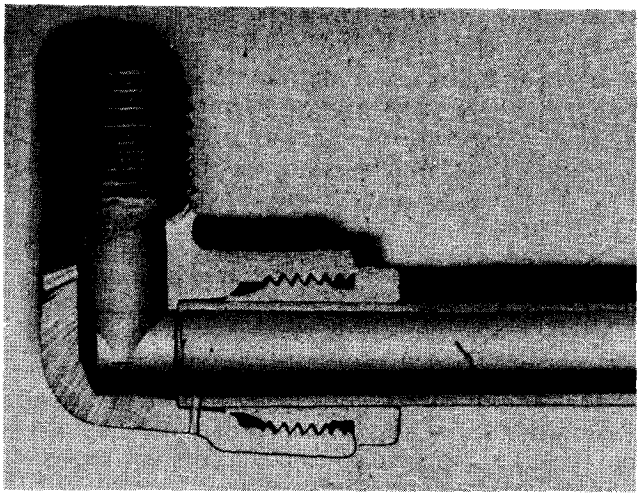


Fig. 21-9 Cutaway view of a threaded sleeve.

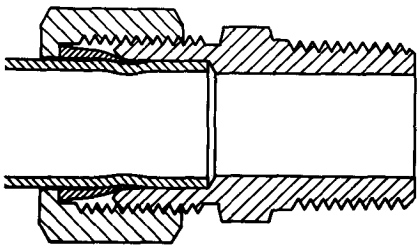


Fig. 21-10 Schematic view of a self-aligning fitting. *(The Weatherhead Co. of Canada, Ltd.)*

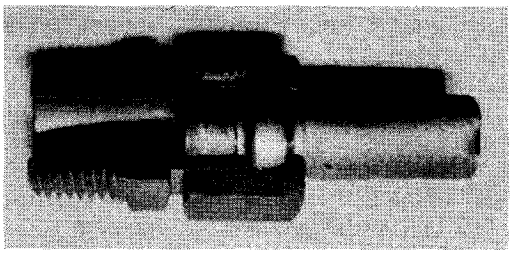


Fig. 21-11 Cutaway view of a compression fitting.

try today to connect fuel, oil, and lubrication lines to instrumentation panels. This type of tubing has gained wide acceptance because of its adaptability, durability, and high vibration resistance. Nylon tubing is preferred in diesel engines because of its resistance to deterioration by petroleum products.

Table 21-4 outlines the required data for proper selection of tube size, wall thickness, bend radius, working pressure, and fitting size.

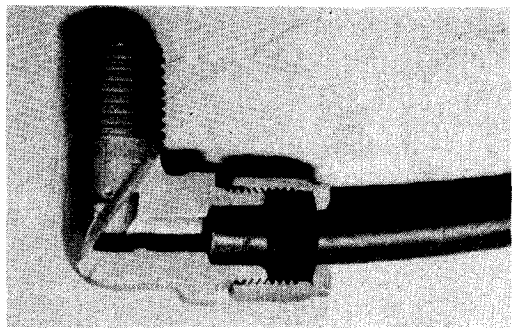


Fig. 21-12 Cutaway view of a synthetic grommet-type compression fitting.

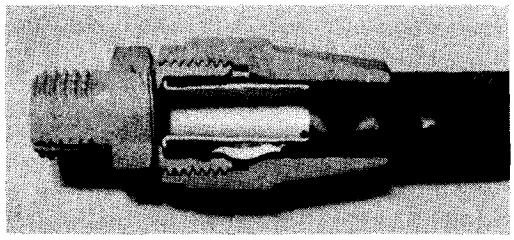


Fig. 21-13 Cutaway view of a compression fitting using nylon tubing with an insert.

The synthetic grommet-type fitting is highly recommended for diesel applications (Fig. 21-12) because it remains a flexible connection after the nut is tightened against the adapter (and overtorquing is not possible). Consequently there is no distortion of the tube or restriction to the fluid flow.

However, when using nylon or synthetic tubings it is advisable to insert a sleeve in order to maintain a good seal and avoid tube distortion (see Fig. 21-13). This should be done regardless of the type of compression fitting used.

Cooling-system and Heater Hoses In this textbook, when reference is made to hydraulic hoses, they are limited to those used in cooling systems or to heater hose, low-pressure and medium-pressure hoses only. The coolant hoses are classified in nominal size, inches (in), to indicate the inside dimension (ID), whereas all standard hose styles use a dash number system for this measurement.

TABLE 21-4

FLEXIBLE NYLON TUBING

For fittings dash no.	Size	OD, in*	ID, in	Wall thickness, in	Max. working pressure, psi at 70°F	Min. burst pressure, psi at 70°F	Min. bend radius, in
−2	1/8	1/8	0.096	0.015	333	1000	3/4
−3	3/16	3/16	0.138	0.025	333	1000	1 1/2
−4	1/4	1/4	0.190	0.030	333	1000	2 1/2
−5	5/16	5/16	0.242	0.035	333	1000	3
−6	3/8	3/8	0.295	0.040	333	1000	3 1/2
−8	1/2	1/2	0.375	0.062	333	1000	4

* Refer to Conversion Tables for metric conversions.

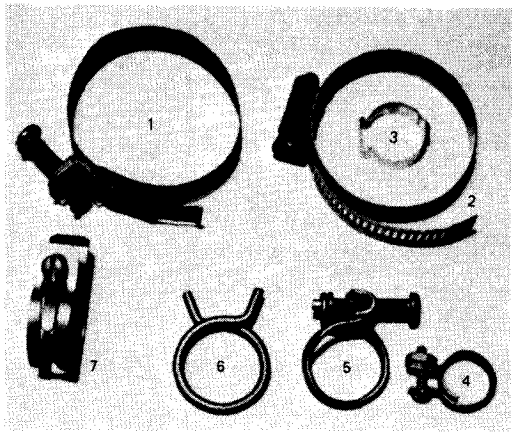


Fig. 21-14 Hose clamps: (1) type D, (2) type F, (3) crimp type, (4) type B, (5) type A, (6) type E, (7) type A.

Today's diesel engine cooling systems operate at a maximum pressure of 25 psi [179.27 kPa]. The burst pressure of a 2-in [50.8-mm] cooling-system hose is about 70 psi [482.65 kPa]. The hose must be flexible to a temperature of −40°F [−40°C] and must not expand more than 2 percent at 212°F [100°C].

The inner hose is usually made from buna, Teflon, or silicone because these materials are oil-resistant and do not swell or peel. They are reinforced with a single or double fiber or coarse steel braid. The outer cover is usually neoprene, silicone, or synthetic rubber. Some radiator hoses, especially on the inlet side of the water pump, are susceptible to collapse. To compensate for this, spiral steel wires are molded into the hose or inserted over the inner cover, giving the hose more uniform strength. Radiator hoses for diesel uses are usually either molded or flexible.

Hose Clamps Six hose clamp types are shown in Fig. 21-14. The clamp size is indicated by a numbering system which can range from size 6 to 195. This means that there is a clamping diameter range from 0.380 to 6 in [9.6 to 152.4 mm]. The types are identified by the letters A to F; for instance, type E clamp is more suitable for small hoses, whereas the type F clamp is suitable for all hoses.

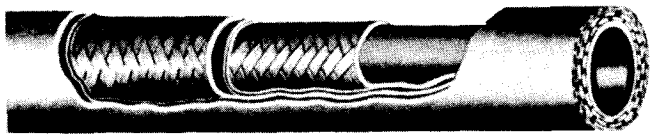
Low- and Medium-pressure Hoses Hose styles and sizes are as numerous and varied as those of pipes and tubings. To distinguish a hydraulic hose by quality (style) and size, a lettering and numbering system is used. No doubt you are already familiar with the names Weatherhead, Aeroquip, and Stratoflex. All three companies use a numbering system. The letter stamped on the hose identifies the manufacturer and the first digit describes the basic hose style. Naturally, the numbers vary from company to company.

To accommodate the many hydraulic applications, manufacturers have included in their product (hose style) four or five groups classified according to working pressure. Each individual group includes different hose compositions to suit different types of liquids. The hose group styles are:

- *Group 1:* low pressure with a maximum working pressure up to 400 psi [2758 kPa]
- *Group 2:* medium working pressure up to 2000 psi [13,790 kPa]
- *Group 3:* high working pressure up to 3000 psi [20,685 kPa]
- *Group 4:* very high working pressure up to 5000 psi [34,475 kPa]

Some companies have special groups for special products.

The next number stencilled on the side of the hose is the dash number. This dash number system is used on both tubing and hoses. However, whenever the dash number indicates the inside diameter of a hose, the dash number of the hose is matched with the number of the tubing in order to determine the proper sizes when connecting a hose with a tube. Figures 21-15 to 21-17 show three hoses from Group 2 hose style. When examining the hoses and charts you will notice that the following four items differ with each manufacturer: (1) the material and construction, (2) the outside diameter of the hose size, (3) the working and burst pressure, and (4) the bend radius. (This change correlates with the variation in pressure.) Note that the above variations are also encountered in the other three hose styles.



Part no.	Hose size*	Hose ID, in	Hose OD, in	Min. burst pressure, psi	Max. working pressure, psi	Min. bend radius, in
205-4-L	−4	3/16	33/64	8000	2000	2
205-5-L	−5	1/4	37/64	8000	2000	2 1/4
205-6-L	−6	5/16	43/64	6000	1500	2 3/4
205-8-L	−8	13/32	49/64	6000	1500	4 5/8
205-10-L	−10	1/2	59/64	6000	1500	5 1/2
205-12-L	−12	5/8	1 5/64	5000	1250	6 1/2
205-16-L	−16	7/8	1 15/64	2500	600	7 3/8

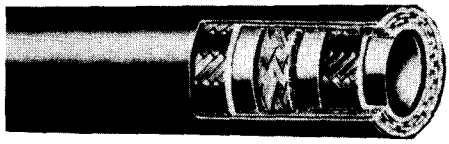
*Dash number.

Fig. 21-15 Stratoflex hose construction. This hose is made up of a seamless synthetic rubber inner tube reinforced with one braid of fabric cord and one braid of stainless steel wire, and covered with a synthetic rubber cover. *(Stratoflex of Canada, Inc.)*



Catalog no.	Hose ID, in	Hose OD, in	Max. working pressure, psi	Min. burst pressure, psi	Min. bend radius, in
H-17-¼	¼	9/16	1250	5000	3
H-17-⅜	⅜	¾	1125	4500	4
H-17-½	½	15/16	1000	4000	5
H-17-¾	¾	1¼	750	3000	6
H-17-1	1	1½	560	2250	8

Fig. 21-16 Weatherhead hose construction. This hose is made up of a Buna-N inner tube reinforced with a two-fiber braid and covered with Neoprene. *(The Weatherhead Co. of Canada, Ltd.)*



Part no.	Hose ID, in	Hose OD, in	Recom. working pressure, psi	Min. burst pressure, psi	Min. bend radius, in	Vacuum, inHg
2651-4	0.188	0.516	3000	12,000	3.00	28
2651-5	0.250	0.578	3000	10,000	3.38	28
2651-6	0.313	0.672	2250	9000	4.00	28
2651-8	0.406	0.766	2000	8000	4.62	28
2651-10	0.500	0.922	1750	7000	5.50	28
2651-12	0.625	1.078	1500	6000	6.50	28
2651-16	0.875	1.234	800	3200	7.38	20

Fig. 21-17 Aeroquip hose construction. This hose is made up of a synthetic rubber inner tube, cotton inner braid, single-wire braid reinforcement, and abrasion-resistant rubber cover. *(Aeroquip Corp.)*

Hose Ends Because of the great variety in hose styles and connections, a large assortment of hose ends are needed. Six examples of hose ends are shown in Fig. 21-18. The hose end has only one purpose—to connect a hose (troublefree) to an adapter or component. Each hose style uses the same socket; the nipple is the only variable factor in connecting with the different types of adapters.

To classify hose ends, all manufacturers use a numbering system. As with most reference systems, the numbering will vary from manufacturer to manufacturer.

Adapters With the great assortment of hose ends an even greater number of adapters are needed (see Fig. 21-19). Here also, to facilitate identification, a

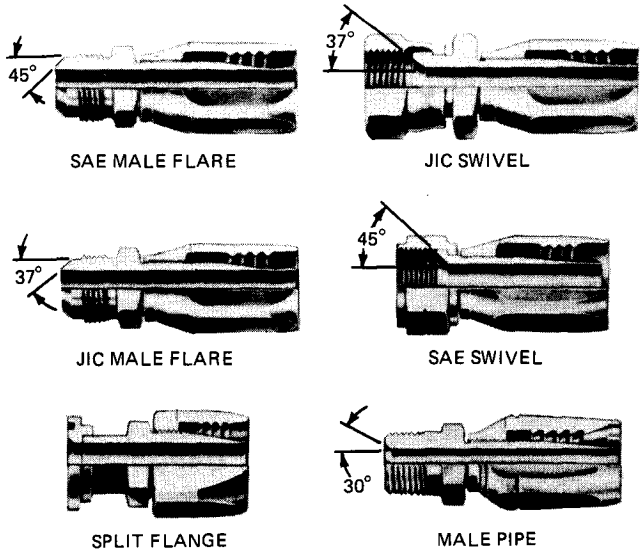


Fig. 21-18 Cutaway views of hose ends. *(Stratoflex of Canada, Inc.)*

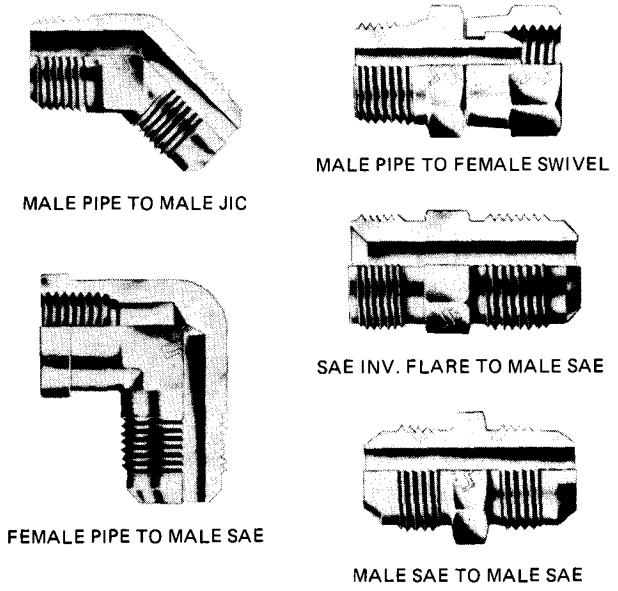


Fig. 21-19 Cutaway views of hose-end adapters. *(Stratoflex of Canada, Inc.)*

numbering system is used. The adapters illustrated are manufacturered by Stratoflex (SF). The "male pipe to male JIC" in Fig. 21-19 is a 45° elbow. The thread and flare design is JIC on one side and pipe thread on the other side. The thread size is ½ in and the hose size is ½ in.

Hose Service When hoses are installed and assembled correctly, they seldom break down or require servicing. Any problems which do arise in this area will be due to improper assembly of hose ends, incorrect length, or improper installation.

A number of improper hose installations are shown in Fig. 21-20. Before you read any further, try to figure out what's wrong with each installation. Here are the answers:

1. A hose will change in length (from 2 to 4 percent) when pressurized. Slack in the hose should be provided to compensate for any change in length which may occur.
2. Hose or tubing passing close to a hot exhaust manifold will deteriorate. It should be protected with a fireproof baffle.
3. For neater appearance and easier maintenance, use elbows and adapters if the flow volume is low. Remember, however, that where flow volume is high, the use of elbows should be kept to a minimum.
4. Any vibration or external force here could cause failure due to the insufficient support of the hose or tubing. If rubber-coated clamps had been used, external damage and excessive vibration would have been prevented.
5. The bend radius on this hose does not allow sufficient flow volume, so pressure is reduced. Any high pressure here might cause line failure. To assure maximum connection security, the bend radius should be increased.
6. A twisted hose will reduce flow volume. Also the socket will loosen under high pressure.

Servicing Hydraulic Hoses The mounting of a hose to a hose end need not be difficult if the correct assembly procedure is used. However, because of the many varieties of hose sizes, fittings, and styles, small but sometimes very costly mistakes can be made. Another problem that creates hose failure is the lack of uniformity among manufacturers in the numbering system and outside dimension. Therefore, when assembling hose ends to a hose, it is essential to make all purchases from the same manufacturer.

Perhaps the next greatest contribution to hose failure is the mechanic's disregard for the recommended assembly procedure. The following points may seem obvious, but they are the key if accuracy and perfection are desired.

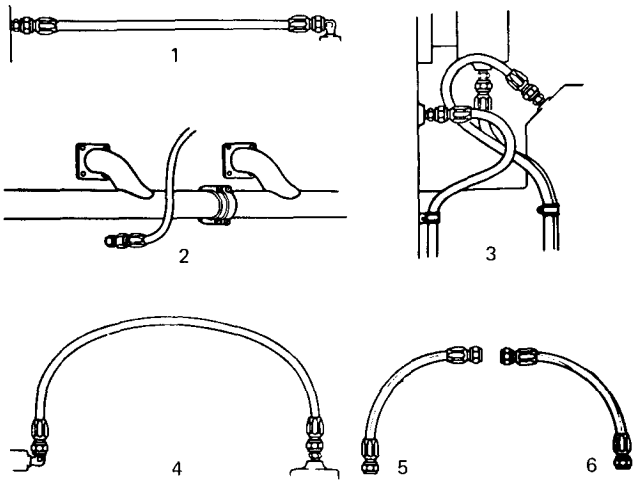


Fig. 21-20 Improper hose installations. *(Sperry Rand Canada, Ltd., Vickers Div.)*

Assembly Procedure The correct assembly procedures for the four most popular hose styles follow:

SOCKETLESS

1. Cut the hose to the required length.
2. Oil the inside of the hose and the outside of the nipple.
3. Push the hose onto the fitting underneath the protective cap. (If available, the Aeroquip socketless fitting assembly machine may be used.)

MEDIUM PRESSURE

1. Cut the hose square to the length required with a fine-tooth hacksaw or a cutoff wheel.
2. Put the socket in the vise and screw the hose counterclockwise into the socket until it bottoms, then back off one-quarter turn. *(NOTE: An assembly tool is required for all single wire-braid hoses in sizes of ¼ to ¾ in [6.35 to 19.05 mm].)*
3. Liberally oil the nipple threads, the assembly tool mandrel, and the inside of the hose.
4. *Male ends:* Push the assembly tool into the nipple. Oil the nipple, and then screw it clockwise into the socket and hose. Tighten the nipple until it is snug against the socket.
5. *Swivel ends:* Tighten the nipple and the nut on the assembly tool. Oil the nipple and then screw it clockwise into the socket and hose. Leave 1/32- to 1/16-in [0.79- to 1.59-mm] clearance between the nut and the socket so that the nut will swivel.

HIGH PRESSURE

1. Cut the hose to the length required.
2. A double wire-braid hose must be stripped of its rubber cover before inserting it in the socket. To locate the stripping point, lay the hose end next to the high-pressure fitting. The hose end should align with the notch on the socket. To strip the hose, cut around down to the wire braid, slit it lengthwise, raise the flap and pull it off with pliers. Then clean the wire braid with a wire brush or soft wire wheel, being careful not to fray or flare it.
3. Put the socket in a vise and screw the hose into the socket counterclockwise until it bottoms.
4. Oil the nipple threads and the inside of the hose liberally. (No assembly mandrel is needed for a double wire-braid hose.) Use grease instead of oil for larger sizes.
5. Screw the nipple into the socket and hose. Leave 1/32- to 1/16-in [0.79- to 1.59-mm] clearance for take-up.

TEFLON

1. Cut the hose to the correct length. Trim any loose wires flush with the tube stock. Remove any burrs on the tube end with a knife.
2. Slip the two sockets back to back over the neck-down end of the hose, positioning them 3 in [76.2 mm] from each end.
3. Mount the nipple hex in a vise. Work the hose bore over the nipple to size the tube and aid in separating the braid prior to fitting the sleeve. Then remove the hose from the nipple.
4. Start the sleeve over the tube and under the wire braid by hand. Complete the positioning of the sleeve by pushing the hose squarely against a hard surface. Make sure that the tube butts against the shoulder of the sleeve.
5. Lubricate the nipple and socket threads. For stainless steel fittings, use carbon tetrachloride; for other material combinations use standard petroleum lubricants.
6. Push the hose over the nipple with a twisting motion until it is seated against the nipple chamber. Push the socket forward, and hand-start the threading of the socket to the nipple. Wrench-tighten the nipple hex until the clearance with the socket hex is 1/32 in [0.79 mm] or less. Then tighten a little further in order to align the corners of the nipple and socket hexes.
7. To disassemble, unscrew and remove the nipple. Slide the socket back on the hose by tapping against a flat surface, then remove the sleeve with pliers.

Questions

1. List the materials of which pipes and tubes may be made.
2. List three different ways in which pipes may be constructed.
3. Explain how to cut a ¾-in pipe to a given length and cut a thread onto that pipe.
4. When pipes are assembled, why is a compound or a pipe tape used?
5. When is a double-flare tube required?
6. When double or single flaring a ½-in tube (either SAE 45° or JIC 37°), why is it important that the tube be cut square and the inside reamed?
7. Why is it important not to overtorque a fitting?
8. If a hose replacement has a smaller inside diameter than that of the original it would (*a*) increase velocity, (*b*) increase the volume, or (c) decrease the volume?
9. What is the difference between the identification on a hose fitting to be used (*a*) on a medium-pressure hose, or (*b*) on a high-pressure hose?
10. Why is it necessary to cut a hose very close to the vise and use a hacksaw blade which has 32 teeth?
11. Why is it advisable during assembly to hold the fitting socket, rather than the hose, in the vise?
12. Why is it important to have the correct hose length between fittings?

UNIT 22 • FILTERS

Need for Filters The most common cause of engine trouble is contaminants in the system; therefore, the most sensible way to maintain and preserve a high-performance hydraulic system is simply to keep the system clean. Many different types of filters are manufactured to accommodate the various types of hydraulic systems. Filters are a lifeline because they remove contaminants and thus protect the system. The manufacturers originally install the filters, strainers, and breathers. They also provide service manuals with precise instructions in order to ensure troublefree operation of the system components. Nevertheless, foreign matter enters the system usually through careless or inadequate maintenance, or through normal wear of the components within the system.

Filter-element Materials There are three classes of filter materials: mechanical, inactive absorbent, and active absorbent. The mechanical filter consists of closely woven metal screens or metal disks. It generally removes only fairly coarse insoluble particles.

Inactive absorbent filters are composed of materials such as cotton, yarn, cloth, impregnated cellulose paper, or porous metal. They will remove quite small particles and some types even remove water and water-soluble contaminants. The elements often are treated to give them an affinity to the contaminants found in the system.

Active absorbent filter materials, such as charcoal or Fuller's earth, remove particles by absorption as well as by filtering. They are *not* used as filter material for the lubrication or fuel-injection systems. They are, however, used as a filter material for the exhaust system.

Micrometer The unit of measurement for determining the effectiveness of a filter is the *micrometer* (μm) (old term: micron). One micrometer is equal to 0.000039 inch (1 μm = 0.000039 in), or in metric units of measurement, 0.000001 meter (1 μm = 0.000001 m). When new and clean, a filter will prevent a specific percentage of particles measuring a specific minimum size from entering the fluid.

Filter Types Four basic types of filters are used: screen and strainer, surface type, deep type, and edge type. The type, size, and micrometer rating is dictated by the system itself.

SCREENS AND STRAINERS Screens or strainers are surface-type filters and sometimes are referred to as mechanical filters (Fig. 22-1). These inlet screens

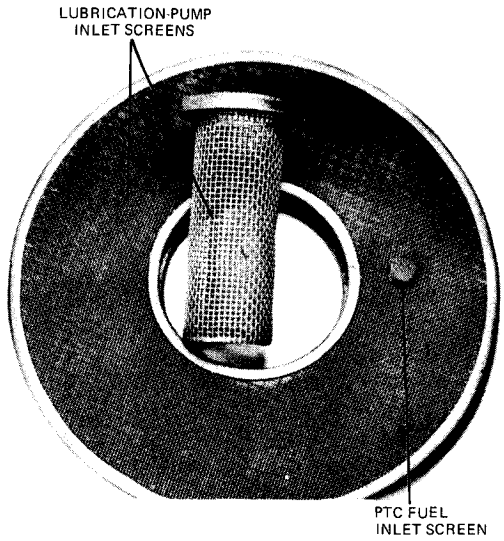


Fig. 22-1 Inlet screens.

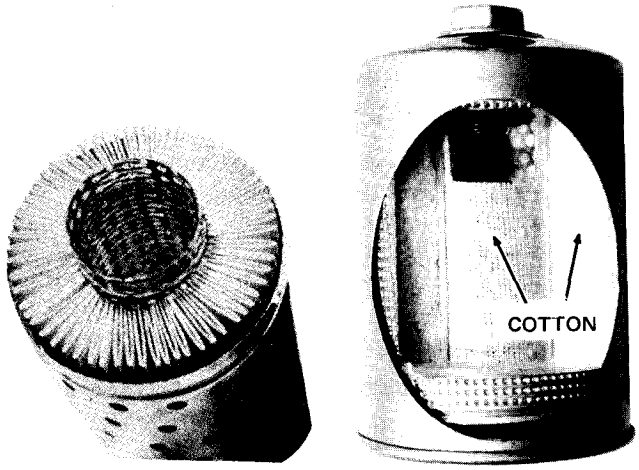


Fig. 22-2 *(a)* Surface-type filter, *(b)* deep-type filter (cotton).

prevent large foreign particles from entering the system. They are classified according to a sieve number which relates to the micrometer rating.

SURFACE-TYPE FILTER The surface-type filter element shown in Fig. 22-2*a* is composed of a specially treated micrometric cellulose paper. The paper is formed in vertical convolutions (wrinkles) and in a cylindrical pattern. It is reinforced on the inside and outside and is equipped with a seal on the top and bottom. Sometimes multifolded paper elements are used.

DEEP-TYPE FILTER The design of the deep-type filter is quite different from that of the surface filter (see Fig. 22-2*b*). It is more efficient and has a longer service life. Figure 22-3 shows two types of filter materials and illustrates the substantial depth of the filter material.

Deep-type filters of porous materials consist of fine woven copper or cinder bronze elements formed to fit the filter housing (Fig. 22-4). They can also be made of minute stainless steel balls joined as one inflexible piece.

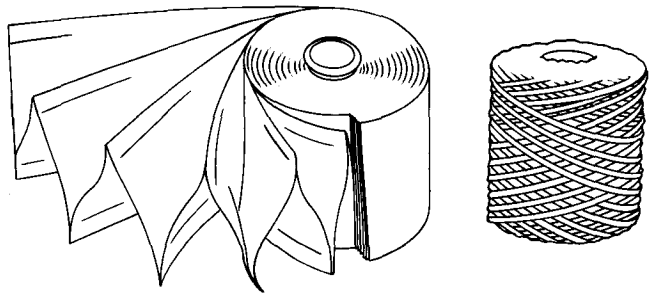


Fig. 22-3 Deep-type filter materials.

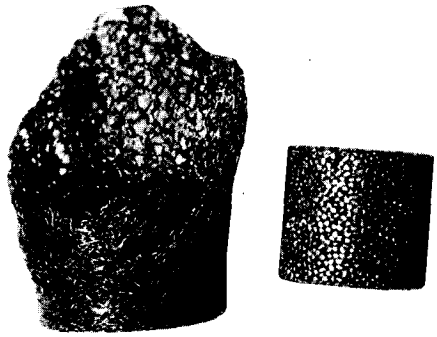


Fig. 22-4 Deep-type filter materials (porous).

EDGE-TYPE FILTER Edge-type filters are used as primary filters for the lubrication and fuel-injection systems. In this design, many copper, bronze, paper, or steel disks are positioned over the center tube. The tube acts as a hydraulic line and directs oil to the outlet port. Some edge-type filters have the added convenience of an automatic scraper or a hand-operated scraper for cleaning the outside of the disk (Fig. 22-5). This, of course, helps to extend the life of the filter.

Liquid Flow through Filter Regardless of the design or the type of a filter element, a filter element is sealed in a housing. O rings or gaskets separate the filtered from the unfiltered liquid. Liquid enters near the top of the filter housing or, with a screw-on-type oil or fuel filter, it enters via the adapter plate, and flows into the outer area of the filter element (Fig. 22-6). The system pressure forces the liquid through the filter element into the center area. Filtered liquid then passes through the center and on to the outlet port. Some filter designs incorporate an antidrain check valve to prevent fluid from draining from the filter bowl when the engine is stopped. This ensures instant oil or fuel pressure when restarting.

Full-flow oil filters have either a built-in bypass valve or a bypass valve which is mounted separately. The purpose of the bypass valve is to bypass oil ensuring lubricant to the system in the event that the filter element becomes plugged. A bypass valve is also used in oil coolers for the same purpose.

Full-flow and Bypass Filters Both full-flow and bypass filter arrangements are used on today's diesel

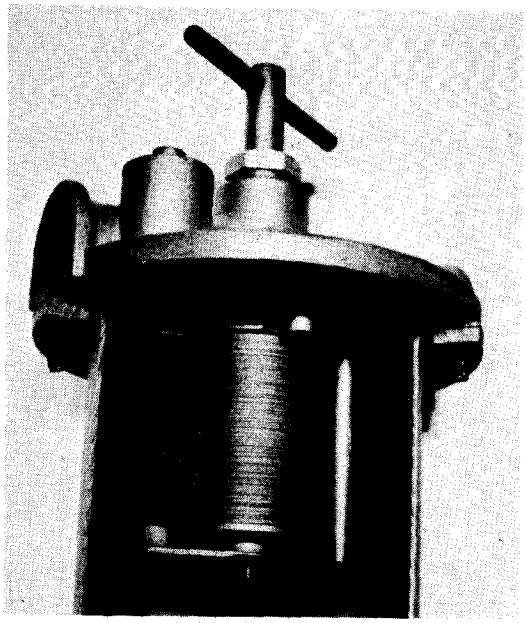


Fig. 22-5 Edge-type filter with hand-operated scraper.

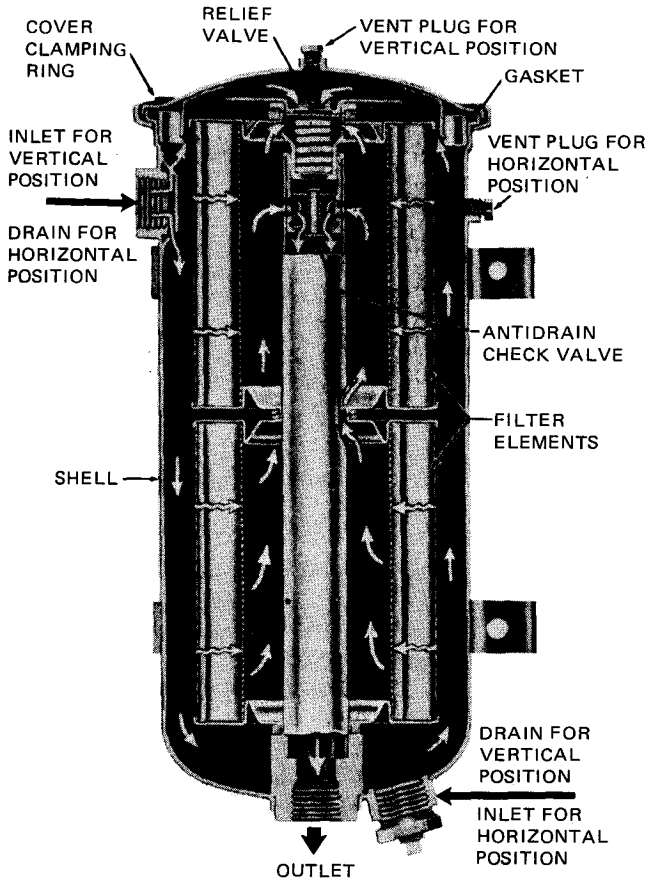


Fig. 22-6 Liquid flow through an oil filter. *(Mack Trucks Canada Limited.)*

engines. Full-flow filters are connected directly to the pump outlet. All fluid must pass through the filter element before entering the system (Fig. 22-7). In the bypass filter arrangement, the filter is connected to the oil galley or cooling system and only a portion of the liquid flow passes through the filter element. This filtered liquid then returns to the crankcase or radiator and is recycled. Eventually, all the fluid finds its way through the filter.

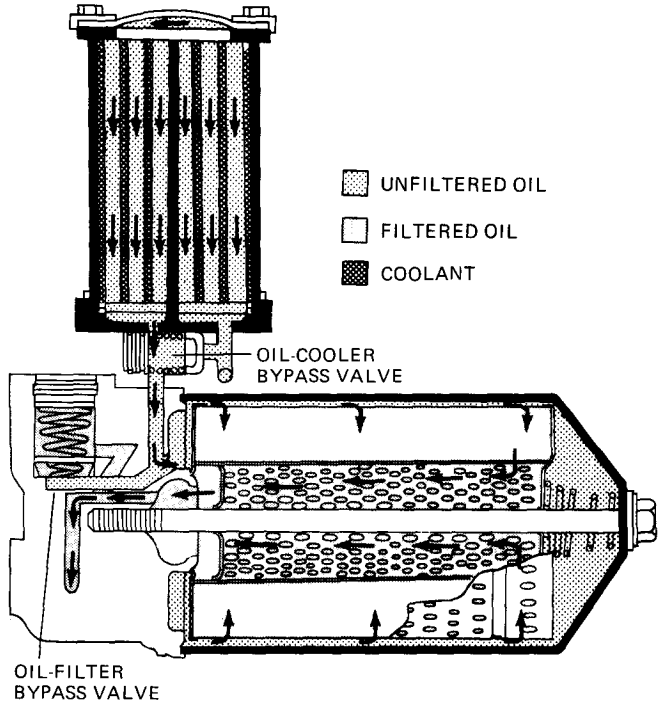


Fig. 22-7 Full-flow filter with oil cooler. Note the bypass valves for the oil cooler and filter. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

Servicing Oil Filter

1. In order to replace a filter element, remove the drain plug and drain the filter housing.
2. Remove the cover and filter element.
3. Clean and inspect the bowl and cover.
4. Clean and examine the relief valve. Make sure that the return outlet holes and orifices are free of any foreign materials.
5. Replace the drain plug and install a new filter element.
6. Fill the filter. Use the correct amount, type, and grade of lube oil, fuel oil, or coolant.
7. Place a new gasket on the cover. Make sure that the cover is positioned correctly.
8. Check the oil level. Start the engine and run it at a low idle.
9. Loosen the vent plug and as soon as the oil appears close it.
10. Run the engine at least 4 to 5 minutes to verify that there are no oil leaks.
11. Stop the engine and check the oil level. Add more oil if it is required.

Servicing Coolant Filter The recommended procedure for changing a coolant-filter element is similar to that for the lube oil and fuel filters. In addition you must:

1. Close off the inlet or outlet valves to prevent coolant losses. If there are no shutoff valves the radiator must be drained to the level of the filters.
2. Clean or replace the corrosion-resistant plate if it has become thin or pliable.
3. With the engine running, check (by means of the condition indicator) the coolant flow and color. Also check for the presence of air locks.

Servicing Fuel-filter Elements The recommended procedure for changing a fuel-filter element is similar to that for changing a lube-oil filter. The exceptions are:

1. Any air present in the filter housing must be removed by using a hand primer, gravity, or a low-pressure source to create a fuel flow.
2. When an edge-type element is used, the filter element must be washed in solvent and blown with shop air from the inside to the outside to remove any foreign particles. The procedure must be repeated, if necessary, to ensure that the element is clean.
3. Never blow air from the outside to the inside. This may damage the element by forcing foreign material into the metal shell or disk.

Centrifugal Bypass Filters A centrifugal bypass oil cleaner is shown in Fig. 22-8. The cleaner consists of a cyclone and centrifugal cleaner housing and rotor. The oil is forced under pressure into the cyclone where heavier impurities are thrown out against the walls and then driven downward by the current of oil. The oil in the center of the cyclone is then allowed to pass through the oil passage in the housing and up into the centrifugal cleaner housing and rotor. The force of the oil squirting out of the two nozzles causes the rotor to revolve at high speed. The centrifugal force separates foreign particles from the oil and deposits them on the wall of the rotor. Clean oil then flows through the internal oil line back to the crankcase.

The fuel system of a diesel engine has numerous enemies and water in the fuel heads the list. Fuel is the lubricant for the precise microfinish surfaces of the injection pump and injectors, but when water mixes with the fuel it washes away the delicate oil film, causing the closely fitted parts to scorch and burn and the residue to plug the orifices in the injection pump and/or injectors. For this reason many types of water separators are produced to remove water from the fuel. The simplest type is shown in Fig. 22-9.

Diffuser-type and Water Stop Filter This is a full-flow filter (Fig. 22-9) with only one moving part—the float valve. Its simplicity, however, does not hinder its effectiveness. This filter is equipped with an electric probe. The probe is connected to a warning device which causes the float valve to shut off the fuel flow to the injection pump when the water level exceeds the safety level.

FILTER ACTION Fuel, under pressure, entering through the inlet connection, flows over and around the conical section which acts as a diffuser. The fuel passes through a narrow gap around the periphery. It then flows radially toward the center and then upward and out via the outlet connection. During this period of radial flow, water and the heavier contaminants separate out by gravity and settle into the collecting bowl. As the sediment (water and foreign particles) fill the bowl, the float rises. When the sediment level reaches the probe, the electric alarm circuit closes, warning the operator of a critical buildup in the bowl. At this time the bowl should be drained. If

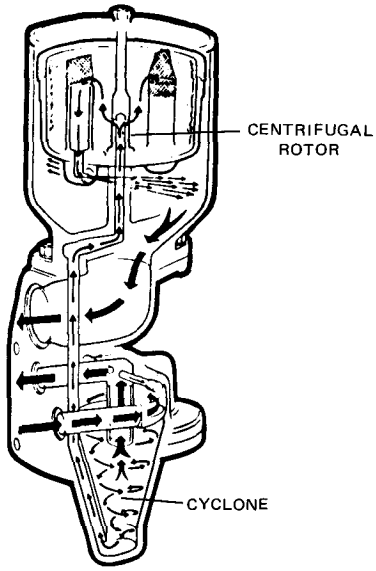


Fig. 22-8 Centrifugal bypass oil filter. (The arrows show the oil flow.) *(Mack Trucks Canada Limited.)*

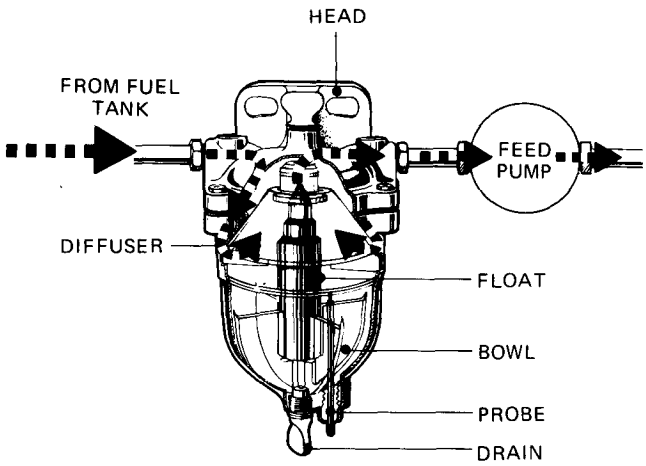


Fig. 22-9 Diffuser-type fuel filter. (The arrows show the fuel flow.) *(CAV Limited.)*

the bowl is not drained, and operation is continued, additional sediment enters the bowl and the float continues to rise upward until the conical tip seats in the valve, thereby stopping the fuel flow to the injection pump. *(NOTE: After the filter is cleaned, the fuel system must be primed.)*

Filter Separator Another type is the three-stage fuel filter shown in Fig. 22-10. This filter can remove 99.9% of free water (water not absorbed by the fuel) and 97.5% of other contaminants from the fuel.

FILTER ACTION As fuel under pressure enters the inlet port, it flows past the check valve and then between the small space of the turbine centrifuge and housing, whereupon the free water and contaminants (more than to 30 μm in size) are separated through the centrifugal action and settle into the bowl. The fuel and lighter contaminants in suspense flow upward through the conical baffle between the filter shell and filter cartridge element where they tend to settle on the wall. As the minute particles accumulate, their weight increases and they gradually fall to the bottom of the bowl. In the final stage of filtration the

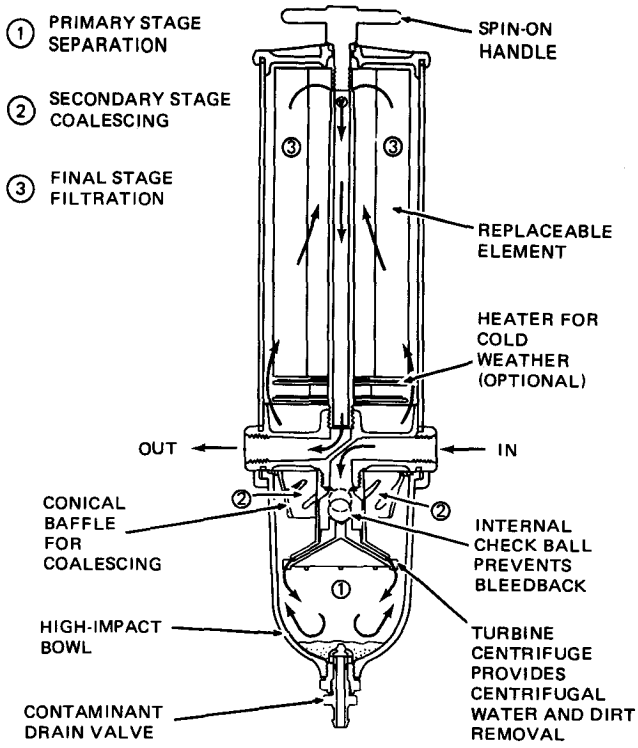


Fig. 22-10 Schematic view of a filter/separator.

fuel is forced through the filter element where the remaining contaminants, down to 1 μm are removed. After the fuel has passed through the element, it flows through the center tube and the outlet port. This type of filter can also be equipped with a water probe similar to the one shown in Fig. 22-9.

Water, dirt, and sludge, so detrimental to the fuel-injection system, can be overcome with careful fuel handling and filter maintenance. However, in climatic regions where the temperature drops below freezing, there is a further problem: that of fuel developing into wax crystals, in other words, into a jellylike substance which cannot pass through the filters. To maintain a fuel flow when starting and during the critical engine warm-up, in-line fuel heaters are used. Although designs vary, most operate on 12 or 24 volts (V) dc, 150 watts (W). These electric fuel heaters are fully automatic. The bimetallic actuator switches the heater on at about 30°F [−1.1°C] and switches it off when the fuel temperature reaches about 80°F [26.6°C].

Servicing Centrifugal and Diffuser-type Filters It is simple to service the centrifugal or the diffuser-type filter. A thorough cleaning and filter-element replacement will restore its serviceability.

Here are some common sense rules to follow when servicing filters:

1. Change or clean strainers, filters, and breathers regularly.
2. When you change filters or strainers, also clean the filter housing and bowl thoroughly.
3. Check for corrosion.
4. Always use new seals.
5. Repair faulty components as soon as possible.
6. Make certain that repair or exchange components are clean before installation.
7. Maintain proper oil and coolant levels.
8. Drain fuel tank and fuel-filter traps weekly, or daily if necessary.

Questions

1. How and when can the mechanic prevent foreign matter from entering the system?
2. Why have strainers or screens been installed in the pump-inlet side?
3. Explain how a full-flow filter operates.
4. Why is a bypass valve necessary with a full-flow filter?
5. Why is the oil flow in all filters from the outside to the inside?
6. There are four basic types of filters. Briefly outline the difference in the construction of these four filter elements.

UNIT 23 • SEALS AND GASKETS

Purpose of Seals and Gaskets Many different types of seals and gaskets are used in hydraulic systems to confine water, lube oil, or fuel; to prevent the entry of unwanted air, dust, dirt, or other foreign material; and to prevent a vacuum buildup. Manufacturers have made great efforts to combat sealing problems caused by high or low temperatures, expansion, contraction, vibration, pressure or vacuum, corrosion, and oxidation. However, even today with the great variety of seals available, it is difficult to find a seal which will be 100 percent effective under all operating conditions.

Engine manufacturers specify the type of seal to be used on their equipment and their instructions should be followed wherever possible. If the specified seals or gaskets are not available, consider the selection of a suitable substitute. Remember that inadequate sealing reduces the service life and efficiency of the components and results in additional costs due to the downtime.

Although seals and gaskets sometimes cease to function properly, they should not automatically be considered the source of the trouble. More often the trouble has arisen because the mechanic did not clean the surfaces to be sealed, did not remove nicks and burrs, did not properly align the components, did not properly install the seals or gaskets, or did not torque the bolts to specification.

Classification of Seals There are two seal classifications: static seals and dynamic seals. The seals which are used between two stationary components are called *static seals*. Seals capable of sealing two components which move in relation to each other are called *dynamic seals*. Dynamic seals are divided into contacting and noncontacting seals. The latter involve no physical contact between the stationary and rotating elements. They are referred to as *labyrinth seals* and are not used on engines.

Mechanical Seals Mechanical seals are found in fuel-injection systems, in coolant systems, and in hydraulic motors and pumps. The most efficient seals are metal-to-metal, metal-to-carbon, and metal-to-synthetic material. The two lapped mating surfaces (stator and rotor) are forced together through a hold-down device or by spring force to form the sealing surface (see Fig. 23-1). The stator is fastened to the nonrotating element and the rotor is fastened to the rotating element. *(NOTE: Both use an O ring as the static seal.)*

O-ring Seals The construction material of today's O-ring seals is such that they can be used as either static or dynamic seals. O rings of a shape similar to that shown in Fig. 23-2 are made of synthetic rubber. They are molded to close tolerances in the cross-sectional areas and to the inside and outside diameters. For dimensional standardization a numbering system is used.

To identify the various synthetic materials from which O-ring seals are made, a lettering system is used. The color has no bearing on the proper selection. However, SAE recommends a yellow stripe marking for oil-resistant O rings and a red marking for fuel-resistant O rings. When a replacement is necessary, use the manufacturer's replacement seals. If these are not available, review the requirements carefully before selecting from another source.

When an O ring is applied statically or dynamically, it is fitted into a right angular or curved groove which has been machined into the components to be sealed. The mating surface compresses the O ring about 10 percent. When it is necessary to improve sealing because of higher pressure, extrusion rings (backup washers) are used. The extrusion ring acts as a dirt wiper, permits a wider clearance between the sealed parts, and forms a seal across the clearance gap.

Removing and Installing O Rings When you remove an O ring, you must be careful not to damage the grooves or corners. A suitable O-ring removing tool should be used. Check the O-ring groove and mating surface for nicks and burrs and make certain that the replacement seal is of the recommended type and size. Check the O ring by rolling it inside-out. Stretching it lightly will help to reveal any small cracks or other irregularities. If it is damaged in any way at all, the O ring must be discarded.

During installation, make certain that the O ring is well lubricated, that it is not twisted, and that it is properly inserted into the groove. When you install a backup washer, remember to insert it toward the lower pressure side and lubricate it well.

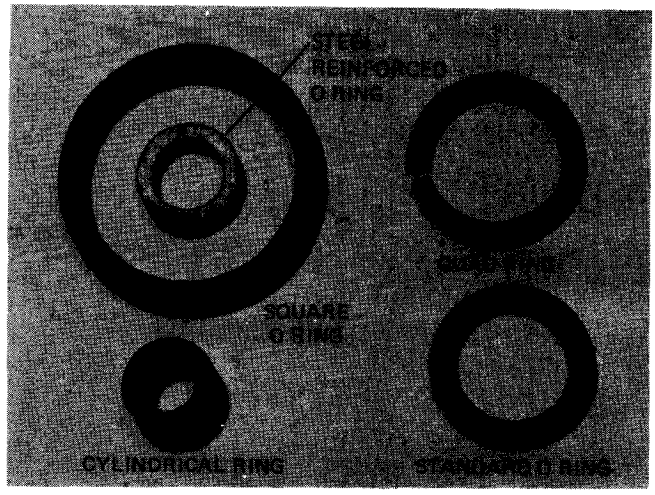


Fig. 23-2 Rings made of synthetic rubber.

Gaskets The most common static seal is the *gasket*. Gaskets are designed to suit particular needs and, therefore, are manufactured from many different materials. When you select a gasket material, you must consider pressure, temperature, hole size, flexibility, smoothness, and the material of the mating surface. You also must consider the function of the gasket, such as whether or not it must seal off oil, water, dirt, and/or air, or whether it is needed to support a vacuum.

Gasket Material Copper, aluminum, steel, cork, fiber, asbestos, Nobestos, synthetic rubber, paper, and various combinations of these materials are used to make gaskets (Fig. 23-3). Copper, aluminum, steel, or fibers frequently are used as gasket material under bolts and adjusting caps or between components. Copper gaskets can be reused in an emergency by *annealing*—softening by heat—until the material changes color slightly and then cooling them in water. This process makes copper more pliable.

CORK The physical properties of cork make it the most versatile of the gasket materials (see 6 in Fig. 23-3). It is a suitable seal where vibration, expansion,

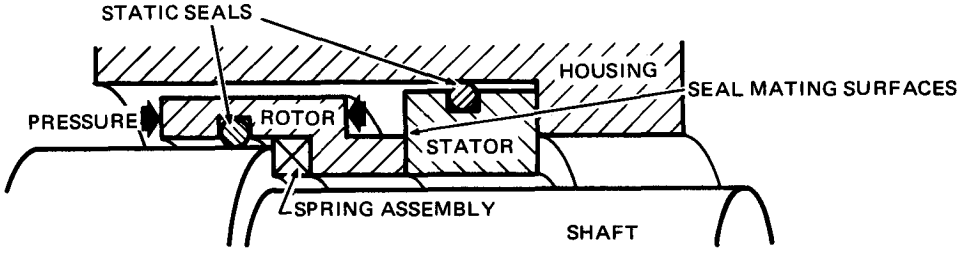


Fig. 23-1 Schematic view of a mechanical seal.

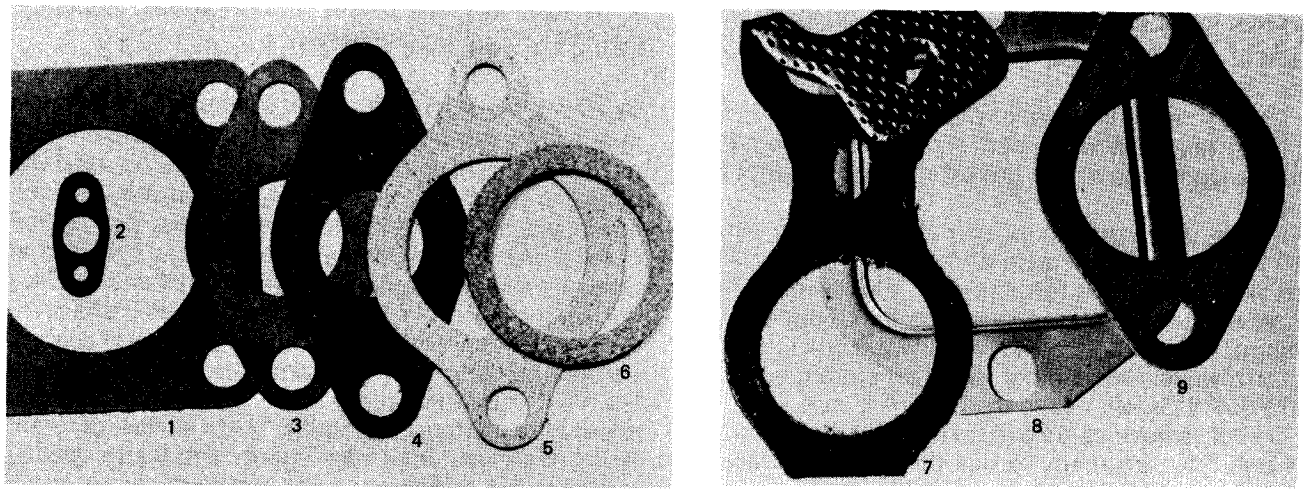


Fig. 23-3 Gaskets of different materials: (1) paper, (2) synthetic rubber, (3) asbestos and paper combination, (4) chloroprene and asbestos, (5) asbestos, (6) cork, (7) multilayer of asbestos and aluminum, (8) steel, (9) fiber.

or uneven surfaces occur. The cork gasket is improved by coating its surface with synthetic rubber or with a combination of synthetic rubber and cork. When using cork gaskets, however, frequent retorquing is necessary in order to maintain a leakfree seal.

SYNTHETIC RUBBER Although wide ranges of synthetic rubber gaskets are available, they are seldom used on diesel engines (2 in Fig. 23-3).

PAPER (CHLOROPRENE) Chloroprene is widely used as a material for making gaskets. It is water- and oil-resistant, varies in strength and softness, and is adaptable to low and high temperatures and to high pressure. To increase chloroprene's ability to withstand temperature changes and high pressure, rubber, asbestos, or other fibers are added to the original chloroprene composition (1, 3, and 4 in Fig. 23-3).

Gasket Construction On the whole, the majority of gaskets have a simple construction. This means that a single layer of gasket material is cut to fit the opening and surface contour to be sealed, without reinforcement.

Where heavy stress may be encountered, the common gasket cannot be used. Under these circumstances, the gaskets must be of a more sophisticated composition.

Head Gaskets Cylinder-head gaskets are the most complicated in design and construction because they must withstand extreme pressure, vibration, high temperature, and expansion changes. They must seal against compression, gases, oil, and coolant. They must resist extrusion, elongation, oxidation, and chemicals, and, in fact, must possess the same strength requirements as the other combustion chamber components. A number of head-gasket designs are shown in Fig. 23-4.

A head gasket consists of a multilayer of materials. The two outer gasket layers may be of similar materials or of different types of alloys. The material used for the center layer is Nobestos, asbestos, or an asbestos composite. Some head gaskets include two outer layers of asbestos or Nobestos with a center layer of alloy. Some are of the single- or double-sheet design. Regardless of which design is used, the openings for the cooling passages, oil passages, and the piston sleeves are reinforced. Grommets are used to increase sealing, to ensure an unrestricted flow of oil or coolant fluid, and to strengthen the head gasket. Some head gaskets include copper or a special rubber is bonded around the lube oil and coolant openings. A special alloy ring (fire ring) may be located above the cylinder sleeve to improve sealing.

Since meticulous care must be taken when installing a head gasket, this subject was covered separately in Unit 14, "Cylinder Head and Valves."

Rules to Prevent Sealing Failure

1. Whenever possible avoid reusing a seal or gasket. Their elasticity deteriorates and small nicks and cracks which are invisible to the naked eye reduce the sealing capacity.
2. Make certain that the mating surfaces are straight

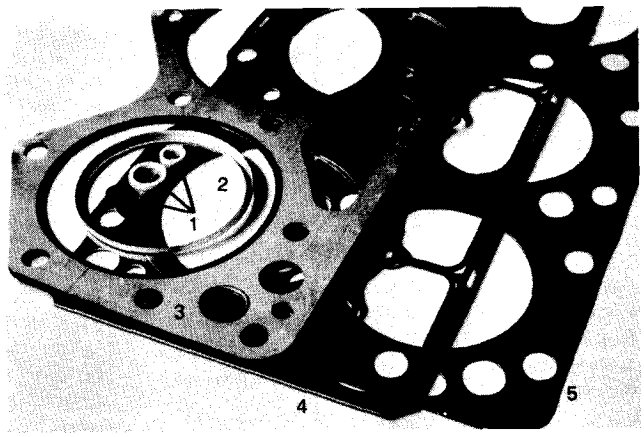


Fig. 23-4 Head gaskets. (1) synthetic O rings to seal oil and coolant passages; (2) Detroit Diesel; (3) reinforced multilayer: aluminum and asbestos; (4) reinforced multilayer: copper, asbestos, and steel; (5) reinforced multilayer: copper and asbestos.

and that the grooves or shafts are free of any foreign material before reassembling. Inspect for cracks, nicks, burrs, or dents.

3. Always check the seal or gasket for proper fit. The opening which holds the seal should not be enlarged and the openings of the gasket must not restrict the flow.

4. Before you install cork or paper gaskets, which may have shrunk because of long or improper storage, soak them for a few minutes in lukewarm water. Since wet cork or paper gaskets have a tendency to enlarge, put the wet gasket in a warm place before use. However, remember that temperatures over 100°F [37.8°C] will cause the gasket to curl.

5. Do not remove seals or gaskets from their packing kits until you are ready to use them. Inspect fittings for contamination before installation.

6. Follow installation instructions carefully.

7. Torque the bolts or nuts in the proper sequence, taking care not to overtorque.

Sealing Compound At one time or another you may have used a liquid sealing compound to hold a gasket in place, to repair an old gasket, or, used the compound instead of a gasket, to stop a leak. Then again, you may have used it to seal a hose connection or to improve a gasket seal which had an oxidized or uneven surface. You might recall that this sealing compound was not always satisfactory. Its ineffectiveness may have been due to your selection of sealing compound. Applying the correct sealing compound is a very important factor. It is obvious, then, that you should be thoroughly familiar with all the different types of sealers, their application, and their capacity to withstand temperature, or pressure, or to resist liquids. Figure 23-5 analyzes some common sealants.

Product	Method of application	Temperature range and pressures	Uses	Resists	Drys/sets/solvent
Permatex High Tack Spray-A-Gasket® Adhesive-Sealant No. 99	Aerosol spray can	−65 to +500°F [−53.8 to +260°C] 5000 psi [34,474 kPa]	All engine gaskets, transmission and rear-end housing gaskets. All threaded connections, radiator and heater hose connections, antislip agent for fan belts, adhesive for general use. Tubeless-tire beads, battery terminal protector and wire waterproofer. Can be used on any type of gasket, felt, cork, metal, paper, asbestos, etc.	Gasoline oil, kerosene, lube oils, water, steam, antifreeze solutions	Sets up fast . . . super tacky . . . yet allows gasket movement. Under engine operating temperatures, it converts to super sealant Lacquer thinner
Permatex High Tack Brushable Adhesive-Sealant No. 98	Brush in can	−65 to +500°F 5000 psi	All engine gaskets, transmission and rear-end housing gaskets. All threaded connections, radiator and heater hose connections, antislip agent for fan belts, adhesive for general use. Tubeless-tire beads, battery terminal protector and wire waterproofer. Can be used on any type of gasket, felt, cork, metal, paper, asbestos, etc.	Gasoline, oil, kerosine, lube oils, propane, butane gases, water, steam, antifreeze solutions	Sets up fast . . . super tacky . . . yet allows gasket movement. Under engine operating temperatures, it converts to super sealant Lacquer thinner
Permatex High Tack Super Adhesive No. 97	Tube has applicator tip or use spatula or putty knife	−60 to +450°F [−51.1 to +232.2°C] 5000 psi	All-purpose adhesive-sealant for bonding weatherstrip, trim, feathering sanding disks, leather, vinyl cloth, rubber, glass, metal, wood, silencer pads, mats, cork, asbestos, paper, insulation, repairing arm rests, holding engine gaskets, fastening headers and padded dash. Sealant for drip rail, car seams, convertible tops, water-proofing cracks, etc.	Gasoline oil, kerosene, glycol, transmission fluid, brake fluid, antifreeze solutions, grease, glycerin, lube oil, propane or butane gases, or water	Fast Firm, nonbrittle stage Lacquer thinner

Fig. 23-5 Permatex sealant chart.

Product	Method of application	Temperature range and pressures	Uses	Resists	Drys/sets/solvent
Form-A-Gasket® No. 1 Mil Spec. Type 1 MIL-S-45180B (Ord.)	Spatula, putty knife, etc.	−65 to +400°F [−53.8 to +204.4°C] 5000 psi	Permanent assemblies, repair gaskets, fittings, uneven surfaces, thread connections, cracked batteries	Water, steam, kerosene, gasoline, oil, grease, mild acid, alkali and salt solutions, aliphatic hydrocarbons, antifreeze mixtures	Fast Hard Alcohol
Form-A-Gasket® No. 2 Mil Spec. Type II MIL-S-45180B (Ord.)	Spatula, putty knife, etc.	−65 to +400°F 5000 psi	Semipermanent reassembly work. Cover plates, threaded and hose connections	Water, steam, kerosene, gasoline, oil, grease, mild acid, alkali and salt solutions, aliphatic hydrocarbons, antifreeze mixtures	Slow Flexible Alcohol
Aviation Form-A-Gasket® No. 3 Mil Spec. Type III MIL-S-45180B (Ord.)	Brush	−65 to +400°F 5000 psi	Sealing of close-fitting parts. Easy to apply on irregular surfaces	Water, steam, kerosene, gasoline, oil, grease, mild acid, alkali and salt solutions, aliphatic hydrocarbons, antifreeze mixtures	Slow Flexible Alcohol
All-Purpose Cement No. 50	Spatula, putty knife, etc.	−40 to 225°F [−40 to +100°C]	Glass to glass, glass to metal, glass to rubber	Water, polishes, and cleaners	Fast Hard Toluene
Pipe Joint Compound No. 51 U.L. approved	Brushable, viscous liquid	−65 to +400°F 5000 psi	Threaded fittings, flanges. Can be applied over oil and grease film.	Hot and cold water, steam, natural gas, propane, butane, fuel oils, kerosene, lubricating oils, petroleum base hydraulic fluids, antifreeze mixtures	Slow Flexible Alcohol
Super "300" Form-A-Gasket® No. 83	Brush	−65 to +425°F [−53.8 to +218.3°C] 5000 psi	Assembly work on high-compression engines, diesel heads, cover plates, high-speed turbine superchargers, automatic transmissions, gaskets	High-detergent oils and lubricants, jet fuels, heat-transfer oils, glycols 100%, mild salt solutions, water, steam, aliphatic hydrocarbons, diester, lubricants, antifreeze mixtures, petroleum-base hydraulic fluids, aviation fuels	Slow Flexible Alcohol
Indian Head Gasket Shellac No. 5	Brush	−65 to +350°F [−53.8 to +176.4°C] Variable	General assembly work and on gaskets of paper, felt, cardboard, rubber and metal	Gasoline, kerosene, greases, oils, water, antifreeze mixtures	Slow Hard Alcohol

Fig. 23-5 *(Continued)*

Liquid sealants should be used sparingly. (Too thick a coat will plug small oil, water, or air passages.) Always follow the manufacturer's directions to assure a good seal.

Antiseizure Compounds As its name indicates, the function of an antiseizure compound is to prevent seizure of bolts, nuts, or shafts. It also prevents corrosion, oxidation, galling, and chemical reaction between two elements and reduces friction. This compound should be applied to exhaust-manifold bolts and to pipes where a corrosive condition or chemical reaction is likely to occur. Where precise torquing is important, a light coat should be applied on the bolts and nuts to reduce friction.

Lock-type Compounds A lock-type liquid compound is used to prevent bolts, nuts, seals, bearings, cones, and other components from becoming loose or moving out of position. This compound fills the space between the components and, in principle, makes them inflexible. It should, of course, only be used in cases of emergency, or as recommended. Once it has been applied and allowed to set, this compound often makes it difficult to remove the components without damage. If it does become necessary

to loosen the grip of the compound, use moderate heat.

Making a Gasket Sometimes it becomes necessary to make your own gasket. If a gasket made from cork, polyacrylic, or asbestos is required, the procedure is fairly simple. Two different methods of making gaskets are available to you.

METHOD 1
1. Lay the gasket material over the components to be sealed.
2. Secure the material so that when you are tracing the outline of the component the gasket material will remain in place.
3. Cut the inner and outer circumferences with tin snips or scissors, and use a hole punch to cut bolt holes.

METHOD 2 This method is recommended only when the edges of the component are sharp. If the edges are not sharp, the material will not cut properly and damage will result.

1. Lay the gasket over the components and use a ball peen hammer to gently tap out one bolt hole.

CAUTION If the hole is threaded, take care not to damage the threads.

2. Insert a bolt in the tapped out hole.
3. Begin by tapping out only a minimum number of holes to secure the gasket material to the component.
4. Finally, tap out the remaining bolt holes and openings.
5. Tap gently around the edges of the material so that it is cut to the contour of the compartment.

Lip-type Seals Lip-type seals are found in large numbers on diesel engines and their accessories. The designs vary depending on whether they are to be used for sealing off oil, water, dirt, or low pressure or for sealing in two directions.

TYPES AND DESIGNS OF LIP SEALS The most common lip-type seal designs are illustrated in Fig. 23-6. All these designs have two common factors: a sealing element is bonded to the seal metal case, and the opening side faces the higher pressure side.

There are several variable factors in the design of lip-type seals. Some seals utilize a garter spring to increase lip contact. A rubber coat over the outer circumference of the seal case can be utilized to improve housing sealing. The sealing itself can be either internal or external.

The composition of the lip seal is very important and depends on its intended use and location. Silicones, polyacrylics, and Viton are heat-resistant and the least vulnerable to chemicals. However, these products are not as effective against abrasives as nitrile rubber compounds; certain chemicals used in lube oil can cause them to deteriorate when exposed to high temperature. A lip-type seal design which may replace the conventional lip-type seal is shown in Fig. 23-6*a*. It is comprised wholly of various types of synthetic rubber.

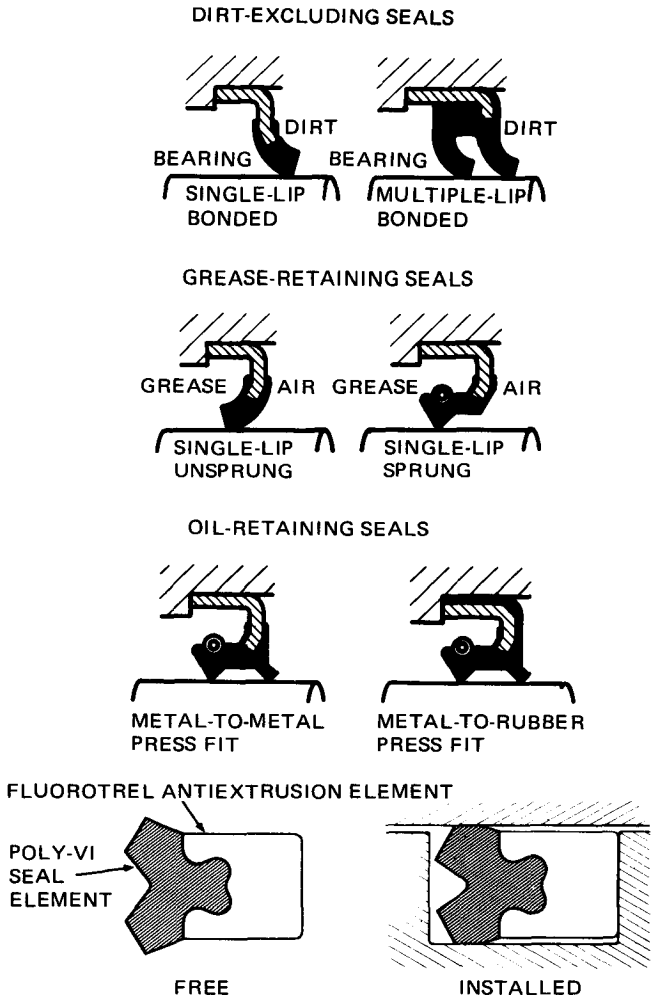


Fig. 23-6 Various lip-type seals.

It follows, of course, that the best replacement possible is the one specified by the manufacturer. Replacement should be done as early as possible to safeguard the engine or component against costly failure. Needless to say, proper storage, handling, and installation procedures are also important.

Removing and Installing Seals

1. Before you clean the components, inspect them to determine the cause of leakage. After locating the leakage area, check for accumulation of oil, carbon, or rust.
2. Check the alignment of the seal on the shaft and in the bore.
3. Look for tool marks.
4. Check the shaft and the seal cage housing as a possible origin of leakage.

Almost any method is acceptable for the removal of a seal providing no damage occurs to the shaft or the housing bore. The three most common ways to remove a seal are shown in Figs. 23-7 to 23-9.

After you have removed the seal, examine the components to determine the cause of oil leakage.

1. Measure the shaft and housing for roundness.
2. Check the shaft for roughness, misalignment, or grooves.
3. Check the shaft for runout or bearing wear.

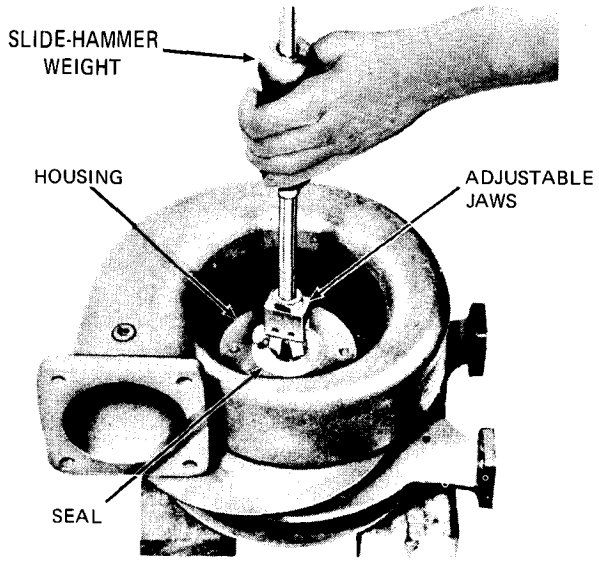


Fig. 23-7 Removing an oil seal from the turbine housing with a slidehammer puller. *(Allis-Chalmers Corp. Engine Division.)*

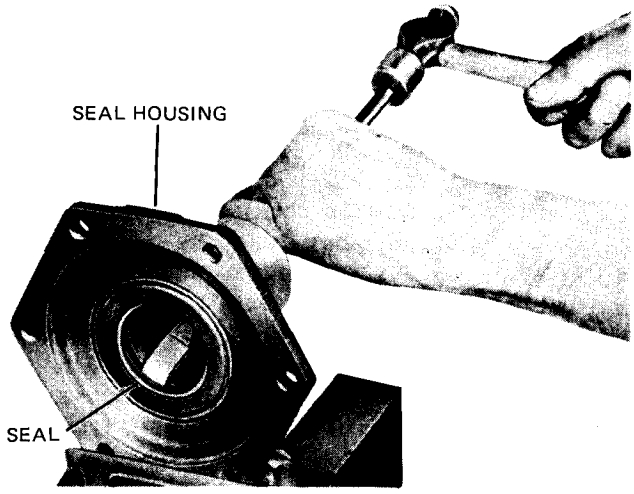


Fig. 23-8 Removing an oil seal with a punch and hammer. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

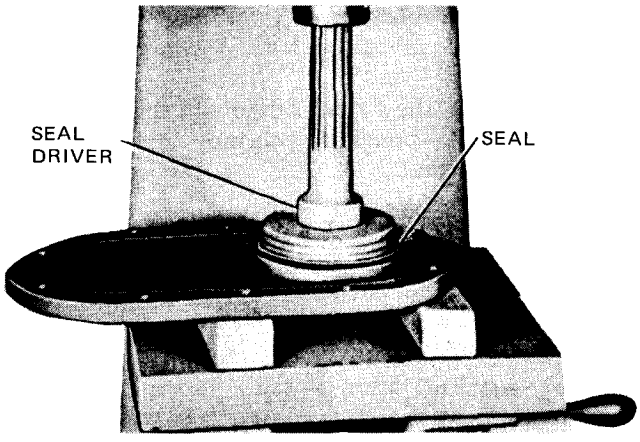


Fig. 23-9 Using a driver to remove an oil seal from the bearing cover. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

4. Check the seal-wear pattern with respect to problems of misalignment.
5. Check for evidence of abrasive wear. Note the type of abrasive.
6. Check for previous installation damage.
7. Check for contaminants.

Pointers for Installing Lip-type Seals Before you begin installation, recheck to be certain that you have selected a seal with the correct inside and outside diameters. Make sure that the seal case is also of the correct dimension.

Clean the bore opening or recess and remove any nicks or burrs.

Polish the shaft with 600-grit oil paper or crocus cloth.

When the shaft is grooved, use either a spacer or a sleeve to make a new lip contact (see Fig. 23-10). When using this method, however, you must first check that the lip has a sealing surface and that the seal case will not rub on the rotating surface.

If you are using a seal case without rubber coating, first apply a thin coat of nonhardening sealing compound to the counterbore in order to ensure easy installation. This will improve the sealing as well.

Having taken the above precautions, you may then place the open side of the seal with its face toward the oil side into the bore. Since fluid pressure increases lip force when the component is moving, a reversed seal may cause the oil pressure to lift the seal lip off its shaft.

After the shaft is in place, take care not to damage the lip or the seal element when you slide the seal over the shaft. When the shaft end and counterbore are in the same plane, or when the shaft is splined or has a keyway, use the sleeve guide provided by the manufacturer. If this is not available, use a pro-

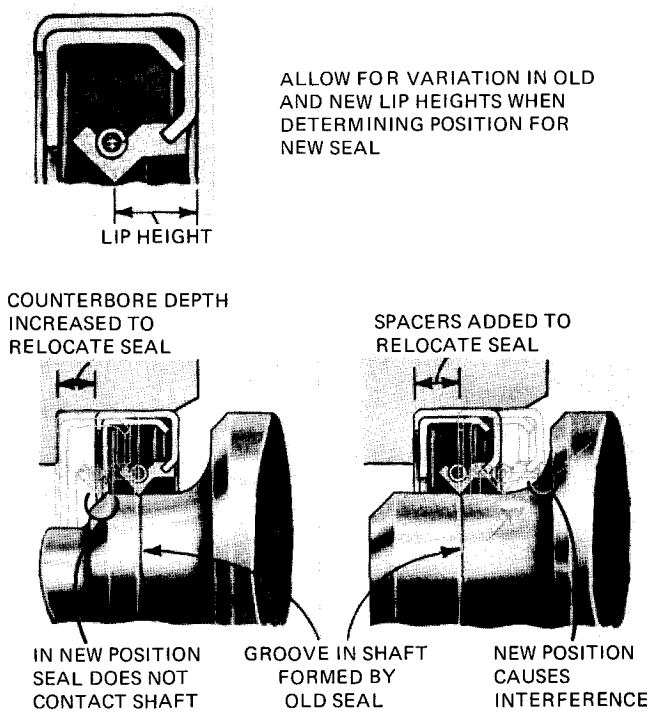


Fig. 23-10 Making a new lip contact. *(Caterpillar Tractor Co.)*

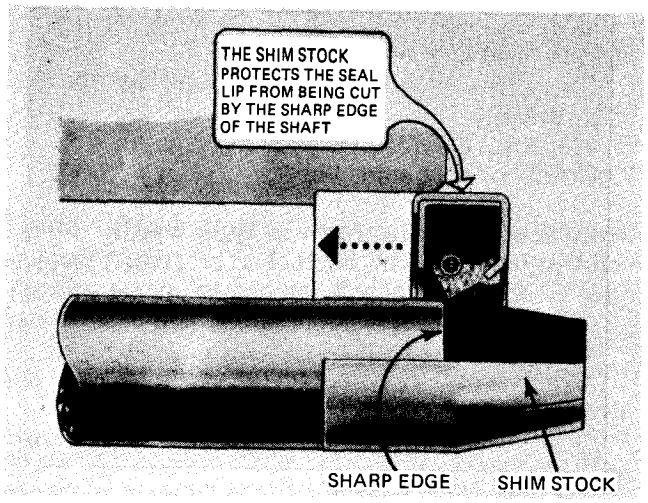


Fig. 23-11 Using a shim-stock sleeve when sliding the seal over the shaft. *(Caterpillar Tractor Co.)*

tective shim-stock sleeve, as shown in Fig. 23-11. If it is at all possible, you should solder the seams and then smooth the surface. This will help prevent lip damage during installation.

If the seal must be driven below the face, select a seal driver which fits loosely in the counterbore (Fig. 23-12). Under all circumstances the force on the seal case must be exerted on its strongest point, that is, the outer circumference. In the event that a seal driver is not available, use a socket or pipe of a size close to the ouside diameter of the seal. Avoid driving the seal in place with a hammer because this will deform the seal housing as well as the sealing element. Never use a punch to install a seal.

Questions

1. When is a seal called a *static seal?*
2. When is a seal called a *dynamic seal?*

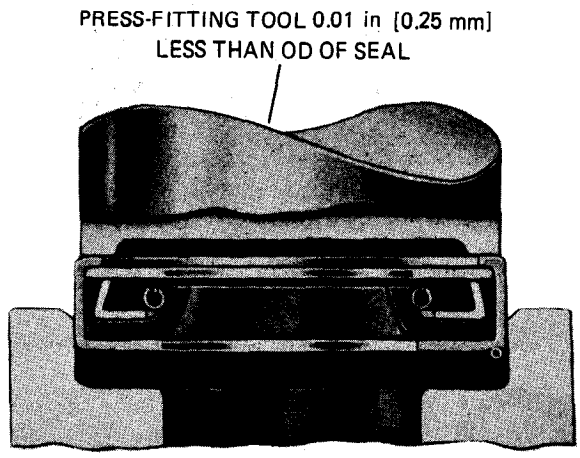


Fig. 23-12 Installing an oil seal in the housing. *(Mack Trucks Canada Limited.)*

3. List the precautionary measures which must be taken when installing a new O ring.
4. Explain how to cut a new gasket for an inspection cover.
5. When is a cork gasket used?
6. Why are cylinder-head gaskets commonly made of multilayer materials?
7. Why should you avoid reusing a seal or gasket?
8. Why should gaskets and/or seals remain in their packing kits until you are ready to use them?
9. Why is it essential to use specified torque and specified sequence when installing components which have a gasket between them?
10. List six reasons or circumstances under which a gasket could fail?
11. List all the checks to be made before installing a new seal.
12. Under what circumstances is it essential to use a sleeve guide?

SECTION 4

FUEL-INJECTION SYSTEMS

UNIT 24 • DIESEL FUEL

Fuel Classification (Grades) Diesel engine fuel ranges from a highly refined distillate fuel obtained from fractional distillation of crude oils, to a product of residual materials obtained from crude-oil distillation, cracking processes, and fractions removed during the production of crankcase oil. However, the fuels with which the diesel mechanic is most concerned are those known as middle distillates, that is, grades 1D, 2D, and occasionally 4D.

To meet the needs of the various engine designs and sizes, and to accommodate frequent speed and load changes, permissible limits of fuel properties have been suggested by the American Society for Testing and Materials (ASTM) and by the United States Bureau of Mines. Choice of the correct fuel allows easier starting and abates wear of fuel-injection equipment, piston rings, valves, and cylinder sleeves.

The ASTM defines three grades, 1D, 2D, and 4D, which are equivalent to types C-B, TT, and RR of the United States Bureau of Mines (see Table 24-1). Recommended fuel specifications are listed in Table 24-2.

Cetane Number (Ignition Quality) The cetane number of a diesel fuel expresses its igniting quality. The higher the cetane number, the shorter the ignition delay period.

The cetane number may be defined as the percentage by volume of the normal cetane in a blend with alpha-methylnapthalene to match the ignition quality of the test fuel. The cetane number affects cold starting, combustion, warm-up, deposits under ideal and light load operation, roughness, acceleration, and exhaust smoke density. However, the ignition requirement of a diesel engine changes with the design of the combustion chamber, engine speed, and operating condition as well as ambient temperature and altitude.

High-speed engines require a higher cetane number to prevent engine roughness and knock, but the shorter delay period may lead to a darker exhaust

TABLE 24-1

PROPERTIES OF ASTM GRADES OF DIESEL FUELS

Grade[a]	Flash point, °F [°C]	Pour point, °F [°C]	Water and sediment, vol %	Carbon Residue on 10% residuum, %	Ash, wt %	Distillation temperatures, °F [°C] – 90% point		Viscosity at 100°F [37.8°C] kinematic, centistokes, (or Saybolt Universal sec)		Sulfur, wt %	Copper strip corrosion	Cetane number[b]
	Min.	Max.	Max.	Max.	Max.	Min.	Max.	Min.	Max.	Max.	Max.	Min.
1D	100 or Legal [37.8]	[c]	Trace	0.15	0.01		550 [287.8]	1.4	2.5 [34.4]	0.50	No. 3	40[d]
2D	125 or Legal [51.7]	[c]	0.10	0.35	0.02	540[e] [282.2]	640 [338]	2.0[e] [32.6]	4.3 [40.1]	0.7[f]	No. 3	40[d]
4D	130 or Legal [54.4]	[c]	0.50		0.10			5.8 [45]	26.4 [125]	2.0		30[d]

SOURCE: Chevron Research Company

[a] To meet special operating conditions, modifications of individual limiting requirements may be agreed upon between purchaser, seller, and supplier.

[b] Where cetane number by Method D 613 (Test for Ignition Quality of Diesel Fuels by the Cetane Method) is not available, ASTM Method D 976 (Calculated Cetane Index of Distillate Fuels) may be used as an approximation. Where there is disagreement, Method D 613 shall be the referee method.

[c] For cold weather operation, the pour point should be specified 10°F [5.6°C] below the ambient temperature at which the engine is to be operated except where fuel oil heating facilities are provided.

[d] Low atmospheric temperatures as well as engine operation at high altitudes may require use of fuels with high cetane ratings.

[e] When pour point less than 0°F [−17.8°C] is specified, the minimum viscosity shall be 1.8 cSt (32.0 SSU) and the minimum 90 percent point shall be waived.

[f] For all products outside the United States, the maximum sulfur limit shall be 1.0 wt. %.

TABLE 24-2

RECOMMENDED FUEL SPECIFICATIONS

Characteristics	Fuels	
	1D	2D
Cetane number	45	40
Gravity	35–40	26–34
Pounds per gallon [kg/gal]	6.95 [3.16]	7.31 [3.32]
Btu per gallon average	137,000	141,800
Sulfur, percent by weight max.	0.5%	0.1%
Viscosity 100°F [37.8°C]	45 seconds	32 seconds
Flash point	100°F [37.8°C]	125°F [51.7°C]
Pour point	10°F [5.6°C] below ambient temperature	
Water sediment	No more than a trace should be present	
Carbon residue	0.15	0.35
Ash	0.01	0.02
Corrosion	Pass	Pass
Volatility:		
10% point	350–475°F [175–250°C]	400–500°F [209–260°C]
90% point	450–600°F [230–315°C]	550–650°F [280–340°C]
End point	500–625°F [260–320°C]	625–700°F [320–360°C]

smoke under maximum torque. This is because the raw fuel which is sprayed into the combustion chamber at this point ignites because of the shorter delay period.

Distillation Range The distillation range influences the Btu, API° gravity, and viscosity of the fuel. It affects power output, starting, smoke, and exhaust odor. The higher the distillation range, the greater is its effect on the foregoing.

Btu (Heating Value) and API° Gravity Although heating value and API° gravity are not specified in the ASTM classification, they are very important. They affect the power output, combustion, starting, and exhaust emission.

The heat value of a fuel is expressed in Btu per pound or per gallon (Btu/lb or Btu/gal) [kilojoules per kilogram or per liter (kJ/kg or kJ/L)]. A fuel with a higher heat value (more Btu/gal) will produce more power than a fuel of lower heating value; however, the difference of power output between 1D and 2D is between 4 and 11 percent depending on combustion chamber and fuel-injection pump design.

Btu and API° gravity are directly related. The higher the API° gravity (or the lower the specific gravity), the lower the heat value (see Fig. 24-1). Fuel may range from 26 to 40 API° gravity which corresponds with a range in specific gravity of 0.8963 to 0.8155. This is equivalent to 142,000 to 135,500 Btu/gal (U.S.) [68,095.4 kJ/kg to 64,978.4 kJ/kg] or 170,400 to 138,210 Btu/gal (Imp.) [680,437.0 kJ/L to 662,859.3 kJ/L], which is about 7.53 to 6.79 lb/gal (U.S.) at 60°F [15.6°C], or 9.03 to 8.14 lb/gal (Imp.).

Heat Value For the moment let us approximate the heat value of a fuel that has 19,000 Btu/lb [9111.3 kJ/kg] and consists of 15 percent hydrogen and 85 percent carbon. To burn the fuel, air is needed. Atmospheric air at sea level is composed of 20.95 percent oxygen (O), 78.9 percent nitrogen (N), and miscellaneous gases at 0.06 percent. 1 ft^3 [28.32 L] of air at 32°F [0°C] sea level registers 29.9 inHg [75.96 cmHg] and weighs 0.0807 lb [0.0326 kg]. Under the ideal conditions outlined above, 1 lb of air equals 12.4 ft^3 [0.351 cubic meter (m^3)]. This figure should be adjusted to actual temperature and atmospheric pressure and air density. In this respect SAE standard test code for a diesel engine is:

Barometric pressure = 29.38 inHg [74.6 cmHg]
Temperature = 85°F [29.4°C]

This calculates out to approximately 1 lb equaling 14 ft^3 [0.396 m^3] of air.

For complete combustion of 1 lb of fuel, about 260 ft^3 [7.36 m^3] of air is required. It is essential to remember these facts when servicing the air-intake system.

Sulfur The presence of excessive (more than 0.5 percent) sulfur content in the fuel will eventually damage the engine unless the intervals between oil

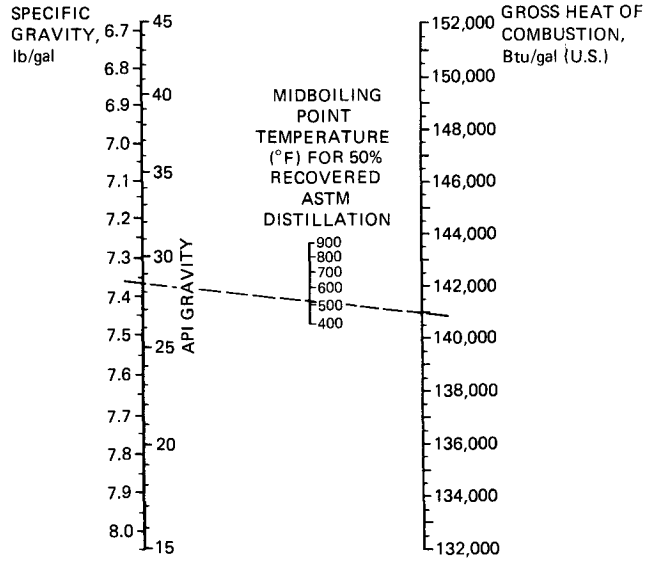


Fig. 24-1 Relation between API gravity and Btu. *(Chevron Research Co.)*

changes are shortened. If the oil is not changed frequently enough, the cylinder liners (sleeve), pistons and rings, exhaust valves, and the fuel-injection system components will rapidly deteriorate. Such deterioration is brought about by oxidation of the sulfur during combustion. As the sulfur combines with the moist intake air, it produces sulfuric acid. This acid collects in the engine's lubrication system, becomes suspended in the oil, and thus causes the damage. Diesel engines using direct injection are more affected than engines using a precombustion chamber, a turbulence chamber, or power cells. Direct-injection engine components are also more subject to acid attack when the coolant temperature is low.

Viscosity A viscosity lower than specified reduces the effectiveness of the fuel as a lubricant and, therefore, accelerates wear of injection components. Component wear can cause reduction in the amount of metered fuel because of leakage in the injection pump or injector.

High viscosity can also reduce the amount of fuel metering within the system due to higher flow resistance. Higher or lower viscosity alters the spray pattern droplet size which, in turn, changes the time of ignition (combustion) (Fig. 24-2).

Flash Point The temperature at which a substance will give off a vapor that will flash or burn momentarily when ignited is called the *flash point*. The flash point has no effect on engine performance. It is specified simply as a guide for handling and storage safety.

Pour Point The *pour point* is the minimum temperature at which the fuel can flow through the filters or be transferred by the transfer pump to the fuel-injection pump. The fuel flow is affected only when the ambient temperature is below the pour point temperature.

Water and Sediments If the amount of water exceeds specification, it can cause corrosion and adversely affect all moving parts of the fuel-injection system, especially the injector nozzle. Water droplets will not pass through a multihole nozzle; therefore, it can be damaged. Sediments cause sludge buildup within the system, which plugs the filters and causes injection component wear.

Carbon Residue *Carbon residue* is the deposit left in the combustion chamber because of inefficient combustion or the use of fuel made from residual blends.

Ash *Ash* originates from additives or from the crude oil itself. It causes wear of fuel-injection components, pistons, and piston rings.

Volatility Any substance that may be readily vaporized at relatively low temperatures is said to have *volatility*. Volatility affects power output, performance, starting, warm-up, and exhaust smoke.

Fuel Additives Additives are sometimes used to improve certain characteristics of diesel fuel. Inhibitors and preventitives may be used to improve ignition quality, to reduce oxidation and corrosion, and to keep the fuel-injection system clean. Sometimes additives are used to reduce smoke and odor.

Fuel Storage and Handling When it is not practical to use a large storage tank and storage of fuel in drums is the only alternative, take all the precautions outlined in the section Storing and Handling Crankcase Oils (Unit 12). As far as possible, avoid storing the drums outside. The effects of the weather on drums stored outside is illustrated in Fig. 24-3.

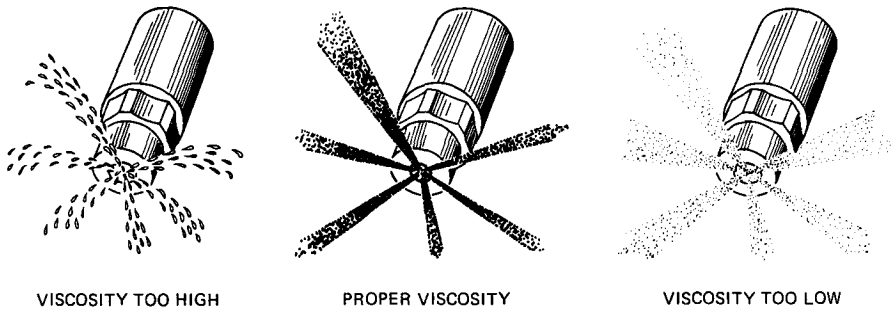


Fig. 24-2 Effect of viscosity on fuel injection. *(Chevron Research Co.)*

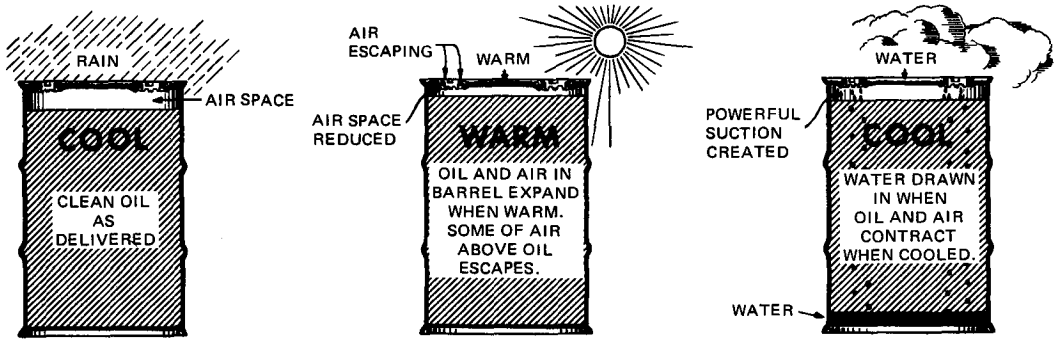


Fig. 24-3 Effects of weather on drums stored outside. *(J.I. Case Agricultural Division (TENNECO).]*

If fuel is being stored in drums, do not use them as a convenient method for transporting the fuel to the tractor or motortruck. Instead, drive the equipment to the fuel location. This way the sediment in the drums will not be disturbed.

When a hand dispensing pump is used to pump fuel out of the drum, make certain the standpipe is about 2 in [50.8 mm] shorter than the drum and make certain the drum is tilted slightly at all times.

Questions

1. What is the difference between fuel acquired from fractional distillation and the product of residual materials?
2. List the major differences between 1D and 2D fuel.
3. What advantage (in addition to improving starting) has fuel with a high cetane number over regular fuel?
4. When the viscosity of the fuel is too high or too low, what effect does it have on ignition, combustion, and exhaust smoke?
5. Why does ASTM specify maximums on certain properties of diesel fuel, that is, water and sediments, carbon residue, and ash?
6. What would result if the ash content in a fuel were higher than specified?
7. Grey exhaust smoke can be the result of (*a*) a fuel of high cetane rating, (*b*) a fuel of high Btu rating, (*c*) a 1 percent sulfur content, or (*b*) a fuel of high ash content.
8. Fuel of high sulfur content will cause (*a*) corroded injector tips and corroded spray orifices, (*b*) low engine power output, (*c*) pitting of the main bearings, or (*d*) clogged fuel filters.
9. An engine will operate more efficiently in cold weather by (*a*) lowering the sulfur content of the fuel, (*b*) increasing the Btu rating, (*c*) increasing the cetane rating, or (*d*) lowering the cetane rating.

UNIT 25 • GOVERNORS

Function of Governor A governor is a device used to limit high- and low-idle rpm and/or maintain a selected uniform rpm within the power range of the engine. Only a few engine applications do not require a governor. An outstanding example of engine application without a governor is in the conventional passenger car. Here the engine speed and engine load changes are sensed by the driver. The driver's movement of the throttle is an extension of conditioned reflex; the driver acts as a governor (the driver controls the airflow).

However, human beings are not capable of reacting to load and speed changes quickly enough insofar as the diesel engine is concerned, since it can accelerate at a rate of more than 2000 revolutions per second (rps). The driver must, therefore, rely on modern mechanics, hydraulics, or the electronic robot (governor).

Types of Governors Numerous types of governors are manufactured, each for a specific engine application and each capable of readjusting automatically to its load and speed. The five different types of governors are: (1) mechanical, (2) pneumatic, (3) servo, (4) hydraulic, and (5) electronic governors.

The name of the governor indicates its design and its ability to control speed and/or load. However, regardless of the type of governor required to do a particular job, each must perform two major tasks. The governor must measure engine rpm and it must have the capability (power) of moving the fuel rack or controlling the fuel flow or the pressure. Furthermore, it must (1) limit maximum speed and prevent the engine from overspeeding; (2) control idle speed to prevent the engine from stalling; (3) regulate engine speed between low and high idle; (4) be capable of providing for more fuel when the engine lugs down to maximum torque; (5) have the capability to shut down the engine; and (6) have the capability of providing fuel for starting.

Governor Terminology Before studying the basic fundamentals of the different types of governors, you should first understand certain terms related to the subject:

- *Low-idle speed* is the lowest speed (no load) at which a governor (maintains) controls the engine speed. Under the *no-load* condition, the engine is operating without producing work. Under the *low-idle load* condition, the engine is operating at or near low-idle speed but also producing some work.
- *High-idle speed* is the maximum speed at which a governor allows the engine to run.
- *Droop speed* is the speed reduction from high idle after a load is placed on the engine. The average speed droop of a mechanical governor is between 5 and 10 percent.
- *Maximum torque speed* (sometimes also called *rated speed* or *stalled speed*) is the speed at which the engine develops its maximum torque. At maximum torque, the engine cylinders apply maximum force onto the crankshaft, which thereby exerts its maximum twisting effort.
- *Torque range* is the rpm range from maximum torque to the rpm when the torque sharply reduces.
- *Overspeed* is a speed above high idle.
- *Governor cutoff speed* is the speed at which the governor moves the control rack to the no-fuel position or cuts off the fuel flow.
- *Sensitivity* is the response of a governor to speed change expressed in percentage.

■ *Momentary speed change* is the change of the engine speed immediately after a sudden change in engine load or throttle setting.
■ *Speed drift* is the gradual variation in the engine speed above or below set governor speed.
■ *Hunting* is a constant or repeated rhythmic change in the engine speed.
■ *Stability* is the ability of a governor to maintain engine speed without hunting or a speed drift.
■ *Promptness* is the ability of a governor to respond to engine speed changes.
■ *Speed regulation* is the change of the engine speed between high and low idle through the action of the governor lever.

The most common governors used on diesel engines for motortrucks, truck-tractors, and marine and industrial applications are of the limiting-speed or of the variable-speed, mechanical, servo, or hydraulic types. Less common, and used for special engine applications, are the constant-speed, load-limiting, torque-converter, and the load-control (mechanical, hydraulic, or electronic) governors. Some small diesel engines use a variable-speed pneumatic governor.

A *limiting-speed governor* maintains the engine speed at the set idle speed and limits high-idle engine speed. A manually operated throttle controls the speed between idle and maximum speeds.

A *variable-speed governor* controls the engine speed over the entire speed range and load. A throttle control sets the governor to the desired engine speed.

A *constant-speed governor* has the ability to hold the engine at constant speed, regardless of the load, providing the load is within the power of the engine.

A *load-limiting governor* limits a load applied to the engine at any given speed. Its purpose is to prevent overloading of the engine.

A *torque-convertor governor* senses the speed of the torque-convertor output shaft and in conjunction with the governor limits the set engine speed.

An *overspeed governor* prevents overspeeding of the engine.

MECHANICAL GOVERNORS

Mechanical governors and most hydraulic and electronic governors have a speed-measuring mechanism and a fuel-changing mechanism and operate at the speeds shown in Table 25-1. These mechanisms (with the exception of the Cummins mechanical, electronic, and pneumatic governors) consist of the components shown in Fig. 25-1. Two L-shaped weight arms (flyweights) are pivot-mounted to the governor-driven gear or directly fastened to the camshaft. To reduce governor pulsation some governors have a friction clutch, a rubber damper, or a spring arrangement positioned between the drive and weight assemblies. To increase the centrifugal force (working power) of the flyweights, most weight assemblies are driven at a speed higher than the fuel-pump camshaft speed. To oppose the weight force, the governor spring (speeder spring) is positioned between the flyweight finger and the throttle lever. The spring force can be increased or decreased by the throttle lever. The throttle lever travel is limited by the high- and low-idle adjusting screws; thus the energy of the governor spring can be controlled within the range of the adjusting screws. A thrust bearing is positioned between the sliding components and the rotating flyweights to reduce friction and smooth the levers' motion.

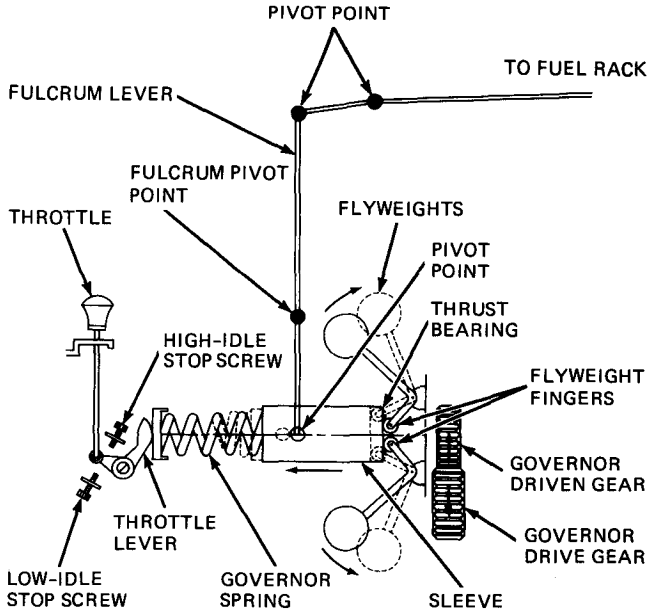


Fig. 25-1 Simplified illustration of mechanical governor.

The fuel-changing mechanism of a mechanical

TABLE 25-1

ENGINE SPEEDS AND GOVERNOR POSITIONS

Speed	Flyweights	Governor spring	Fuel control rack
High idle, no load	Maximally outward	Maximally compressed	High-idle fuel position
Droop speed	Slightly inward (from maximally outward)	Slightly expanded (from maximally compressed)	Increased fuel position (from high idle)
Maximum torque	Slightly inward (from droop speed)	Slightly expanded (from droop speed)	Maximum fuel position
Low idle, no load	Slightly outward (from low idle, load)	Slightly compressed (from low idle, load)	Low-idle, no-load fuel position
Low idle, load	Slightly outward (from maximally inward)	Slightly compressed (from maximally expanded)	Low-idle, load fuel position
Not operating	Maximally inward	Maximally expanded	Maximum fuel position
Starting	Maximally inward	Maximally compressed	Starting fuel position

governor used with port and helix fuel-injection pumps consists of the fuel rack, lever, and linkages and the sliding component positioned between the flyweight finger and governor spring (it may also be positioned between the flyweight finger and the lever which is indirectly connected to the fuel rack, or the sliding component may be connected with the flyweights, through bell cranks). The sliding component is also known as the *shifter, sliding sleeve, sliding bolt,* or *spring seat* (see Figs. 25-2 to 25-5).

Mechanical Governor Operation Regardless of which type mechanical governor is used, the basic movements within the governor components are the same. However, as you can see from the four illustrations (Figs. 25-2 to 25-5), their connections between lever and linkages from the throttle shaft to the fuel rack differ, as well as the method used to achieve starting fuel position and high idle, and the torque-range fuel control and adjustment. Use the above four figures and Table 25-1 as a reference when reading the ensuing paragraphs.

OPERATION, ENGINE STOPPED When the engine is not operating, the governor spring force moves the governor flyweights toward each other and moves the fuel control rack toward the increased fuel position.

GOVERNOR START POSITION To start the engine, the operator places the throttle into the full fuel position, the governor spring force increases to its maximum, and the fuel rack moves into the starting fuel position. The starting fuel position may deliver equal fuel or exceed by 25 percent the fuel delivered during maximum torque speed.

In Fig. 25-2 the governor spring has moved the spring seat, the fuel rack, bolt, and collar to the right and the collar bends the torque spring against the governor housing.

In Fig. 25-3 the governor spring force is increased from the throttle shaft, over the stop lever, torsion spring (latter two components not shown), spring plate, and fulcrum-lever pivot point onto the sliding sleeve, and the torque cam moves on the stop plate to point *A*.

In Fig. 25-4 the throttle lever (through its guide in the *S* plate) moves the floating lever downward. This allows the fulcrum lever (through its sliding bolt and guide lever) to move down to its right-hand bottom position. The fulcrum lever pivots in the *S* plate and brings the swivel lever below the stop cam where it is magnetically held in position.

In Fig. 25-5 the throttle (control) lever pivots the swiveling lever downward. This increases the force on the main governor spring and it pulls the tension lever against the full-load stop. The link and guide levers then move to the left. The guide lever moves the fulcrum lever and through the connecting link moves the fuel rack into the start position.

HALF-THROTTLE OPERATION When the engine is operating at half-throttle, no load—say, 1000 rpm—the centrifugal force of the rotating flyweights and the governor spring force are in balance. In Fig. 25-2 the spring seat, bolt, collar, and fuel rack have moved to the left into the half-fuel position.

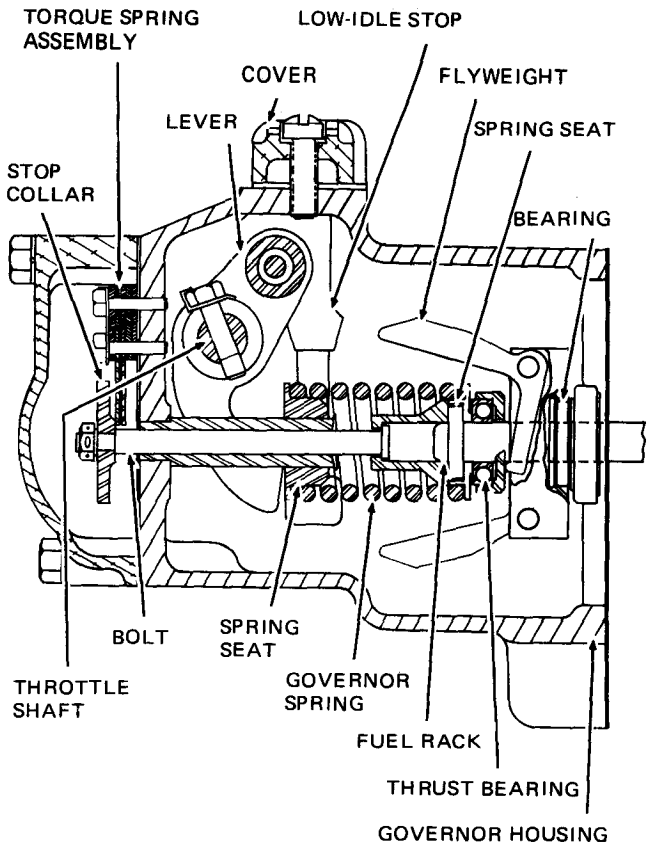


Fig. 25-2 Schematic view of a limiting-speed governor in the rated speed position. *(Caterpillar Tractor Co.)*

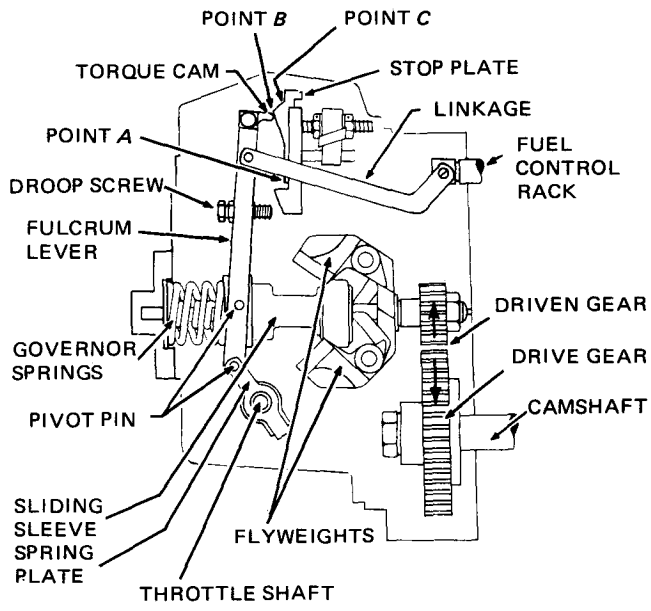


Fig. 25-3 Schematic view of a limiting-speed governor in the rated speed position. *(American Bosch, United Technologies Automotive Group.)*

In Fig. 25-3 the sliding sleeve and fulcrum-lever pivot point have moved to the left and because the spring-plate pivot point remains fixed, the top of the fulcrum lever and the fuel rack move to the left. The torque cam is now about 10 mm from the stop plate.

In Fig. 25-4 the outward movement of the flyweights pivots the bell cranks, moving the sliding bolt, the lower end of the fulcrum lever, and the top of the guide lever to the left. Simultaneously the fulcrum

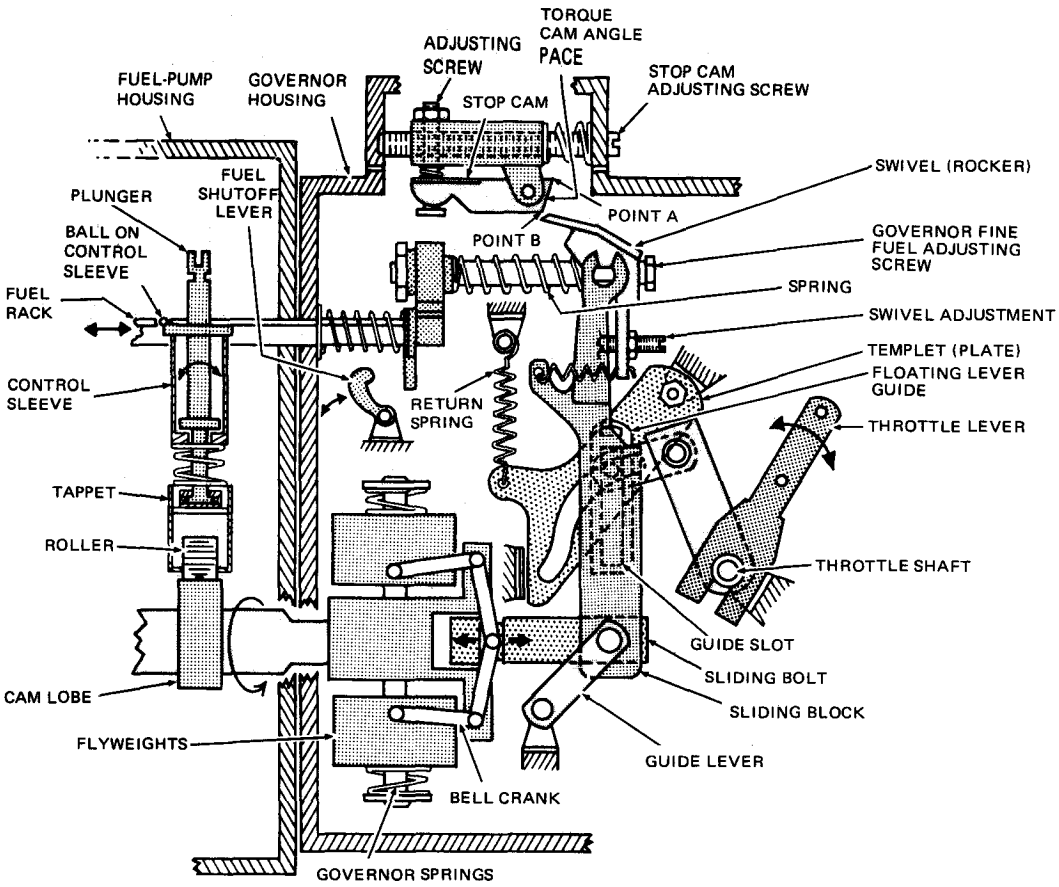


Fig. 25-4 Schematic view of RQV governor in idle-speed position. *(Allis-Chalmers Corp. Engine Division.)*

lever moves upward through the combined action of the guide lever and sliding block. The fulcrum lever pivots in the *S* plate, which causes the swivel to move to the right, about 10 mm from the torque-cam angle face.

In Fig. 25-5 the link and the guide lever have moved to the right, and through the guide lever the fulcrum lever and fuel rack are moved to the right into the half-fuel position.

FULL THROTTLE, NO LOAD With the throttle in full-fuel position and no load on the engine (high idle), the same internal action occurs within all four governors until (Fig. 25-2) the stop collar is about 4 mm away from the torque spring. In Fig. 25-3 the torque cam is about 4 mm from the stop plate.

In Fig. 25-4 the swivel is about 4 mm from the torque-cam angle at point *A*.

In Fig. 25-5 the end of the tension lever is about 3 mm away from the full-load stop and the torque-control piston spring is compressed.

FULL THROTTLE, PART LOAD When a load is placed on the engine (say it operates 10 percent below high idle speed), the force of the flyweights decreases. The spring force (Fig. 25-2) then moves the spring seat, bolt, collar, and fuel rack to the right to the increased fuel position, until the stop collar butts against the torque spring. When no load or throttle changes have been made the flyweights and governor spring forces are again in balance.

In Fig. 25-3 the spring force has moved the sliding

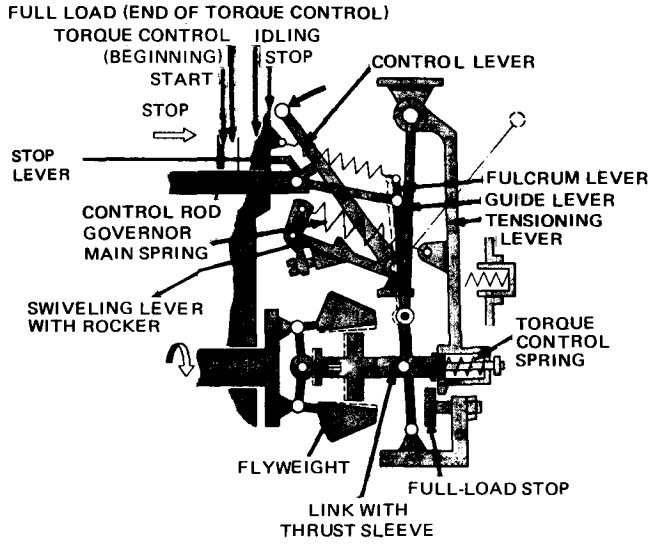


Fig. 25-5 Schematic view of RSV governor in torque-control-range position. *(International Harvester Company.)*

sleeve and fulcrum-lever pivot to the right, the torque cam butts against the stop plate at point *B*, and the governor spring and flyweight forces are in balance. *(NOTE: The pivot point at the spring plate remains fixed.)*

In Fig. 25-4 the now higher spring force moves the flyweights inward, pivots the bell cranks, and moves the sliding bolt and the fulcrum lever slightly to the right. The guide lever and sliding block lower the

fulcrum lever, causing the top of the fulcrum lever to move to the left and the swivel comes to rest at point *A*.

In Fig. 25-5 the now higher spring force moves the tension lever, link, and guide lever to the left, and the tension lever end butts against the full-load stop. The guide lever and the fulcrum lever move the fuel rack to the beginning of torque-control position.

TORQUE SPEED When the engine operates at full throttle, part load, and the engine load increases, the engine speed and the flyweights' force decrease. To achieve a balance between the weights' and spring forces, the governor spring moves (Fig. 25-2) the spring seat, bolt, collar, and fuel rack to the right and the torque spring starts to bend. At maximum engine torque the torque spring end is resting against the governor housing.

In Fig. 25-3 the governor spring moves the sliding sleeve and with it the fulcrum-lever pivot point and the spring-plate pivot point to the right. The spring-plate pivot point can move to the right because the throttle shaft's torsion spring allows the spring plate to move right. This action moves the fulcrum lever upward and causes the torque cam to move toward point *C*. At maximum engine torque the torque cam is at point *C*.

In Fig. 25-4 the inward movement of the flyweights has moved the sliding bolt (over the bell crank) to the right. This starts the *S* plate moving away from the stop plate (to the right). Consequently the fulcrum pivot point in the *S* plate moves to the right and slightly downward, causing the swivel to move from point *A* toward point *B*. At maximum engine torque the swivel is near point *B*.

In Fig. 25-5 the inward movement of the flyweights allows the torque-control spring to expand and to move the link and guide lever to the left. The guide lever moves the fulcrum lever to the left, and moves the fuel rack beyond the torque-control "beginning" position.

STOPPING THE ENGINE To stop engine operation (Fig. 25-2), the solenoid hooked into the collar is de-energized and its spring force moves the collar, bolt, spring seat, and fuel rack to the no-fuel position.

In Fig. 25-3 the stop lever (not shown) semirotates counterclockwise and moves the fuel rack to the no-fuel position.

In Fig. 25-4 the fuel shutoff lever is semirotated clockwise. This pulls the fuel rack against the fine-fuel adjusting-bolt bracket and moves it and the bolt to the right, which, in turn, places the fuel rack in the no-fuel position.

In Fig. 25-5 the stop lever is semirotated counterclockwise, which moves the fuel rack to the no-fuel position.

Stanadyne Diesel Systems' Mechanical Governor The mechanical governors in the Stanadyne diesel systems' (formerly Roosa Master) fuel-injection pumps which are used on agricultural and industrial engines are all similar in design and consist of the components shown in Fig. 25-6.

OPERATION, STARTING When the engine is stopped, the governor spring pivots the governor arm on the governor shaft and the linkage hook is moved to the left. The linkage hook is connected at one end to the governor arm and at the other end to the metering valve arm. The movement of the linkage hook semirotates the metering valve counterclockwise and consequently the metering valve helix allows an unrestricted fuel flow to the opposed plungers.

To start the engine (and to maintain the metering valve position), the throttle lever is placed in the full-

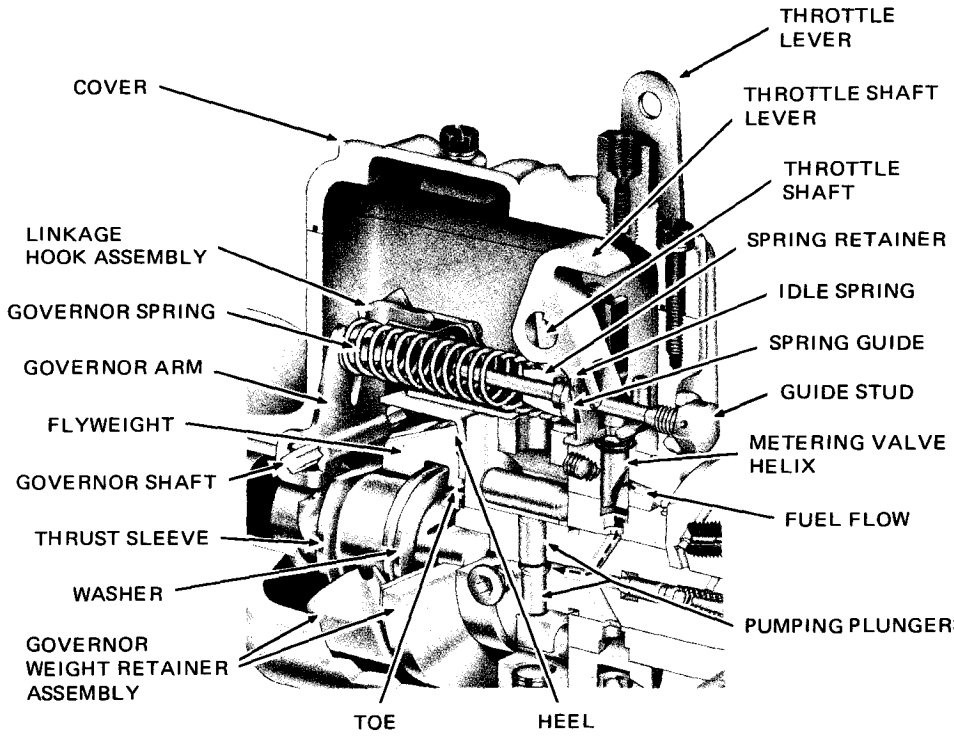


Fig. 25-6 Sectional view of a DB2 industrial fuel-injection-pump governor in the starting fuel position. *(Stanadyne Diesel Systems.)*

fuel position and comes to rest against the high-idle adjusting screw. The rearward movement of the throttle lever semirotates the throttle shaft and lever clockwise and increases the governor spring force to its maximum. This moves the governor arm and thrust sleeve to the right and loosely fitted weights in the pocket of the weight retainer come to rest against the thrust sleeve. Because of the extended metering time factor while attempting to start the engine, maximum fuel enters the opposed plungers. (See Unit 34, "Stanadyne Diesel Systems' and DPA Distributor-type Fuel-injection Pumps.")

OPERATION, LOW-IDLE SPEED When the engine has started and the throttle is moved forward against its low-idle adjusting screw, the throttle shaft and lever semirotate counterclockwise. This places only a moderate force on the idle spring, over the spring retainer and governor spring, and onto the governor arm. At the same time the metering valve rotates clockwise and the helix reduces the fuel passage to the opposed plungers. The governor weight retainer rotation pivots the weights on their heels, and the toes move the thrust sleeve and the lower portion of the governor arm to the left, and the top portion of the arm to the right, into balance with the idle spring force.

OPERATION, HIGH IDLE When the throttle is moved to the full-fuel position, the helix is momentarily placed in the starting fuel position. However, the weight force increases quickly and moves the thrust sleeve to the left, pivoting the top of the governor arm to the right, which, in turn, moves the linkage hook to the right until balance is achieved. The metering valve semirotates counterclockwise to the high-idle fuel position.

OPERATION, TORQUE RANGE When the throttle is in full-fuel position and a load is placed onto the engine, the engine speed is reduced, say by 10 percent, the flyweights' force decreases, and the top of the governor arm and the linkage hook move slightly to the left until the spring and weights' forces are in balance again. The metering valve rotates ever so slightly in counterclockwise direction and the helix then increases the flow passage. *(NOTE: This is the beginning of torque control.)* When the engine load further increases, the flyweights' force decreases and the governor spring force moves the governor arm and linkage hook further to the left until the weights' and spring forces are again in balance. As a result the metering valve helix increases the fuel flow passage to its maximum. Furthermore the reduced engine speed provides more time for the fuel to flow into the opposed plungers; therefore more fuel is metered per cycle.

To shut the engine down, an electric shutdown solenoid is fastened to the inside of the cover. When the solenoid is energized or de-energized (depending on the application), the linkage hook moves the metering valve helix to the position where it blocks the fuel flow to the opposed plungers. (See Unit 33, where Cummins mechanical governors are discussed, Unit 35, which covers American Bosch governors, and Unit 36, which describes Caterpillar sleeve-metering mechanical governors.)

Detroit Diesel Limiting-speed Governor Detroit Diesel engines may use any one of nine mechanical governors, or any one of five hydraulic governors. Automotive applications generally use the limiting-speed and the variable-speed mechanical governors. A limiting-speed mechanical governor (used on a V71 Detroit Diesel engine) is shown in Figs. 25-7 and 25-8. When the engine ceases to operate, the force of the high-speed spring holds the high-speed plunger against its stop; the low-speed spring holds the low-speed spring cap against the gap adjusting screw (which is located on the operating shaft lever) (see Fig. 25-7). The expanded

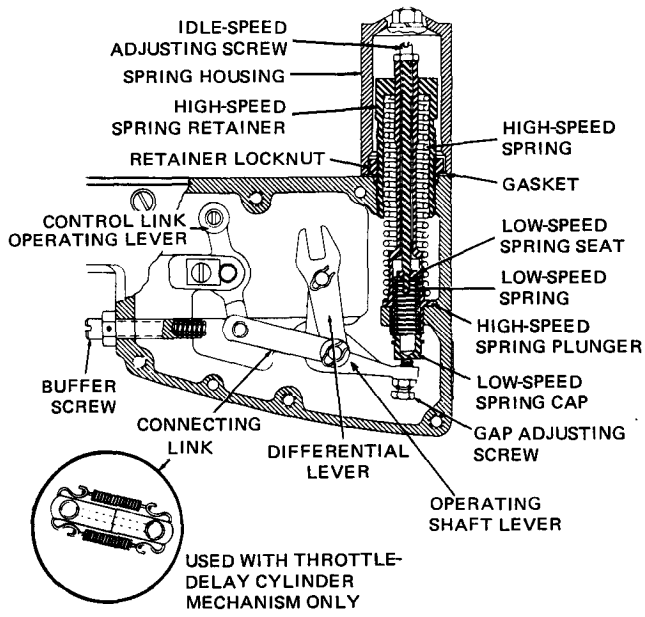


Fig. 25-7 V71 limiting-speed governor (top view). *(Detroit Diesel Allison, Division of General Motors Corporation.)*

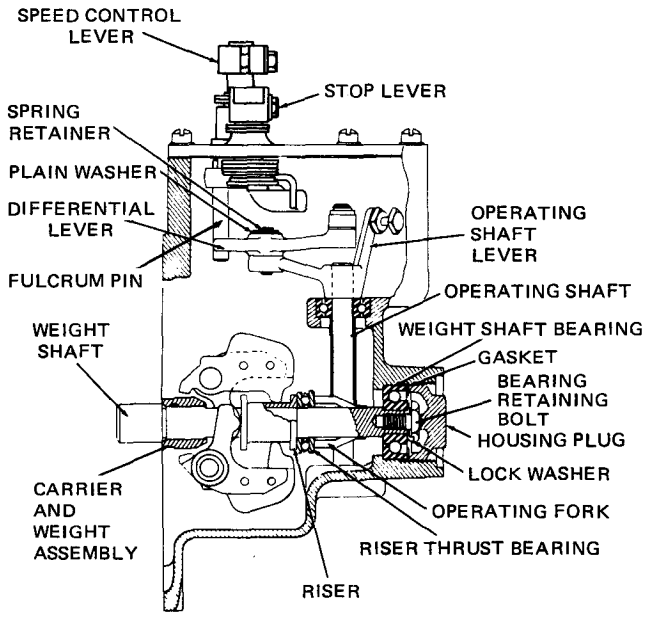


Fig. 25-8 V71 limiting-speed governor (side view). *(Detroit Diesel Allison, Division of General Motors Corporation.)*

springs pivot the operating shaft lever, the operating fork then rests against the thrust bearing, and the riser rests against the flyweight finger of the low- and high-speed weights (see Fig. 25-8).

The semirotation of the operating shaft lever causes the differential lever to pivot on the fulcrum pin (which is located on the speed control shaft). This moves the connecting link so that it pivots the control-link operating lever on its shaft. The fuel rod (which is connected to the control-link operating lever, shown in Fig. 25-7) moves to the maximum-fuel position.

When the operator moves the speed control lever so that the engine operates at 1000 rpm, the fulcrum pin then moves the differential lever to the left, pivoting the operating shaft lever and adding force to the low spring without dislodging the fuel rod from the full-fuel position. Once the engine begins to operate, the flyweight force of both the low- and high-speed governor weights moves the riser, the thrust bearing, and the fork to the right, causing the operating shaft to pivot and the operating lever to place a greater force on the lower spring cap. The low-speed spring is compressed and closes the gap 0.0015 in [0.038 mm] between it and the high-speed plunger.

During this time the differential lever was forced (by the operating-shaft lever) to the pivot on its fulcrum pin. The pivoting operating-shaft lever moves the connecting link and pivots the operating lever, which in turn moves the fuel rod to decrease fuel. When the flyweight force is equal to the low-speed spring force, the engine operates at the set speed.

When the operator moves the speed control lever to the full-fuel position, the differential lever is instantly moved through the fulcrum pin, which causes the differential lever to pivot on the pin of the operating-shaft lever. This action moves the connecting link and the control-link operating lever, and as a result moves the fuel rack to the full-fuel position. The engine responds to the increased fuel and the flyweight force increases. This action moves the low-speed spring cap against the high-speed spring plunger. From approximately 1200 rpm on, only the high-speed weight force acts on the riser. The low-speed governor weights meanwhile have contacted their limiting stops. When the flyweight force is in balance with the high-speed spring force, the engine operates at high-idle speed.

MAXIMUM-FUEL POSITION When the speed control lever is in the full-fuel position and the engine is operating at high idle, the flyweight force and the high-speed spring force are equal, and the fuel rod is about three-quarters toward the maximum-fuel position. When the engine speed is reduced, because of an increased load on the engine, the flyweight force reduces and the high-speed spring slightly expands. This pivots the operating shaft and its lever. The pivoting motion of the operating shaft moves the differential lever to the right (in Fig. 25-8) because the differential lever slides on the fulcrum pin. The connecting link then moves to the right, pivoting the control-link operating lever and causing the fuel rod to go into the maximum-fuel position.

HIGH- AND LOW-IDLE ADJUSTMENT The idle speed is adjusted by increasing or decreasing the low-speed spring energy with the idle-speed adjusting screw (Fig. 25-7). The high-idle (maximum no-load) speed is adjusted by increasing or decreasing the energy on the high-speed spring retainer.

Detroit Diesel Variable-speed Governor The primary difference between a Detroit Diesel limiting-speed governor and a variable-speed mechanical governor (Fig. 25-9) is that the variable-speed governor has only one spring. It uses a variable-speed plunger instead of the low-speed spring cap. The speed control lever acts (through the spring lever) directly onto the spring retainer and spring, whereas the speed control lever of the limiting-speed governor acts (over the pin) onto the differential lever, the operating shaft lever, onto the lower spring cap, and

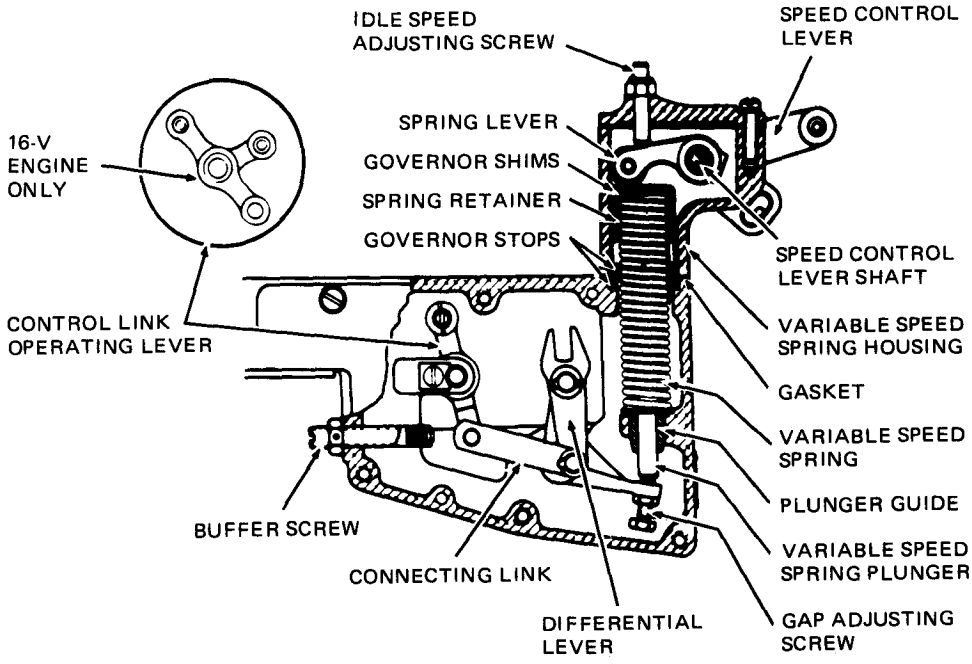


Fig. 25-9 Schematic view of a V92 variable-speed governor (top view). *(Detroit Diesel Allison, Division of General Motors Corporation.)*

then onto the high-speed plunger and spring. Idle speed adjustment is made through the idle speed adjusting screw, and high-idle (no-load) adjustment is made by adding or removing shims between the spring retainer and the variable-speed spring.

PNEUMATIC GOVERNORS

Pneumatic governors, as mentioned previously, are used on smaller diesel engines and effectively control engine speed from idle to maximum speed. The movement of the fuel control rack is a joint effort of the atmospheric pressure, the governor spring, and the low pressure. As illustrated in Fig. 25-10, the pneumatic governor consists of two separate main units: the venturi unit and the diaphragm unit.

The venturi unit is positioned between the air cleaner and the air-intake manifold. The venturi opening (venturi throat) limits the maximum airflow and, therefore, controls the maximum engine speed. The butterfly valve is connected through a linkage to the accelerator pedal and controls the airflow and, therefore, the engine speed between low idle and high idle. The auxiliary venturi, butterfly valve, and the vacuum connections are positioned at the narrowest point of the venturi.

The diaphragm unit is mounted to one end of the fuel-injection-pump housing and a leather or rubber diaphragm divides the unit in two to form atmospheric and vacuum chambers.

The left-hand side is always under atmospheric pressure either directly through a filter or through a pipe connection to the crankcase. The diaphragm is connected by a pin to the fuel control rack.

The vacuum chamber is connected through a tube to the auxiliary venturi. The governor spring in the vacuum chamber maintains the diaphragm under pressure and, therefore, holds the fuel control rack in the full-fuel position. A mechanical control is connected to the stop lever and the thrust lever is fastened to its shaft. When the stop pull button is moved outward, the thrust lever moves the fuel rack to the no-fuel position to stop the engine.

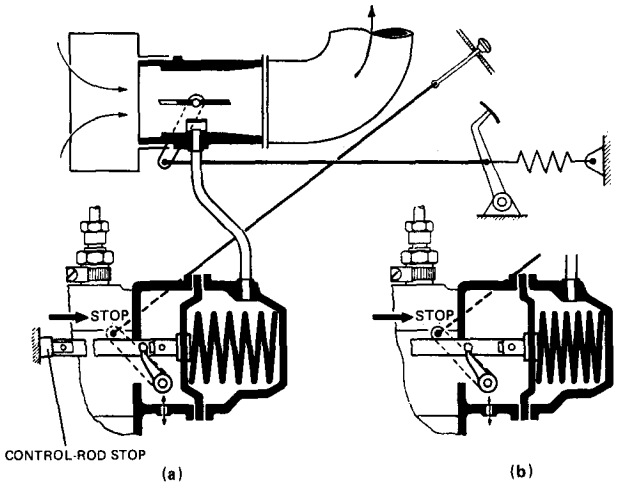


Fig. 25-10 (*a*) Momentary governor position at maximum fuel, (*b*) governor position at high idle, no load. *(Robert Bosch GmbH, Stuttgart, West Germany.)*

PNEUMATIC GOVERNOR OPERATION When the engine is stopped, the governor spring moves the fuel control rack to the full-fuel position and the diaphragm rests against the full-fuel stop. When the engine is running and the butterfly valve is resting against the idle stop screw, the valve is nearly closed and a low pressure (vacuum) is created at the engine side of the butterfly valve because the airflow to the cylinders is restricted. The same vacuum (low pressure) also exists in the vacuum chamber and, therefore, the atmospheric pressure forces the diaphragm and the fuel control rack to the no-fuel position against the idle-speed adjusting screw. The engine speed reduces in response to reduced fuel, and the vacuum at the engine side of the butterfly decreases. The governor spring and the remaining pressure in the vacuum chamber move the diaphragm and fuel control rack against the atmospheric pressure to increase fuel, and the engine operates at idle speed (Fig. 25-10).

When the butterfly valve is opened, say to half engine speed, more air is allowed to enter the cylinder and the vacuum at the engine side of the butterfly decreases. Instantly the diaphragm and fuel control rod move to the left until the governor spring force and the remaining pressure in the vacuum side of the chamber equal atmospheric pressure.

When the engine speed is reduced, because of increased load, the vacuum decreases and the pressure in the vacuum chamber increases, moving the diaphragm and the fuel control rod in the direction of the full-fuel position.

When the butterfly valve is fully open, it rests against the adjustable full-load stop screw. The vacuum in the manifold and in the vacuum chamber are very low because of the decreased air velocity in the venturi. The diaphragm momentarily moves against the extended piston of the torque-control spring (Fig. 25-11). The fuel control rod moves to the maximum-fuel position. As the engine speed increases (to high idle), the air velocity and the vacuum increase in the auxiliary venturi and in the vacuum chamber. Atmospheric pressure moves the diaphragm and fuel control rack away from the full-load stop in the direction of the no-fuel position (Fig. 25-11). When the engine speed decreases (because of added load) to its max-

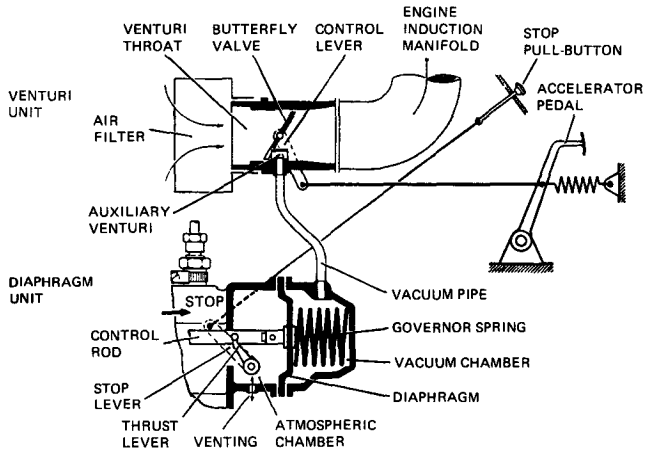


Fig. 25-11 Position of pneumatic governor components at high idle. *(Robert Bosch GmbH, Stuttgart, West Germany.)*

imum torque speed, the air velocity decreases. The pressure in the vacuum chamber approaches atmospheric pressure. The governor spring then forces the diaphragm against the torque-control piston, compresses the torque spring, and moves the fuel rack to its maximum position.

Maximum fuel is controlled by the full-load stop or the movement of the torque-control piston. The maximum airflow is controlled by the venturi. To have a smoke- and sootfree engine over a wide range of engine loads, the governor spring and the torque-control spring must control the fuel delivery.

SERVO-TYPE GOVERNORS

When constant engine speed changes are required because of engine application and more power is demanded from the governor to move the fuel-changing mechanism, servo or hydraulic governors are used to move the fuel rack through hydraulic action. Both types of governors reduce the effort required to move the throttle since only a small force is necessary to move the governor control mechanism.

Servo Construction Servo-type governors are mechanical governors to which a servo mechanism has been added. The servo consists basically of a hydraulic piston and an oil-control valve (the cylinder) (Fig. 25-12). The piston which forces the governor spring against the sleeve assembly is loosely fitted inside the end cover and the cylinder is fitted over the outside of the end cover. The sleeve assembly is connected through levers to the fuel control rack and the cylinder is linked, through levers, to the throttle. The spindle is center- and cross-drilled to supply engine oil to the piston cavity and the spring retainer (thrust sleeve). One end of the spindle is supported in the end cap and the other end is fastened to the drive gear and the flyweight carrier.

SERVO-TYPE GOVERNOR OPERATION Study Fig. 25-12 as you read the following section. "Left" and "right" refer to directions in the illustration.

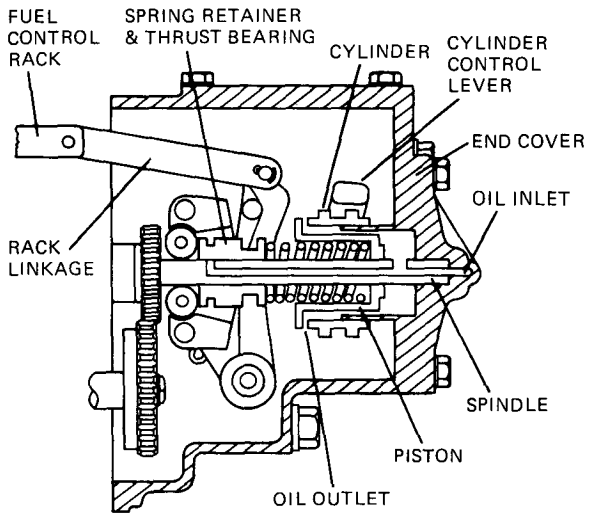


Fig. 25-12 Schematic view of a servo-type governor. *(Caterpillar Tractor Co.)*

When the engine is not operating, the piston rests against the cylinder and the spring retainer is forced to the left by the governor spring. The spring force causes the flyweight to move inward and causes the fuel rack to move to the full-fuel position.

Assume that the operator positions the throttle so that the engine will operate at 1000 rpm. This moves the cylinder against the piston, closing the oil outlet passage. Under this condition, and when the engine is operating, the oil pressure increases and pressurizes the area between the end cover and the piston. The oil pressure forces the piston to the left and increases the force on the governor spring. The thrust bearing moves to the left, which causes the linkage assembly to move the fuel rack to the increased fuel position. During this time the oil outlet passage opens through the movement of the piston, allowing oil to drain and the pressure to be reduced between the piston and the end cover. The flyweight force, meanwhile, has become greater and, therefore, increases the force on the governor spring. This moves the piston to the right and reduces the oil outlet passage. When the flyweight force and the force created on the piston are equal, the engine operates at a constant speed.

When the operator moves the throttle to high idle, the cylinder closes the oil outlet passage but its movement is limited through the high-idle adjusting screw. The oil pressure increases and the force on the piston increases. The governor spring moves the spring assembly to the left, and allows the fuel rack to move to the increased fuel position. With the movement of the piston, the oil outlet passage opens again and the pressure in the piston area is reduced until a balance between the governor weight force and the force on the piston is established.

When the operator moves the throttle to the low-idle position, the cylinder instantly increases the drain oil passage between it and the piston and the oil pressure then drops. Subsequently the governor spring is allowed to expand to the right, moving the piston to the right and reducing the drain opening. Engine speed reduces and the governor weight collapses, allowing the spring retainer and thrust bearing to move to the left. The governor weight force and hydraulic force are now in balance, and the engine operates at idle speed. However, the reduced opening results in an increase in oil pressure and the piston stops (or moves slightly to the left). Once again the governor weight force and the force on the piston are in balance, and the engine operates at idle speed.

HYDRAULIC GOVERNORS

There are many types of hydraulic governors, the simplest of which is the governor used on the DPA distributor-type fuel-injection pumps (see Fig. 25-13). The speed sensing is solely through hydraulics and the fuel metering is a combination of hydraulics and mechanics. (Also see Unit 34, "Stanadyne Diesel Systems' and DPA Distributor-Type Fuel-Injection Pumps.")

Not all hydraulic governors are so simple in design;

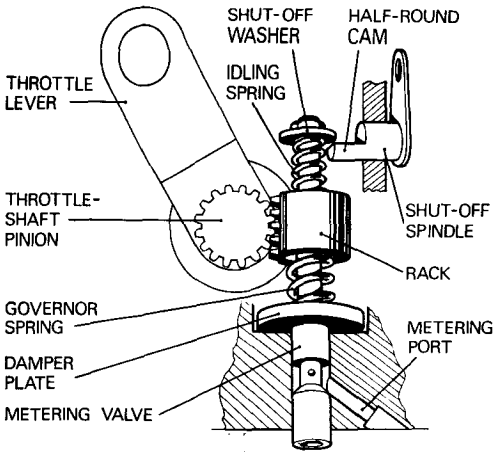


Fig. 25-13 Schematic view of a DPA hydraulic governor. *(CAV Limited.)*

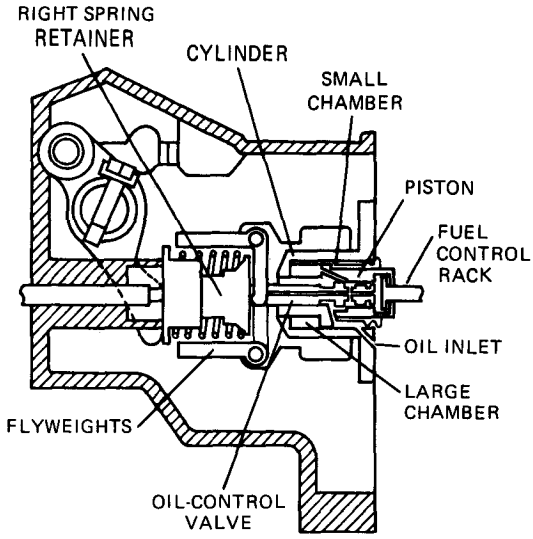


Fig. 25-14 Schematic view of a direct-acting hydraulic governor. *(Caterpillar Tractor Co.)*

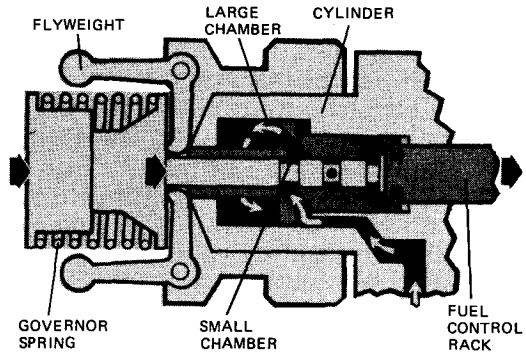


Fig. 25-15 Schematic view of oil flow to increase speed. *(Caterpillar Tractor Co.)*

indeed, some are very complex. However, nearly all hydraulic governors use mechanical speed-sensing mechanisms known as *flyweights*. The control valve, which controls the oil flow to and from the power piston is linked directly or indirectly by the flyweights. A single-acting piston, a double-acting piston, or a servo piston acts as the fuel-changing mechanism.

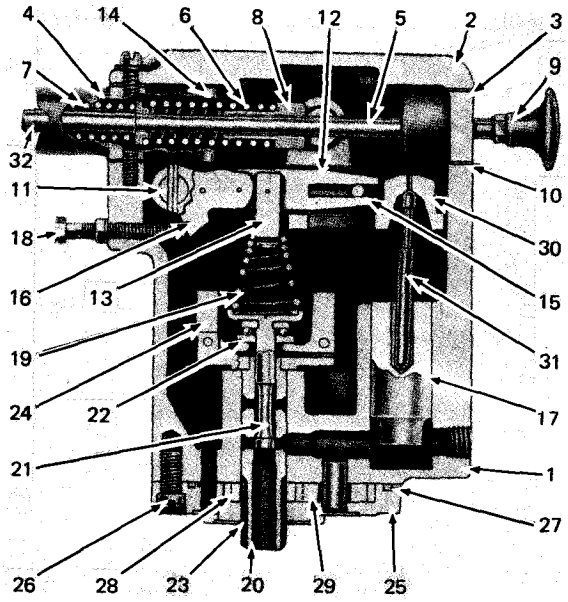
Direct-acting Hydraulic Governor Figure 25-14 illustrates a direct-acting hydraulic governor with a single-acting piston. The flyweights and the carrier are fastened to the governor drive gear and the assembly rotates on the stationary cylinder. The piston is hooked to the fuel control rack and is lap-fitted within the cylinder. The oil-control valve is center- and cross-drilled and fastened to the right-hand spring retainer. Oil passages within the cylinder lead into the small chamber, to the piston, to the oil-control valve, and into the large chamber (between the piston and the cylinder).

HYDRAULIC GOVERNOR OPERATION When the engine is not operating, the governor spring forces the right-hand spring retainer, the oil-control valve, the fuel control rack, and the piston to the right (see Figs. 25-14 and 25-15). This places the control rack in the full-fuel position because the oil-control valve then butts against the fuel control rack. When the operator moves the throttle to half engine speed, the force on the governor spring is immediately increased but no other action takes place. However, as soon as the engine begins to operate, engine oil enters the cylinder, flows into the small chamber, and passes by the open land on the oil-control valve into the larger chamber. It pressurizes both chambers, but the fuel control rack remains in the full-fuel position. At the same time the engine responds to the injected fuel and the engine speed and the flyweight force increase. The flyweight fingers move the oil-control valve to the left, which aligns the cross-drilled valve land with the piston passage and the large chamber. Oil drains from the large chamber, through the center of the valve into the governor housing. The pressure in the large chamber then drops. The pressure in the small chamber, however, remains the same, forcing the piston and the fuel control rack to the left. When the piston catches up to the valve land, it closes the drain passage. The engine then operates at constant speed because the piston is hydraulically locked, holding the fuel rack in a fixed position.

Indirect-acting Governor The three most common indirect-acting governors used on medium and large diesel engines are the Woodward SG and PSG and the UG-8L.

Two schematic drawings of an SG hydraulic governor with a single-acting piston are shown in Figs. 25-16 and 25-17. These governors are of the variable-speed design with an adjustable droop-speed mechanism. The one shown in Fig. 25-16 is used on Detroit Diesel engines and the one shown in Fig. 25-17 is used with various types of fuel-injection pumps. The governor flyweights are pinned to the ballhead assembly which is driven from the fuel-injection pump camshaft or from the blower. The ballhead shaft at the lower end drives the auxiliary-governor oil-pump gear. These pumps have a pressure relief valve to limit the maximum operating pressure. The engine lubrication system supplies oil to the auxiliary pump.

The lower governor spring seat is part of the lap-fitted pilot-valve plunger and fits into the upper part of the ballhead shaft. The governor spring (speeder spring) is located between the lower spring seat and the spring fork. The spring fork is pinned to the floating lever and the floating lever is pinned to the speed



1. Governor housing
2. Cover
3. Gasket
4. Cap
5. Fuel rod
6. Shutdown spring
7. Fuel-rod spring
8. Fuel-rod collar
9. Knob
10. Gasket
11. Speed-adjusting lever
12. Floating lever
13. Spring fork
14. Stop pin
15. Droop-speed pin
16. Speed-adjusting lever
17. Power piston
18. High-idle adjusting screw
19. Governor spring
20. Ballhead assembly
21. Pilot valve
22. Thrust bearing
23. Lock ring
24. Flyweight
25. Governor base
26. Screw
27. Ring
28. Oil-pump drive gear
29. Oil-pump driven gear
30. Terminal lever
31. Piston pin
32. To fuel-changing mechanism

Fig. 25-16 Schematic view of an SG governor used on a Detroit Diesel engine. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

adjusting lever. The speed adjusting lever is pinned to the speed adjusting shaft.

The high- and low-speed adjusting screw (Figs. 25-16 and 25-17) limits the travel of the speed adjusting lever, thus limiting the high- and low-energy placed on the governor spring. The power piston is slide-fitted into its cylinder (which is part of the governor housing) and is linked through the floating pin to the terminal lever. The terminal lever is connected to the fuel-changing mechanism and pivots on the terminal lever shafts. The load-limiting screw limits the pivoting of the terminal lever and therefore limits the travel of the fuel-changing mechanism. When the engine is not operating, the fuel-changing mechanism is held in the no-fuel position by a spring, and the power piston has been forced downward by the terminal lever.

To overcome prolonged engine cranking when using this type of governor, the terminal lever shaft must be rotated to the fuel-on position, as this moves the fuel-changing mechanism into the full-fuel position. (A long cranking period would otherwise be required to create enough oil pressure to move the power piston upward in order to move the terminal lever and the fuel rod to the fuel-on position.)

An advantage of this type of governor arrangement

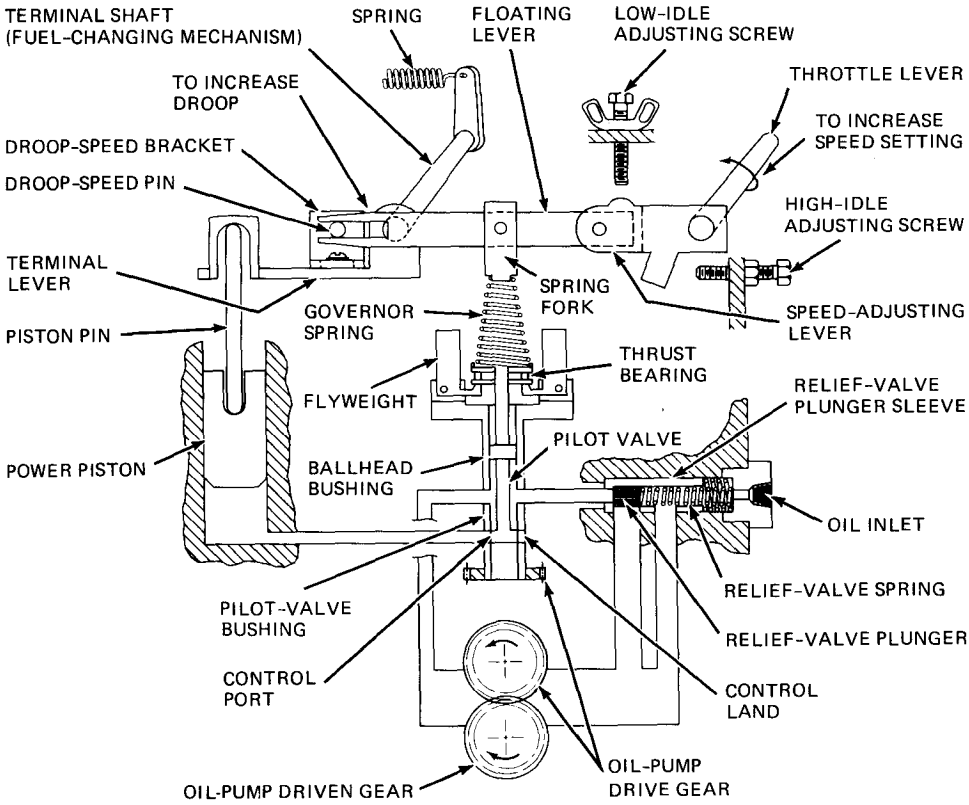


Fig. 25-17 Schematic view of an SG governor used with various types of fuel-injection pumps. *(Allis-Chalmers Corp. Engine Division.)*

is that the governor acts as an automatic shutdown device. In the event that the engine oil supply to the governor is lost, the auxiliary pump cannot supply oil to the power piston. The power piston is then forced downward, causing the fuel-changing mechanism to move to the no-fuel position.

When the engine is operating and the operator has moved the speed adjusting shaft to half engine speed, the speed adjusting lever rotates, and the floating lever pivots on the droop-speed adjusting pin causing the spring fork to move downward and compress the governor spring. This action moves the pilot-valve plunger against the flyweights' force. The land on the pilot-valve plunger opens the oil passage to the power piston. (During this time, engine oil from the engine lubrication system is supplied to the auxiliary pump and the auxiliary pump raises the pressure to the set value of the relief valve.)

Oil (under pressure) then enters the area below the power piston (see Figs. 25-16 and 25-17). The power piston and the piston pin rise, pivoting the terminal lever and causing the fuel-changing mechanism to move toward the full-fuel position. However, when the terminal lever pivots, it immediately reduces the spring force on the governor spring because the droop-speed adjusting bracket is bolted to the terminal lever. The pin of the droop-speed adjusting bracket lifts the floating lever and reduces the spring force on the governor spring. The engine responds to the increased injected fuel, the flyweights' force increases, and the flyweight fingers cause the thrust bearing to move the plunger upward. The upward movement of the pilot-valve plunger opens the oil passage in the ballhead, reducing the oil pressure below the power piston. The spring force of the fuel-changing mechanism now moves the terminal lever and the droop-speed pin downward, which moves the floating lever slightly downward, increasing the force on the governor spring. At the same time the piston pin moves the piston downward. Upon equalization of the force on the governor spring and the force of the flyweights, the pilot-valve plunger closes the oil port in the ballhead. The oil pressure remains fixed in the passage and below the power piston.

NOTE: To decrease the droop speed, move the droop-speed adjusting bracket toward the piston pin. (This will increase the fulcrum lever ratio.) To increase the droop speed, move the droop-speed adjusting bracket away from the piston pin. (This will reduce the fulcrum lever ratio.)

When one force is changed (say the operator moves the throttle to the high-idle position), the force on the governor spring is increased and the pilot-valve plunger opens the oil passage to the ballhead and the power piston. When the engine speed drops because of increased load, the flyweights' force decreases and the governor spring force moves the pilot-valve plunger downward, opening the oil passage. In either instance, the power piston is forced upward, resulting in an increase in fuel.

When the operator moves the throttle to reduce speed, the force on the governor spring is reduced and the flyweights' force moves the pilot-valve plunger upward. The passage in the ballhead opens, and the pressure below the power piston reduces. The power piston then moves downward, resulting in reduced fuel and reduced engine speed.

When the engine is operating at a fixed speed and suddenly its load decreases, the flyweights' force increases because of the increased engine speed. The governor finger moves the lower spring seat and the pilot-valve plunger, thus opening the oil passage in the ballhead. Oil drains from below the power piston and the fuel rod moves toward the low-fuel position.

Isochronous Governor To have more power to move the fuel control mechanism and also have a greater engine speed control, isochronous governors are used. *Isochronous,* insofar as governors are concerned, infers the ability to maintain constant engine speed independent of the load being carried by the engine as long as the load does not exceed the engine power. One of these types of governors is the Woodward PSG (Fig. 25-18), and another is the UG-8L (Fig. 25-19).

PSG Governor Design For the most part, the PSG governor is a modified SG governor. Its pilot valve bushing drives the ballhead and also the oil-pump drive gear. The oil pump has four check valves which allow the governor to rotate either clockwise or counterclockwise. The governor spring force is increased or decreased through the speed-adjusting shaft lever, terminal lever, and spring fork. The left-hand terminal-lever pivot point is the droop-speed pin. The output shaft rotates through the terminal lever; however, the droop screw bracket is slide-fitted to the lever so that the speed droop can be adjusted externally. The reversible synchronizing motor which also can be installed on the SG governor provides remote speed control. The clutch assembly is a safety device to protect the motor in the event the motor is energized and the speed-adjusting lever comes to rest against the high-idle adjusting screw. When the synchronizing motor is not used, it is replaced by a cover plate which has a low-idle adjusting screw. The isochronous feature of this governor is provided through the use of a compensating system which establishes temporary droop speed stability and then dissipates this droop so that the engine speed is constant (with the throttle in a fixed position) whether or not the engine load increases or decreases. The compensating system includes a buffer piston (floating between the buffer springs) to establish a pressure differential as oil flows to or from chamber A or B. The pressure differential is achieved through the compensating land on the pilot valve plunger and pilot valve land. The needle valve is used to dissipate the pressure difference.

OPERATION When the engine is shut down, the return spring moves the strut and power piston downward and rotates the terminal lever and output shaft counterclockwise. This action brings the fuel control mechanism to the no-fuel position.

When the engine operates at a constant speed, the flyweights' force and governor spring force are in

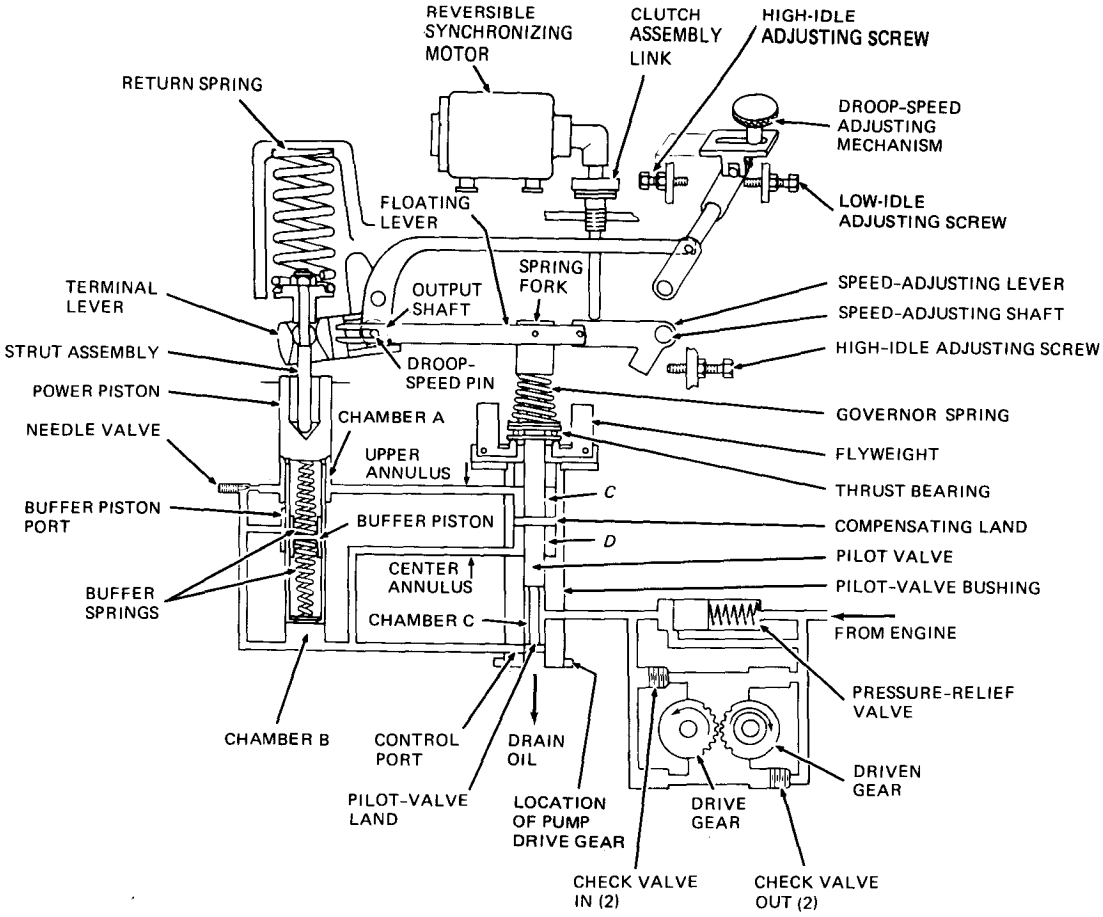


Fig. 25-18 Schematic view of a PSG governor. *(Caterpillar Tractor Co.)*

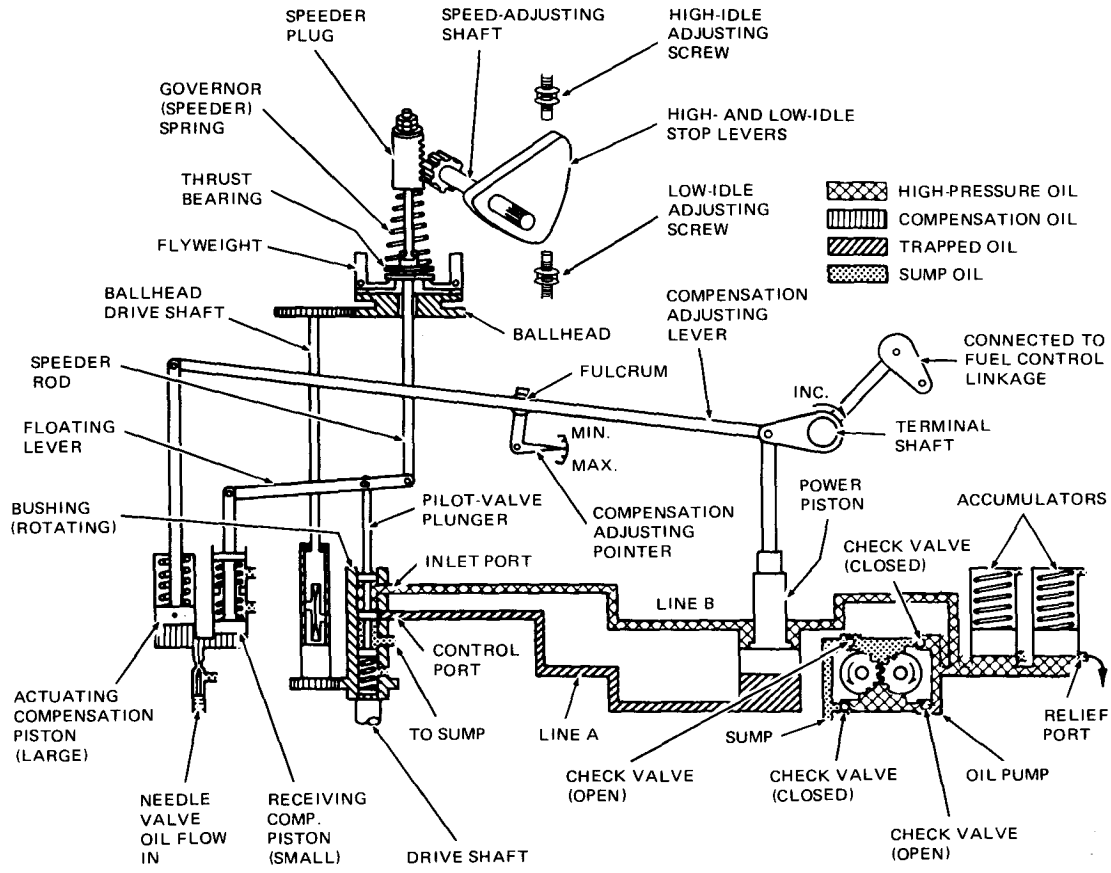


Fig. 25-19 Schematic view of UG-8L lever governor. *(Caterpillar Tractor Co.)*

balance. The pilot valve land blocks the control port and a fixed force is exerted onto the power piston through the oil pressure in chamber A, the oil pressure in chamber B, and the buffer spring force. The buffer port is open to chamber A and the relief valve maintains a pressure of about 170 psi [1172.1 kPa] in chamber C.

OPERATION, SPEED CHANGE Upon reduction in engine speed from a set rpm due to reduced engine load, or due to increased engine speed by increasing throttle position, the centrifugal force of the flyweights is reduced and the governor spring force moves the pilot valve plunger downward. This movement causes the pilot valve land to open the control port, permitting oil under pressure to enter the lower annulus leading to chamber A and past the buffer piston port into chamber B. *(NOTE: The power piston area in chamber A is smaller than in chamber B.)*

The increased oil flow into the chambers forces the power piston and strut assembly upward against the force of the return spring. This pivots the terminal lever clockwise and results in two actions: The output shaft pivots clockwise to the increased fuel position, and the floating lever moves upward to reduce the governor spring force. Simultaneously the piston moved upward because of the reduced pressure in chambers A and C closing the buffer port. The oil forced out by the buffer piston flows into the upper annulus and into chamber C, creating a pressure differential across the buffer piston and compensation land. The higher pressure in chamber D supplements the flyweights' force, causing the pilot valve land to close the control port before the set speed has been regained. The higher pressure in chamber B decreases as the oil flows past the needle valve into chamber A, equalizing the pressure and centralizing the buffer piston and thus opening the buffer piston port. In the meantime the engine has returned to its set speed.

The high-idle and droop-speed adjustment procedures are the same as those for the SG except that the droop-speed adjustment on the PSG can be made externally.

UG-8L Governor Design The UG-8L governor shown in Figs. 25-19 and 25-20 is a lever control governor, but there are others which use a reversible isochronous motor to change the force on the governor spring.

Governor Components and Purpose Commencing with the speed-sensing mechanism—the governor ballhead is driven from the drive shaft over the ballhead drive shaft. The governor spring force is increased or decreased through the speed-adjusting shaft gear and the speeder plug. The speeder rod is connected to the right-hand end of the floating lever. The left-hand end is connected to the receiving compensation piston. The pilot valve plunger, located in the rotating pilot valve bushing, is also connected to the floating lever. Note, however, the lever ratio is about 1:4, which means a small movement of the receiving compensation piston has a greater effect on the pilot valve plunger, or the movement of the speeder rod has a greater effect on the pilot valve plunger, than on the receiving compensation piston.

The fuel-changing mechanism consists of the self-contained oil pump (also driven by the drive shaft), two accumulators, a pressure relief valve, and four check valves. The purpose of the accumulators is to maintain a constant pressure of 120 psi [827.4 kPa] in the supply line B and between the top and center valve lands of the rotating pilot valve bushing. The power piston (servo piston) has an area ratio of about 5:1 and is connected to the terminal shaft lever. The shaft may be directly or indirectly connected to the fuel-injection-pump fuel rack. Also connected to the terminal shaft is the compensation adjusting lever, the fulcrum of which is adjustable. The left-hand end

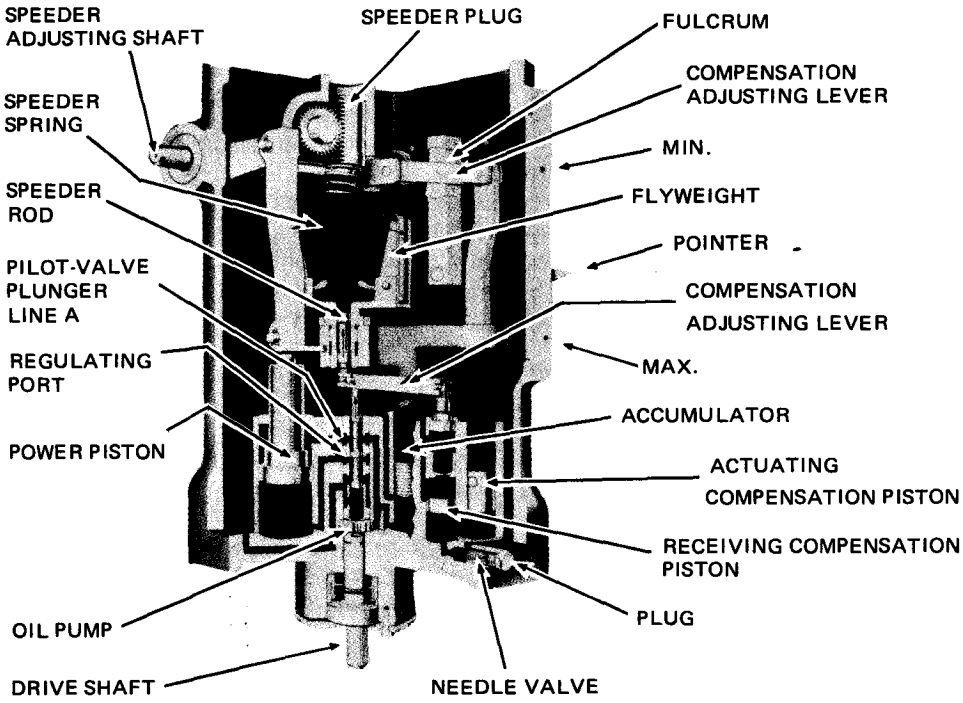


Fig. 25-20 Sectional view of UG-8L governor.

of the compensation adjusting lever is connected to the actuating compensation piston. Both the receiving and actuating compensation pistons have a common oil pressure which is controlled by the compensation needle.

GOVERNOR OPERATION When the engine is operating (at a constant speed), the drive shaft rotates the pilot bushing, which, in turn, rotates the ballhead drive shaft, and the ballhead with flyweights. At the same time the pilot bushing gear drives the oil pump. This action creates a fixed oil pressure in line B, on top of the power piston, and between the pilot valve top and center spool lands. Because a balance exists between the governor spring and flyweights' force, the center land blocks the control port, thereby holding a fixed oil pressure in line A, thus holding the power piston stationary. At all times when the engine is operating, a reduced compensation oil pressure is exerted onto the actuating and receiving compensation pistons.

When a very small load is removed from the engine which results in a slight increase in engine rpm, several actions occur simultaneously. The flyweights move outward, thus moving the speeder rod upward and with it the floating lever. Consequently the pilot valve moves upward (since the receiving piston has not yet moved) and its land opens the control port, allowing oil to flow from line A into the sump. This causes the power piston to move downward because of the greater oil pressure above the piston which turns the terminal shaft counterclockwise toward the reduced fuel position.

The movement of the power piston pivots the compensation adjusting lever on its fulcrum and moves the actuation piston upward, thus reducing the pressure below the receiving piston. The receiving piston's spring force then moves the receiving piston downward and with it the left-hand side of the floating lever and also the pilot valve. The pilot valve closes the control port and maintains a fixed pressure in line A (because the speeder rod is at this time held stationary through the equal flyweights and spring force.) *(NOTE: The receiving piston is the floating fulcrum of the floating lever, to counteract the movement of the speeder rod.)*

When the engine load increases, the rpm and flyweights' force decrease and the governor spring forces the speeder rod downward. The floating lever and pilot valve also move downward because, at this point, the receiving piston is held stationary. The control port then opens, the oil pressure in line A increases, the power piston and the right-hand side of the compensation adjusting lever are forced upward, and the terminal shaft rotates clockwise to increase fuel. This action moves the left-hand side of the compensation adjusting lever downward and the oil displaced by the actuating piston forces the receiving piston upward. As a result the pilot valve closes the control port, and maintains a fixed pressure in line A, holding the power piston stationary.

If the operator indirectly semirotates the speed-adjusting shaft, its gear transmits the motion to the speeder plug so that more or less force is placed on the governor spring. The governor response is the same if a load were placed on the engine or removed from the engine.

ADJUSTMENT High- and low-idle speed adjustment is made by limiting the travel of the speed-adjusting shaft through the high- and low-idle adjusting screw. (Always make certain the engine is at operating temperature before making any governor adjustment.)

If the governor hunts or surges after a load or speed change is made, the compensation is out of adjustment, that is, the needle valve is too far open or too far closed, or the fulcrum point is not correctly positioned.

To make an adjustment, loosen the locknut of the compensation adjusting pointer and move it to the minimum end position. This changes the fulcrum point of the compensation lever (see Figs. 25-19 and 25-20). Remove the plug from the base of the governor to get access to needle valve. Insert a screwdriver into the slot and turn the needle valve clockwise until it is seated. Then turn it three turns counterclockwise and move the compensation adjusting pointer downward to its maximum position. Now turn the needle valve clockwise until the engine surge stops and take note of the number of turns you have made. When the surge stops and the needle valve is one-half to three-quarters open, the governor compensation is correctly adjusted. However, if the needle valve is more than three-quarters open, move the compensation adjusting pointer two marks toward the minimum and repeat the needle-valve adjustment. *(NOTE: The needle valve* must *be between one-half and three-quarters of a turn open, and by moving the pointer step by step toward the minimum, the needle-valve opening can be reduced to specification.)*

Questions

1. Why do diesel engines require a governor?
2. What are the two functions of a governor?
3. List the major differences between (*a*) a mechanical governor and a servo governor, (*b*) a mechanical governor and a hydraulic governor, and (*c*) a mechanical governor and a pneumatic governor.
4. Why do most governors use some kind of a pulsation device?
5. List the basic components of most governors.
6. What would happen to engine speed and governor action if the governor spring were broken?
7. Name the components which limit the maximum engine speed on an engine having a pneumatic governor.
8. If the diaphragm of a pneumatic governor were punctured, how would rated speed and idle speed be affected?
9. List the main differences between the hydraulic governor shown in Fig. 25-15 and the governor shown in Fig. 25-17.
10. Name the components which limit the maximum speed of the governor shown in Fig. 25-17.
11. In order to accomplish maximum engine torque, which of the following is necessary: (*a*) the plunger must turn more and the governor weight must move

further outward; (*b*) the fuel rack must move inward and the speeder spring must expand; (*c*) the engine speed must drop from high-idle to torque speed and the fuel rack must move to the increased fuel position.

12. The narrow band of speed variation through which the governor makes no corrective movement is called (*a*) speed group, (*b*) dead band, or (*c*) speed droop.

13. Which of the following factors are involved in the Robert Bosch torque backup arrangement: (*a*) torque-cam adjustable stop plate, (*b*) control rack and bumper spring, or (*c*) torque-cam stop plate and torsional spring.

UNIT 26 • ANTIPOLLUTION CONTROL DEVICES

Function of Control Devices A diesel engine which emits excessive smoke should be tuned up or serviced, as obviously one or more systems or components are not operating effectively. However, it is normal for a diesel engine to emit excessive smoke during acceleration because the governor momentarily over reacts and causes too much fuel to be metered and injected. This is even more apparent on the turbocharged engine.

Antipollution regulations are becoming increasingly strict and engine manufacturers are therefore working extensively to minimize engine noise and to reduce exhaust smoke. As one solution to the problem of dense exhaust smoke emission during acceleration, control devices have been designed for turbocharged engines to limit the fuel-rack travel or the metering valve rotation, or to reduce the fuel manifold pressure, or to slow down the motion of the injector control lever (G.M.). Each of these devices reduces or delays the quantity of fuel injected during engine acceleration to counteract the quick governor action. The pressure lag in the intake manifold remains until the exhaust gases force the turbine of the turbocharger to turn at a higher speed. The compressor wheel can then develop a higher manifold pressure. The end result is a smooth proportionate fuel-air ratio.

Aneroid Control The control devices referred to above are known as *aneroids, fuel-ratio controls, puff limiters, manifold pressure compensators,* or *throttle delay mechanisms.* The word "aneroid" is derived from the Greek language and means "without liquid." The aneroid control senses changes in the intake-manifold air pressure without the use of liquids.

Basically an aneroid is a housing separated by a piston or diaphragm in two parts. The diaphragm or piston is fastened to the operating rod with the rod either directly or indirectly linked to the fuel-metering device. The left-hand side of the aneroid is a sealed chamber and is connected through a hose to the intake manifold. The operating spring is positioned in the right-hand side of the aneroid housing which is vented to the atmosphere. The purpose of the operating spring is to oppose the boost pressure (Fig. 26-1).

Cummins' turbocharged engine was one of the first to use an aneroid control valve. This valve bypasses fuel to reduce the fuel pressure in the fuel manifold until there is sufficient turbocharged pressure in the intake manifold (Fig. 26-2).

During cranking, the gear pump supplies fuel to the injectors and to the aneroid inlet. The starting

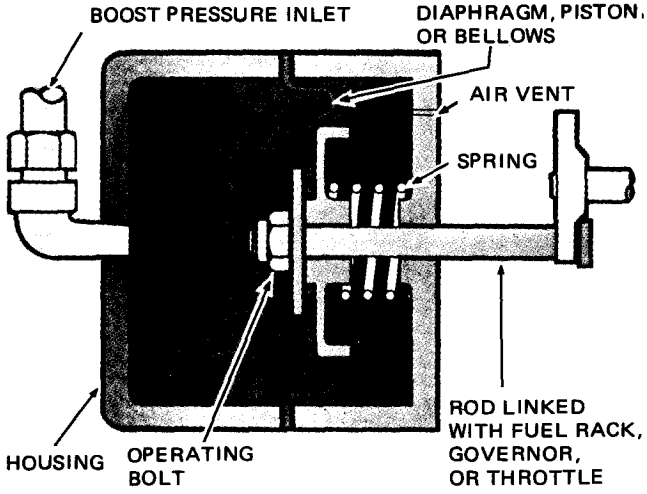


Fig. 26-1 Simplified schematic view of basic aneroid design.

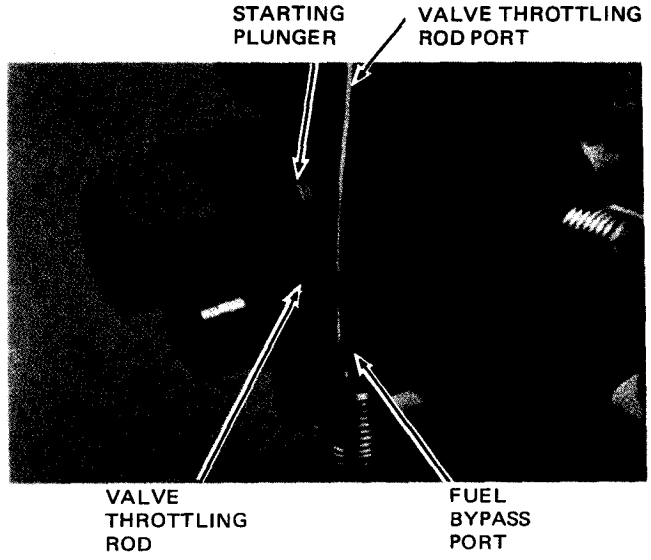


Fig. 26-2 Sectional view of aneroid. *(Cummins Engine Company, Inc.)*

plunger blocks the fuel passage and this increases the fuel pressure in the fuel manifold (injectors). When the fuel pressure has increased to, say, 12 to 20 psi [82.7 to 137.9 kPa], it forces the starting plunger upward against the plunger spring, opening the fuel passage, and the aneroid is then connected to the fuel system.

After the engine has started and its speed has increased, the turbocharger pressure also increases. This pressure acts on the bellows. The bellows and bellow rod are forced downward, rotating the valve throttling rod in proportion to the intake-manifold pressure. The valve opens or reduces the fuel bypass opening, thus varying the fuel pressure in the fuel manifold. When the intake-manifold pressure reaches, say 30 inHg [76.2 cmHg], the bypass valve is fully closed and the PT fuel pump then controls the fuel manifold pressure. If the intake-manifold pressure drops below 30 inHg [76.2 cmHg], the bellows spring forces the bellows upward, and the valve throttling rod starts to rotate. The bypass port starts to open, thus causing a reduction in the fuel manifold pressure and consequently a more proportionate air-fuel ratio. The aneroid control valve now used is located within the PT fuel pump and is called *air-fuel control* (AFC) (see Unit 33, "Cummins Fuel-injection System").

Indirect-acting Aneroid An indirect-acting aneroid is shown in Fig. 26-3. From this illustration you can see that the pushrod is indirectly linked to the fuel rack. When the engine is *not operating* and the operator moves the throttle to half engine speed, the aneroid spring forces the diaphragm to the right against its stop. The flyweight sleeve at this point has moved to its extreme left-hand position. This action moves the guide lever and floating lever to the left, thus positioning the fuel rack to the starting fuel position.

When the engine is *running* at half-speed, the intake-manifold pressure is low, the flyweight sleeve moves to the right, and the fuel rack moves to the reduced fuel position. In the meantime the aneroid diaphragm has moved slightly to the left, moving the lever, the floating lever, and the fuel rack to the left, thus governing the fuel quantity injected to the boost pressure. Any changes by the flyweight sleeve due to engine rpm or throttle setting are relayed over the guide and floating levers to the fuel rack. Likewise any changes in the boost pressure are relayed over the lever, guide, and floating levers, to the fuel rack. At maximum boost pressure and full throttle, the lever and floating lever are in their maximum left-hand position, and the fuel rack is in the maximum fuel position. If there is any reduction in the boost pressure

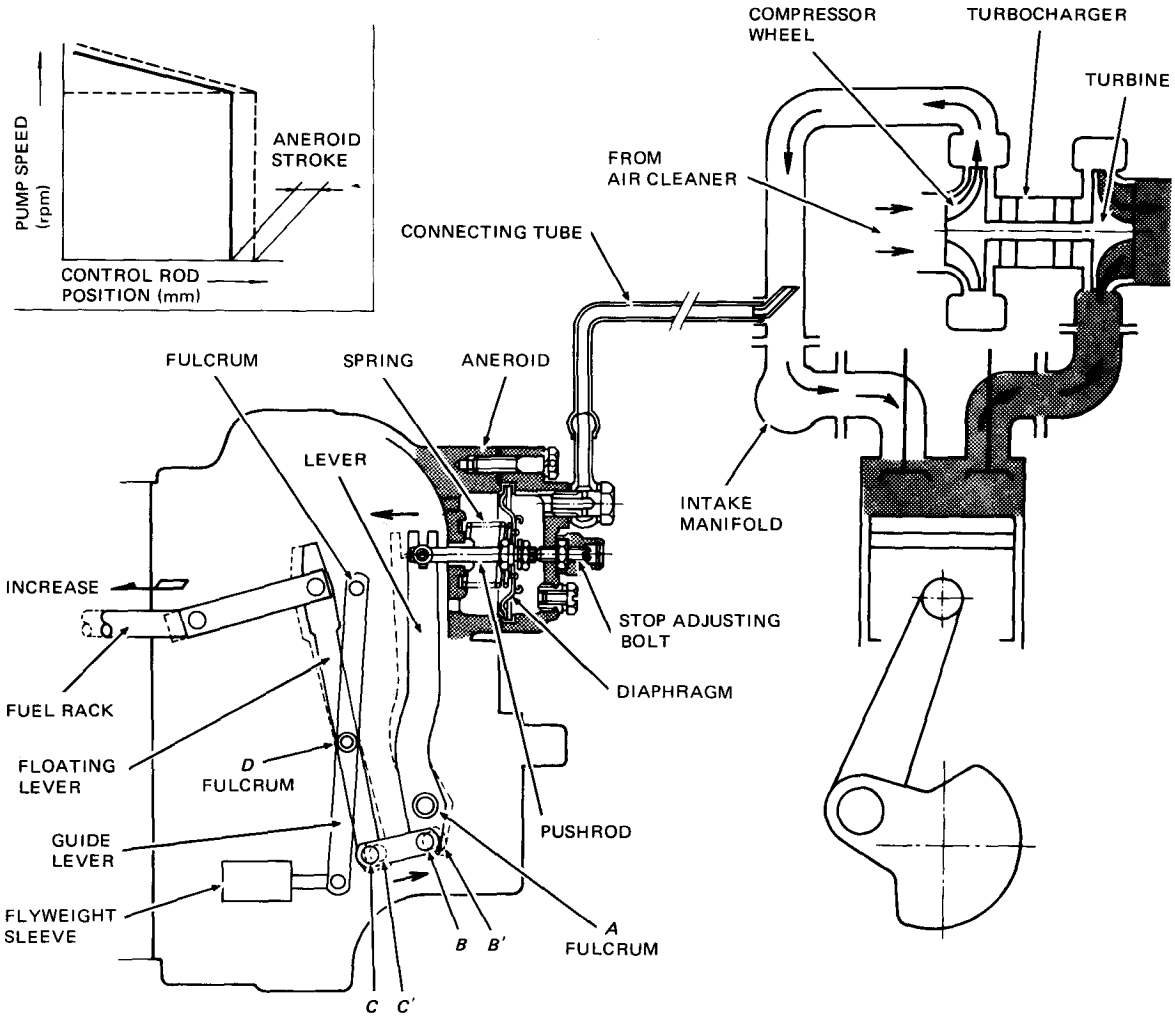


Fig. 26-3 Schematic view of an aneroid and its related components.

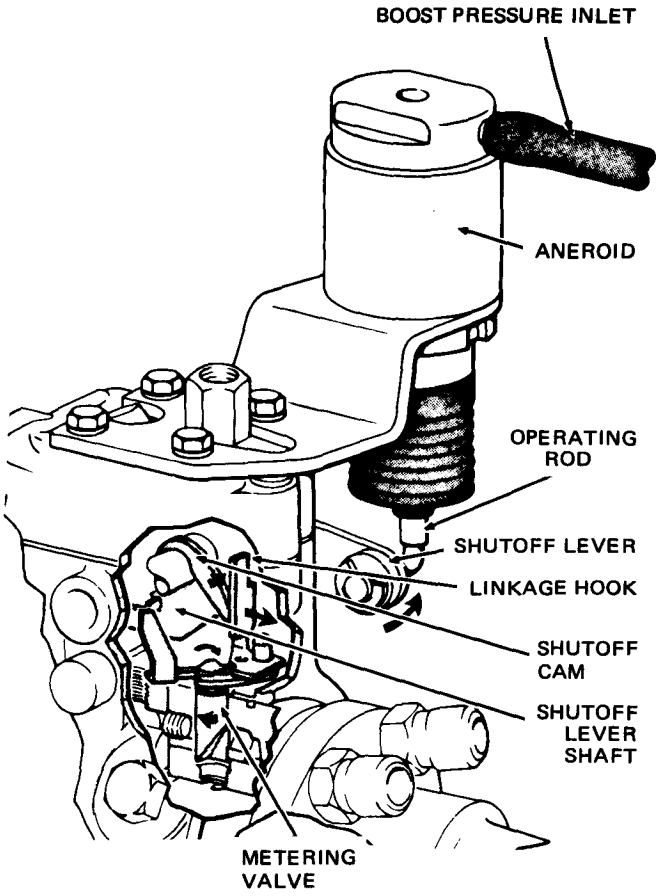


Fig. 26-4 Schematic view of the aneroid fuel control action. *(Stanadyne Diesel Systems.)*

without a throttle change, the diaphragm, lever, floating lever, and fuel rack move to the right, reducing the fuel flow.

Another aneroid control linkage is shown in Fig. 26-4. It is used on Stanadyne fuel-injection pumps. Here, however, the operating rod is connected to the shutoff lever. Its maximum upward movement is limited by the front adjusting screw, therefore limiting maximum fuel reduction. Its maximum downward movement is limited by the rear adjusting screw. This aneroid operates much like the indirect-acting aneroid outlined above except that the fuel control reacts from the operating rod, which rotates the shutoff lever, and its rotation is transmitted over the shutoff cam, onto the linkage hook, over the linkage hook spring, and onto the metering valve (see Unit 33 also).

Hydraulic Air-fuel-ratio Control Another type of aneroid is shown in Fig. 26-5. This aneroid is used on one of Caterpillar's recent engine designs. It is known as a *hydraulic air-fuel-ratio control.* Basically it is a conventional aneroid into which a piston and valve assembly is incorporated. The purpose of the added assembly is to circumvent fuel-rack limitation during startup which would otherwise occur and thereby pull the fuel rack into the reduce fuel position.

OPERATION Refer to Fig. 26-5. When the engine is started, the boost pressure is low in the boost pressure chamber and the piston and valve assembly remains in the upward position. At this time lubrication oil enters the inlet passage A and flows below the oil valve piston into the chamber F, from there through a large passage C, into chamber E, and out of a smaller passage B into the governor housing. This moves the oil valve piston upward against its inner spring force, but not far enough for the piston land to close the inlet port C in the oil valve. The fuel rack, therefore, remains free and can move in response to the governor. When the boost pressure is about 3 psi [20.6 kPa] the force on the diaphragm, through the upper spring force and boost pressure, moves the piston downward and its land closes the outlet passage B. This hydraulically locks the oil valve to the piston and from this point on the maximum fuel-rack travel is controlled by the boost pres-

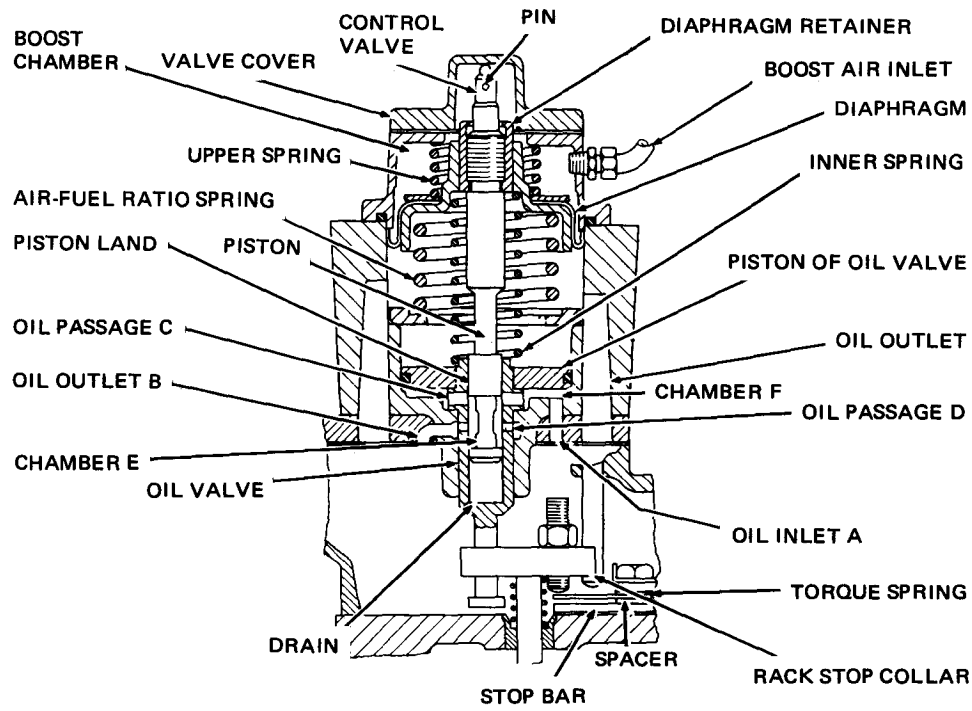


Fig. 26-5 Schematic view of hydraulic air-fuel-ratio control. *(Caterpillar Tractor Co.)*

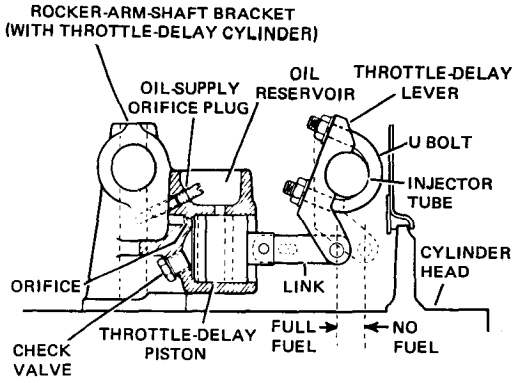


Fig. 26-6 Schematic view of the throttle-delay mechanism. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

sure. When maximum boost pressure is exerted onto the diaphragm, the oil valve flange end moves away from the collar, and therefore the fuel rack can move to maximum fuel position by bending the torque spring. When the boost pressure is reduced because of reduced load on the engine, the diaphragm, the piston, and the oil valve move upward and limit the fuel-rack travel.

Throttle-delay Mechanism The emission device used on some two-cycle Detroit Diesel engines is a throttle-delay mechanism (Fig. 26-6). (See also the sections on the throttle-delay mechanism in Unit 31.)

This device also reduces the exhaust smoke during acceleration. It delays the action of the governor by holding the control tube hydraulically until the spring force moves the throttle-delay piston. The movement of the piston is restricted. It must force the oil out of the cylinder through a small orifice. This action slows the rotation of the control tube and thereby the movement of the fuel rack. The engine speed increases, gradually reducing the density of the exhaust smoke.

Questions

1. *(a)* What is the purpose of the antipollution device? *(b)* What function does it perform?
2. What would occur if the spring-loaded starting plunger (Cummins) seized in the open position?
3. What evidence would indicate that the diaphragm is ruptured?
4. How would engine performance be affected if the atmospheric side of the aneroid or fuel ratio control were plugged?
5. If the diaphragm spring were broken: *(a)* how would the engine performance be affected? *(b)* Would the exhaust smoke density increase or decrease?
6. What two purposes does the hydraulic air-fuel-ratio control serve?

UNIT 27 - FUEL-INJECTION NOZZLES AND HOLDERS (INJECTORS)

For the most part, high thermal efficiency and lowered emission in a diesel engine is relevant to the working effectiveness of its injector assembly. The selection of the injector holder and nozzle assembly depends on the construction of the combustion chamber, the location of the injector, and the type of fuel-injection system. This unit will cover injector assemblies used with Robert Bosch, American Bosch, CAV Sims, and Stanadyne diesel systems' fuel-injection pumps. Caterpillar, Detroit Diesel, and Cummins injectors will appear in a later unit.

Nozzle Holder The purpose of the nozzle holder assembly is to position and to hold the injection nozzle to the nozzle holder, to provide fuel passage to and from the injection nozzle, to provide a pressure adjustment mechanism, to vary the opening pressure of the nozzle valve, and to provide a means to position the injector securely to the cylinder head.

A lettering and/or numbering system is/are used to identify the manufacturer, its design, and the method used to hold the nozzle holder to the cylinder.

Five of the most common nozzle holder assemblies are shown in Figs. 27-1 to 27-4 and Fig. 27-14, but there are actually hundreds. Some of the primary differences between holder assemblies, and which are codified, lie in the shank diameter, the method of connecting the injection and bleedoff line, the location and method of pressure adjustment to limit the nozzle-valve lift, and the method used to hold the nozzle holder to the cylinder.

All nozzle holders are of similar internal design, having machined passages within the body to (1) connect the inlet fuel with the nozzle and (2) connect the leakoff fuel (which is used to lubricate the nozzle valve and valve-adjusting device) to the fuel tank. To provide a fueltight joint between the nozzle body and nozzle holder, the lower flat surfaces of the nozzle body and nozzle holder are lapped.

Injection Nozzle The purpose of the injection nozzle is to direct and atomize the metered fuel into the combustion chamber. The combustion chamber design dictates the type of nozzle, the droplet size, the spray pattern, and the spray angle required to achieve complete combustion within a given time and space. Each injection nozzle is codified by a lettering and/or numbering system to identify the nozzle de-

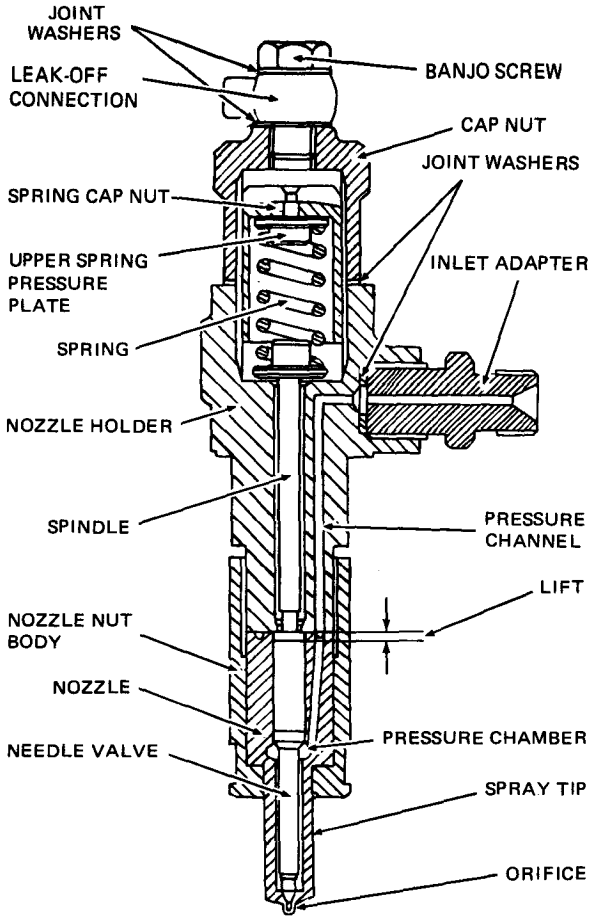


Fig. 27-1 Schematic view of an injector having a flange-type nozzle holder and external pressure adjustment (flange not shown). *(CAV Limited.)*

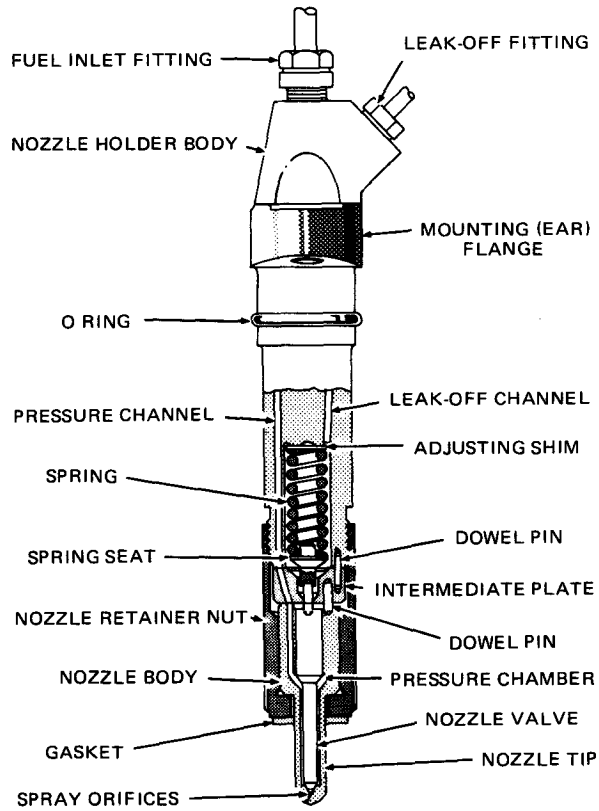


Fig. 27-2 Schematic view of an injector having a flange-type nozzle holder and internal pressure adjustment. *(International Harvester Company.)*

sign, dimensions, spray angle in degrees, hole size, number of holes, sac hole size, and valve lift (see Combustion Chamber Design, Unit 4).

Differential-type nozzles which open inwardly are the most common. Their designs include the short- or long-reach multihole type, single-hole (straight or offset) type, standard pintle type, throttling type, or pintaux type. The multihole nozzles are used in engines with direct-injection combustion chambers, and the pintle or throttling types are used in engines with precombustion chambers, turbulence chambers, or air or energy cells (Fig. 27-5).

The nozzle comprises the body and a nozzle valve (Fig. 27-6). The lapped joint face of the body has an angular groove and one to three fuel passages leading to the pressure chamber (gallery). The nozzle bore and the nozzle valve are lapped as a matched set to a close tolerance. The diameter of the lower nozzle-valve section is kept relatively large to reduce the sac volume and thus minimize the amount of fuel which could be scavenged or boiled out into the combustion chamber and pass through an unburned hydrocarbon (HC). *(NOTE: The sac volume is the area below the needle-valve tip.)*

The nozzle body seat is commonly 1½° smaller than the angle of the needle-valve seat. This not only improves the valve seating but also helps keep the seat in clean condition.

When the axis of the spray cones are not in line with the axis of the nozzle, dowels are used to position and hold the nozzle body to the nozzle holder.

When the opening pressure-adjusting device is external, the pressure pin on the nozzle valve protrudes into the holder and rests in the recess of the spring-loaded spindle. See Fig. 27-1. The needle valve's upper shoulder protrudes inward. The distance from the shoulder to the face of the nozzle body is called the *needle lift,* and, depending on the nozzle type, fuel flow, and spray pattern, the lift varies from 0.012 to 0.027 in [0.30 to 0.68 mm]. The spring force acting on the spindle can be altered by turning the spring cap nut clockwise to increase the force, or counterclockwise to decrease the force. The cap nut is used to lock the adjustment.

On other types of nozzle holders an adjustment screw is threaded into the spring cap nut to increase or decrease the spring force.

When the pressure adjustment is internal (Figs. 27-2 and 27-4), the pressure pin on the nozzle valve protrudes through the valve stop plate (intermediate plate) and rests in the recess of the spring seat. The spring force on this type of nozzle holder is increased or decreased by adding or removing shims.

Injector Action Fuel (under pressure) from the injection pump enters the supply passages and pressure chamber. When the force on the lift areas is greater than the set spring force on the spindle or spring seat, the nozzle valve lifts off its seat and comes to rest with its upper shoulder against the face of the holder or valve stop plate. (The lift area is the predetermined angle surface on the nozzle valve located in the pressure chamber and the exposed valve-seat surface.) Fuel is then sprayed out into the combustion chamber according to the velocity and

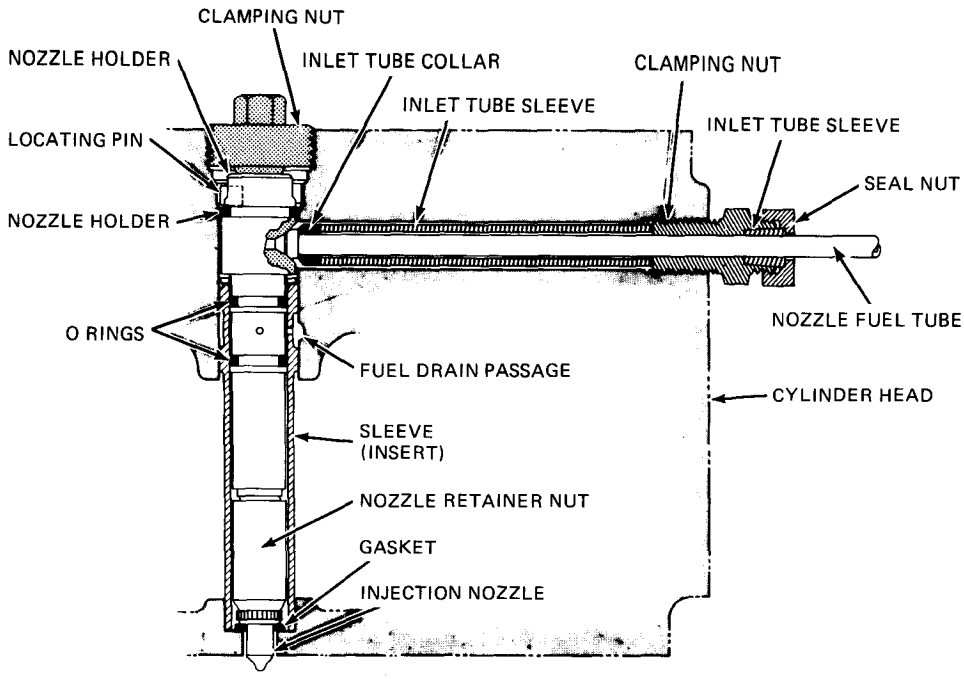


Fig. 27-3 Schematic view of an injector having internal pressure adjustment using a clamping nut. *(Mack Trucks Canada Limited.)*

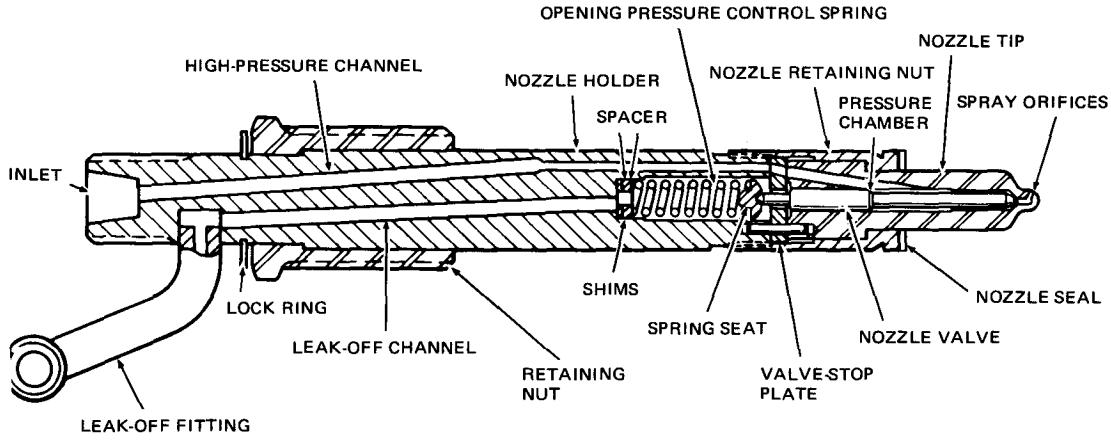


Fig. 27-4 Schematic view of an injector having a retaining-nut-type nozzle holder and internal pressure adjustment. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

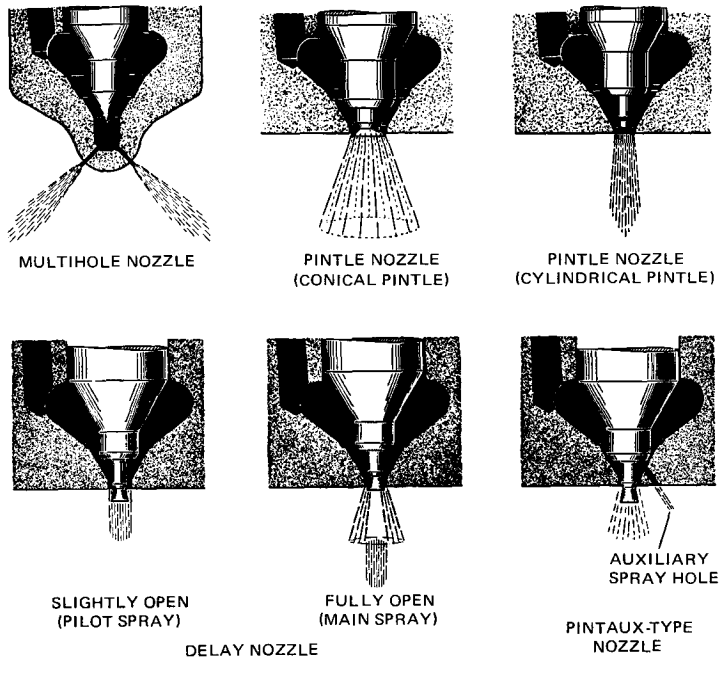


Fig. 27-5 Spray patterns of various nozzle types. *(Robert Bosch GmbH, Stuttgart, West Germany.)*

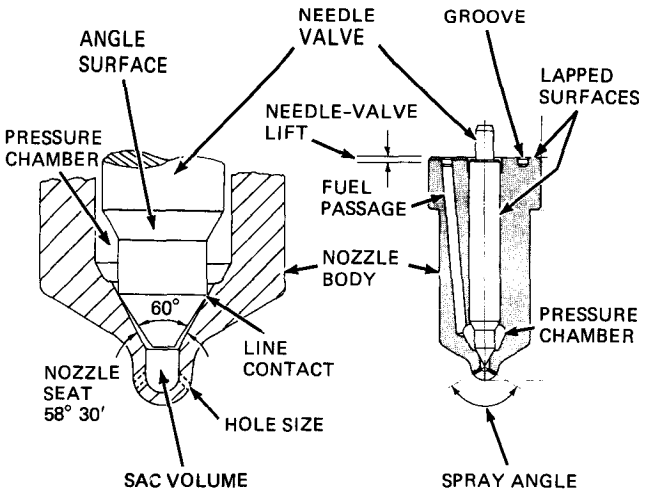


Fig. 27-6 Schematic view of a multihole nozzle.

pattern design of the particular nozzle being used (see Fig. 27-5). The opening pressure of pintle-type nozzles varies from 1000 to 2200 psi [6895 kPa to 15169 kPa] whereas multihole-type nozzles vary in opening pressure from 2500 to 5000 psi [17237.5 to 34475.0 kPa].

As the fuel is sprayed into the combustion chamber, a pressure drop occurs within the injector and likewise within the pressure chamber, forcing the valve onto its seat. As the pressure builds up, the valve is again lifted off its seat. This action repeats itself many times per second and is audible as "chatter." To the naked eye the injection spray cone appears to be solid; however, you can see from Fig. 27-7 that it is not. Spray cones are precisely calculated to achieve maximum fuel efficiency, to achieve complete combustion, and to reduce emissions. These objectives are achieved through the nozzle hole size, length of the nozzle holes, the spray angle, and the injection pressure.

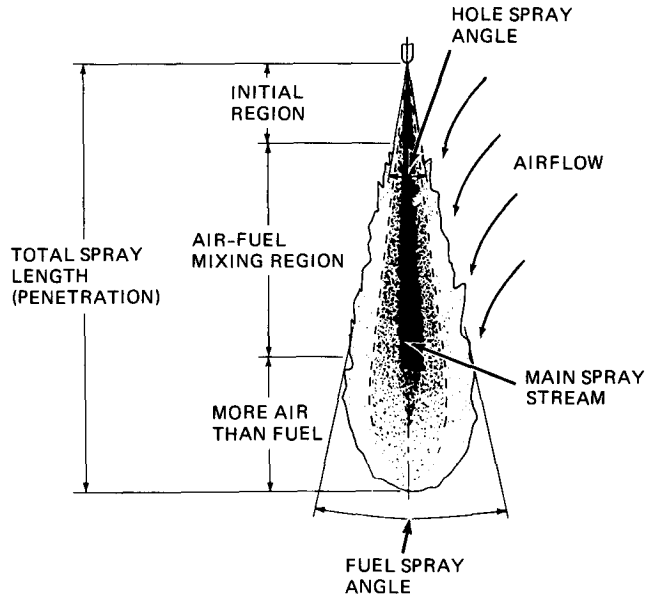


Fig. 27-7 View of a typical fuel spray cone.

It is important, therefore, when servicing the injector to strictly follow the test specifications. For example, if the injector opening pressure were inadvertently increased by 150 psi [1034.2 kPa], the start of the spray would be delayed and the fuel spray velocity would increase. This would cause the spray cone to lengthen, the spray angle to decrease, the fuel droplet size to decrease, and the fuel to settle in places out of reach of the air stream. This combination of events would cause an increase in delay time and result in high emissions, loss of power, and high fuel consumption.

When the pumping element spills back, delivery from the pump ceases, the pressure in the pressure chamber drops instantly, and the pressure spring snaps the needle valve onto its seat, preventing raw fuel from leaving the nozzle.

Fuel-injection Nozzle and Holder Service The main factors which reduce the service life of an injector are abrasives (dirt), heat, water, excessive sulfur, and improper installation. Abrasives wear down the fuel-carrying components, enlarge the tolerances of the needle valve and bore, and sometimes damage the injector seat and the spray hole. Excessive heat changes the expansion rate of the nozzle and thus accelerates wear, causes higher leakby, and reduces the quantity of fuel for injection. Water causes corrosion and dilutes the lubricant. Furthermore, since water will not pass through a multihole-type nozzle tip, it may break off the tip. Excessive sulfur in the fuel leaves deposits and causes corrosion. Improper installation can result in inadequate cooling, seizure of the needle valve, or poor valve seating.

Locating Faulty Injector An injector should only be removed when it causes a rough running engine, or when the engine is in the shop for a major overhaul. However, some manufacturers recommend a readjustment of the opening pressure after 2000 hours of operation to maintain a good spray pattern. This readjustment should preferably be made with the injector installed. If this is not possible, the injector must be removed and tested on an injector tester.

To locate a faulty injector which may have caused incomplete combustion, engine misfiring, rough running, or excessive smoke emission, start the engine and check for leaking high-pressure connections. Crack open the individual fuel-injection lines one at a time, either at the injector or at the fuel-injection pump. With one fuel-injection line cracked open, listen for a change in engine sound. The injector is faulty if the sound of the engine has not changed.

Removing Injector The injector position and its hold-down device may differ from engine to engine, but the removal procedure is much the same.

It is essential, first, to clean the surrounding area thoroughly (cleanliness cannot be overemphasized) and, when possible, use compressed air. Remove the high-pressure fuel lines from the injector inlet and remove the leakoff fuel lines. Instantly cap all openings to prevent dirt from entering. Use two wrenches

when loosening the connections, in order to prevent damage to the fitting or twisting of the fuel line.

To remove a flange-type injector (Fig. 27-2), remove the hold-down cap screw or the nuts from the stud bolts, and on the clamp-type injector (Fig. 27-15) remove the cap screw and slide the clamp out of the injector groove. With two injector bars, pry the injector parallel-upward out of its bore. When the injector is removed, cap the nozzle tip to protect it from damage, and cover the cylinder-head opening.

To remove the injector shown in Fig. 27-4, use an extension and crowfoot wrench to turn the retaining nut counterclockwise. As you turn the nut, it comes to rest against the snap ring and forces the injector upward. When the nut is out of the cylinder head's threaded bore, lift the injector from the bore.

To remove the injector shown in Fig. 27-3, you need a special nozzle-holder removing and installation tool. Start the removal by removing the seal nut and the clamping nut, and then pull out the nozzle fuel tube. Next, remove the nozzle holder clamping nut and attach the removing tool to the injector holder. This places the puller screw into the threaded bore of the nozzle holder and the sleeve onto the cylinder head. By turning the nut on the puller screw against the sleeve, the injector is pulled from the injector sleeve (insert).

Testing Injector prior to Disassembly A superficial check will often help you to establish the cause of failure and/or determine if the assembly needs to be tested, repaired, or merely cleaned and readjusted. If the spray tip, nozzle, or nozzle holder shows discoloration, damage, and/or corrosion, it must be serviced.

Fuel-injection shops do not test injectors before servicing unless specifically requested to do so. Testing the fuel injector, however, is an essential procedure for the engine mechanic as it will establish whether or not the injector caused the rough engine operation; if it did not, you have been saved considerable time (Fig. 27-5).

CAUTION When installing the injector to the tester, install it in such a way that the spray cannot injure you or nearby workers. Human skin is easily punctured by the high pressure of the spray and such punctures may result in blood poisoning.

After the air is removed from the injector line, tighten the connection and switch on the air blower so that the fuel spray will be drawn back and will drain into the reservoir.

Testing Opening and Closing Pressure To test the opening and closing pressure, first close the pressure-gauge valve and slightly open the fuel-supply valve. Operate the hand pump rapidly for a few strokes to clear the air from the injector. With the air removed from the assembly, open the pressure-gauge valve about one-eighth of a turn. Slowly operate the hand pump to raise the pressure until the needle valve lifts off its seat and fuel sprays from the nozzle.

Observe and record the opening and closing pressure indicated on the pressure gauge. The valve closing pressure should not fall below 300 psi [2068.5 kPa], less than the opening pressure. If it is lower, the needle valve is sticking.

Valve-seat Test The valve-seat test should be made next. Wipe off the nozzle tip and bring the pressure to about 200 psi [1379 kPa] below the opening pressure. Check the spray tip. The tip must stay dry. If there is any evidence of fuel at the tip, the needle-valve seat is defective.

Back Leakage Test Next, check for leakoff (back leakage). This test is used to check the fit of the needle valve to the nozzle bore, and the lapped surface of the nozzle body and nozzle holder. Raise the pressure within 100 psi [689.5 kPa] of the opening pressure and time the pressure drop. An average pressure drop of not more than 880 psi [6067.6 kPa] in 6 seconds is an indication that the mating surfaces are not leaking and the needle valve is adequately lubricated. If the pressure drop is higher, then the needle valve fits too loosely or the lapped surfaces are not sealing. If the pressure drop is less than 300 psi [2068.5 kPa], the needle valve lacks lubrication and the nozzle assembly must be cleaned.

Spray Pattern Test Finally, check the spray pattern. Close the pressure-gauge valve and operate the hand pump with a sharp stroke at least twice every second to simulate its normal operating cycle. There should be no spray distortion, and no unatomized fuel should be visible. Each spray cone (multihole nozzle) should have the same pattern, each should have the same cone length, they all should be spaced evenly from one another, and you should hear a chatter. If the spray pattern is distorted, there may be a damaged or choked hole. If there is no audible chatter, the needle valve is sticking. If there is no injector tester available, remove one injector at a time and reconnect the injector to the fuel line so that the spray pattern and nozzle seat leakage can be observed while the engine is being cranked.

NOTE: After the injector has passed all its tests, use a fine brass wire brush to clean the external deposits from the nozzle and nozzle holder. Retest and adjust the opening pressure before installing or storing the injector.

Disassembling the Injector If the injector has failed any of the tests, it must be disassembled, cleaned, examined, reassembled, and adjusted.

Injector servicing is simple, providing you follow the correct procedure and have the necessary equipment and facilities to do the job. A clean workbench is the first essential. Necessary equipment for this job includes a holding rack for the injectors, trays to hold the dismantled components, wash containers, a holding vise, tools for cleaning the components (Fig. 27-8), and an injector tester for readjusting the units after reassembly.

NOTE: Disassemble one injector at a time and place the components in a container filled with fuel. Nozzle bodies and needle valves are never interchangeable. They are lap-fitted as a unit.

First wash and brush off all external dirt and carbon from the injector. Place the injector in a holding fixture and dismantle the injector in the correct sequence (Fig. 27-1). Remove the cap nut and washer, the spring cap nut, spring seat, spring, and spindle, and place them in clean fuel. Place the injector in an upright position in the holding fixture. Remove the nozzle nut and nozzle assembly, and place them in clean fuel. Take care not to let the needle valve fall from the nozzle body since it is easily damaged.

To disassemble the injector shown in Fig. 27-2 or 27-15, place the injector in an upright position into the holding fixture. Remove the nozzle nut and, in sequence, the nozzle assembly, valve stop plate, spring seat, spring spacers, and shims from the holder.

CAUTION Never use hard or sharp tools, emery cloth, or other abrasive material to clean the nozzle-valve body or any part of the assembly.

Some service shops clean the disassembled injector in a 15 percent caustic soda solution, an air-agitated solvent tank, or in an ultrasonic cleaner. When the nozzle valve cannot easily be removed even after soaking in a carbon solvent, use a hydraulic nozzle-valve extracter. Apply hydraulic pressure from the nozzle test stand to force the nozzle valve out of the nozzle body.

First clean the needle valve with a brass wire brush and then use a soft brass tool to remove any remaining carbon from the needle tip or tip area. Next, clean the needle valve with mutton tallow placed on a soft cloth or felt pad and then check the valve for pitting and discoloration. Check the needle-valve seat. If it is excessively worn, the nozzle assembly must be replaced. If the valve seat has only disjoined seating areas, it may be serviced by regrinding. Nicks and scratches on the nozzle valve usually are attributable to poor fuel storage and handling practices and/or poor fuel-filter maintenance.

The nozzle body should first be cleaned externally with a soft brass brush and visually checked for discoloration and damage to the pressure face and spray holes. The pressure surface of the body that contacts the holder must be clean, and the surface must be lapped on a lapping plate. Check the lapping plate for nicks and burrs and if necessary refinish the lapping surface, then thoroughly clean the lapping plate. Apply tallow or jeweller's rouge evenly on the plate so that there is no danger of a dry surface contacting the nozzle body. Hold the body so that an even force will be exerted on the entire surface while moving the nozzle body smoothly and steadily in the form of a figure 8.

CAUTION Do not rock the nozzle body during lapping as this will produce an uneven surface.

Rinse the nozzle body thoroughly in clean diesel fuel. Inspect the lapped surface to ensure that it is smooth and without any elongation. Then use a drill or a wire to clean the internal fuel duct (Fig. 27-9). Use the special scraper tool provided to clean the fuel pressure chamber (cavity). Press the hook end of the tool hard against the side of the cavity and rotate it to free any carbon (Fig. 27-10). After selecting a suitable cleaning-tip size, clean the dome cavity as shown in Fig. 27-11. A bronze scraper should be used to remove any remaining dirt and carbon from the nozzle seat (Fig. 27-12). To clean carbon from the spray holes, use a hand (pin) vise and the correct

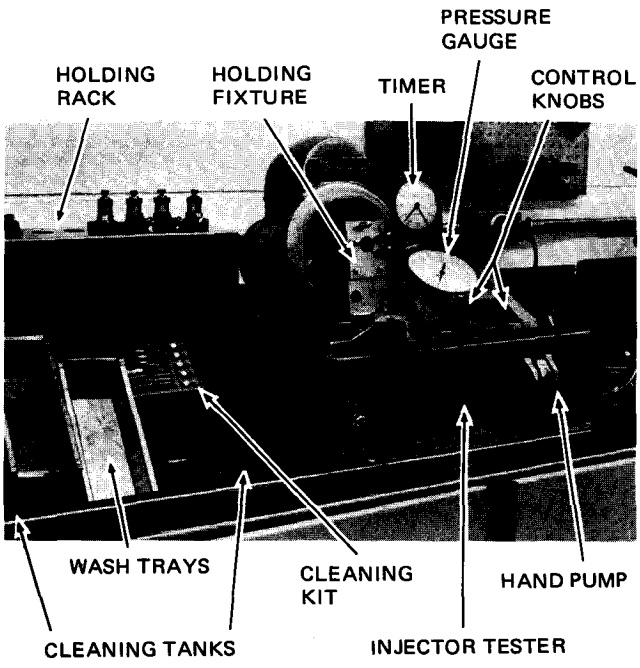


Fig. 27-8 Tools and test equipment needed to service an injector.

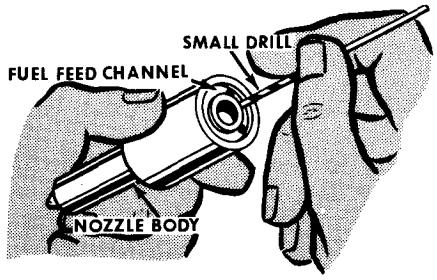


Fig. 27-9 Cleaning the fuel feed channel. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

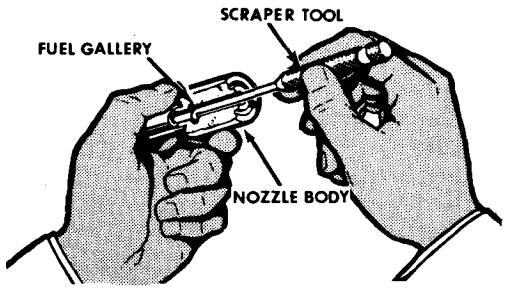


Fig. 27-10 Cleaning the fuel pressure chamber. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

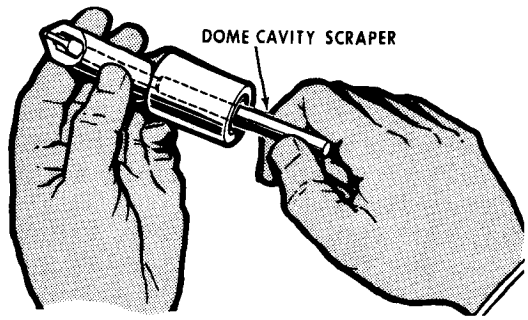


Fig. 27-11 Cleaning the dome cavity. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

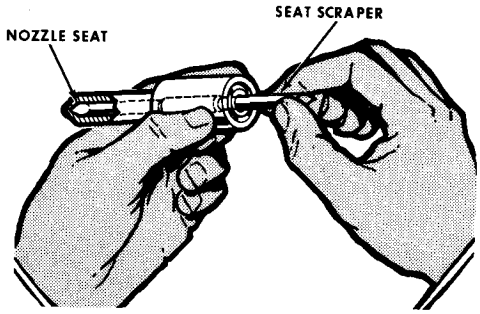


Fig. 27-12 Cleaning the nozzle seat. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

size wire (supplied with the cleaning kit). With an oil stone make the wire end round, grind off any burrs, and if necessary taper the end. Insert the wire in the hand vise allowing it to extend about ⅛ in [3.175 mm]. Take extreme care when cleaning the holes to gently rotate rather than push the wire through the hole (Fig. 27-13). Thoroughly rinse the valve and nozzle body in clean diesel fuel before you reassemble them.

A better cleaning method, however, is to utilize a nozzle-flushing device. Insert the nozzle and secure it in the flushing device and then mount it to the injector tester. Start pumping the test oil through the nozzle. The test oil will flow from outside the nozzle through the spray holes to the inside, flushing out the carbon particles.

To check freedom of the nozzle valve within the nozzle body, lift the needle valve about one-third of its length out of its body and hold the body at a 45° angle. The valve should slide onto its seat, as shown in Fig. 27-14. If the valve is sticky, clean it with mutton tallow or remove any varnish or carbon from the surfaces. If the valve continues to stick, the nozzle assembly must be replaced.

Checking Needle-valve Lift It is important that you measure the lift height of the nozzle valve to be sure it is within specification. If it is higher or lower, the liftoff time, the flow, the spray cone, and the pattern will be affected. To measure the needle lift height, place the spindle of the depth dial indicator against the upper shoulder of the nozzle valve. Zero the dial. Then place the spindle against the face of the nozzle body. The difference on the dial reading indicates the lift height of the nozzle valve. If it is greater than specified, you may lap the face of the nozzle body to bring the lift height to specification or replace the nozzle assembly.

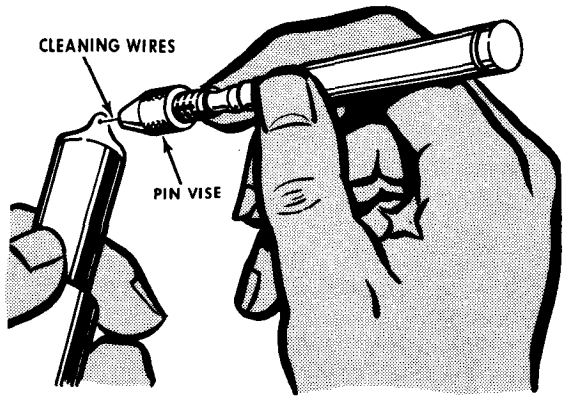


Fig. 27-13 Cleaning the spray hole. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

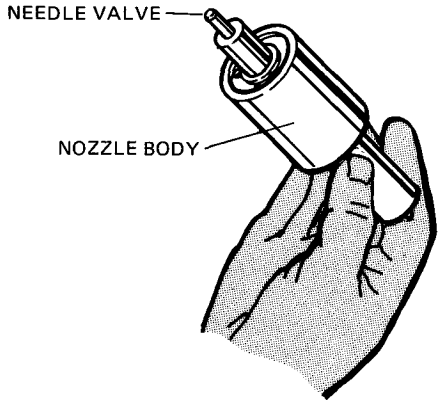


Fig. 27-14 Checking valve freeness. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

Holder Service Next, clean the external and internal surfaces of the remaining parts of the holder assembly. After cleaning, carefully inspect the holder. The pressure face must show no sign of erosion scoring or corrosion and the dowel pins and valve stop plate, if used, must be in good condition. If the surface is damaged, remove the dowel pins and lap the mating surface of the nozzle body and valve stop plate to a mirror surface finish. If the pressure spring is not damaged, measure its free height and compression. If either one is out of specification, the spring must be replaced.

NOTE: After using the lapping plates, wipe them clean and apply a protective coating of petroleum jelly to protect them against corrosion.

Reassembling the Injector After the final rinse (Fig. 27-1), position the nozzle holder in the holding fixture and place the nozzle assembly over the dowels (if dowels are used). Install the nut and, using a torque wrench, tighten the nut to the recommended torque. Remember that an overtorqued nut can cause distortion and nozzle-valve seizure. If it is too loose, metered fuel may be lost.

NOTE: Some manufacturers recommend placing a centering sleeve over the nozzle tip to ensure tip concentricity.

Turn the injector over and install the spindle, spring, upper spring plate, and spring cap nut fin-

gertight. Place a new gasket onto the spring cap nut and screw the cap nut onto the spring cap nut.

To reassemble the injector shown in Figs. 27-2 and 27-15, place the injector upside down in the holding fixture. Use petroleum jelly to glue together (in the following order) a spacer, shims, and a spacer, and insert the assembly into the holder bore. Place the spring and spring seat into the bore, place the valve stop plate and nozzle assembly onto the holder, and align the dowel pins. Apply petroleum jelly to the nozzle body flange and torque the nozzle retaining nut to the specification.

NOTE: When you do not lubricate the flange with petroleum jelly, the dowel pins could shear off when the nut is torqued and dislocate the nozzle orifices.

NOTE: With American Bosch and CAV pintle-type nozzles, use a centering sleeve before you tighten the nozzle nut to ensure proper alignment.

Testing and Adjusting the Injector The reassembled injector is now ready to be tested and adjusted. First, adjust the opening pressure to specification by using the adjusting screw or by removing or installing shims.

NOTE: A 0.001-in [0.25-mm] shim varies the opening pressure by about 55 psi [379.2 kPa].

As a general rule when new injector springs are used, the opening pressure should be set about 50 psi [344.7 kPa] higher than the specified opening pressure to allow for initial settling of the spring. Next, check or test in the following order: spray pattern and atomization, back leakage, and needle-valve-seat (forward) leakage. When the injector performs satisfactorily, remove it from the test stand and replace all protection caps.

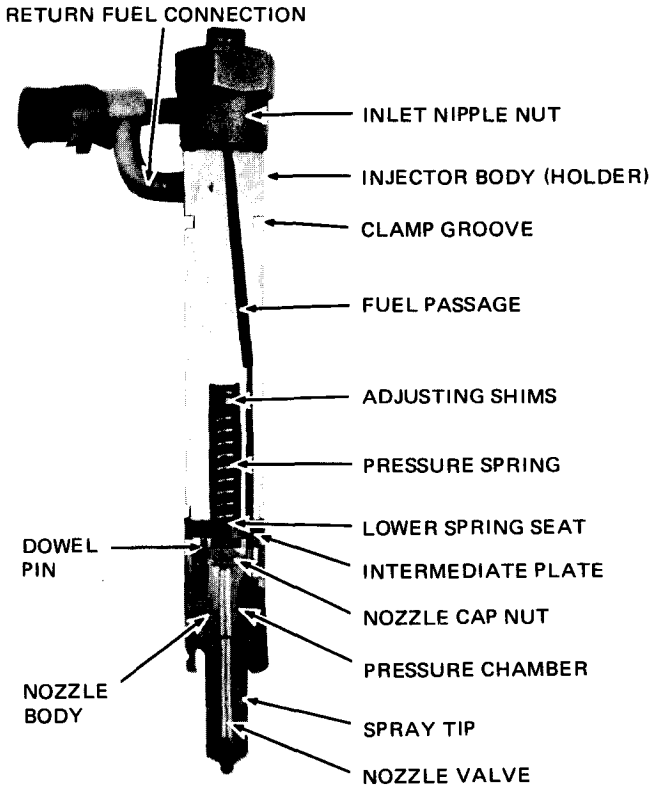


Fig. 27-15 Sectional view of an injector having a clamp-type nozzle holder and internal pressure adjustment. *(International Harvester Company.)*

Reconditioned Needle Valve and Nozzle Seat If the needle valve and the nozzle bore are not damaged but the seat leaks, or if the seats are corroded, the seats can be reconditioned. However, such reconditioning should be done by someone who is not only particularly skilled in this field but who also has the required special service tools. It is vital that the components be ground and lapped to precision.

Installing the Injector Regardless of the type of injector you are installing, the injector bore (recessed in the cylinder head) must first be cleaned thoroughly and the seating surface of the nozzle or nozzle nut made smooth. Use only the recommended reamer to clean the bore and the seating surface.

Turn the reamer in a clockwise direction only; otherwise it can be damaged. Apply a light coat of grease to the cutting flutes of the reamer so that the scraped-off carbon will cling to it and prevent carbon from entering the combustion chamber.

Clean all bores and then crank the engine over to blow out the remaining loose deposits. Remove the nozzle protection cap. Install a new gasket onto the nozzle or into the bore. *(NOTE: Be sure you have removed the old gasket if gaskets are used.)*

Install the injector into the bore and take care not to damage the nozzle tip. If the injector cannot be placed into the bore without applying force, then obviously all the carbon has not been removed.

Tighten the hold-down capscrews or nuts to the manufacturer's specified torque. When two hold-down capscrews or nuts are employed, use a torque wrench and tighten, alternately, first one and then the other, in three steps, to the specified torque.

When installing the injector shown in Fig. 27-4, secure the sealing gasket (using petroleum jelly) to the nozzle and insert the injector into the bore. Start the retaining nut into the threaded bore and finger-tighten it. Connect the leakoff lines loosely to the injector as this will align the injector. Now, with a 3/8-in open wrench hold the injector, and with a 7/8-in crowfoot wrench torque the retaining nut to specification.

When installing the injector shown in Fig. 27-3, also affix the gasket to the nozzle, and screw the puller screw onto the top of the injector. Install two new O rings into the holder body grooves, lubricate the O rings, and insert the injector into the bore. Align its pin with the notch in the bore and then, with a quick push, force the injector into position. To ensure the injector is correctly installed, that the gasket is not missing, and that two gaskets are not used, measure the distance from the top of the injector to the cylinder-head surface; it must be as specified. Next, torque the clamping nut to specification, install the nozzle fuel tube assembly and then torque the fuel-inlet tube-clamping nut and the seal nut to specification.

Remove the dust-protection cap from the high-pressure fuel lines. Pull the decompressor, crank the engine over to flush, and bleed the high-pressure fuel line. Remove the dust-protection cap from the injector and connect the high- and low-pressure fuel lines. Make certain that the connections are tightened to specification. Start the engine and check all the fuel lines for leakage. Check the injector for compression blowby past the nozzle or nozzle nut seat.

Stanadyne Diesel Systems—Pencil Nozzle The Stanadyne diesel systems' pencil nozzle is of the multihole differential pressure type (Fig. 27-16). The spray tip body and inlet fitting is permanently fastened to the nozzle body. The needle valve and the spindle are one unit. The valve is guided by the spray-tip body and by the closely fitted valve guide. The lower spring seat rests against the needle valve whereas the upper spring seat rests against the pressure-adjusting screw. The lift-adjusting screw, which varies in design, is threaded into the pressure-adjusting screw.

The inlet fittings vary in length as well as in configuration to suit the different engine applications. Two seals are used: a Teflon seal to prevent carbon accumulation in the cylinder-head bore, and a nylon seal to prevent loss of cylinder compression and prevent debris from entering the nozzle bore. The nozzle body is Teflon-coated from the carbon seal to the compression seal to prevent carbon buildup to the body and to facilitate removal and installation.

The operating principle of the Stanadyne diesel systems' pencil nozzle is the same as for the injectors previously discussed; however, the Stanadyne diesel systems' needle valve opens and closes more rapidly and, when being tested, a distinct chatter is noticeable. The leakoff fuel that passes through the closely controlled clearance of the valve and valve guide lubricates the upper half of the injector and returns through the leakoff connection to the tank. The lift of the needle valve is limited by the extension of the lift-adjusting screw. *(NOTE: Various types of leakoff boots are used, and when the injector is used with certain types of injection pumps, the end is capped and bleedoff fuel returns into the injection lines.)*

Removing a Stanadyne Diesel Systems' Injector It is essential to clean the areas around the injectors and fuel line before loosening the high-pressure fitting and to use one hand and two wrenches to prevent damaging the inlet connection or twisting the fuel line. After removing the clamp assembly, twist and pull the nozzle from its bore. If you cannot remove the injector easily by hand, use a nozzle puller designed for this purpose. *(NOTE: Never use other devices such as screwdrivers or pry-bars, because they may distort the nozzle body and the nozzle will then have to be replaced.)*

Testing Prior to Servicing A Stanadyne diesel systems' injector must also be tested prior to servicing according to the test procedure previously outlined.

When you perform the seat leakage test, a slight dampness after 10 seconds is permissible with used injectors. When you make the leakoff test, install the injector as shown in Fig. 27-17, then raise and maintain the pressure to 200 psi [1379 kPa] below the opening pressure. As soon as a leakoff drop appears at the return end of the injector, start counting the drops. When using 2D fuel at a temperature of 70°F [21.1°C], the leakoff should be 3 to 10 drops in 30 seconds. If the leakoff is higher, the nozzle must be replaced because there is excessive clearance between the valve guide and the needle valve.

Servicing a Stanadyne Diesel Systems' Pencil Nozzle Remove both seals. Take care not to damage the carbon dam groove or the Teflon coat-

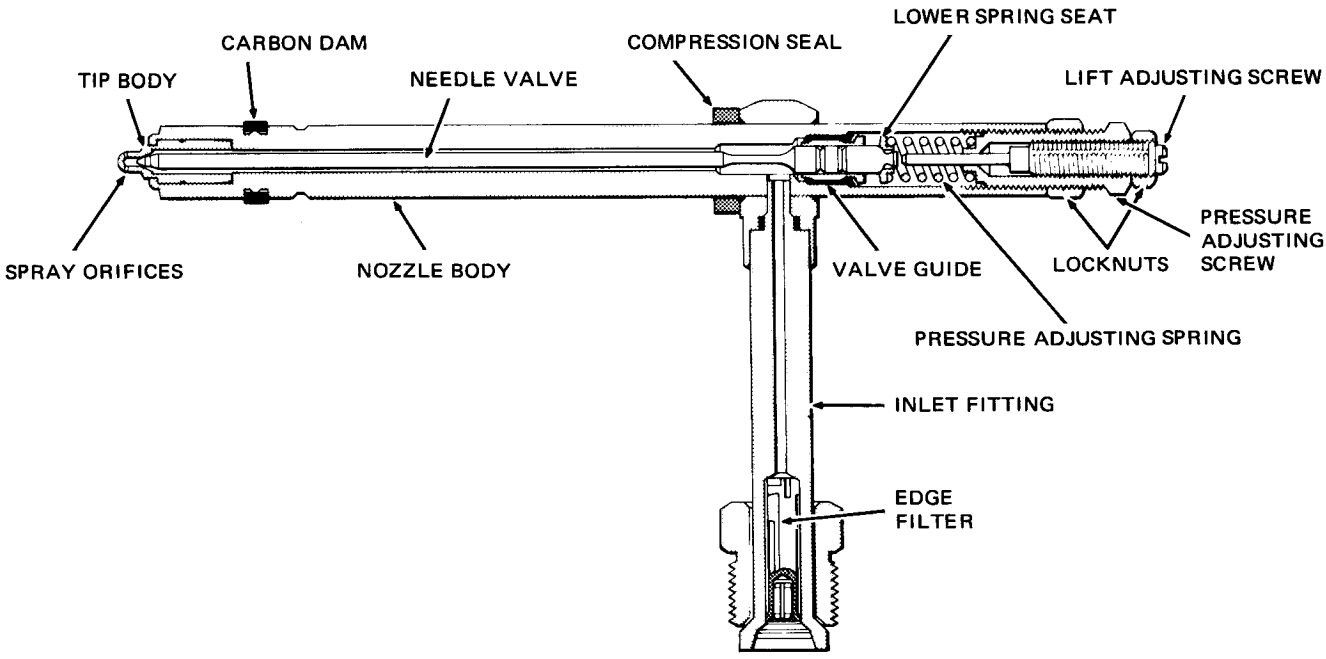


Fig. 27-16 Sectional view of a Stanadyne diesel systems' injector. *(Stanadyne Diesel Systems.)*

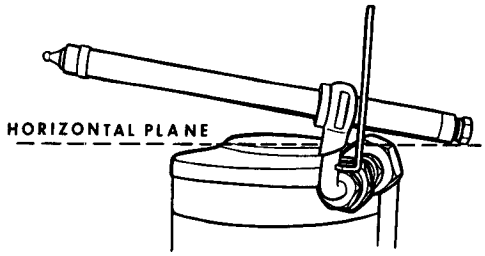


Fig. 27-17 Injector leakoff test. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

ing on the injector body. Clean the nozzle tip and inlet connection with a brass wire brush.

Mount the nozzle in the holding tool and loosen the lift- and pressure-adjusting locknuts. Then hold the nozzle in one hand, tilt it backward, and remove the pressure-adjusting screw, the lower spring seat, and the needle valve. *(NOTE: Some pencil nozzles have a ball washer and an upper spring seat.)* If the valve does not slide out, push the needle-valve retracter onto the valve, secure it to the valve by turning the knurled nut, and pull the valve from the body.

The cleaning procedure and methods are the same as previously outlined under Disassembling the Injector and Cleaning and Inspecting the Injectors. If cleaning does not restore the needle-valve seat, the valve may have to be serviced by lapping it to the tip seat (nozzle seat). Excessive lapping, however, will destroy the interference angle, causing a loss of chatter and poor atomization.

To lap the seat, install the retracting tool to the needle valve and apply a moderate amount of the recommended lapping compound to the seat. Insert the valve and rotate it a maximum of three times clockwise, and then a maximum of three times counterclockwise, applying gentle pressure on the valve. Do not use power apparatus to lap the seat. Always handle the valve with care because it is easily bent.

If testing indicates that the leakoff is too low, clean the valve guide thoroughly and, if necessary, also lap the guide and needle valve to increase the leakoff. If the leakoff is too high, replace with the next oversize needle valve and lap it to the valve guide. *(NOTE: The needle-valve size is codified on the inlet fitting. Replacement needle valves come in increments of 20 millionths of an inch.)*

Reassembling a Stanadyne Diesel Systems' Pencil Nozzle Before being reassembled, the components must be thoroughly flushed clean. Reassemble the nozzle in precisely the reverse order to which it was disassembled.

CAUTION Take care not to dislodge the lower spring seat during reassembly. Turn the pressure adjusting screw sufficiently inward to hold the components in place (Fig. 27-18).

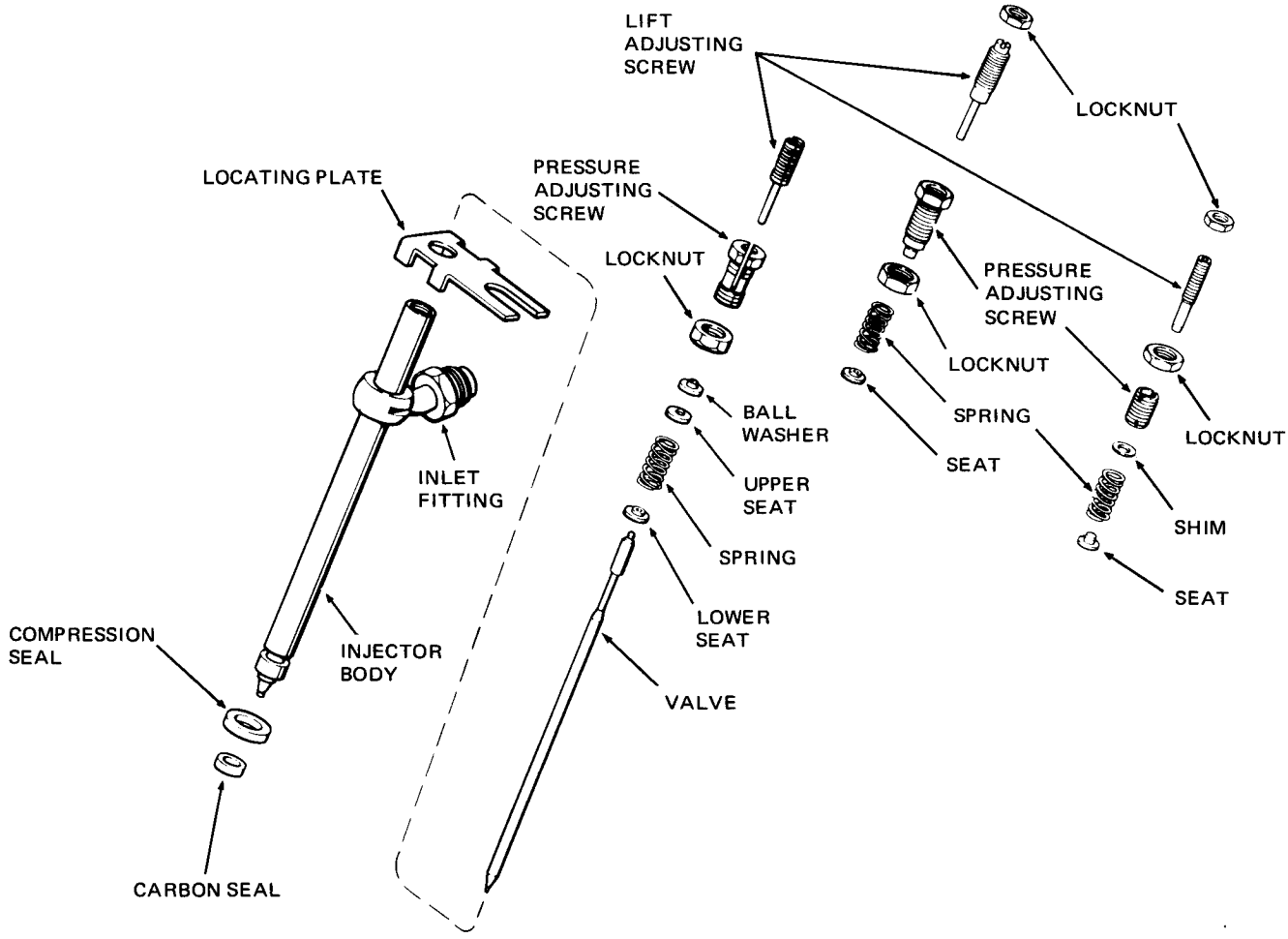


Fig. 27-18 Exploded view of injector components with three types of pressure and lift adjusting components.

Testing and Adjusting Pencil Nozzle After the air is removed from the injector, adjust the opening pressure. This adjustment is made by turning the lift adjusting screw inward until it bottoms, then giving it two turns counterclockwise. Using the test-stand pump, raise the pressure and check the opening pressure. If an adjustment is necessary, hold the lift adjusting screw with a screwdriver while turning the pressure adjusting screw clockwise to increase, counterclockwise to decrease, the opening pressure. When the opening pressure is adjusted, place the nozzle in the holding fixture and torque the locknut to specification while holding the pressure adjusting screw stationary.

SETTING VALVE LIFT To set the valve lift, reconnect the injector to the test stand and turn the lift adjusting screw slowly inward as you pump fuel through the injector until the valve ceases to open. Raise the pressure to about 400 psi [2758 kPa] above the opening pressure to check the valve seating. (Some dampness on the tip is acceptable, but the formation of droplets or dribbles is not acceptable.)

Next, turn the lift screw the specified number of turns, counterclockwise, to obtain the specified lift height. Always recheck the opening pressure. After the opening pressure and lift height have been adjusted, check the spray pattern, chatter, and leakoff.

When the nozzle has passed these tests, remove it from the test stand and place a protection cap over the nozzle tip. Insert it in the nozzle holding tool and torque the lift adjusting screw locknut to the specified torque, as shown in Fig. 27-19.

Installing the Pencil Nozzle Clean the cylinder bore with the bore-cleaning tool. Clean and check the sealing surface of the cylinder head. Install the compression seal and with a carbon seal tool install the carbon seal.

When you install the nozzle, use a turning or twisting motion to place it in position but do not use any lubricant. Install the spacer and clamp assembly, and torque the hex bolt to 20 ft·lb [27.12 N·m]. Use one hand and two wrenches to tighten the high-pressure connection.

FUEL-INJECTION TUBING AND CONNECTIONS

The injection tubings used to connect the fuel-injection pump with the injectors are cold-drawn from low-carbon steel billets, then pierced to remove all internal surface defects. They are afterwards annealed to prevent formation of scale and to produce an accurate size having a smooth inside surface with no inside or outside surface imperfection. Other important characteristics necessary to fuel-injection tubings are:

1. They must have a tensile strength of 45,000 to 55,000 psi [310,275 to 379,225 kPa] to assure that the tubing will not expand under the high injection pressure.
2. They must be capable of being easily shaped to a small bend radius without causing flow restriction.

As indicated in Table 27-1, the basic outside diameter is ¼ in [6.35 mm]. However, 5/16 in [7.938 mm], ⅜ in [9.525 mm], 7/16 in [11.113 mm], and ½ in [12.7 mm] are also used.

The inside diameter varies and is identifiable by a color code to suit the various injection pressures and fuel flow.

NOTE: Use extreme caution when bending the injection tubing. Use only a mechanical tube bender to prevent flat spots or kinks. Do not make a bend radius of less than 1 in [25.4 mm].

Fuel-injection-line Connections The four most common fuel tubing connections are shown in Fig. 27-20. *(a)* and *(b)* show the swaged-tapered-seat type. This connection consists of an upset tapered male seat formed on the end of the tubing itself, or the swaged tapered seat is formed and then brazed to the end of the tubing. The nut compresses the seat against the mating seat in the fuel-pump discharge

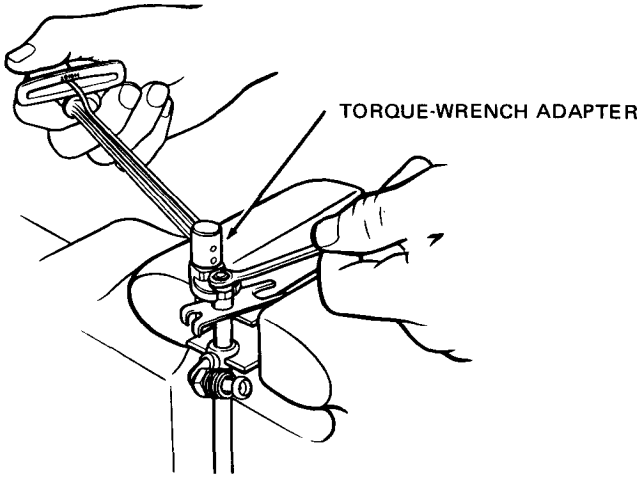


Fig. 27-19 Tightening the locknut. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

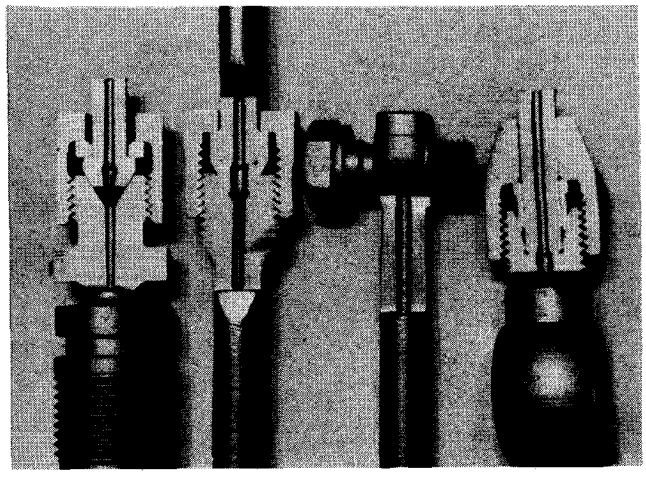


Fig. 27-20 Cutaway view of fuel-injection-line connections.

TABLE 27-1

FUEL-INJECTION TUBING IDENTIFICATION

Nominal tubing OD, in	Outside diameter, in					Inside diameter, in			Color code for basic ID
	Basic	Tolerance				Basic	Tolerance		
		Standard		Optional			Standard	Optional	
		Plus	Minus	Plus	Minus		±	±	
¼	0.250	0.005	0.000	0.002	0.000	0.063	0.0025	0.001	Red
	0.250	0.005	0.000	0.002	0.000	0.067	0.0025	0.001	Black
	0.250	0.005	0.000	0.002	0.000	0.078	0.0025	0.001	Yellow
	0.250	0.005	0.000	0.002	0.000	0.084	0.0025	0.001	Blue
	0.250	0.005	0.000	0.002	0.000	0.093	0.0025	0.001	White

Note: In this chart, the color code identifies the basic tubing ID. The color code shall be applied the OD of the tubing in the form of an intermittent stripe (gaps not longer than 12 in), using Dykem dye or other suitable marking material. See Conversion Tables for metric equivalents of English tube sizes.

fitting or nozzle-inlet fitting. The style shown in Fig. 27-20*a* has a collar and a short tapered seat. Some have an extended collar and nut to support the tubing beyond the end of the nut.

The ferrule-type connector shown in Fig. 27-20*c* consists of a loose ferrule which is slipped over the tubing. It is compressed by the nut into the seat formed by the fuel-pump discharge fitting or nozzle-inlet fitting and the tubing, causing the ends of the ferrule to bite into the tube wall.

NOTE: When installing the ferrule type of connection, make sure that the tubing butts against the fitting counterbore and that it is held there until the nut is drawn up tight.

The tube connection shown in Fig. 27-20*d* is of the flared type. This style consists of a flared union formed on the end of the tubing, an inlet union screw, and two copper or special-alloy gaskets. The inlet union screw threads into the threads of the fuel-pump discharge fitting or the nozzle-inlet fitting. On one side it compresses the gasket against its shoulder and against the surface of the inlet union. On the other side it compresses the gasket against the surface of the inlet union and the fuel-pump discharge fitting or the nozzle-inlet fitting.

The same type styled with the inlet union brazed to the supply tubing is used as a fuel-supply connection.

NOTE: When you use the flared style, make certain that you use a new gasket of the specified material. Use a torque wrench to draw the union screw to specification.

Questions

1. What factors determine the type of injector holder and injector nozzle to be used?
2. Name the four most common fuel nozzles.
3. Why does the needle lift differ between various types of nozzles?
4. Why do all needle-valve nozzles chatter to some extent?
5. What changes would occur in the spray pattern if the needle lift were greater than specified?
6. What are the main differences between an inward-opening and an outward-opening pintle nozzle?
7. Outline the steps to remove an injector.
8. Why should an injector be tested before it is disassembled?
9. In what way does a needle valve indicate that one or more orifices are clogged?
10. How would spray pattern and combustion be affected if the lapped surface of the nozzle and holder were nicked or burred?
11. List the main differences between the injector shown in Fig. 27-1 and a Stanadyne diesel systems' pencil nozzle.
12. Why should only a hammer puller be used to remove a Stanadyne diesel systems' pencil nozzle?
13. When servicing a Stanadyne diesel systems' pencil nozzle, what tests and adjustments must be made in addition to those required when servicing a CAV or Bosch injector?
14. When removing or installing a high-pressure injection line from a pencil nozzle, why should you use the "one-hand, two-wrench" method to tighten and loosen the fittings?

UNIT 28 • INTRODUCTION TO FUEL-INJECTION SYSTEMS

Fuel-injection System Components The fuel-injection system (of any design) is the heart of a diesel engine and, therefore, in many ways controls its performance. Fuel-injection systems (see Fig. 28-1) may be classified into two separate systems: (1) the low-pressure fuel-supply system, and (2) the metering-injection system. All fuel-supply systems use the same components although the components vary in size and location within the system.

A low-pressure system consists of one or more fuel tanks, a transfer pump (feed pump), fuel filters, hand priming pump, overflow valve, and, in some cases, a return orifice.

The fuel tank, the importance of which is often overlooked, must be well designed to perform all its intended functions. It must not only store and cool the fuel but must also act as a settling tank. Furthermore it must have: (1) baffles to strengthen the structure and to prevent the fuel from splashing back and forth, (2) a settling bowl and drain valve to remove contaminants, (3) an outlet screen to remove relatively large foreign particles as the fuel leaves the fuel tank, (4) an inlet screen to prevent relatively large contaminants from entering the fuel tank when filling the fuel tank, (5) a filler cap with a built-in internal air filter, or one screwed to the tank, so that only clean air can enter the fuel tank, (6) a return line, so located that it is always in the fuel and thus prevents aeration and warm fuel from instantly mixing with the cooler fuel, and (7) a shutoff valve to prevent fuel from leaving the tank when the injection system is being serviced.

The purpose of the transfer pump is to supply fuel under pressure to the fuel-injection pump (unit injectors, fuel pump, and injectors). On some fuel-injection systems it has a second purpose, that is, to lubricate and cool the components. There are four types of transfer pumps: two positive displacement types (external gear pumps and vane pumps), and two non-positive displacement pumps (displacement-piston-type and diaphragm-type pumps).

The purpose of the fuel filters is to remove very fine contaminants and water from the fuel as it passes through the filter elements.

The hand primer is a piston-type pump. It is used to pump fuel into the system, so as to remove the entrapped air (system bleeding).

The overflow valve is a spring-loaded check valve which maintains the required low pressure. When a restriction orifice is placed in the return line, the orifice serves the same purpose as the overflow valve.

Low-pressure Fuel Flow To bleed the low-pressure system, that is, to remove the entrapped air, first open the bleed valve, unlock the hand primer, and

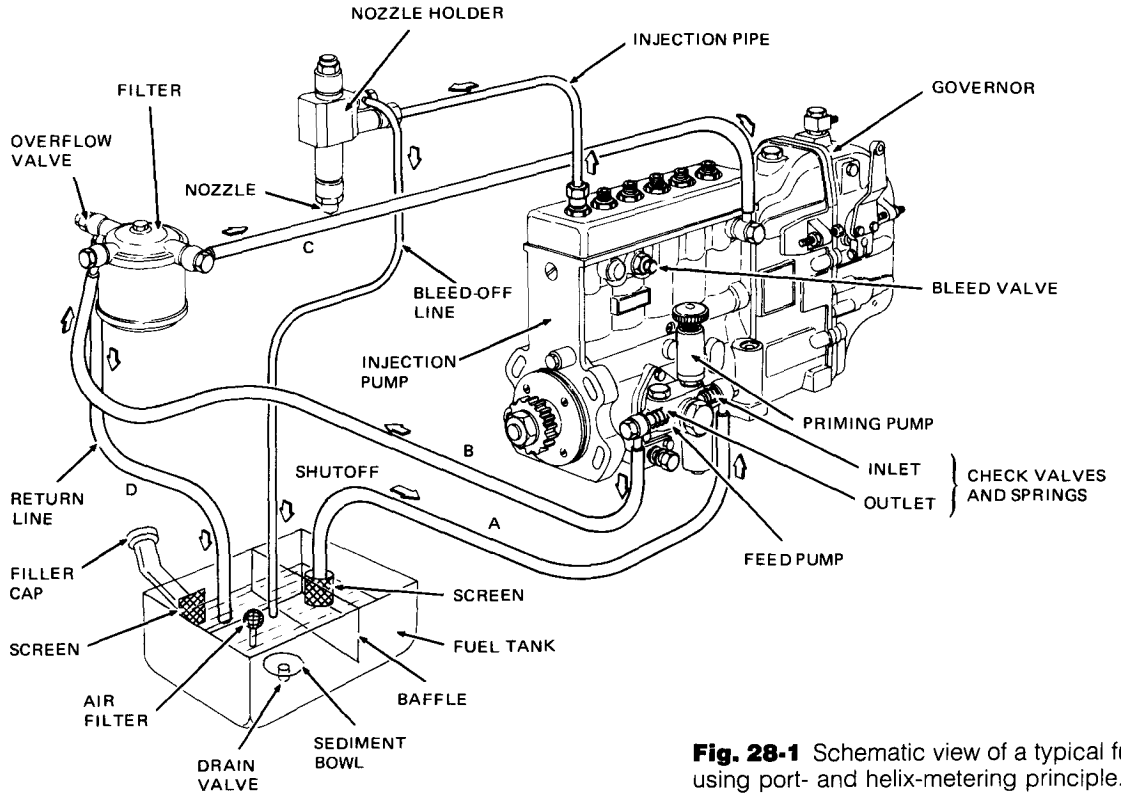


Fig. 28-1 Schematic view of a typical fuel-injection system using port- and helix-metering principle.

move its knob up and down. On the upstroke, the priming piston reduces the pressure below atmospheric pressure, and the atmospheric pressure forces the fuel from the fuel tank into line A, (Fig. 28-1), past the inlet check valve into the transfer pump. As the pressures in the fuel line and transfer pump equalize, the inlet check-valve spring seats the check valve. On the downstroke fuel and air are forced past the outlet check valve, into line B, and the air can escape from the bleed valve. The check-valve spring closes the check valve as the pressures within the transfer pump and line B equalize. After repeated priming-piston movement, the fuel filter fills with fuel and air which may leave the bleed valve. When only fuel leaves the bleed valve, close it and lock the hand priming piston; the injection-pump fuel manifold is then filled with fuel.

When the engine is operating, the fuel flow is the same as outlined above but the transfer pump now creates the fuel flow. To provide the low-pressure system with a specific fuel pressure (ranging from 20 to 35 psi [137.9 to 241.3 kPa]), the overflow (relief) valve positioned in the return line floats between its open and closed positions to maintain the fuel pressure. When a positive-type transfer pump is used, an additional (pressure-relief) valve is used to protect the transfer pump from damage in the event of overflow valve malfunction.

Metering and Injection Systems There are many types of metering and injection systems available. They consist primarily of the injection pump and the injector, and are generally categorized as fuel-injection systems using: (1) fuel-injection pumps of the port and helix metering principle, from Robert Bosch, American Bosch, Caterpillar, CAV., etc.; (2) unit injectors such as those used on Detroit Diesel and Caterpillar diesel engines; (3) PT pressure-time (controlled bypass) metering principle, used on Cummins diesel engines; (4) fuel-injection pumps of the opposed-plunger inlet-metering, distributor-type metering principle, from Stanadyne diesel systems and DPA; (5) and sleeve-metering fuel-injection pumps from American Bosch and Caterpillar.

Units 29 through 36 cover the operating principles, service, and adjustments of each of the above metering and injection systems.

Although the principles of the five metering and injection systems differ, they each have common objectives: (1) to meter the quantity of fuel required by the engine at all loads and speeds, and to equalize the fuel quantity delivered to each engine cylinder to ensure equal power, (2) to start injection at the appropriate time within the cycle of the engine in regard to load and speed, (3) to ensure quick beginning and ending of injection so that the injected fuel is evenly atomized, (4) to inject the fuel at the rate necessary to control combustion and to control the pressure during combustion, and (5) to direct, distribute, and atomize the fuel uniformly, as required by the combustion chamber design.

To apprise you of the uncompromising engineering accuracy required of fuel-injection system componentry, consider a six-cylinder, four-cycle diesel engine running at full load, 2300 rpm, using 4½ gallons (U.S.)/hour (gal (U.S.)/h) [17.03 liters/hour (L/h)] of fuel. Its fuel supply system must provide a fuel flow of about 9 gal (U.S.)/h [34.0 L/h] to the injection pump, unit injectors, or injectors (Cummins). This would entail 6900 fuel injections per minute, or 414,000 fuel injections per hour. A quantity of 4½ gal (U.S.) would have to be divided (metered) into 414,000 portions and then sprayed, at a precise time, into each cylinder, against the high pressure existing within the cylinder. A minute quantity, that is, in this case 0.041 cm^3, must be metered within the time in which the crankshaft rotates approximately 600°. At this engine speed, that would be within 0.043 second. Furthermore, this quantity must be injected within a specific time, which, on the average diesel engine, is about 15° of crankshaft rotation, or in other words, 0.001 second. Of course, at low idle the quantity would be much smaller, about 0.008 cm^3, and the time factor for metering and injection would be increased to 0.152 second.

It is apparent from the foregoing that fuel-injection systems are highly specialized and sophisticated to meet such unique requirements. Moreover, they are technologically designed to last the lifetime of the engine, presuming the system is well maintained.

UNIT 29 • AMERICAN BOSCH, ROBERT BOSCH, AND CAV PORT AND HELIX FUEL-INJECTION PUMPS

One of the first principles on which fuel-injection pump metering was based is the port- and helix-metering principle and it still applies to most of today's fuel-injection pumps. Its injection pumps are of the constant-stroke, lapped-plunger, and port- and helix-metering design. They are manufactured not only by the companies listed above, but by many others. The differences which exist among fuel-injection pumps are minor in degree and generally lie in their pumping elements, governor construction, and the manner in which they are adjusted. They range in design from a single pumping element (barrel and

plunger) with or without a camshaft or governor to a fuel-injection pump having 12 pumping elements in one housing, or V shape in design with four pumping elements in each bank.

Fuel-injection-pump Identification The fuel-injection pumps and governors are identified by an identification plate fastened to their housings. The identification plate describes precisely fuel-injection-pump and governor internal design so that the mechanic may correctly select the replacement parts and correctly reassemble, test, and adjust the injection pump. An example of a fuel-injector-pump identification plate is given below; however, note that not all fuel-injection manufacturers use the same letter-numbering system or follow the same sequence.

	NAME OF MANUFACTURER
line 1	123 456789
line 2	PE(S)6P D120/420 LS 152
line 3	123 456 789

The first three digits of line 1 are coded to the year and month in which the injection pump was manufactured and the remaining digits indicate the injection-pump serial number. In regard to line two, letters and numbers mean the following:

P		Description of pump (P Robert Bosch A—Am. Bosch pump; S—CAV pump; and NP—Kiki pump).
E		Has a camshaft and is base-mounted.
(S)		Flanged-mounted.
6		Number of pumping elements.
P		Basic size, plunger lift 10 mm, diameter 10 mm.
D		Designates (model) modification of previous model.
120		Diameter of plunger in tenths of a millimeter (12 mm).
(*1*)	4	Placement of camshaft notch, and camshaft location.
(*2*)	2	Location of governor.
(*3*)	0	No automatic timing device.
(*4*)	L	Left-hand pump rotation.
S 1 5 2		Design-change letter modification for a specific application, e.g., delivery-valve retraction volume and lift, drive side rotation, and additional modification.

(*1*) 1: Notch at the left, without feed pump
2: Notch at the right, without feed pump
3: Notch at the left, with feed pump
4: Notch at the right, with feed pump
5: Notch at the left, with two feed pumps
6: Notch at the right, with two feed pumps
7: Notch at the left, with feed pump mounted on the back of the pump
8: Notch at the right, with feed pump mounted on the back of the pump
9: Notch at the left, with two feed pumps mounted on the back of the pump
10: Notch at the right, with two feed pumps mounted on the back of the pump

(*2*) Location of governor 0: without governor
1: governor at the left side
2: governor at the right side

(*3*) Automatic timing device 0: without timing device
1: timing device on the left side
2: timing device on the right side

(*4*) Pump rotation (viewed from the drive side)
R: clockwise rotation
L: counterclockwise rotation

NOTE: Left and right are determined when viewing onto the identification plate.

The third line on the identification plate is the manufacturer's computer number and has no bearing on pump identification.

Governor Identification An example of a governor identification plate is shown below:

MANUFACTURER'S NAME
123 4567
RQV 300- 1025PA- 112KR

The first 7 or 8 numbers of the second line are the engine manufacturer's governor number. Letters and numbers on the third line mean the following:

R	Centrifugal-type governor
Q	Floating-lever ratio change
V	Variable-speed governor
300	Low-idle pump rpm
1025	High-idle pump rpm
P	Size of injection pump
A	Design number
112	Application number
KR	Torque control type of governor

Single-cylinder Fuel-injection Pumps Single-cylinder fuel-injection pumps are designed to meter the fuel for each cylinder, individually. The engine could be a 1- to a 24-cylinder design and range in horsepower from 4 to 1500 hp per cylinder with a plunger diameter variation from 5 to 30 mm. Single-cylinder injection pumps are identified by the letter "F" (APF, PF, SF, NP-PF). APF is the identification for an American Bosch flange-type mounted individual fuel-injection pump without a camshaft (Fig. 29-1). The fuel pump camshaft and governor form part of the engine. However, regardless of the number of pumping elements used, or whether or not the pump has a built-in camshaft, the components which make up a fuel-injection pump are basically the same and serve the same purpose. Each injection pump must include the following components:

- A housing to hold and support the components
- A fuel-inlet connection to connect the transfer pump with the injection pump

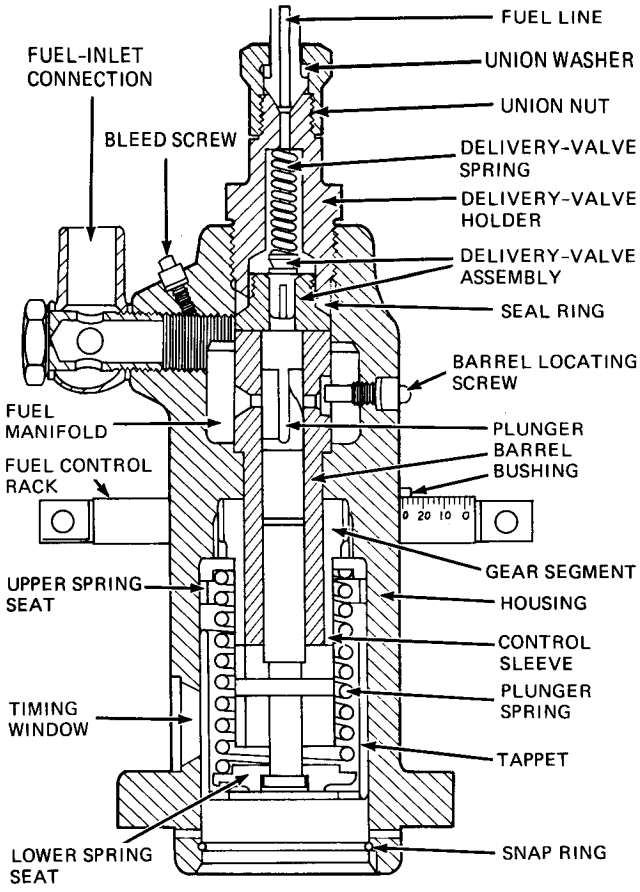


Fig. 29-1 Schematic view of an APF fuel-injection pump. *(American Bosch, United Technologies Automotive Group.)*

- A fuel manifold to connect (the manifold) with the barrel ports
- A bleed screw to remove air from the inlet manifold
- A pumping and metering element (plunger-and-barrel assembly) to meter and deliver the fuel
- A barrel-locating screw or dowel pin to locate the barrel in the bore of the pump housing and to act as a fuel deflector for the high-return fuel pressure
- A delivery-valve assembly to assist in the beginning and ending of injection
- A delivery-valve spring to hold the valve on its seat and to assist in maintaining residual pressure in the injection line
- A delivery-valve holder to connect the high-pressure fuel line to the pump and to hold the pump element and delivery valve in the pump housing
- A union washer and nut to connect the fuel line
- A gear segment which is bolted to the control sleeve to convert the linear motion of the fuel rack to the rotary motion of the plunger
- A control sleeve to transmit control-rack motion to the plunger
- A control rack (fuel rack) to transmit governor motion to the gear segment
- A control-rack bushing to reduce friction
- A plunger spring positioned between the two spring seats to maintain the plunger on the tappet and the tappet roller on the camshaft
- Two spring seats to maintain spring-end position and alignment
- A tappet (follower) to transmit rotary motion from the camshaft and reciprocating motion to the plunger (the lower spring seat is hooked to the plunger)
- A snap ring to hold the tappet in the pump housing
- A high-pressure fuel line to connect the injection pump with the injector
- A timing window to time the injection pump to the engine
- A screw to limit the control-rack travel (not visible in Fig. 29-1)

Multicylinder Fuel-injection Pumps (PE) Almost 85 percent of the 1.5 million port and helix fuel-injection pumps produced in 1981 by fuel-injection-pump manufacturers (worldwide) are of the enclosed camshaft design, and almost all have the governor directly bolted to the fuel-injection-pump housing. To identify multicylinder fuel-injection pumps the letter "E" is used (Fig. 29-2).

The components in the upper portion of a PE fuel-injection pump are similar to those in the PF fuel-injection pump; however, a bleed valve is usually added to bleed the air from the fuel manifold, and an inspection cover is fastened to one side or on the bottom of the housing. Its purpose is to give access to the tappet adjusting screws or to the camshaft.

The camshaft is located in the lower portion of the

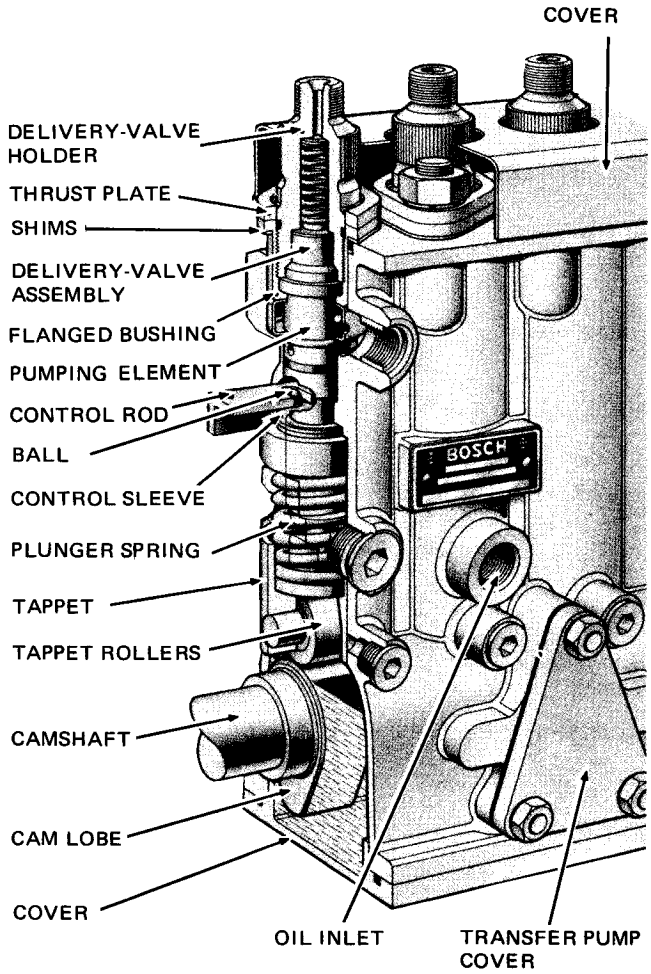


Fig. 29-2 Sectional view of a PES6P fuel-injection pump. *(International Harvester Company.)*

fuel-injection-pump housing. Its purpose is to transmit rotary motion to the tappets. It is supported on both ends by tapered roller bearings. Injection pumps having six or more pumping elements use a center bearing consisting of split bushings to support the camshaft in the center.

The tappet assembly reduces friction and transmits up and down motion to the plunger, and its adjusting screw or spacer is used to adjust the plunger height. This assembly consists of the tappet body, inner and outer rollers, tappet pin, adjusting screw and locknut, or an adjusting spacer (Fig. 29-3).

A machined surface on the lower housing provides the mounting pads for the transfer pump. Threaded bores in the housing provide access for adjustment and disassembly. Two bores are used to connect the inlet and drain oil hoses.

The governor is bolted to the injection-pump housing and its output lever or arm is connected to the fuel rack.

Other major differences between the injection pumps lie in the governor design and its adjustment, the method used to transmit the motion from the fuel rack to the plunger, the method of fuel adjustment, the helix design of the plunger, and the method of plunger height adjustment (Fig. 29-4).

Pumping Element Design The function of a pumping element is to meter and deliver the metered fuel to the injector. The plunger motion within the barrel is dual: a rotary motion which regulates (meters) the quantity of fuel, and an upward motion which delivers the metered quantity of fuel (pumping). The aforementioned plunger motions are described in detail under the headings Pumping Principle Using Lower Helix, Pumping Principle Using Upper Helix and Upper and Lower Helix, and Metering Principle later in this unit.

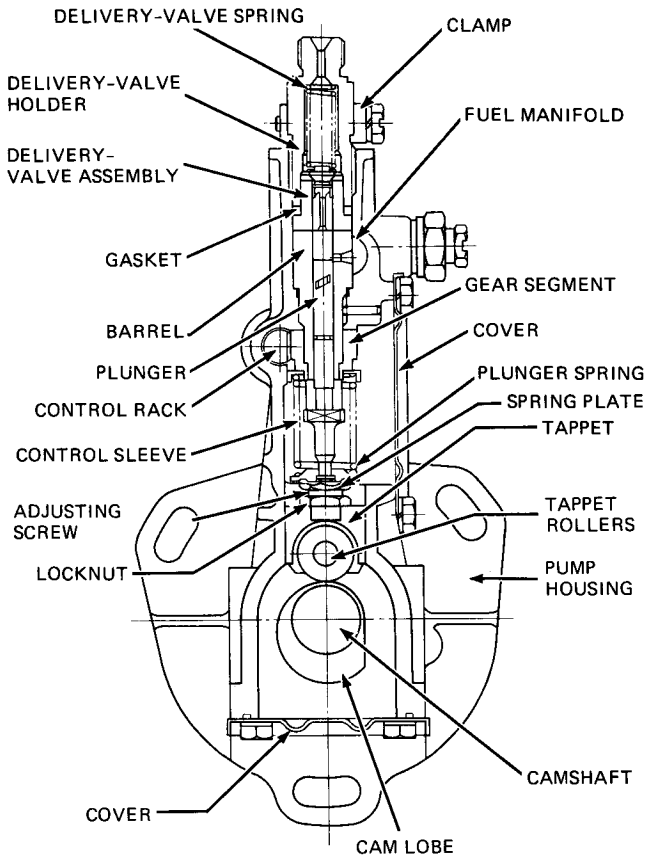


Fig. 29-3 Schematic view of a PES8A fuel-injection pump. *(Allis-Chalmers Corp. Engine Division.)*

Each pumping element consists of a barrel and a plunger (see Figs. 29-1 to 29-4). The plunger is lapfitted to the barrel within very close tolerance (a few thousandths of a millimeter), so that the fuel, at high or low pressure, lubricates the pumping element but prevents leakage to the lower side of the barrel. The barrel shoulder rests against the counterbore in the pump housing or in the housing flange. The barrel usually has two round openings, the inlet port and the spill port, to allow fuel to enter the area above the plunger when the assembly is mounted in the pump housing and the plunger is on the camshaft-lobe base circle. The spill port on some barrels is recessed to form a slot which serves to locate the barrel in the housing by means of a deflector screw, or the pin in the housing flange aligns the barrel. On some barrels the spill and fill ports are at different heights, as shown in Fig. 29-5. Other barrels have only one port to the fuel manifold. Still other barrels have an internal passage from the lubrication groove to the inlet port to allow the fuel used for lubricating the pumping element to return to the fuel manifold. Some have a gear segment pinned to the plunger.

The upper part of the plunger has a vertical (no-fuel) and a horizontal pressure-compensating machined-out groove and, depending on the objective for which it is designed, has one or two spiral machined-out grooves called the *helix* or *helices*. The shape and the position of the helix govern the fuel delivery curve, the beginning or the ending of injection, or both beginning and ending of injection.

The plungers shown in Fig. 29-6 are of the lower-helix design. Their beginning of delivery is constant and their ending of delivery is variable. The right-hand helix is used when the governor is at the right-hand side, or the fuel rack is behind the plunger (viewing onto the identification plate). The left-hand helix is used when the governor is on the left-hand side or when the fuel rack is in front of the plunger.

The plungers shown in Fig. 29-7 are of the upper-helix design. Their beginning of delivery is variable and the ending of delivery is constant. The plungers shown in Fig. 29-8 have an upper helix and a lower helix; therefore both the beginning and the ending of delivery are variable.

Smaller plungers in the range of 5 to 10 mm in diameter, and of the constant beginning and variable ending design, have a diagonally cut groove instead of a curved helix. To provide spill, each plunger is either center- or cross-drilled or has a no-fuel groove (see Fig. 29-5*a*).

On the lower part of some plungers are two flanges (rack control boss) which slide in the control sleeve. Others have either a lever arm or the gear segment is pinned to the plunger to link the control (fuel) rack with the plungers.

To improve the starting ability of diesel engines, the more recently designed fuel-injection pumps using plungers have a starting notch (groove) on top of the plunger. The starting groove provides, on the av-

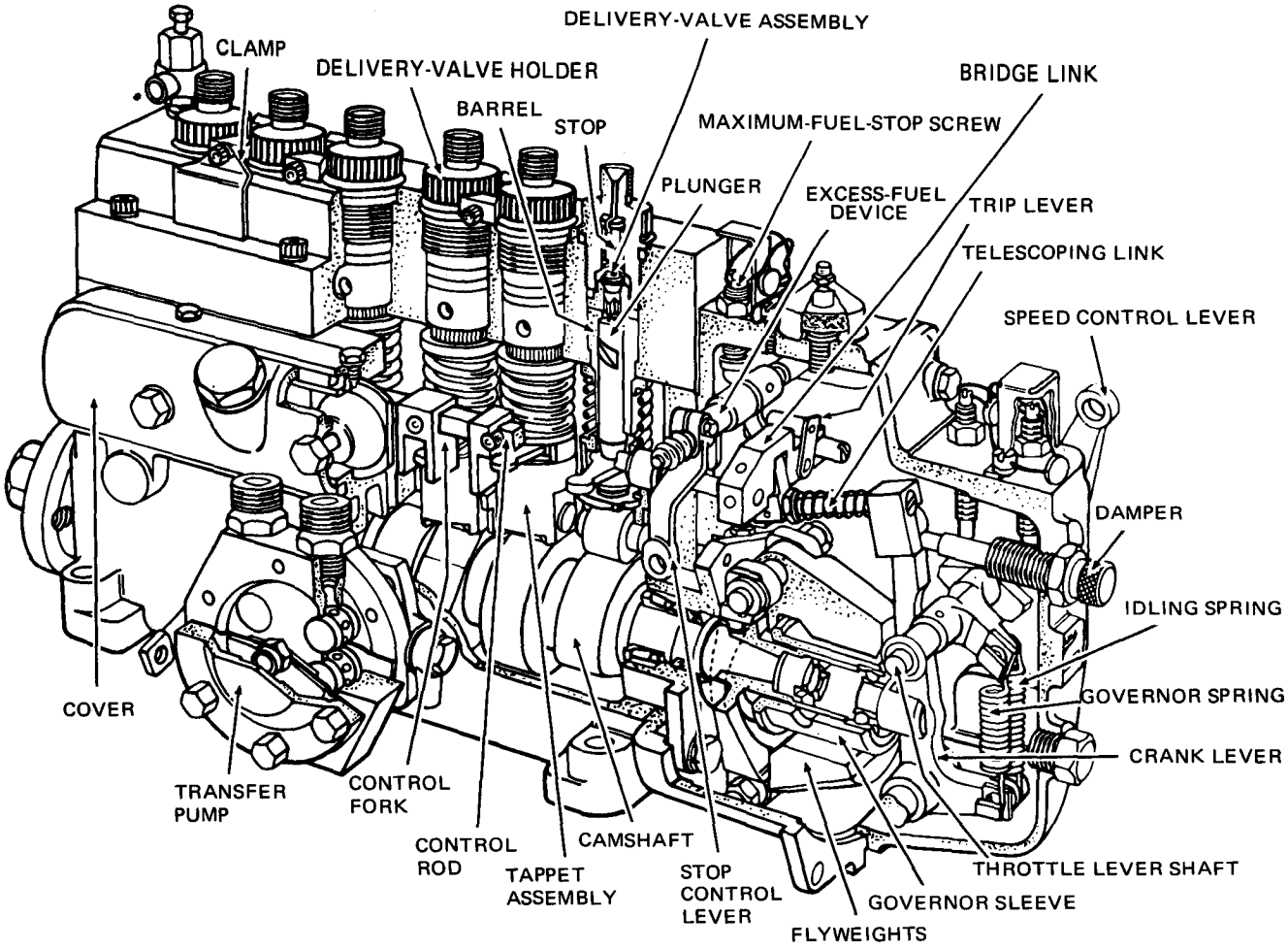


Fig. 29-4 Schematic view of an SPE Majormec fuel-injection pump. *(CAV Limited.)*

erage, about 20 percent more fuel to each injector than is used at maximum torque speed, and a retardation of injection, on the average, of about 10°. For a specific engine example see Fig. 29-9: The plunger starting groove is 2.69 mm deep, which causes a retardation of 9°, and the effective stroke is 5.2 mm, which provides 0.13 cm^3 of fuel to each injector while attempting to start the engine and when operating

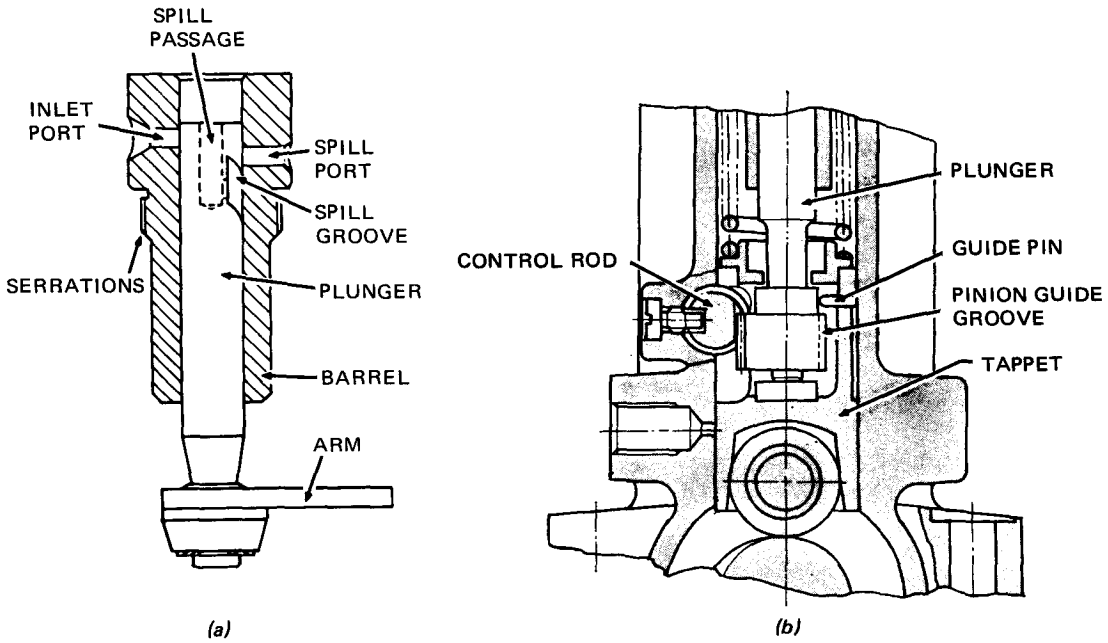


Fig. 29-5 Schematic views of (a) Majormec fuel-injection-pump's pumping elements *(CAV Limited.)*; (*b*) PE(S)PD. A fuel-injection-pump's pumping elements. *(Robert Bosch GmbH, Stuttgart, West Germany.)*

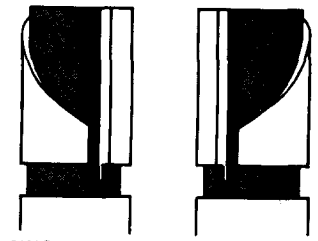


Fig. 29-6 Plungers of the upper-helix design. *(American Bosch, United Technologies Automotive Group.)*

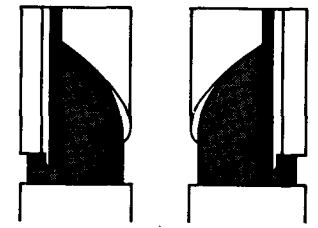


Fig. 29-7 Plungers of the lower-helix design. *(American Bosch, United Technologies Automotive Group.)*

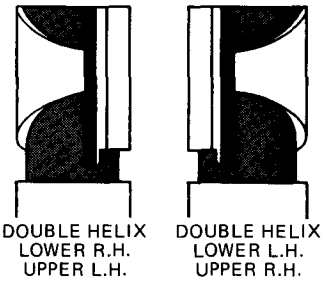


Fig. 29-8 Plungers of the upper-and-lower-helix design. *(American Bosch, United Technologies Automotive Group.)*

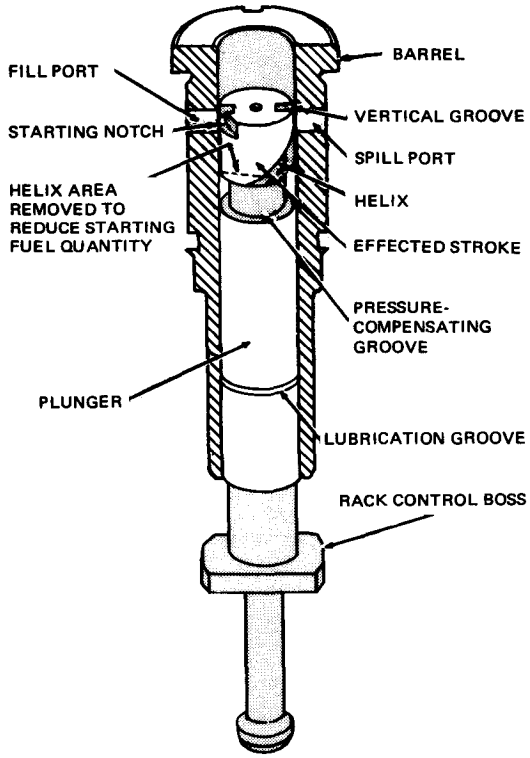


Fig. 29-9 Schematic view of plunger having a starting notch (groove). *(International Harvester Company.)*

below idle speed. Effective stroke is the distance of plunger travel while fuel is being forced out of the pumping chamber. The same injection pump at maximum torque speed provides 0.09 cm^3 to each injector.

Pumping Principle Using Lower Helix When the tappet roller (follower) is on the base circle of the cam, the upper surface of the plunger is below the inlet port and spill port. Fuel under transfer-pump pressure enters the ports and fills the area above the plunger and the area below the helix (Fig. 29-10). As the cam moves the tappet and plunger upward, the ports are closed by the plunger (Fig. 29-10). Fuel pressure builds up rapidly, causing the delivery valve to lift off its seat and allows the fuel to enter the high-pressure injection line (Fig. 29-10).

As the lower helix opens the spill port, the fuel pressure quickly decreases because fuel from above the plunger flows through the vertical groove into the helix area and through the spill port, to be deflected by the barrel-locating screw into the fuel manifold (Fig. 29-10*d*). As soon as the pressure drops from below the delivery valve, the delivery valve is forced on its seat through the injection-line pressure and its spring force, preventing fuel from leaving the injection line. Once the spill port is open, the plunger can no longer pressurize the fuel as it continues to move upward. The upward movement of the plunger stops when the follower rides on the cam nose.

As the tappet roller passes the cam nose, the plunger spring forces the plunger, and the plunger forces the tappet roller to follow the contour of the cam. Fuel at transfer-pump pressure enters the spill port and fills the area vacated by the plunger. When the spill port closes momentarily, no fuel can enter the area until the plunger uncovers the inlet port.

Pumping Principle of Plungers Having a Starting Groove When the throttle is placed in the starting position, the starting groove aligns with the fill port (Fig. 29-9), and the vertical plunger groove passes the spill port. *(NOTE: This occurs whether or not the plunger has an upper helix, a lower helix, or both.)* As the plunger moves upward, it closes the spill port, and after 2.69 mm the fill port is closed by the starting groove and the delivery begins. The delivery ends when the helix opens the fill port. When the engine is operating above low-idle speed, the governor starts to control the fuel rack and consequently the plunger position.

Pumping Principle Using Upper Helix and Upper and Lower Helix Whether using a plunger with an upper or a lower helix, or a plunger with both an upper and a lower helix, the mechanical action during the upward and downward movements of the plunger is the same. However, when using a plunger having an upper helix, the inlet port is not closed by the top of the plunger; rather, it is closed by the upper helix. Therefore, the beginning of delivery is variable because the upper-helix position depends on the governor action. When the governor is in the full-fuel position, the beginning of delivery is earlier (advanced) (Fig. 29-11). Notwithstanding the helix po-

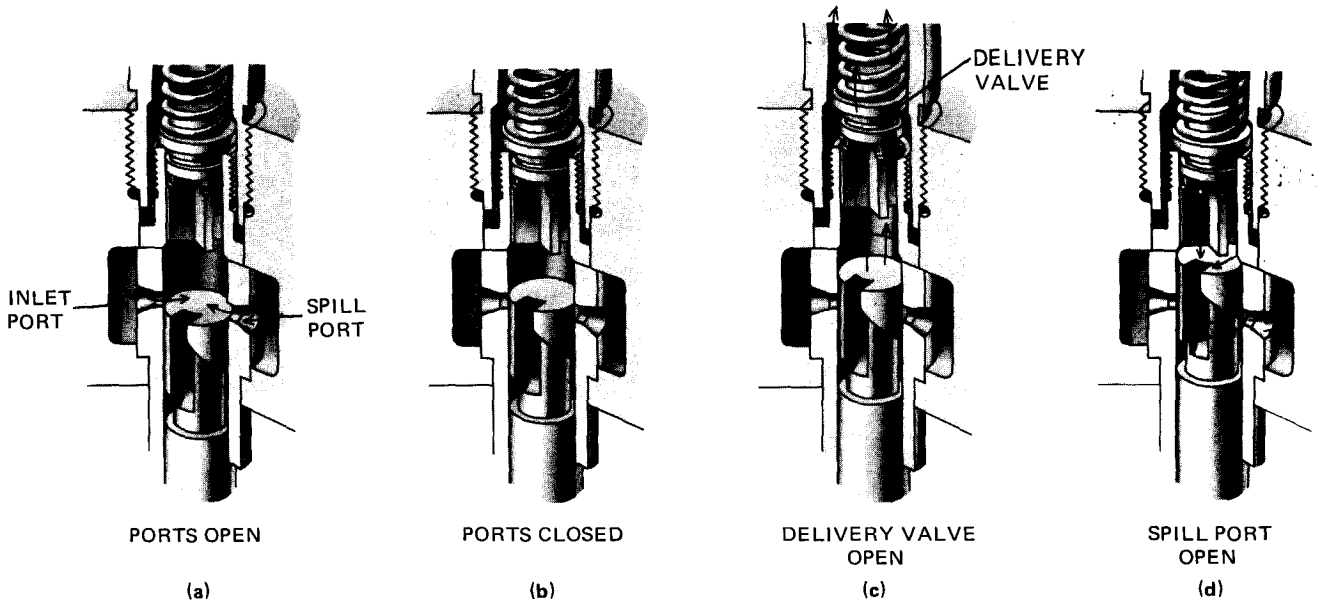


Fig. 29-10 Pumping principle with the lower helix design (arrows show the fuel flow). (*a*) Fuel enters barrel, (*b*) start of delivery, (*c*) delivery, (*d*) end of delivery. *(Robert Bosch GmbH, Stuttgart, West Germany.)*

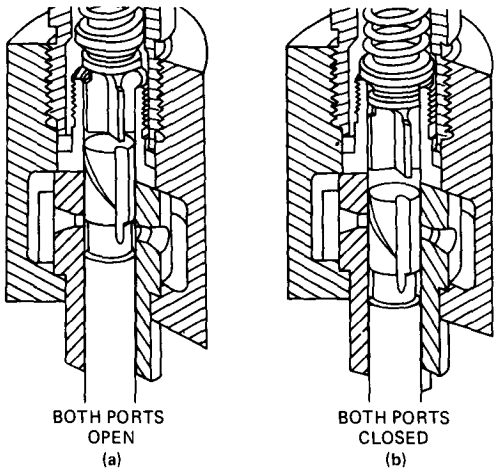


Fig. 29-11 Pumping principle with the upper-helix design. (*a*) Advanced delivery—governor in full-fuel position (ending injection); (*b*) retarded delivery—governor in half-fuel position (starting injection). *(Robert Bosch GmbH, Stuttgart, West Germany.)*

sition, the ending of delivery always occurs when the edge of the horizontal groove on the plunger opens the spill port.

When using a variable-beginning (upper-helix) and a variable-ending (lower-helix) plunger design, both helices are combined, giving the manufacturers a greater working range to tailor the fuel curve precisely to a specific engine (Fig. 29-12).

Metering Principle The governor, which measures the engine speed and senses engine speed changes, transmits its motion to the fuel-changing mechanism to control the engine speed. The fuel-changing mechanism consists of various lever arrangements, the fuel rack, the connecting link to the plunger, and the pumping element. (See Unit 25, "Governors.")

NO-FUEL POSITION When the governor moves the fuel rack to the no-fuel position, the plunger rotates within the barrel to place the vertical groove in line

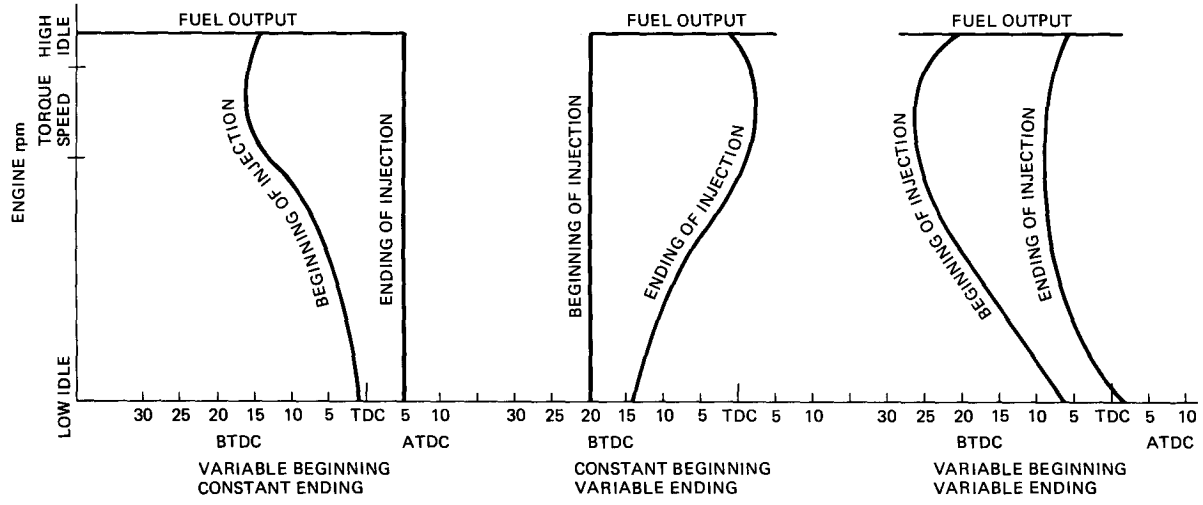


Fig. 29-12 Diagrams of plunger position in relation to engine rpm fuel quantity, beginning and ending of injection.

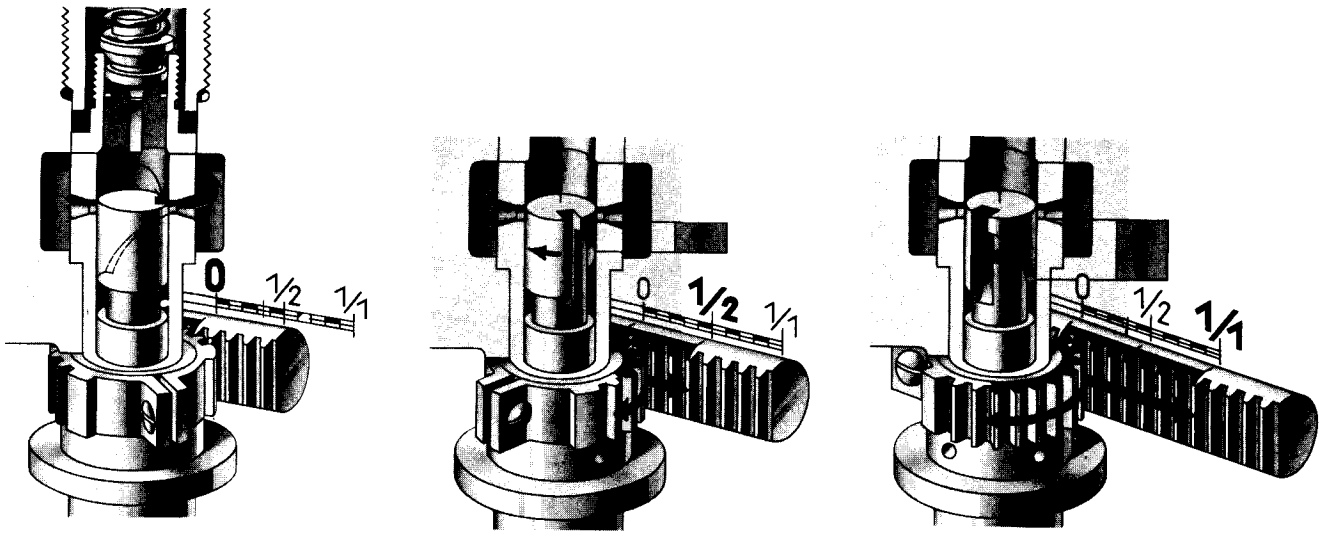


Fig. 29-13 Metering principle: (*a*) governor in no-fuel position, (*b*) governor in half-fuel position, (*c*) governor in full-fuel position. *(Robert Bosch, GmbH, Stuttgart, West Germany.)*

with the spill port (Fig. 29-13*a*). The port cannot close the spill port since the vertical groove rides over it on the total upward and downward stroke. Fuel displaced during the plunger movement runs up or down the vertical groove to and from the base of the helix and runs out or in, through the spill port.

HALF- AND FULL-FUEL POSITIONS When the governor moves the fuel rack to the half-fuel position, it rotates the gear segment, the control sleeve, and the plunger (Fig. 29-13*b*). This changes the position of the helix relative to the spill port and the effective stroke. (When the governor moves the fuel rack to the full-fuel position, the helix is as shown in Fig. 29-13*b*.) The longer the spill port is closed, the longer is the pumping period (effective stroke), and therefore more fuel is delivered.

Delivery Valves—Purpose and Design All port- and helix-metering fuel-injection pumps (with the exception of Detroit Diesel and Caterpillar engines) using a unit-injector injection system employ a delivery valve. Its purpose is to accelerate the beginning of injection, to assure quick ending of injection, and to maintain residual-line pressure about 30 percent lower than the injector opening pressure.

Variations among delivery-valve assemblies are mainly in their overall size and the displacement plunger volume. The valve assembly consists of the valve body, delivery valve, valve spring, and valve stop (if used). The valve body is lap-fitted to the barrel and has the valve seat. The valve itself is odd-shaped. On top is a displacement piston (valve cone), then the valve seat, the relief (retraction) piston, the relief annulus, and the fluted stem. The valve stop, if used, limits the upward travel of the delivery valve to a specified limit of around 2 mm.

DELIVERY-VALVE OPERATION As illustrated in Fig. 29-14, the delivery-valve body is seated on the barrel and is held in position through the delivery-valve holder, which is screwed into the fuel-injection pump housing. The valve is held on its seat by the valve spring.

As the plunger rises, fuel becomes trapped above the plunger and in the base area of the helix, causing the pressure to rise rapidly. This pressure is exerted on the fluted stem, the valve face, and the relief piston. When the force increases beyond the combined force of the spring and the residual injection line pressure, the valve moves upward. With the upward movement of the valve, the displacement piston is forced into the spring area. This reduces the fuel volume in the spring area and, therefore, increases the pressure in the injection line. As the relief piston leaves its bore, fuel is forced past the relief piston into the fuel line, and injection takes place.

The valve stop limits the upward movement of the delivery valve. The open position of the valve is maintained until the helix on the plunger uncovers the spill port. As this happens, the sudden drop in pressure in the base area of the helix and above the plunger, plus the higher fuel line pressure and spring force

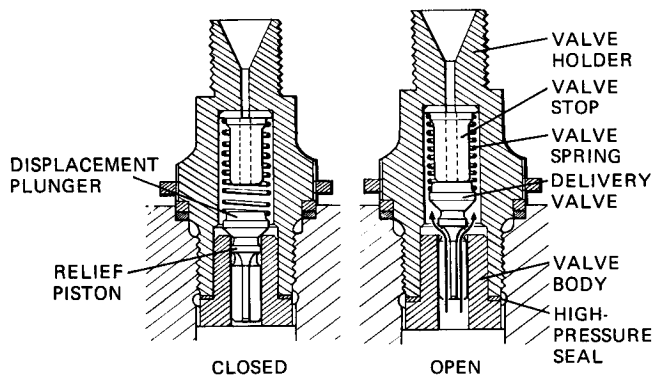


Fig. 29-14 Schematic view of a delivery valve. *(CAV Limited.)*

acting on the displacement piston, cause the delivery valve to retract quickly and snap onto its seat. Simultaneous with delivery-valve retraction, the relief piston first prevents a return fuel flow to the plunger and then the valve seats. The retraction of the valve into its bore increases the spring area by the volume of the withdrawn displacement piston. The effect is that the volume in the injection line, before the valve rests on its seat, is suddenly decreased and the pressure reduced, causing the nozzle valve in the injector to snap onto its seat. This prevents dribbling or secondary injection which might otherwise occur because of high-pressure wave reflection (pulsation).

American Bosch and Robert Bosch fuel-injection pumps on engines having a high injection pressure (around 4000 to 5000 psi [27,580 to 34,475 kPa] may use a snubber valve (orifice) between the inner bore of the delivery-valve holder and spring seat (see Fig. 29-15). The purpose of the snubber orifice is to reduce high-pressure pulsation after injection has ended and thereby reduce cavitation, erosion, and secondary injection. *(NOTE: Any damage to the delivery-valve assembly has a greater effect on engine performance and emission than has a damaged plunger or barrel.)*

FUEL-INJECTION-PUMP SERVICE

Examination before Removal

Most fuel-injection system trouble is the direct result of dirty fuel, although you should not assume dirty fuel is the only problem source. Damaged or defective components also contribute to system malfunction; therefore, a number of checks should be made if the problem is to be corrected (see also Unit 53, "Troubleshooting and Tuneup").

Begin by checking the general condition of the engine, that is, for oil leakage, dirt accumulation, belt tension, radiator condition and/or coolant level, oil level, etc. Test-run the engine to analyze its operating condition. Look for fuel leakage, excessive exhaust smoke, check governor action and governor response, and note the engine temperature.

Check throttle freeness, the high- and low-idle rpm, and the aneroid (fuel-ratio control) boost pressure. Check the fuel-transfer-pump pressure. When necessary, change the fuel filters, and then repeat the fuel-pump pressure test.

If the engine is hard to start but the cranking speed is adequate, check the air-intake system and the cylinder compression. Check the timing (by the spill method) or use an electronic timing device to ensure that the injection pump is properly timed to the engine.

To determine if all injectors are operating properly, pry each pump element upward using a screwdriver. If this procedure can be applied, the injector nozzle should boss (chatter). Otherwise, operate the engine at the rpm where its rough operating condition is most noticeable and then loosen the injection line nut of one fuel-injection-pump element. This will release the fuel out of the loose fitting and the injector will no longer operate. If this is the faulty injector, there will be no difference in the engine's performance. Tighten the injection line nut and repeat this procedure with the remaining injectors.

Another method of testing injectors is to install a pressure gauge in the high-pressure fuel line to check the opening pressure of the injector. Not until the injection pump is proven to be faulty should it be removed.

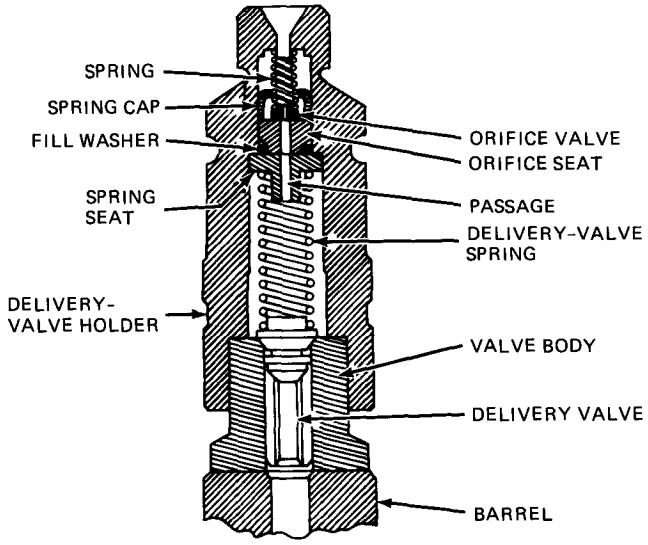


Fig. 29-15 Schematic view of a delivery valve with snubber valve.

Injection-pump Removal Although the removal procedures are similar for all injection pumps, individual service manuals should always be referred to before you remove a fuel-injection pump. Obtain the necessary data in regard to pump construction, performance, and engine manufacturer specifications.

The general removal procedure is as follows: (1) First clean the area surrounding the injection pump and injectors to prevent dirt from entering the system. (2) Turn the crankshaft to bring No. 1 piston on compression stroke and align the engine timing marks, then check injection-pump timing. (3) Close off the fuel supply, remove or disconnect the throttle and/or shutoff lever, and remove the air line from the aneroid and the connecting wire from the shutoff solenoid, if used. (4) Remove the oil supply and return lines and cap the hose ends and pump openings. (5) Disconnect and cap the inlet fuel connection and the return line connection, if used. (6) Disconnect the high-pressure fuel lines from the injectors, or from the injection pump, whichever is easier, or remove them entirely. Cap the openings of the fuel lines as each line is being removed. (7) Loosen the mounting bolts. Remove the drive coupling and driven gear from the automatic timing device, and then remove the mounting bolts and lift the injection pump from the engine. On large pumps use a sling and hoist to support and to lift the pump from the housing.

Disassembly Procedure The disassembly procedure for injection pumps varies to some extent among different manufacturers and even among different models within the same company. Conse-

quently, it is impractical to include here all types of injection pumps, and therefore only the major differences are discussed in this unit. For detailed procedures, follow service manual instructions.

Regardless of the type of pump to be disassembled, the exterior of the injection pump must first be cleaned. The work area and tools must also be clean. It is also essential to keep all the components of the same element in a separate container (Fig. 29-16). Never interchange the barrels and the plungers or the delivery valves and bodies. Keep the tappet spacer or shims with the pump elements to speed up reassembly.

Begin the disassembly by mounting the injection pump in a swivel vise or in a holding fixture. Remove the transfer pump, inspection cover, and governor cover. Remove the necessary pins and springs which connect the governor with the control rod (fuel rack). Using a puller, withdraw the weight assembly and drive hub or coupling from the camshaft. From this point on the disassembly procedures vary slightly because of differences in the fuel-injection-pump housing designs.

Removing Camshaft and Plunger Assembly

To remove the camshaft from an inline or V fuel-injection pump having a side cover (Fig. 29-17), turn the camshaft until No. 1 tappet roller is on the cam nose, then install a tappet holder. This lifts the tappet roller from the cam nose.

NOTE: On American Bosch fuel-injection pumps, you must gently pry the plunger upward and install the tappet holder into the bore provided in the tappet roller.

Next, turn the camshaft until No. 2 tappet roller is on the cam nose, and install another tappet holder. When all tappet holders are installed, the camshaft should turn freely. Remove the front and rear bearing retainer screws and with a puller remove the retainer. If a center bearing is used, remove the retainer screws and then with a puller remove the bearing retainer and withdraw the camshaft.

To remove the tappet holder (in order to remove the plunger from the injection pump shown in Fig. 29-17), remove the base cover, or, when base plugs are used, drive them inward using an appropriate driver, and remove them. Now, with the tappet remover (or a small hammer handle) push the tappet roller upward and remove the tappet holder. When all tappet holders are removed, lift the plunger's lower spring seat, plunger spring, upper spring seat, and plunger from the bore, and slide the control sleeve from the barrel. Place all components from each pump element together, in individual containers of clean fuel.

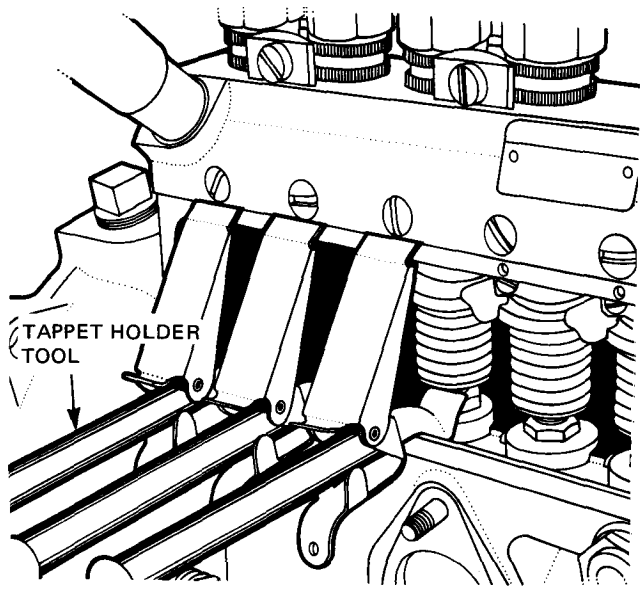


Fig. 29-17 Schematic view of tappet holder tools installed. *(International Harvester Company.)*

CAUTION Take care not to damage the plunger.

To remove the camshaft from a Robert Bosch P model (PEP) fuel-injection pump (Fig. 29-18), also

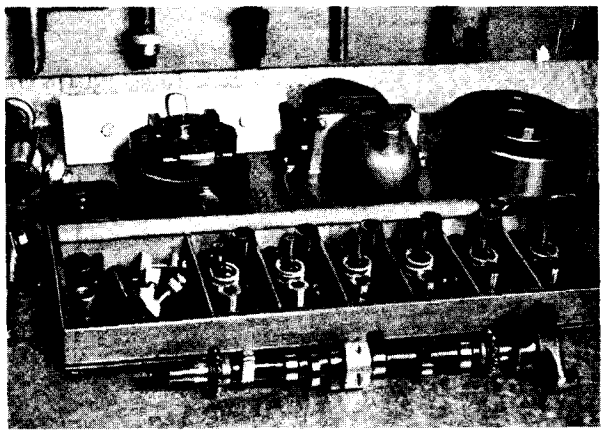


Fig. 29-16 View onto a typical work area showing storage of components. *(Robert Bosch, GmbH, Stuttgart, West Germany.)*

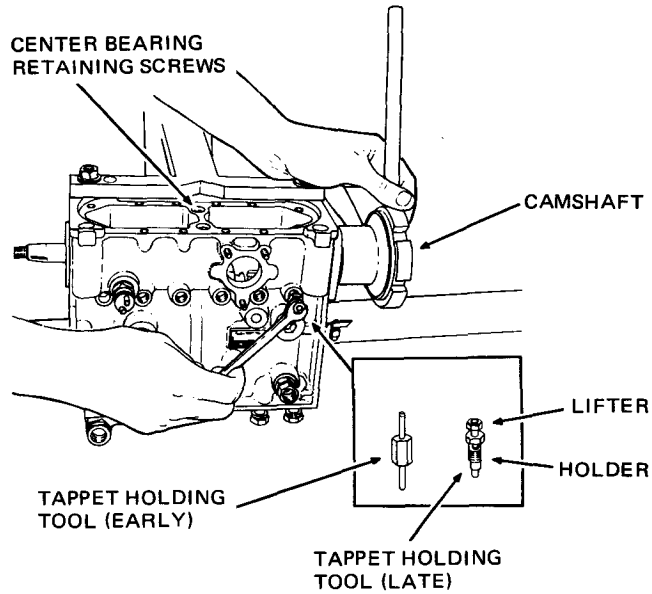


Fig. 29-18 Schematic view of installing tappet lifter holding tools.

bring No. 1 tappet roller onto the cam nose, screw the special tappet holder into the bore, and turn the tappet lifter 180°. The eccentricity of the tappet lifter raises the tappet roller from the cam nose. Install the remaining tappet holders and then remove the camshaft using the same procedure as outlined above.

To remove the tappet holder from a PEP injection pump (Fig. 29-18), install the removal tool (which is similar to the one shown in Fig. 29-19). Align the pushrod plunger over the tappet roller and, with the handle, force the pushrod downward, holding it while unscrewing the tappet holder. After all tappet holders have been removed, lift out the tappet rollers and, with pliers or a special removing tool, withdraw the plunger and lower spring seat. Remove the spring, upper spring seat, and control sleeve.

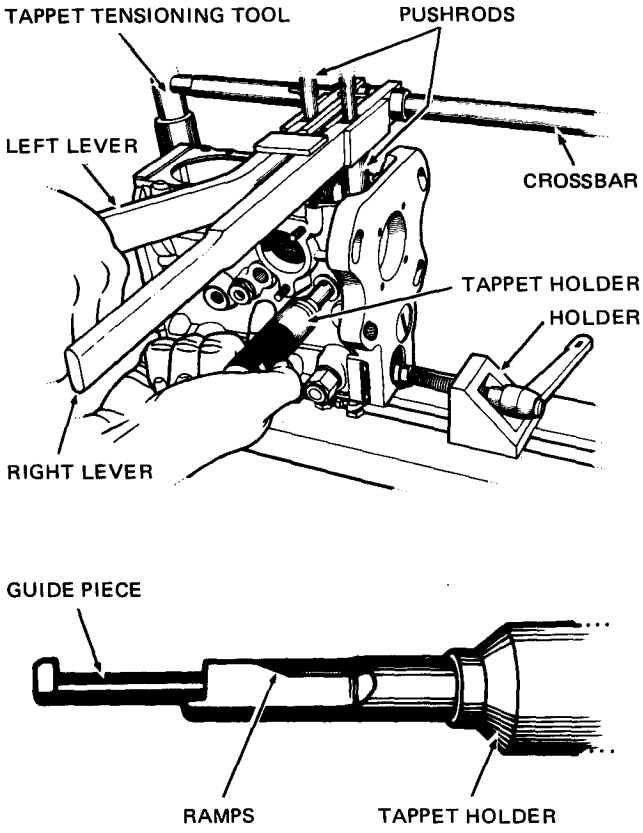


Fig. 29-19 View of tappet tensioning tool installed to remove tappet holder. *(International Harvester Company.)*

To remove the camshaft from the fuel-injection pump shown in Fig. 29-19, first remove (with a special puller) the side plugs, and (with a magnet) remove the camshaft spacers. Bring No. 1 tappet roller onto the cam nose, apply grease to the tappet holder ramp and guide, and turn the rotating handle counterclockwise to its maximum. With the ramp facing toward the camshaft, insert the tappet holder as far as possible into the first side hole. This will lift No. 1 tappet from the cam nose. Rotate the camshaft to bring No. 2 tappet onto the cam nose and, with the palm of your hand, forcefully push the tappet roller inward. This will lift No. 2 tappet from the cam nose. *(NOTE: When the tappet holder is correctly installed, No. 1 and No. 2 tappet rollers have been lifted from the camshaft.)* Install the remaining tappet holders. Now remove the camshaft bearing retainer plate and camshaft center bearing retaining screw, and, with an arbor press, push out the camshaft. Handle the intermediate bearing with care and do not let the camshaft fall to the floor.

To remove the tappet holders from the injection pump shown in Fig. 29-19, install the spring compression tool and position the right- and left-hand pushrods over the first two tappet rollers. Adjust the crossbar height (fulcrum point) slightly downward so that you have handle clearance. Now, with one hand, firmly hold the tappet holder, and with the other hand depress the left-hand lever *only* as this will compress both plunger springs and at the same time remove the tappet holders.

Next, position the compression pushrods over the adjacent two tappet rollers and repeat the steps outlined above. After all tappet holders are removed, lift out the tappet rollers, lower spring seats, plunger, and springs. Position the control rack (also known as the *control rod* or *fuel rack*) so that the control sleeve ball is in the pump housing notch. Then with a magnet lift out the control sleeves (see Figs. 29-20 and 29-32).

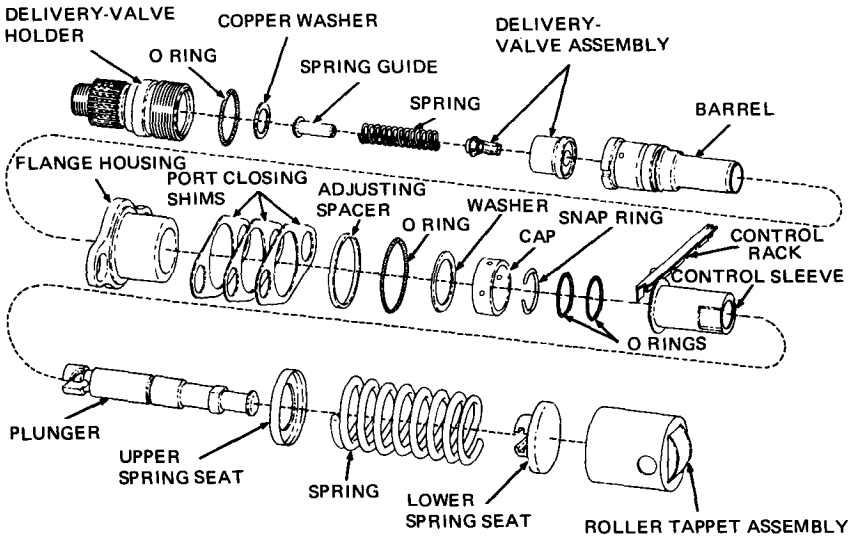


Fig. 29-20 Exploded view of a PE(S)P pumping element assembly. *(Allis-Chalmers Corp. Engine Division.)*

Removing Delivery Valve and Plunger Barrel To remove the delivery-valve assembly from the fuel-injection pump shown in Fig. 29-3, first remove the holder clamps, and then remove the delivery-valve holders. From each bore lift out the filler (stop), spring, and gasket, and, by gently forcing the barrel upward, remove it and the delivery valve assembly. As soon as the barrel is removed, insert the mating plunger as this will protect both the plunger and the barrel.

Removing the barrel from the fuel-injection pump (Figs. 29-2 and 29-19) is a very similar procedure. First, loosen all delivery-valve holders, then remove the flange nuts, lock washers, and washers, and by using two screwdrivers gently pry each barrel assembly from the housing, (Fig. 29-20). As soon as each is removed, insert its mating plunger. Always keep the port closure adjusting shims with the pumping element as this will speed up reassembly. Next, unscrew the delivery-valve holder from the flange housing and remove the washer, spring guide, spring, and delivery-valve assembly. From the barrel or housing remove the spacer and O rings, and from the barrel remove the snap ring, cap, and flange housing.

To remove the fuel racks, remove the rack position screw, the rack bracket screws, or the threaded bushing, then pull out the fuel rack.

Disassembling CAV Minimec or Majormec To disassemble a CAV Minimec or Majormec fuel-injection pump (see Fig. 29-21), remove the clamp screws, lock washer, and clamps. Then loosen the delivery-valve holders and remove all the pump body screws and sealing washers. When lifting the pump body from the housing, take care that the plungers do not fall from the barrel (Fig. 29-22). Pull the plunger from the barrel with one hand while holding the other hand below the spring and upper and lower spring seat. The tappet assembly and the tappet locater can now be lifted from the lower housing.

To remove the barrels from a Majormec injection pump (Fig. 29-23), first remove the two air vent screws, then the delivery-valve holder, and lift out the valve stop (volume reducer) and the delivery-valve

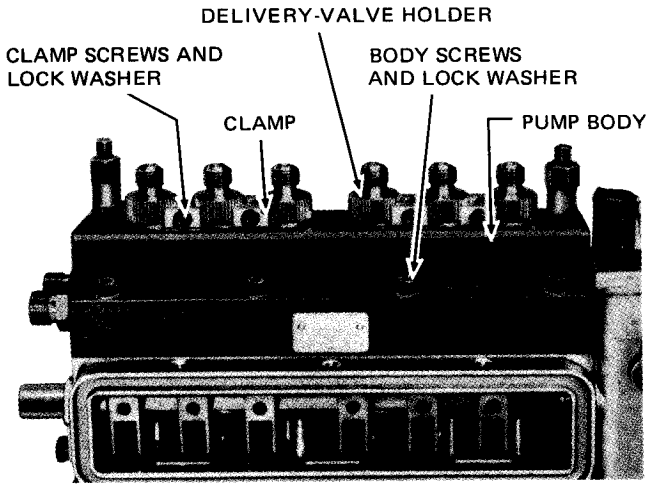


Fig. 29-21 View of preparing to remove pump body. *(CAV Limited.)*

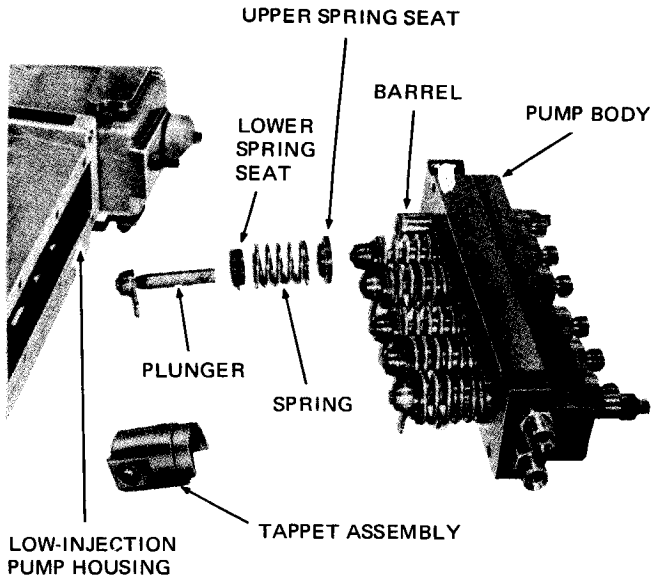


Fig. 29-22 Exploded view of one pumping element removed from pump body.

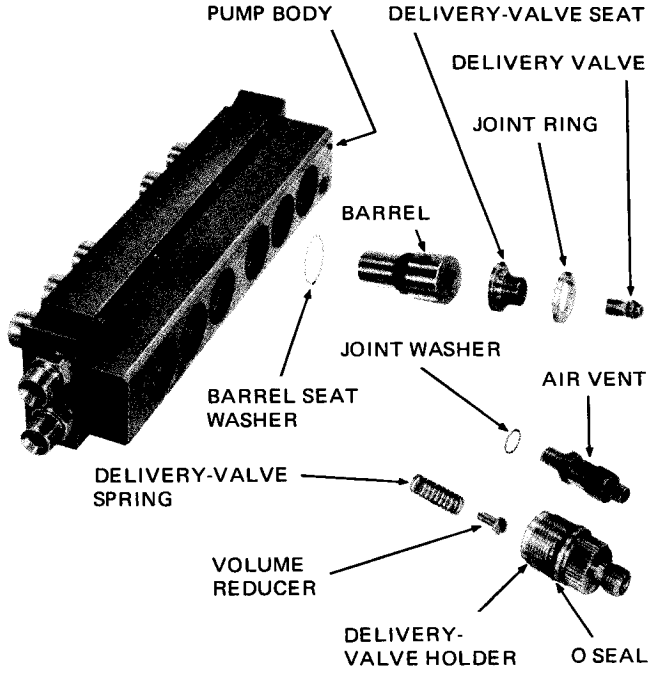


Fig. 29-23 Exploded view of one pumping element assembly. *(CAV Limited.)*

spring from the bore. Using a soft-face hammer, tap on the bottom of the barrel to dislodge the barrel and to force the sealing ring (joint ring) and the delivery-valve body from the bore; then remove the barrel-seat washer.

Remove the control rod cover and loosen the control fork screws. Simultaneously slide out the control rod and remove the control forks (Fig. 29-24). The camshaft can now be removed.

Turn the pump over and remove the inspection plate. If an intermediate camshaft bearing is used, remove the lower bearing holder. With a puller, remove the drive coupling or mechanical timing device. After removing the screws from both end plates, use a puller to withdraw the end plates from the housing. Slide the camshaft off the housing.

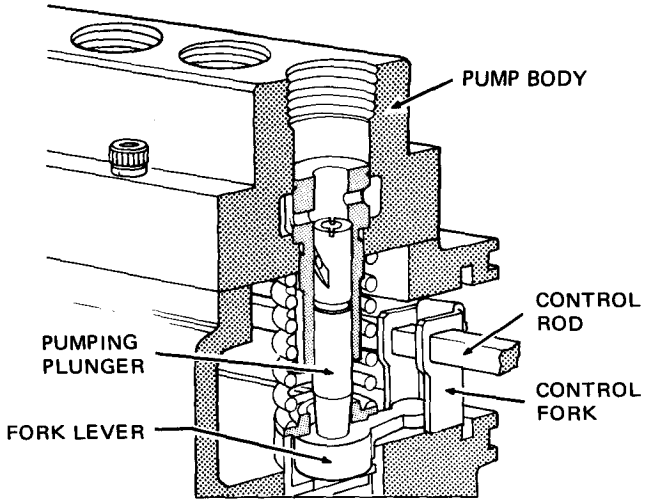


Fig. 29-24 Schematic view of control rod and control fork. *(CAV Limited.)*

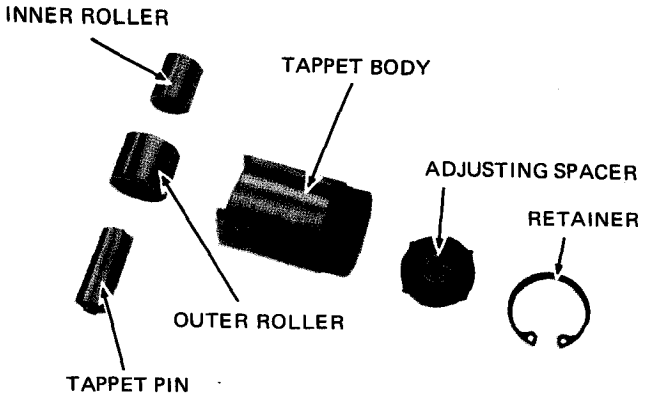


Fig. 29-25 Exploded view of one tappet assembly. *(CAV Limited.)*

Cleaning and Inspecting Pump Housing Remove all gasket materials from the pump housing and end plates. With a puller, withdraw the bearings or the bearing races. Remove all O rings and sealing washers. Clean the components thoroughly and dry them with compressed air.

Inspect the pump housing for damage to bearing bores and mounting surfaces. Smooth out any slightly damaged spots. If the camshaft bearing bores are worn, the pump housing must be replaced.

Check the stud bolts and the threaded bores for damaged threads. Check the tappet-roller bores. If they are rough or badly grooved, the housing must be replaced. Otherwise, smooth out the bore surface with a piece of fine emery cloth. On older types of fuel-injection pumps when the barrel seats are damaged, use the recommended reseating cutter to reseat their surfaces.

Control Rod and Bushings Examine the control rod to determine if the seal seats are damaged or if the bearing surface is worn. Check for worn control rod notches in which the balls of the control sleeve ride (Figs. 29-20, 29-24, and 29-27), or check the gear teeth on the control rod. When the control rod is in the housing, it should slide smoothly, but not too loosely.

Check the control rod bushings for wear and, if necessary, replace them. It is essential to ream newly installed bushings with a special reamer to ensure free control rod movement.

Camshaft and Camshaft Bearings If there is any damage to the camshaft lobes, bearings, or sealing surfaces, the camshaft must be replaced. Large camshafts should be checked for runout, and when the runout exceeds specification the camshaft must be straightened. If there is any doubt about the serviceability of the bearings, they must be replaced.

Tappet Rollers Some manufacturers recommend measuring for tappet roller and pin wear with a special tool. Others recommend pressing out the tappet pin from the tappet body (see Fig. 29-25) to examine the inner and outer rollers and pin for damage to their bearing surfaces. If there is any evidence of wear, the defective part should be replaced. If the tappet body is rough or grooved, or if the guide grooves are worn, replace the tappet body also. However, slight wear marks or longitudinal marks may be removed with a piece of fine emery cloth.

When tappet screws are used, check the screw threads and the threads of the threaded bore for damage. Make certain that the plunger contact surface is smooth. Slightly damaged surfaces can be restored by regrinding the surface on a valve refacer.

Barrel and Plunger If there is any evidence of damage to the helix or top area of the plunger, or the plunger and barrel surfaces are grayish in color, it indicates excessive wear and the element must be replaced. However it is not recommended to replace only one element.

Longitudinal grooves on a plunger indicate that dirty fuel has been used. Horizontal pressure marks indicate that the pump element has been forced to operate against excessive pressure, usually caused by one or more choked or plugged nozzle orifices.

Before you clean the barrel and the plunger, apply a moderate amount of mutton tallow to the plunger and with a felt pad clean the plunger. Then clean the plunger in diesel fuel, and again apply tallow. Insert the plunger into the barrel, and rotate it while moving it back and forth within the barrel. This will remove varnish from the surface.

Before you clean the barrel, lap its top surface to ensure a leakfree seal between it and the delivery valve. Place the plunger and the barrel in clean diesel fuel. While still in the diesel fuel, insert the plunger into the barrel and move it back and forth a few times. This will clean both components.

To check the plunger for freeness, pull the plunger out of the barrel about one-quarter of its length vertically. It should slide slowly back into the barrel by its own weight. If it slides back too quickly, the tolerance between the plunger and the barrel is too great and the element must be replaced.

Plunger Spring Check the plunger spring for corrosion and straightness. Measure its free length and energy with a spring compressor. Never use a spring which is corroded because it may break or, if its energy is too low, it may not return the plunger quickly enough. If it is bent it may cause the plunger to stick.

Control Sleeve and Gear If there is any damage to the teeth of the gear segments or to the slots of the sleeve in which the plunger flange rides, the damaged component must be replaced. Measure distance *A* (see Fig. 29-26). It must be within specification. If a replacement is not necessary, slightly loosen the screws which clamp the gear to the control sleeve to assure troublefree calibration.

If the injection pump has a control fork and the plunger has a plunger arm (Fig. 29-24), they should be checked for wear as they must fit snugly with only slight clearance. When you service a pump which has a control sleeve with a ball socket (Fig. 29-27), make certain the socket has no flat spots and the control rod slot is not worn.

Delivery Valve Check the delivery-valve assembly. The seats must show no sign of excess wear and the seating area must be even. If the relief piston shows any sign of wear, the assembly must be replaced. It is common practice to replace the delivery-valve spring. If the valve assembly is acceptable, lap the body surface to assure a leakfree seal between it and the barrel.

Reassembling Fuel-injection Pump When you service a Majormec fuel-injection pump, slide the camshaft into the lower pump housing. If the camshaft is supported by an intermediate bearing, then you must install the bearing shells into the upper and lower bearing housings. Lubricate both bearing housings and install them onto the center journals. *(NOTE: The dowels hold them to the camshaft.)*

Replace the original set of shims on each end of the camshaft after making certain that the sets are equal in thickness. Lubricate the bearings and press them into the camshaft. Press the oil seal into the bearing housing. Install the washer and press the outer bearing race against the shoulder of the bearing housing.

Install the camshaft into its housing with the identification mark to the side indicated by the nameplate

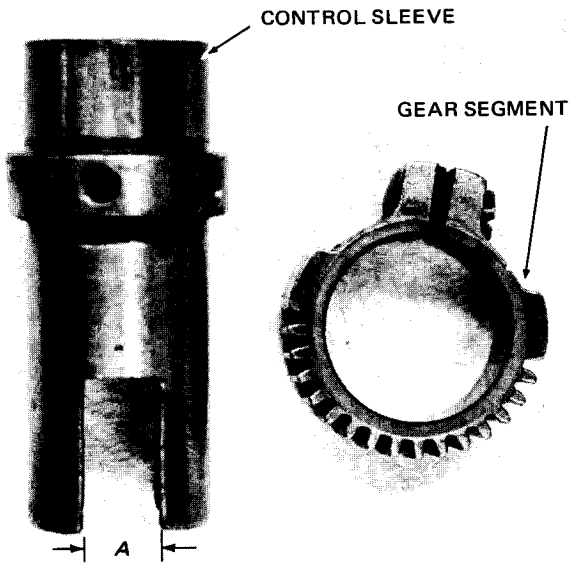


Fig. 29-26 View of control sleeve and gear segment.

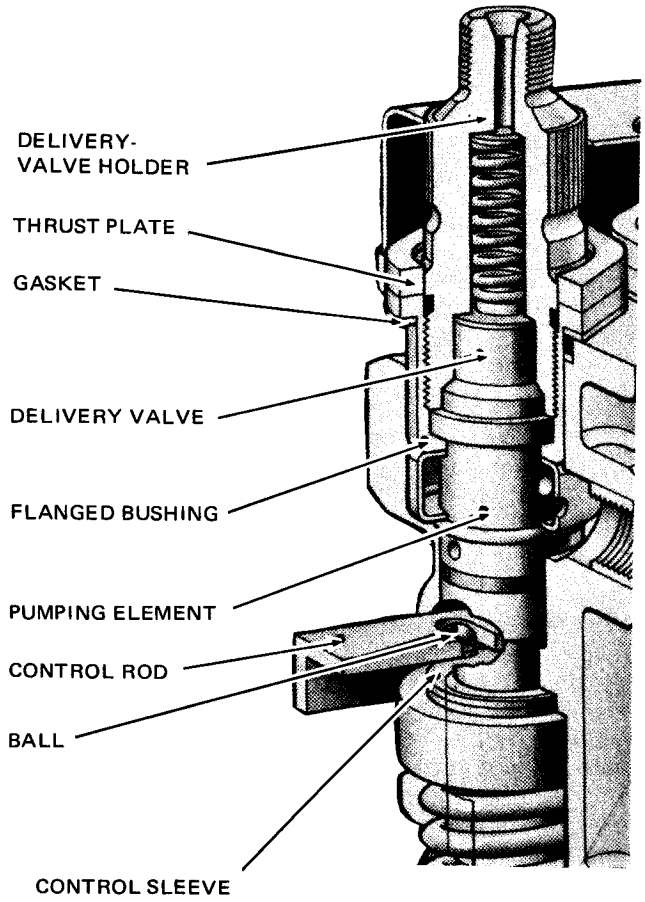


Fig. 29-27 Sectional view of control rod and control sleeve. *(International Harvester Company.)*

number. Install a jointing gasket and tap the bearing housing into place. Secure it to the pump housing, then install the rear bearing housing.

CAUTION While tightening the screws, rotate the camshaft to prevent it from seizing.

When the front and rear bearing housing screws and the center bearing housing screws are torqued to specification, measure the end play by mounting a dial indicator to the housing so that the pointer rests against the end of the camshaft. End-play movement will show on the scale when prying the camshaft to the left and to the right. Average camshaft end play is 0.002 to 0.005 in [0.051 to 0.127 mm].

To adjust the end play, the bearing housing and the bearing cone must be removed, and shims added or removed as required (Fig. 29-28).

Camshaft installation procedures for other fuel-injection pump models are much the same except that the camshaft is installed *after* the pumping element has been installed, and the end play may be different. On PEP fuel-injection pumps, the drive end side must protrude within 13.0 to 14.0 mm. To change the protrusion, remove the governor housing and add or remove shims from the housing counterbore of the thickness to achieve the specified protrusion (Fig. 29-29).

Assembling and Installing PEP Pumping Elements Place the flange housing in a vise and assemble the element in the sequence shown in Fig. 29-20. Lubricate the O rings with the recommended

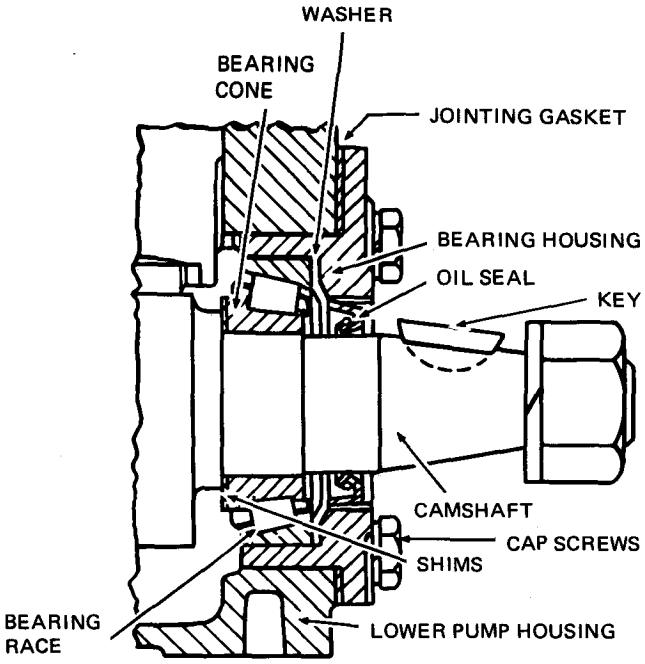


Fig. 29-28 Schematic view of camshaft drive end. *(CAV Limited.)*

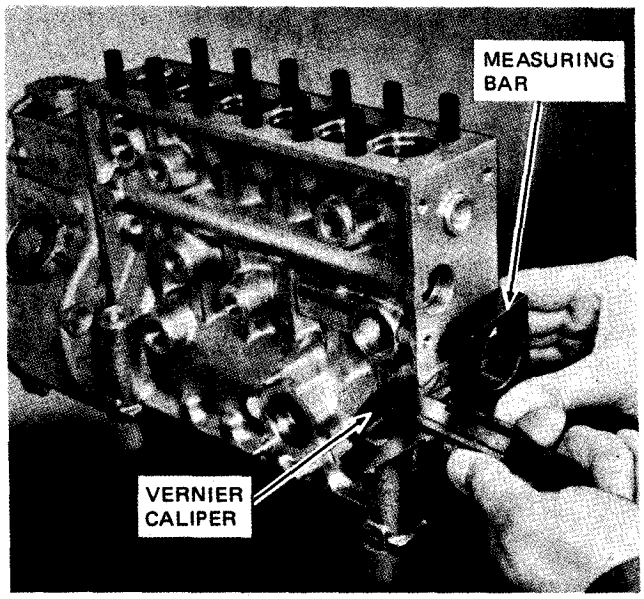


Fig. 29-29 View of measuring camshaft protrusion. *(Robert Bosch, GmbH, Stuttgart, West Germany.)*

grease. (The barrel should slide without force into the locking device of the flange housing.)

When assembled, tighten the delivery-valve holder to the specified torque. Always insert the special O ring (Viton ring) into the housing to prevent damaging it when placing the pumping element into the pump housing.

Place the shim pack, previously removed, on top of the housing. Place the large O ring into the groove of the housing. Next, install the pumping element with the flange housing pin toward the control rod side. Push downward and the barrel assembly should remain down when the force is released. If it does not, the barrel O ring interferes and must be replaced. Next, tighten the nuts to the specified torque.

Turn the pump housing upside down. Move the control rack so that its slots align with the notches in the pump housing. Drop the control sleeves into their respective bores so that the balls fall into the slots of the control rack (see Fig. 29-30). Apply petroleum jelly to each upper spring seat, affix one spring seat to each spring, then position them onto the control sleeve.

Dip the plunger in fuel and slide it into its mating barrel with the plunger marking away from the control rack. After each plunger is installed, move the control rack to assure the plunger moves freely within the barrel. Apply petroleum jelly to the lower spring seats, affix them to the tappet roller, and insert them into their respective bores with the roller axis 90° from the housing centerline.

Install the spring compression tool (see Fig. 29-19), compress the plunger spring, and install the tappet holders in the reverse order of removal. Then install the camshaft.

When you assemble a Majormec pumping element to the body (Fig. 29-22), first place the barrel-seat washer in the body. Then insert the lubricated barrel into the bore so that the missing serration is located at the corresponding missing serration in the body. This aligns the ports with the bores in the body. Install the delivery-valve-seat joint ring, delivery valve, spring, valve stop (volume reducer), and a new O ring onto the delivery-valve holder. Tighten the delivery-valve holder to the specified torque.

When you assemble the pumping element of the injection pump shown in Fig. 29-31, insert the lubricated barrel into the barrel bore with the spill port toward the deflector screw bore. Align the spill port with the bore. Secure the barrel with the deflector screw, or install the barrel-locating screws first, then align the barrel notch with the screw end and insert the barrel. Then install the delivery-valve components in the order shown in Fig. 29-32. Finger-tighten the holders. Position the control rack so that the center punch marks protrude evenly from the housing, or as specified in the service manual. Slide the control sleeve with the gear segments over the barrel so that the index mark on the sleeve faces toward you (see Fig. 29-33a). *(NOTE: The gear segment clamp opening must be in line with the index mark on the control sleeves.)* Install the remaining control sleeves and check their correct installation by centering the con-

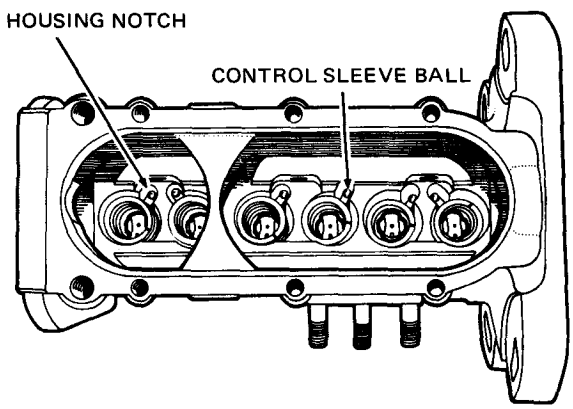


Fig. 29-30 View of correctly installed control sleeves. *(International Harvester Company.)*

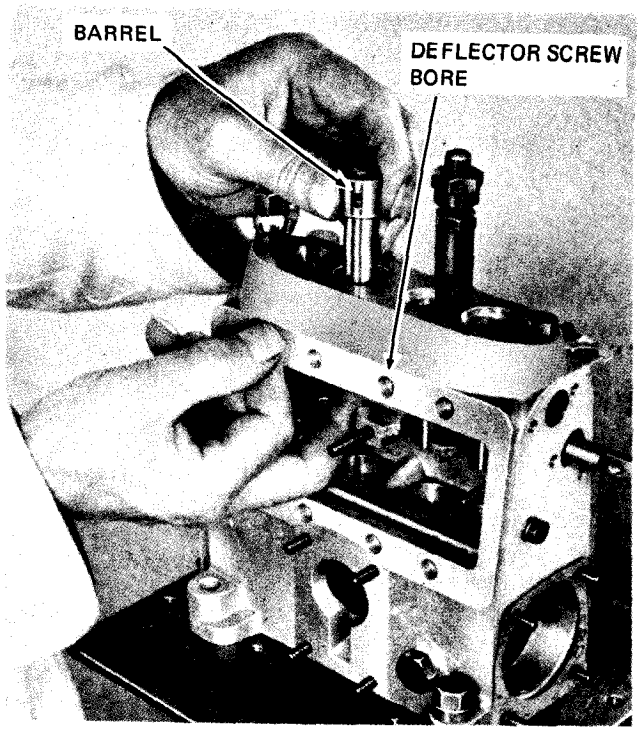


Fig. 29-31 View of installing barrel.

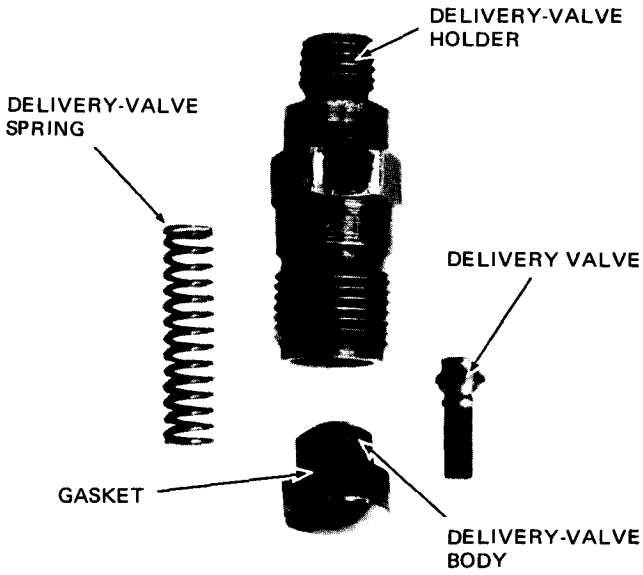
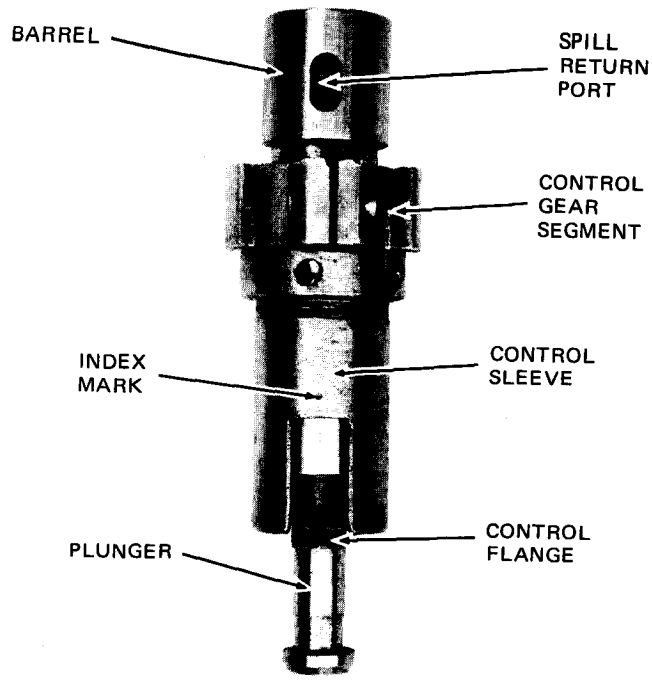


Fig. 29-32 View of delivery-valve components.

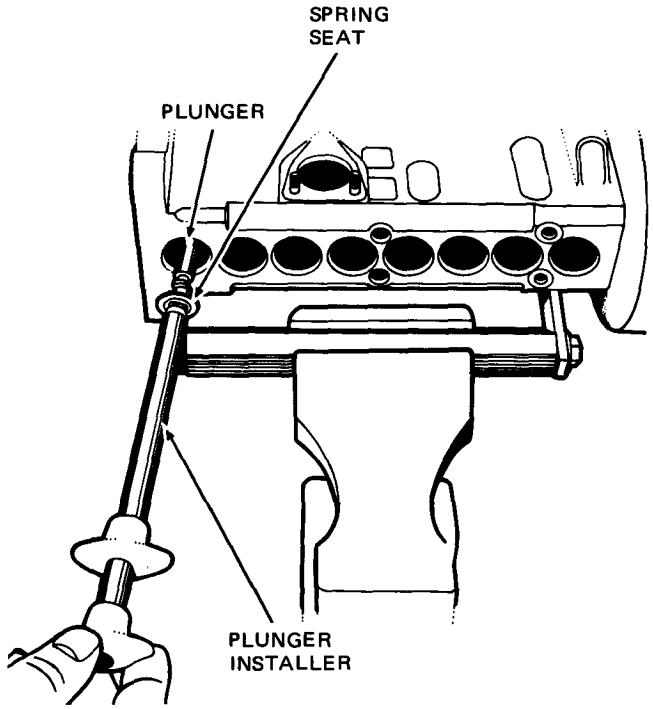
trol rack. The control sleeve slots must all face toward you.

Start at the drive end and torque No. 1 to No. 8 delivery-valve holders to specification. *(NOTE: Tighten the holders to the specified torque and relieve twice before finally torquing. Operate the fuel rack between each sequence to be certain the fuel rack is not binding.)* Next, install the upper spring seat and spring onto the control sleeves. Clamp the plunger to a plunger installer, dip it into clean fuel, place the lower spring seat onto the plunger (Fig. 29-33*b*), and slide the plunger into the barrel.

Make certain that the tappet adjusting screw is loose and turn it about two turns clockwise before attaching it to the installation tool (see Fig. 29-34). Install all tappet rollers and when installed use a small hammer handle to push each tappet roller upward, holding it there while installing its tappet holder. When all tappet holders are in place, install the camshaft and measure the end play.



(a)



(b)

Fig. 29-33 (*a*) View of a correctly assembled pumping element; (*b*) schematic view of installing a plunger.

Testing Barrel Seat and Fuel Gallery Leakage After servicing any port and helix fuel-injection pump, the partly assembled injection pump must be tested for barrel seat leakage and fuel gallery leakage. However, the point of assembly when this test should be made varies according to the injection-

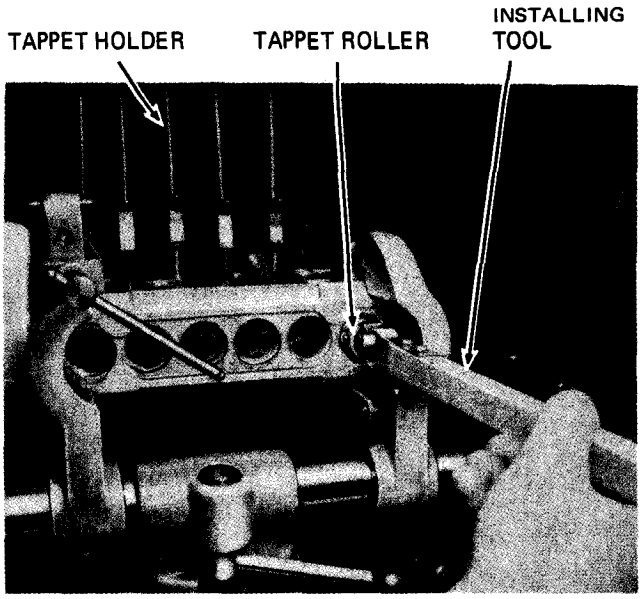


Fig. 29-34 View of installing tappet roller and installed tappet holders.

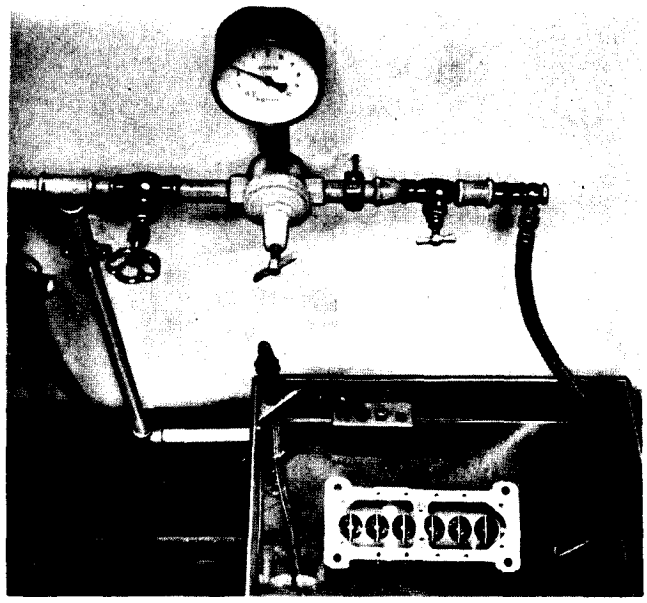


Fig. 29-35 Testing the barrel seat and fuel gallery leakage. *(Robert Bosch, GmbH, Stuttgart, West Germany.)*

pump design. As a general rule the test is made when the barrels and delivery valves are installed and the plungers (without springs) positioned into their barrels. The plungers are held in place by the tappet holders or through special holding bars.

To perform these leakage tests, connect an air line with a pressure regulator to the inlet manifold, and plug all other manifold openings. Immerse the pump in clean diesel fuel and pressurize the manifold to the specified pressure (see Fig. 29-35). Check for air bubbles at the barrel seat but disregard those which may appear at the pump plungers.

The fuel-injection pump [PE (S) PD . . . A type] shown in Fig. 29-36 is different from those previously mentioned but has much in common with a Caterpillar flange-type fuel-injection pump. The pump housing has no inspection covers or cover plates. Almost a completely sealed unit, it has only the necessary openings for the transfer pump, and threaded bores for the transfer-pump stud bolts, the control rod stop screw, the oil inlet, and the filter-mounting stud bolts. The gear segment is pinned to the lower end of the plunger, which brings the plunger in direct mesh with the control rack. The tappet roller has a hardened seat insert and a small guide pin. The pin is used to assist in timing the gear segment to the control rack. The barrel is sealed to the flange sleeve by a gasket. O rings are used to seal the flange sleeve to the pump housing and the delivery-valve holder to the flange sleeve. The barrel is positioned in the flange sleeve through the groove in the barrel and the pin in the flange sleeve. The flange sleeve, as on all PEP-type injection pumps, has elongated holes to adjust the plunger position (metering) and shims between it and the pump housing to adjust port closure. The barrel has a small drain passage leading from the inlet manifold to the plunger, to allow fuel used for lubrication to flow back to the manifold. Because of its design it has a long service life and requires minimal time to service and adjust. The entire pumping element can be moved without any special tools simply by centering the control rack, loosening and removing the flange sleeve nut, and then lifting the assembly from the pump housing. *(NOTE: The control rod must be centered because the slot on the gear segment must align with the guide pin in the tappet body. The camshaft can then be removed.)*

Servicing the Governor Because of the numerous governors available for use with port and helix fuel-injection pumps, only a generalization of common service points will follow. (Also see Unit 25, "Governors.") For detailed instructions, use the relevant service manual.

To service the governor shown in Fig. 29-37, first remove the components in the order suggested in the service manual. Wash all disassembled parts in clean diesel fuel and dry them with compressed air.

Inspect the governor housing for cracks or warpage. Check the fit between the control shaft and the bushings. Replace the bushings and/or the shaft if they are worn.

Inspect the bumper spring for evidence of wear and for weakness. Inspect the tension, guide, and floating lever bosses and pins for excessive wear.

Remove and replace the thrust bearing from the guide lever. (Use a punch in the holes provided to drive it from the guide lever.)

CAUTION Do not lose the adjusting shims.

Check the flyweights for wear. If the fingers have flat spots or if the pins are excessively worn, the weight assembly must be replaced. Use a puller especially designed to pull the assembly from the camshaft.

If the serviceability of the starting and governor springs is doubtful, replace them. Check all pins and bores which connect the various levers. There must be no evidence of looseness between them.

When you reassemble the governor, install new O rings and gaskets. Lubricate all the components during assembly. Governor adjustment is discussed later in this unit, under Adjusting, Calibrating, and Testing

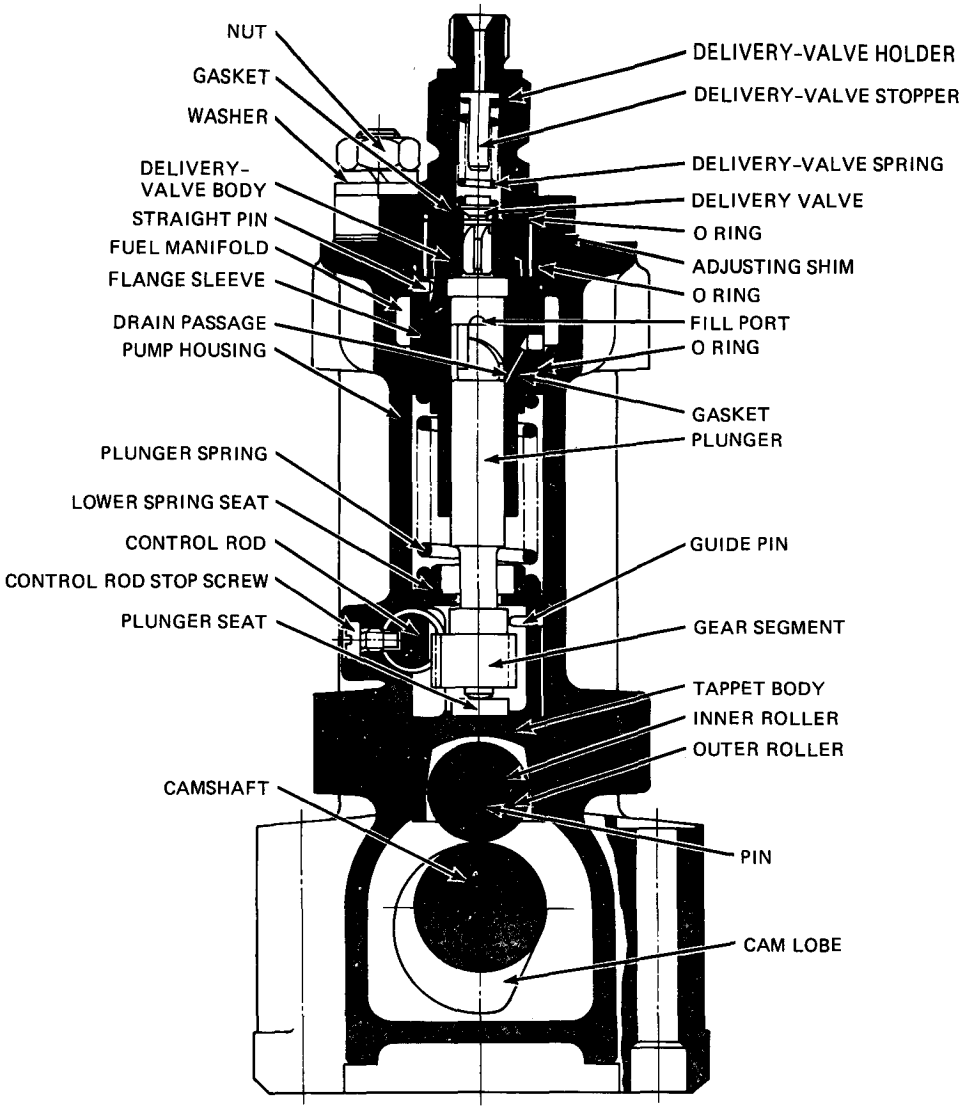
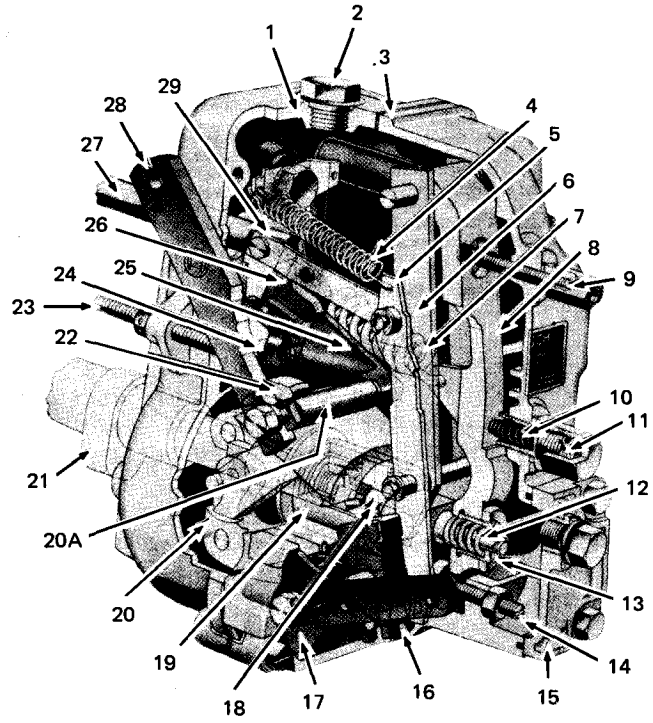


Fig. 29-36 Schematic sectional view of a PE(S)PD . . . A-type fuel-injection pump. *(Robert Bosch, GmbH, Stuttgart, West Germany.)*



1. Governor housing
2. Plug
3. Linkage housing
4. Starting spring
5. Floating lever
6. Guide lever
7. Governor spring
8. Tension lever
9. Low-idle adjusting screw
10. Bumper spring
11. Bumper screw
12. Torque-capsule spring
13. Torque capsule
14. Full-load stop screw
15. Rear plate
16. Shutoff arm
17. Shutoff lever
18. Guide lever link
19. Thrust sleeve
20. Flyweight
20A. Control shaft
21. Camshaft
22. Weight carrier
23. Shutoff adjusting stop screw
24. Rated speed adjuster
25. Control shaft
26. Swivel
27. Fuel rack
28. Throttle lever
29. Floating lever arm

Fig. 29-37 Sectional view of an RSV governor. *(International Harvester Company.)*

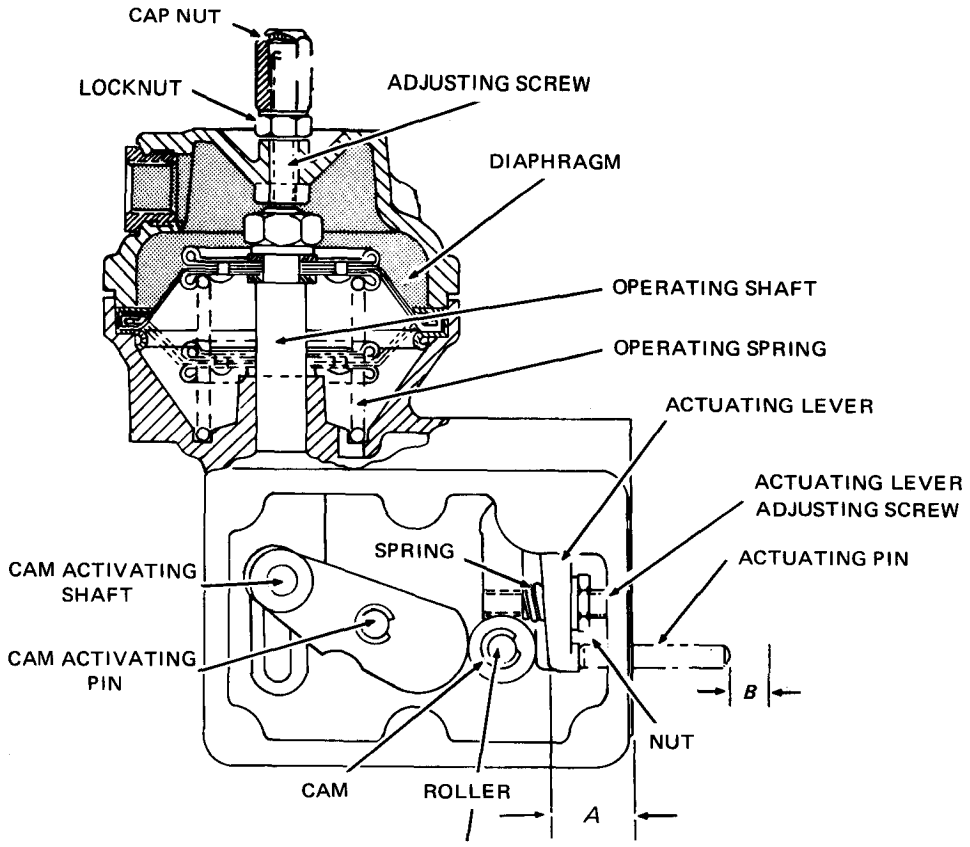


Fig. 29-38 Schematic view of a top-mounted aneroid. *(International Harvester Company.)*

Fuel-injection Pump on Test Stand. (See also Unit 26, "Antipollution Control Devices.")

Aneroids If an aneroid is used, it may be mounted on top of the governor housing or at the rear (see Fig. 29-38). The fuel-injection pumps (American or Robert Bosch) used on Mack engines have an air cylinder (Puff Limiter) screwed to the fuel-rack cap (Fig. 29-39), which acts directly onto the fuel rack. The Puff Limiter consists of two components: the normally retracted (because of spring force) air cylinder, and the reversing relay mounted and connected to the intake manifold. The purpose of the reversing relay is to provide an output (signal) air pressure to the air cylinder that decreases in direct proportion to the increased engine manifold pressure. The purpose of the air cylinder is to move the fuel rack in response to the air signal pressure. The air-spring service line (air brake) is connected to the reversing relay to provide actuating air pressure to the air cylinder, and, when the spring brakes are applied, to provide maximum rack travel for starting. The reversing relay is basically an inverse proportional pressure regulator, that is, the outlet pressure of the relay to the air cylinder is inversely proportional to the signal pressure (manifold pressure) from 0 to 28 psi [0 to 193.0 kPa], or, when the vehicle is operating, the high-limit pressure is governed by the inlet manifold pressure. For example when the service-inlet air pressure is at 100 psi [689.5 kPa], the reversing relay is preadjusted to give 28 psi [193 kPa] of outlet pressure to the air cylinder if zero signal (manifold) pressure is applied,

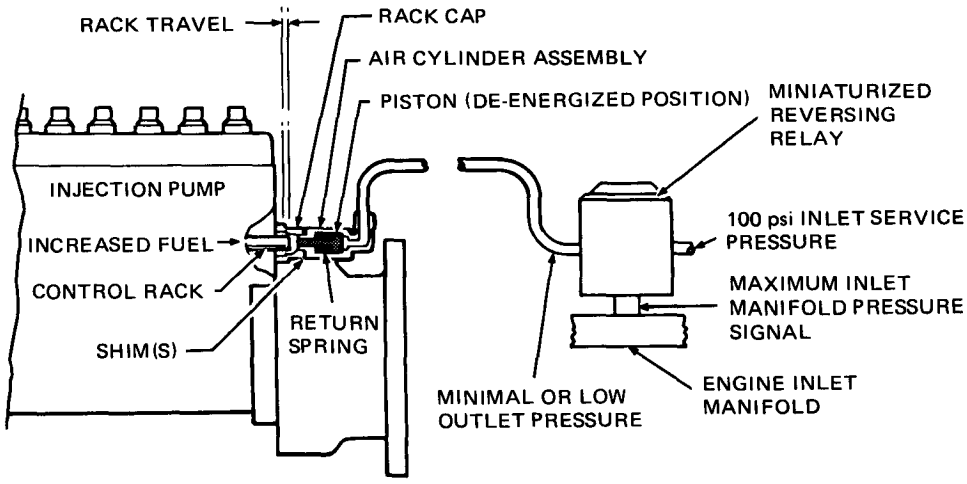


Fig. 29-39 Schematic view of Mack Puff Limiter when the signal (manifold) pressure is at or above 17 psi [117.2 kPa].

at which point the air cylinder moves the fuel rack to the reduced fuel position. If the signal (manifold) pressure increases from zero to 5 psi [34.4 kPa], the outlet pressure becomes 23 to 24 psi [158.5 to 165.4 kPa]. As the signal (manifold) pressure continues to increase, the outlet pressure decreases a like amount. The reversing relay is so designed that when the signal (manifold) pressure approaches 12 psi [82.7 kPa] the outlet pressure (to the air cylinder) is reduced to 16 to 17 psi [110.3 to 117.2 kPa]. This allows the spring force to move the air cylinder piston far enough to allow full rack travel. At 28 psi [193 kPa] of signal (manifold) pressure, the outlet pressure is zero and the piston is fully retracted. *(NOTE: The shims placed between the air cylinder and fuel-rack cap are used to establish at which signal pressure the rack travel is no longer restricted.)*

On American Bosch fuel-injection pumps, the air cylinder dimensions to be measured are stamped on the fuel pump house. Example: PLE 1.037 inches.

Transfer Pumps (Feed Pumps) To supply a constant fuel flow at a fixed pressure to port and helix fuel-injection pumps, four types of transfer pumps are used: (1) a positive displacement external gear-type pump, (2) a single-acting or (3) a double-acting non-positive plunger-type pump, and (4) a diaphragm-type pump.

The nonpositive plunger-type pumps are the most commonly used. When a relatively large fuel flow is required, a double-acting plunger pump is used; otherwise a single-acting plunger pump is used.

DESIGN AND OPERATION The double-acting plunger-type transfer pump, which is bolted to the fuel pump housing, consists of the components shown in Fig. 29-40. The plunger (piston) is loosely fitted within its bore and is forced through the plunger (pressure) spring toward the camshaft, which forces the pressure spindle with its tappet roller onto the fuel-injection-pump camshaft. When the engine is not operating, all four check valves are closed through their spring force. When the engine is operating and the camshaft eccentric approaches point *A* in Fig. 29-40*a*, the plunger is moved upward and several actions occur simultaneously. The pressure in the outer chamber decreases and the atmospheric pressure acting on the fuel in the fuel tank forces the fuel to open check valve No. 2 and to flow into the space vacated by the plunger. The upward movement of the plunger increases the pressure in the inner chamber, and the increased fuel pressure opens check valve No. 1, whereupon fuel flows into the system. When the eccentric has passed its maximum stroke, check valve No. 2 closes because of the pressure equalization in the outer chamber and the inlet line. Check valve No. 1 closes because of the higher pressure in the outlet line. The plunger spring force now moves the plunger toward the outer chamber (Fig. 29-40*b*), which causes the pressure in the inner chamber to decrease and in the outer chamber to increase. Fuel under atmospheric pressure forces check valve No. 4 to open, and fuel flows into the space vacated by the plunger. The increased fuel pressure in the outer chamber forces check valve No. 3 to open and fuel to flow into the system. When the eccentric is on the base circle, check valve No. 4 closes because of the equalized pressure in the inner chamber and inlet line, and No. 3 closes because of the higher outlet pressure.

At low-idle rpm, less fuel is needed and the plunger travel is only a few millimeters from its maximum stroke, or it may remain at its maximum stroke position. Consequently the double-acting transfer pump requires an overflow valve to prevent the fuel pressure from exceeding its specification.

TROUBLESHOOTING On the whole, a plunger-type transfer pump is seldom troublesome; however, if air from the transfer pump gets into the fuel, it may be because of a worn pressure stem or guide, or because of a damaged O ring. If the pump pressure is

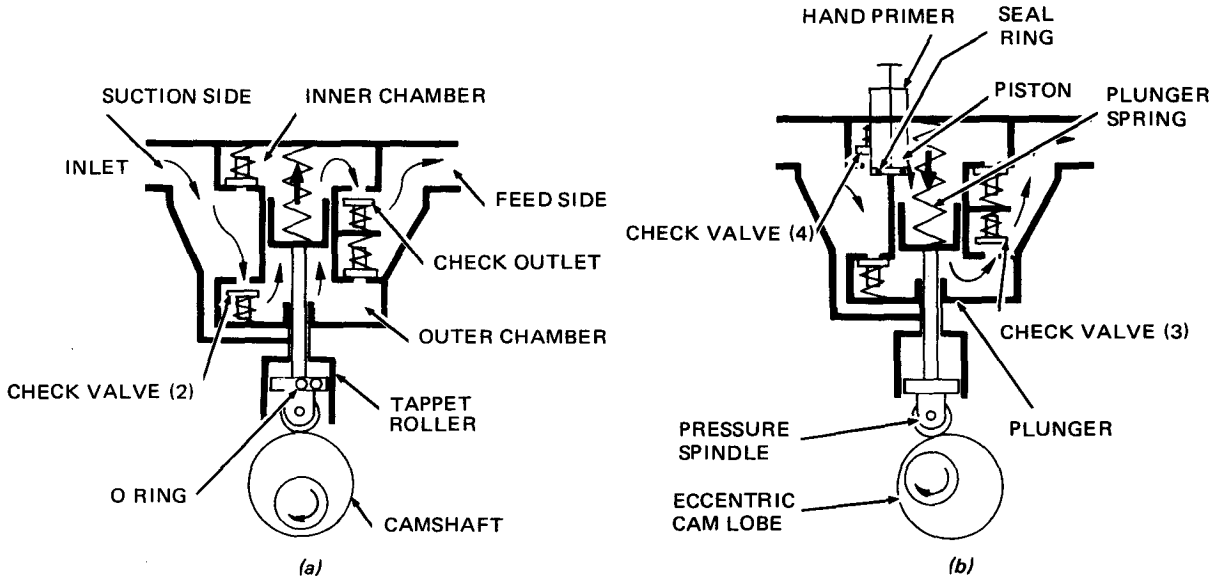


Fig. 29-40 Schematic view of a double-acting transfer pump (feed pump). *(Mack Trucks Canada Limited.)*

lower than specified but the overflow valve is not faulty, then one of the four check valves may be leaking. If the fuel flow is low, it may be because of a broken or weak plunger spring, or the plunger travel may be restricted because of an eroded or damaged plunger.

Automatic Timer To operate diesel engines while conforming to today's stringent emission laws without lowering the engine power, some injection pumps employ an automatic timer. It is positioned between the injection-pump camshaft and timing-gear train.

The automatic timer, in conjunction with the static engine timing, tailors the fuel-injection-pump camshaft at low engine rpm (retarded) to such an extent that the hydrocarbon (HC), which is normally high, is lowered, and tailors the camshaft advance so that the nitrogen oxide (NO_x), which is normally high, is lowered.

The mechanical automatic (advance) timers operate on basically the same principle. They rely on the centrifugal force of the flyweights to change the relation between the drive and driven components. The drive component is the timer housing to which the drive gear is bolted and driven by the timing-gear train. The driven component is a one-piece unit comprised of the driven flange, cam plate, and hub. The hub is fastened to the camshaft. The flyweights' pivot points (pins) are fastened to the timer housing. The inner and outer rollers (which reduce friction) are fastened to the end of the flyweights and rest in the curved contour of the cam plate. The spring seats rest on the flyweights' pivot points and the springs rest in the spring seat guides and cam plate guides. The timer is a self-contained, oil-lubricated unit, sealed through the oil seal, flange cover, and timing housing (Fig. 29-41). *(NOTE: By varying the cam contour and/or spring force, the beginning of advance as well as the advance curve can be tailored to a specific engine.)*

OPERATION When the engine operates below 800 rpm, the flyweights' force is not high enough to overcome the spring force; therefore the camshaft does not advance. As the rpm increase, the flyweights' ends with the rollers move outward within the contour of the cam flange surfaces, thus forcing the assembly (that is, cam flange, drive flange, hub, and camshaft) to rotate counterclockwise, which is the same direction in which the housing is driven. Consequently, the beginning of injection is advanced. At about 1600 rpm, the flyweights' wear buttons have come to rest against the drive flange and therefore the injection-pump camshaft has advanced to its maximum.

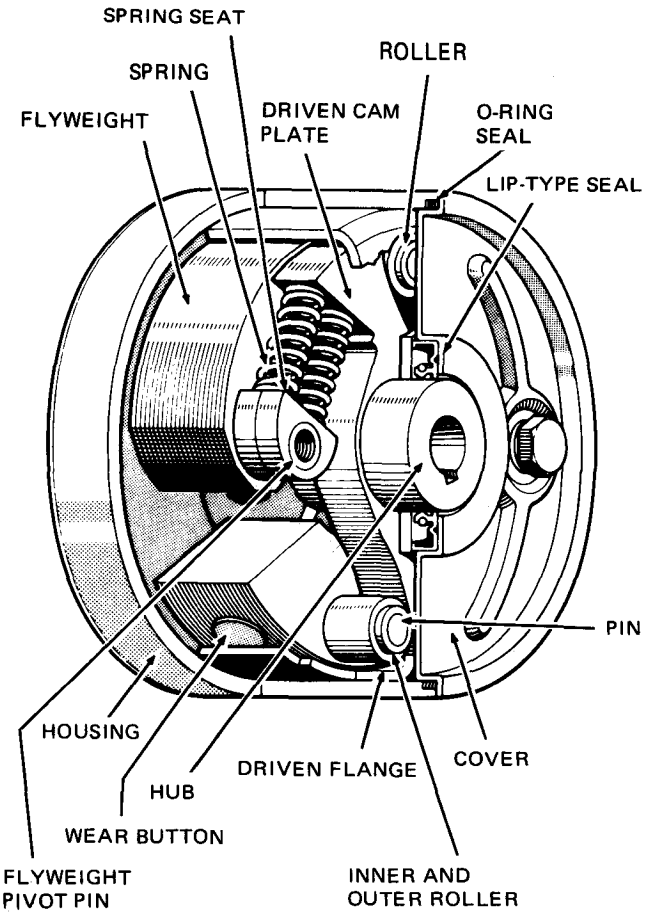


Fig. 29-41 Schematic view of automatic timer in maximum advance position. *(Robert Bosch, GmbH, Stuttgart, West Germany.)*

ADJUSTING, CALIBRATING, AND TESTING FUEL-INJECTION PUMP ON TEST STAND

After a fuel-injection pump is serviced, it must be calibrated and the governor must be adjusted. Calibration is an adjustment of the pumping elements to ensure that each delivers the same specified quantity of fuel, that is, that the beginning of injection is equally divided within 360° (phase angle). The governor must be adjusted to ensure high-idle, low-idle, and maximum fuel delivery.

Mounting Injection Pump to Test Stand Mount the injection pump to the test stand, but make certain that the drive couplings are aligned, and allow a small clearance between them.

Fill the injection-pump housing and the governor housing with lubricant to the specified level or on newer injection pumps connect an oil-supply pump to the recommended fittings. Install the recommended test injectors and injection lines.

With hoses, connect the transfer pump to the test-stand *lift* fitting and the transfer-pump outlet to the fuel manifold of the injection pump.

Back out the high-idle and the low-idle adjusting screws. If equipped with a damper or buffer screw, back it out the specified distance.

If an aneroid is installed, carefully follow the manufacturer's instructions regarding removal or setting.

Open the bleed screw at the injection pump and injector holders. Select the correct test-stand rotation and, if an external oil supply is used, switch on the motor and adjust the oil pressure as specified (Fig. 29-42).

Measuring and Adjusting prior to Pump Calibration Diesel engines are extremely sensitive to injection-pump timing and to the phase angle

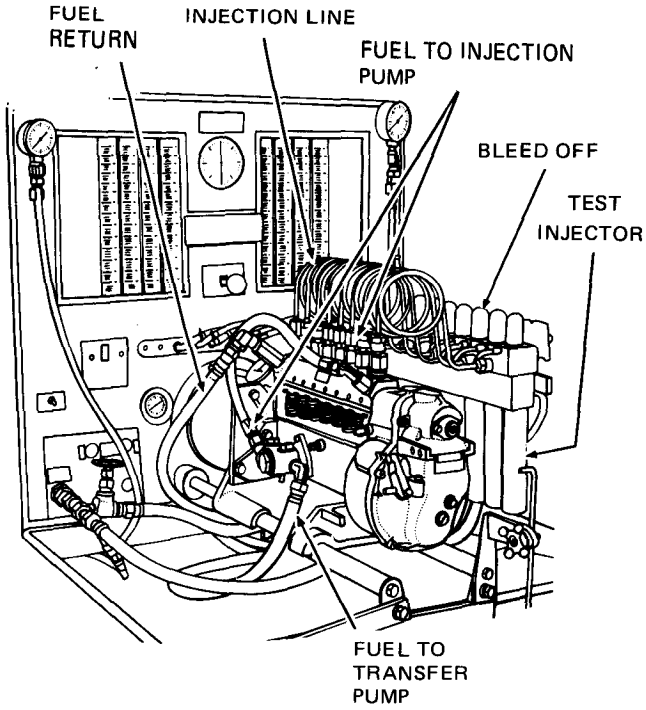


Fig. 29-42 Schematic view of injection-pump-to-test-stand mounting. *(International Harvester Company.)*

between the pumping elements. Therefore these are the first two elements to check when measuring and adjusting pumps.

Measuring and Adjusting Head Clearance (1-mm Specification) To ensure that No. 1 plunger is positioned correctly within the barrel in regard to port closure and camshaft cam-to-plunger alignment, the plunger lift or head clearance must be measured first, and, if necessary, adjusted. To measure the head clearance, remove the delivery-valve holder, valve, and spring. Replace the delivery-valve holder, and tighten it to the specified torque. Place the extension of a depth dial indicator through the delivery-valve holder as shown in Fig. 29-43. With the plunger at TDC, the extension resting on the plunger head, and the base of the dial gauge resting firmly on the holder, zero the dial. Gently lift the tappet roller until the plunger contacts the delivery-valve body. Since the lift is transmitted to the dial gauge, the dial will indicate the distance the plunger has moved. With the tappet screw, adjust the head clearance until the plunger travel is 1 mm.

When a tappet spacer or a shim is used instead of a tappet screw, record the reading, and then bring the tappet roller to the BDC position. Lift out the snap ring, spacer, or shim. Measure its thickness with a micrometer. Select another shim or spacer to give a head clearance of 1 mm. Install the new shim or spacer. Recheck the head clearance.

Another method of adjusting the head clearance is to bring the plunger to the TDC position. Turn the tappet adjusting screw until the plunger lightly contacts the delivery-valve body. Then make one complete turn, counterclockwise, and tighten the locknut. This procedure also gives a 1-mm head clearance since the tappet screw has a 1-mm pitch.

Measuring Pump Lift and Spill-timing Port Closure The preparations for plunger lift measurement varies slightly among manufacturers and even among models of individual manufacturers because of the numerous types of governors. An example of preparation variation would be a fuel-injection pump having an RVO governor from which the stop part assembly must be removed, as compared to certain other injection pumps where the Puff Limiter or the aneroid must be removed. Common procedures from this point are as follows: Remove the fuel-rack end cap, install the dial indicator (Fig. 29-44). From No. 1 pumping element remove the delivery-valve holder, filler, spring, gasket, and delivery valve. Next, screw a dial indicator having the proper extension length onto the flange housing or delivery-valve holder (see Fig. 29-45).

NOTE: The Robert Bosch MW fuel-injection pumps have a side plug so that the dial indicator can be installed in such a way, after the plug is removed, that its lever arm can be placed onto the tappet face. As a result, the delivery valve does not need to be removed.

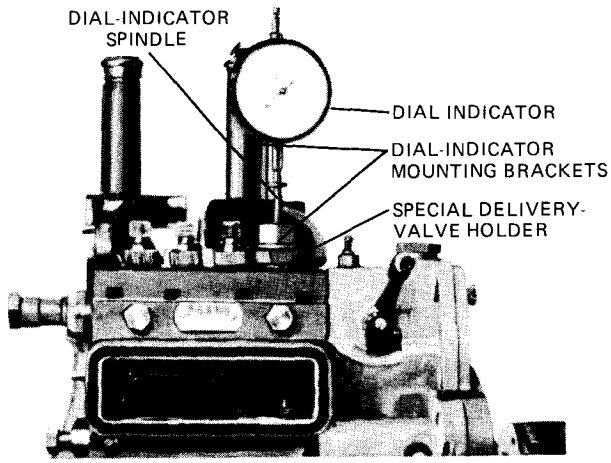


Fig. 29-43 View of dial indicator installed to measure head clearance. *(CAV Limited.)*

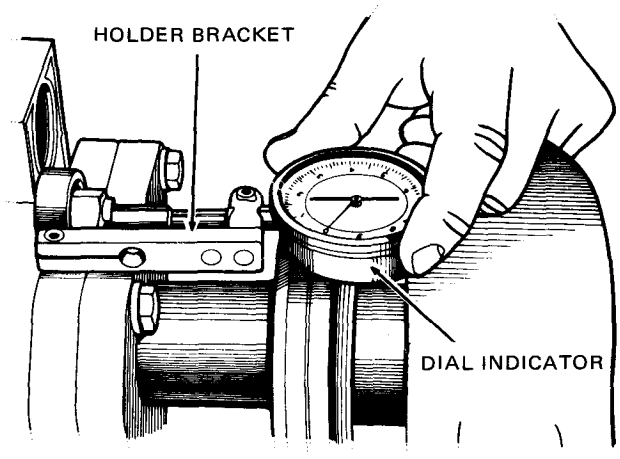


Fig. 29-44 View of dial indicator installed to measure fuel-rack travel. *(International Harvester Company.)*

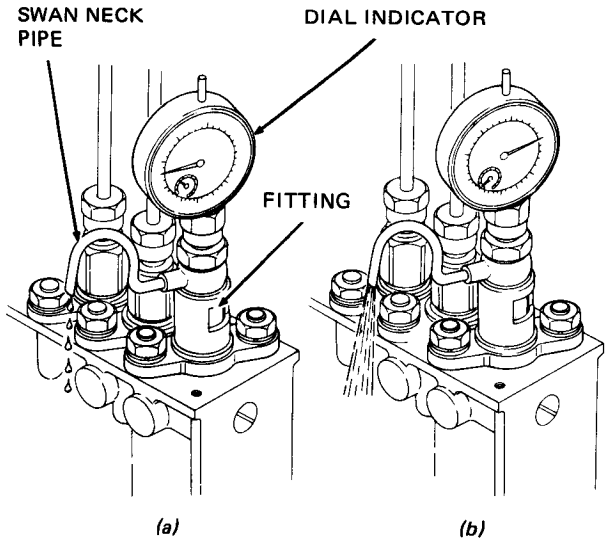


Fig. 29-45 Schematic view of test instrument installed to measure plunger lift and port closing. *(International Harvester Company.)*

Pull the shutoff lever into the shutoff position and zero the dial on the fuel rack. Next, with the shutoff or throttle lever move the fuel rack to the position where the dial gauge reaches the service manual specification. This movement could vary between 10 and 17 mm, depending on manufacturer and model.

No. 1	No. 5	No. 3	No. 6	No. 2	No. 4
0°	60° ±½°	120° ±½°	180° ±½°	240° ±½°	300° ±½°

Determine the injection-pump rotation and firing order. For an example of clockwise rotation, firing order and phase angle, see the chart above. Rotate the camshaft clockwise until the tappet roller of the No. 1 pumping element is on the cam base circle, then zero the dial. Rock the camshaft slightly in both directions. The dial should remain at zero. Open the test-stand fuel supply to introduce a low-pressure fuel flow into the injection pump. At this point fuel should flow freely from the swan neck pipe (Fig. 29-45*b*). Turn the camshaft slowly in clockwise rotation only until the fuel stops flowing from the swan neck pipe (Fig. 29-45*a*), or until the flow is reduced to the specified number of drops within the specified time. Read the dial indicator to determine if the plunger lift measurement is correct. If so, turn the camshaft about 30° counterclockwise, and then again slowly clockwise, only until the fuel flow stops. Both dial readings should be equal and must, for example, be around 2.8 to 2.9 mm. If the dial reading is say, about 4.1 mm, it indicates that the injection-pump plungers have starting notches and that the fuel rack is not in the correct position. If the dial reading is more or less than specified, an adjustment must be made. When the tappets have adjusting screws, the screws must be lowered by the same distance the dial reading is less than specified, or raised when the distance is more than specified. *(NOTE: One complete turn of the adjusting screw is 1.0 mm and about 12° of camshaft rotation.)* When shims or spacers are used on tappet rollers to adjust port closure, the replacing shim or spacer must be slimmer when the dial reading is less than specified, or increased in thickness when the dial reading is more than specified. When shims are used to raise or lower the barrel, loosen the flange housing nuts and with two screwdrivers pry the flange slightly upward. If the dial reading is less than specified, add a shim of the required thickness to bring the plunger lift to specification. Remove a shim when the dial reading is more than specified. The shims are added to or removed from each side, between the flange housing and pump housing surfaces. When adjustment is made and the nuts retorqued to specification, repeat the plunger lift measurement. *(NOTE: On some Robert Bosch fuel-injection pumps you must remove the barrel assembly as well as the O ring and plastic ring from the flange housing in order to install the shims. In such instances make certain you follow the manufacturer's instructions when reinstalling the pumping element.)*

When port closure is established, move the test-stand degree wheel to zero and check the injection-pump timing marks. If they do not align, remove the timing mark from the coupling or from the component recommended, and inscribe a new line to coincide exactly with the timing pointer or bearing housing.

To adjust the first pumping element of an American Bosch fuel-injection pump, the preparation is similar. Remove the delivery valve and fasten a swan neck pipe to the delivery-valve holder. Bring No. 1 tappet roller onto the cam base circle. Introduce a low-pressure fuel flow to the injection pump and turn the camshaft in the rotation of drive until the fuel flow from the swan neck pipe decreases to one drop in 10 seconds. The timing marks on the camshaft and pump housing should align. If not, and say the camshaft timing mark has passed the housing mark, the tappet-roller adjusting screw must be turned counterclockwise to raise the plunger on in-line fuel-injection pumps, and on the V-type fuel-injection pumps a thicker shim must be installed. When the adjustment is made, lock the adjusting nut and repeat the spill-timing procedure previously outlined for No. 1 element. The procedure must be repeated until the timing marks align. When the alignment is achieved, use a screwdriver and gently pry the plunger upward and note its movement. There must be a head clearance.

Spill-timing for Port Opening (Upper Helix)

The preparations when spill-timing an injection pump for port opening (upper helix) are the same as when spill-timing a pump for port closure. However, some manufacturers recommend checking and adjusting the head clearance first.

NOTE: PO (Port Opening) identifies the type of plungers within the injection pump; that is, it has variable-beginning and constant-ending plungers.

To spill-time the No. 1 pumping element, position No. 1 plunger at BDC, turn on the fuel, and allow it to flow out of the swan neck pipe. Slowly turn the camshaft in the drive rotation. This will cause the upper helix on the plunger to gradually close the inlet port, decreasing the fuel flow. From this point on,

slowly rotate the camshaft. As the helix closes the inlet port, the fuel flow will be reduced to a dribble because now the fuel is pumped out of the pipe through the action of the pump plunger. As soon as the upper edge of the vertical groove on the plunger opens the spill port and/or inlet port, fuel under pressure again starts to run out of the swan neck pipe. To be positive that the point of port opening is correct, this procedure should be repeated several times before placing the new timing mark on the drive coupling or zeroing the test-stand degree wheel.

Indexing Timing Pin On some injection pumps, after establishing the plunger travel and port closure you must then index the timing pin. The timing pin, when pushed inward, must slide unrestricted into the camshaft notch without varying the injection-pump timing. If it does not slide in easily, remove the timing-pin assembly, remove the dowel pin from the timing-pin cover, reinstall the cover, and loosely secure the assembly to the pump. Next, index the timing pin and tighten the cover bolts to specified torque, but make certain the injection-pump timing marks are aligned. Then drill a hole for a new dowel pin.

The next step is to adjust the phase angle of the remaining pump elements. *(NOTE: Most injection-pump specifications allow a tolerance of ± ½° in the phase angle.)*

Phase Angle Adjustment (Low Pressure) To adjust the phase angle of the remaining pump elements, remove the delivery valve, delivery-valve stop, and spring from the element next in the firing order (No. 5). Then replace the delivery-valve holder and retorque it to specification. Install the swan neck pipe to this holder. Turn on the low-pressure fuel supply. The point of port opening or port closure for the No. 5 element is obtained by the same method outlined for the No. 1 element. [See earlier sections Measuring Plunger Lift and Spill-timing Port Closure, and Spill-timing for Port Opening (Upper Helix).]

When the tappet screw, shim, or spacer is correctly adjusted, the port closure or port opening should be exactly 30° from the adjacent pump element for a 12-cylinder pump, 60° for a six-cylinder pump, 72° for a five-cylinder pump, and 90° for a four-cylinder pump. If the phase angle is greater than ½°, the plunger must be raised. When the phase angle is smaller than −½°, the plunger must be lowered. Repeat this procedure until all plungers are adjusted.

NOTE: After each port closure or port opening adjustment, check the head clearance using a screwdriver. A clearance is essential, but it need not be measured.

Recheck port closure or port opening of the No. 1 element to be sure that the pointer or degree wheel has not moved during the phasing operation.

Phase Angle Adjustment (High Pressure) High-pressure phasing follows the same procedure outlined under Phase Angle Adjustment (Low Pressure), except that the delivery valves need not be removed. Consequently it is not only faster but also more accurate.

After the plunger lift and spill-timing for port closure is made, or the head clearance and port opening is made, open No. 1 test-nozzle bleed screw and turn the camshaft in the drive rotation until No. 1 plunger is at BDC. Slowly open the fuel feed valve until the fuel pressure lifts the delivery valve off its seat, whereupon fuel will flow out of the bleed hose. Slowly turn the camshaft until the flow reduces to drops or almost stops, for example, one drop every 5 to 10 seconds. (See service manual for specific information.) When this point is established, the injection-pump timing lines should coincide. Set the test-stand degree wheel to zero. Close No. 1 bleed screw and open No. 5 bleed screw. Fuel should flow freely from No. 5 bleed hose. If it does, slowly turn the camshaft until just one drop falls off the hose in about 5 to 10 seconds. Now check the degree wheel. It should be 60° ± ½°. If this is not the case, you must adjust the plunger as outlined previously. Repeat these procedures until all plungers are adjusted.

Calibration It is not practical nor is it the purpose of this text to outline calibration procedures for all fuel-injection pumps. There are service manuals to serve this purpose. However, the calibration procedure for the PE(S)-6 MW fuel-injection pump with an RSV governor will be outlined and a comparison made between it and other fuel-injection pumps.

Testing Transfer Pump After the fuel-injection pump is phased, the flange nuts retorqued, and the fuel-injection lines connected, the transfer pump must be tested. First, set the throttle in maximum fuel position. Operate the test stand at the recommended rpm (1000 rpm). Then gradually close the fuel lift valve until the vacuum gauge shows the required minimum vacuum (18 inHg [45.7 cmHg]). Next, open the valve and check the transfer-pump pressure (32 psi [220.6 kPa]). *(NOTE: Do not proceed with any other tests if the transfer pump is not within specification.)*

Assuming the transfer-pump tests are within specification, the second test is to determine maximum rack travel. The maximum rack travel is measured by moving the shutoff lever fully to the no-fuel position and holding it there while zeroing the dial indicator (see Fig. 29-44). After zeroing the dial indicator, release the shutoff lever. The dial indicator should then read 21.0 mm ± 0.2 mm. Next, select the test-stand rotation, start the motor, and operate it at about 500 rpm to warm up the injection pump and test oil and to reveal any oil or fuel leaks. When the test oil is within 105 to 115°F [40.5° to 46.1°C], stop the test-stand motor and remove the low-idle screw bumper spring and torque capsule. Place the throttle against the high-idle stop screw and hold it there.

Rated Speed Fuel Delivery Restart the motor and gradually increase the rpm to rated speed (1250 rpm). Read the rack travel from the dial gauge. It should be 7.4 mm. If this cannot be achieved, check if the rack bottoms on the dial indicator; if not, remove the rear cover, loosen the maximum-load screw locknut and then, with a screwdriver, turn the maximum-load adjusting screw counterclockwise to decrease rack travel, or clockwise to increase rack travel (Fig.

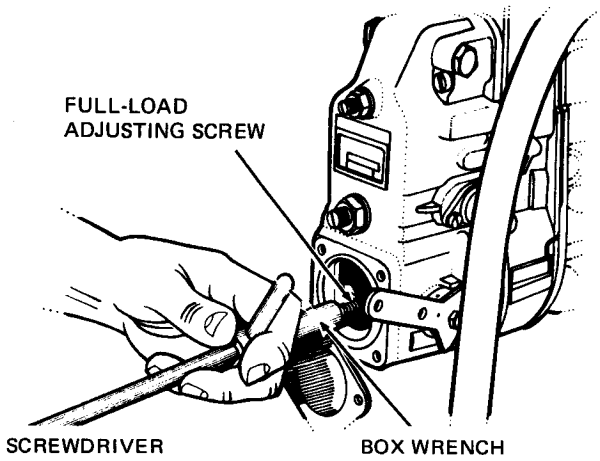


Fig. 29-46 Schematic view of adjusting rated speed fuel-rack travel. *(International Harvester Company.)*

29-46). When the rack-travel adjustment is made, slowly increase the test-stand speed until the dial gauge reads 7.1 mm. The test-stand speed should not have increased more than 20 rpm above rated speed. If the rpm is higher, turn the high-idle adjusting screw clockwise; if it is lower, turn the adjusting screw counterclockwise and retest rated speed fuel delivery.

Breakaway Test Next is the breakaway (cutoff) test. This test determines when the governor moves the fuel rack to reduce fuel. To make this test, increase the test-stand rpm to 1400 rpm and note the rack travel. It should be 3.1 mm. Next, slowly increase the rpm to 1475. At 1475 ± 25 rpm the rack dial indicator should read 1.7 to 0.03 mm. If the breakaway rpm is too high or too low, the governor rear cover must be removed, the governor weight bearing pulled from the guide lever, and shims added to reduce, or shims removed to increase, rack travel. *(NOTE: Use a shim the thickness of one-half the distance which the rack travel exceeds specification. Example: Rack travel measurement 2.7 mm (2.7 − 1.7 = 1 mm). Add a shim at least 0.8 mm thick.)*

Balancing Plunger Delivery Adjust the test-stand rpm to rated speed (1250 rpm). Place the throttle in full-fuel position. Set the test-stand counter to 1000 strokes and trip the counter. Each pump element should have produced an output of 69 to 71 cm^3. If not, an adjustment is necessary. Lower the test-stand rpm to idle speed, then stop the motor. Scribe a line on each flange, extending the line onto the pump housing surface so as to identify the original flange position. Loosen the injection line nut and flange nuts of the elements you must adjust. (Use two wrenches, one on the nut, the other on the holder.) Place a flared-nut wrench onto the delivery-valve holder and turn the assembly slightly, clockwise (viewing from the top) to increase, or counterclockwise to decrease, fuel delivery. This adjustment is, at first, time-consuming for most mechanics because they are inclined to overadjust, but this problem is soon overcome. After the adjustments are made, torque the flange nuts and then the fuel line nut to specification and then repeat the rated fuel delivery test.

Minimec Adjustment On a Minimec fuel-injection pump, set the first control rod fork at 0.020 in [0.5 mm] from the square section on the control rod (Fig. 29-47). Start the test stand. Place the throttle in the full-fuel position. Set the counter to the recommended stroke and then check the delivery of the No. 1 pump element. If the delivery is lower than specified, adjust the maximum fuel stop screw until the maximum fuel delivery from the No. 1 element meets specification. Repeat the test several times to ensure proper adjustment. Then lock the fuel stop screw. Position the other control fork on the control rod so that the delivery from each element is the same as it is from No. 1 element. Operate the test stand at rated speed; then increase the speed by 10 percent. At this point the control rack should retract to the left. If not, use the high-idle adjusting screw to achieve this action.

To check high-idle fuel delivery, place the throttle in full-fuel position, operate the test stand at high-idle rpm, and trip the counter. If the fuel delivery is lower than specification, increase the governor spring tension. If it is higher, decrease the tension.

To check low-idle fuel delivery, place the throttle in low-idle fuel position, operate the test stand at low-idle speed, and trip the counter. If the fuel delivery is not within specification, say it is low, turn the idle adjusting screw clockwise, or if it is high turn the screw counterclockwise. When the adjustment is completed, lock it with the locknut.

To check starting fuel delivery, operate the test stand at cranking speed. Press the excess fuel button inward while placing the throttle in full-fuel position. Trip the counter. The delivery must be within specification.

On fuel-injection pumps having a gear segment fastened to the control sleeve, the adjustment is made by loosening the gear-segment clamp screw, and with a welding rod inserted into the control-sleeve insert (or as shown in Fig. 29-48), turn the control sleeve counterclockwise to increase, or clockwise to decrease, fuel delivery. *(NOTE: When all elements are adjusted, scribe a line from the gear segment onto the control sleeve for future reference.)*

Low-idle Fuel Delivery (MW) Operate the test stand at 350 rpm and place the throttle in low-idle fuel position. If the fuel-rack dial indicator does not read 5.6 mm, then adjust the throttle lever until you achieve this specification. Trip the counter. The fuel delivery should be 18 to 22 cm^3. *(NOTE: The maxi-*

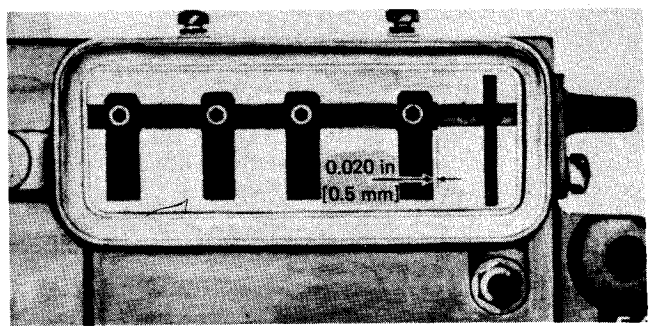


Fig. 29-47 Setting the first control fork to specification. *(CAV Limited.)*

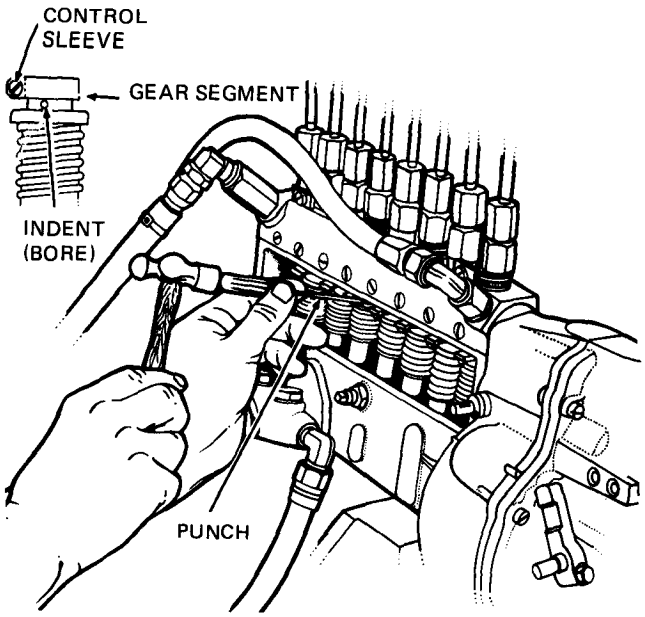


Fig. 29-48 Schematic view of adjusting balance delivery. *(International Harvester Company.)*

mum fuel delivery variation between pumping elements is ± 1 cm³ at rated speed and ± 2 cm³ at idle speed. If fuel delivery cannot be achieved within these limits, the pumping elements must be replaced.)

High-idle Fuel Delivery Operate the test stand at high idle (1400 rpm) and then trip the counter. The fuel delivery should be 25 to 27 cm³ at a fuel-rack travel of 3.1 mm. If the fuel delivery is not within these specifications, place the throttle in low-idle speed position and with a screwdriver (Fig. 29-49) turn the governor-spring control screw (located on the swivel lever with rocker) clockwise to increase, and counterclockwise to reduce, fuel delivery.

If an adjustment has been made, you must recheck high-idle fuel delivery, breakaway, and rated fuel delivery. *[NOTE: At this time, as you check the breakaway, also adjust the bumper spring. When operating at 1475 rpm, screw the bumper spring clockwise until the fuel-rack dial moves slightly. Then back off the bumper screw 1½ turns and lock the adjustment (Fig. 29-50).]*

Overspeed Shutoff Fuel Delivery Operate the test stand at high idle with the throttle in full-fuel position, then slowly increase the rpm to 100 rpm above high-idle speed. Trip the counter; the fuel delivery should then be 0.4 cm³ maximum.

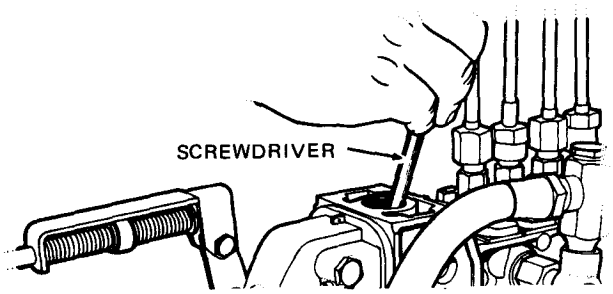


Fig. 29-49 Schematic view of adjusting governor spring control screw. *(International Harvester Company.)*

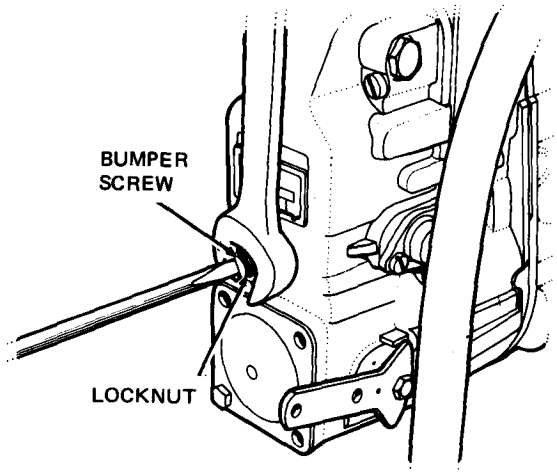


Fig. 29-50 Schematic view of bumper screw adjustment. *(International Harvester Company.)*

Torque-speed Fuel Delivery First install the torque capsule using the special tools shown in Fig. 29-51. Next, operate the test stand at rated (1250) rpm and screw in the torque capsule until the rack dial indicator moves, then back off until the rack setting dial returns to 7.4 mm. Now operate the test stand at 800 rpm (torque check speed) and trip the counter. The fuel delivery should be 82 to 85 cm³ at a rack setting of 8.6 mm. If the rack travel and fuel output is not within specification, turn the torque capsule clockwise or counterclockwise to achieve the rack travel and fuel output. If the fuel delivery remains below specification but rated and high-idle fuel delivery is as specified, yet an adjustment of the torque capsule does not achieve specified fuel delivery, replace the torque capsule and repeat the test.

Cranking Fuel Delivery Operate the test stand at 100 rpm with the throttle in the starting fuel position, then trip the counter. The fuel delivery must be 140 cm³ minimum, with a fuel-rack dial reading of 19.0 mm minimum. If this is the case, increase the rpm and note at which rpm the fuel rack moves from its maximum position. It must hold its maximum position up to 500 rpm. At this point, the force on the fulcrum

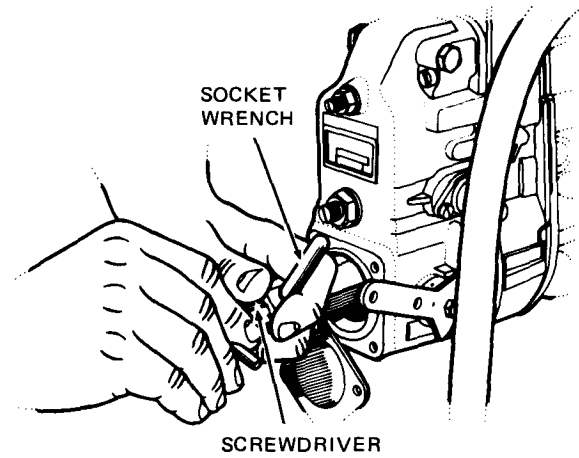


Fig. 29-51 Schematic view of adjusting the torque capsule position. *(International Harvester Company.)*

lever is so strong that the magnet, located in the governor housing, releases the lever. If the rack moves too soon, the magnet is either weak, or loose in the housing, and the magnet must therefore be replaced. If the rack moves out of its position above 500 rpm, this is an indication that some parts of the governor are binding, thus increasing friction; therefore the governor must be rechecked.

Testing and Adjusting Aneroid The last test on an injection pump having an aneroid is to test and adjust the aneroid. To check the aneroid, connect, through a T fitting, an air supply line and a mercury manometer to the inlet port of the aneroid fitting. The air supply line must have a pressure regulator (Fig. 29-38).

Loosen the locknut and turn the adjusting screw until it stops. Now apply a pressure of 2 to 3 inHg [5.08 to 7.62 cmHg] to the chamber and observe the cam. It should have barely moved. Then increase the pressure to 12 inHg [30.4 cmHg]. The cam should have fully extended. If not, remove one of the shims which are between the diaphragm and housing to extend the travel. Increase the pressure to 20 inHg [50.4 cmHg]. Shut off the air supply, and check the pressure drop. It should not exceed 2 inHg [5.04 cmHg] in 10 seconds. If it does, perhaps there is an air leak in the diaphragm. If there is no leak, then the mating surfaces should be checked.

Open the air supply line and maintain a pressure of 20 inHg [50.4 cmHg] in the chamber and measure the distance *A* in Fig. 29-38. If necessary, use the actuating-lever adjusting screw until the specified distance is achieved. This adjustment ensures a clearance of 0.010 to 0.030 in [0.254 to 0.761 mm] between the actuating pin and the activating lever. The adjusting screw limits the retraction of the diaphragm which, in turn, limits the maximum travel of the actuating pin.

To adjust the travel distance, again apply a pressure of 20 inHg [50.4 cmHg] to the chamber, and then measure the distance *B*. Then reduce the chamber pressure to zero. Measure the distance again. It should have decreased by 0.165 in ± 0.010 in [4.191 mm ± 0.25 mm].

Turn the adjusting screw until the travel distance reaches specification. Use pressure to cycle the aneroid a few times to be sure that the assembly is working smoothly without binding.

Electron Phasing and Automatic Timer Check When each pumping element is adjusted for port closure or port opening, check the phase angle and switch on the electronic phase unit and the No. 1 selector switch. Start the test-stand motor and operate it at 500 rpm with the throttle in full-fuel position. Rotate the degree wheel (Fig. 29-52) so that the flash accurately coincides with the zero on the wheel. Then switch on the remaining selector switches. Note the flash and the angle position of all elements.

To check the automatic timer if so equipped, gradually increase the test-stand rpm and note when the camshaft (injection) starts to advance and at what rpm it has reached its maximum advance. Check the test-stand results with the service manual specification.

Injection-pump Installation Before you install a new or reconditioned injection-pump, make certain the cause of the pump failure has been corrected. Replace all the fuel filters and, when necessary, clean the fuel tank.

To position the No. 1 piston on the compression stroke and the crankshaft on the timing mark (when the firing order is 1-5-3-6-2-4), remove the rocker cover to visibly expose the valve action of the No. 6 cylinder. Turn the crankshaft in the direction of normal rotation until the intake valves of the No. 6 cylinder start to open. This ensures that the No. 1 piston is on its compression stroke. Continue to rotate the crankshaft until the engine-timing degree mark lines up with the pulley or flywheel mark.

Loosen the drive-coupling bolts. Align the timing marks on the injection pump and slide the injection pump into place. Align the pump to the coupling (use a feeler gauge). Then tighten the mounting and the drive-coupling bolts.

To recheck the injection pump to engine timing, turn the crankshaft 90° counterclockwise, then clockwise until the engine timing degree mark aligns with the pulley or flywheel mark. Then check the injection-pump timing mark. During the cranking, check the alignment of the drive couplings, if applicable.

When you install and time an injection pump with a fixed drive gear or drive coupling, first time the engine and the injection pump, and then slide the pump into position (Fig. 29-53). Always install a new gasket or well-lubricated O ring to seal the injection pump. Support the pump to its mounting with the nuts or bolts, but do not tighten them because it may be necessary to rotate the pump toward or away from the engine in order to align the injection-pump timing marks. Place the drive gear on the camshaft drive flange, and tighten the bolts to the recommended torque. *(NOTE: Always recheck the timing.)*

Check the engine timing marks and the timing marks of the injection pump. If the timing marks of the pump do not coincide, rotate the pump to bring

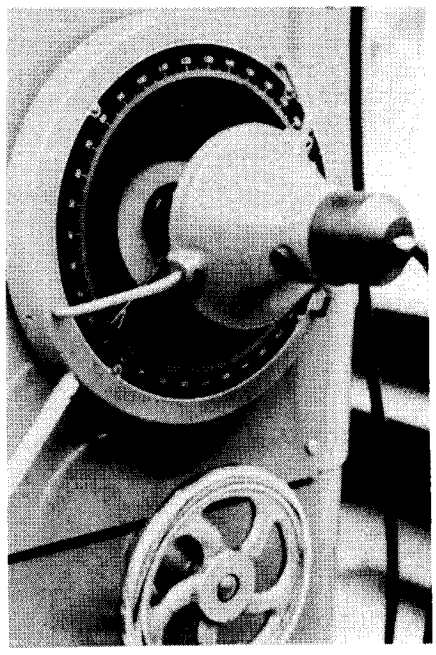


Fig. 29-52 View of electronic phase unit.

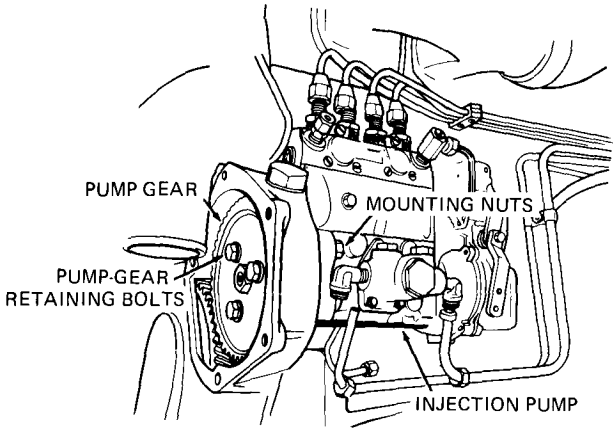


Fig. 29-53 Installing an injection pump having a fixed drive gear. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

them into alignment. Then tighten the mounting nuts or bolts to the recommended torque.

Some fuel-injection pumps are not timed by rotating the pump. Instead the injection-pump driven gear has slotted mounting holes to facilitate timing adjustment. The drive gear is either bolted to the injection-pump coupling, or to an automatic timer (advance unit) (see Fig. 29-54).

To time the injection pump where the drive gear has elongated mounting slots, time the engine and the injection pump. Center the slots, and then install and tighten the injection pump to its mounting flange or base. (On large injection pumps use a sling and hoist to lift and hold it in position.)

Take up the gear backlash before tightening the drive gear cap screws. Rotate the crankshaft 720° to recheck the timing and then secure the capscrews with the locks.

CAUTION When using a timing pin, do not forget to remove it before turning the engine over; otherwise the injection pump will be damaged.

When installing a fuel-injection pump having an adjustable drive coupling, loosen the two cap screws which hold the two halves of the coupling together (Fig. 29-55). Time the injection pump and engine, and then mount the pump to the engine. Then take out the gear lash, but make certain that you do not change the engine or injection-pump timing. Now tighten the two coupling cap screws to specified torque and recheck the injection-pump timing.

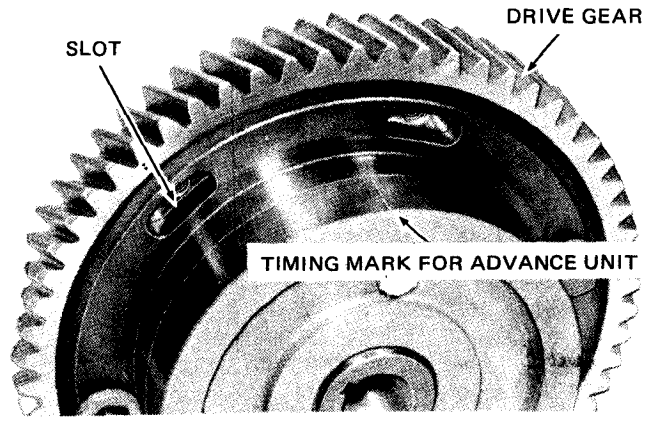


Fig. 29-54 View of injection-pump drive gear installed on timing advance unit. (Advanced unit removed for clarity.) *(International Harvester Company.)*

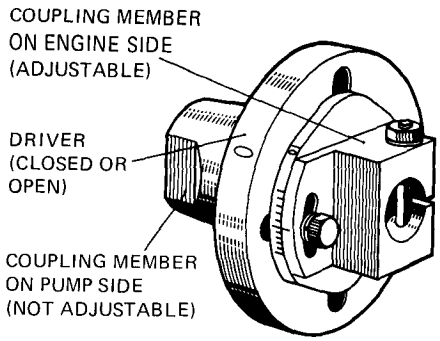


Fig. 29-55 Schematic view of an adjustable drive coupling.

Bleeding (Venting) Fuel-injection System After the injection pump is timed to the engine and its mounting bolts are torqued to specification, connect the low-pressure fuel line, the injection lines, the throttle, the shutoff control, and the lubrication hoses to the injection pump, and the air line to the aneroid.

Bleed the air from the filters, fuel lines, and the injection pump to prevent inadequate pump element lubrication and possible damage to the closely fitted parts.

The bleed method recommended varies relative to the injection-pump construction, the filter arrangement, and the design. Some common bleed procedures are as follows:

When the fuel tank is located higher than the injection pump, check the fuel level. If it is low, fill the tank. Open the fuel-tank shutoff valve, the primary filter, the secondary filter, and the injection-pump vent screws if so equipped; otherwise remove the overflow valve. Allow fuel and air to flow from the vents until the fuel is free of air bubbles. Then tighten the vent screws in rotation, one after another.

If the tank is located below the injection pump, open only the injection-pump vent screw(s), or remove the overflow valve. Pressurize the fuel tank (using a hand pump or shop air) sufficiently to force fuel through the system, out of the overflow valve, until all air has been expelled from the entire system.

NOTE: If a hand primer is in the system, unlock it so that the fuel may pass through it more easily.

If you bleed the system by using the hand priming pump (Fig. 29-1), remove the overflow valve and connect a hose to the opening. Place one end of the hose into a pail to prevent fuel spillage over the engine. Unlock the hand primer and pump fuel through the system until airfree fuel enters the pail. Lock the hand primer and reconnect the overflow valve. *(NOTE: If the hand primer is not locked, there will be no transfer-pump pressure because fuel will circulate within the transfer pump.)*

Bleeding Injection Lines The high-pressure side of the injection lines is usually self-bleeding since the air is forced out through the action of the

pumping element. However, when the cranking power is only moderate, when the engine fails to start, or when it continues to run rough, venting of the injection line is necessary.

To vent the injection line, set the throttle to the full-fuel position and the shutoff lever or the switch in the "run" position. Place the decompression lever in the "decompression" position. Loosen all the injection line fittings at the injectors. Crank the engine until fuel squirts from the injection lines, and then tighten the connections.

Questions

1. Relate each mechanical and hydraulic action which takes place in the pumping element, beginning with the moment fuel is under transfer-pump pressure in the fuel manifold.
2. Why do some injection pumps use an upper-helix plunger?
3. Explain the mechanical action which takes place when the fuel rack moves to the full-fuel position. (Refer to Fig. 29-12).
4. What is the purpose of a delivery valve?
5. List the steps you must take *before* disassembling an injection pump.
6. Identify the inspection or check points of the barrel and plunger, the delivery-valve assembly, the camshaft, and the control rack.
7. Briefly outline the procedure to measure the plunger travel on a PEP injection pump.
8. Explain in detail how to spill-time an injection pump having an upper helix.
9. When servicing a diaphragm transfer pump, which component parts require special attention?
10. List the essential steps or checks to be taken prior to installing an injection pump to an engine having an adjustable drive coupling.
11. When calibrating an injection pump, why is it necessary to use (*a*) only the specified test injectors, (*b*) only the specified high-pressure lines, and (*c*) only test oil which has been brought to the specified temperature?
12. If, when checking fuel delivery on the test bench, you find that (*a*) at idle speed one pump element is lower than specified and (b) at maximum fuel the same pump element is correct (according to specification), what steps would you take to correct problem (*a*) above?

UNIT 30 • CATERPILLAR PORT AND HELIX FUEL-INJECTION PUMPS

The Caterpillar Tractor Company uses three different types of fuel-injection pumps, namely, the port- and helix-metering fuel-injection pump used on engines having 55 to 80 hp [41.0 to 59.7 kW] per cylinder; the sleeve-metering fuel-injection pump used on engines having 20 to 45 hp [14.9 to 33.5 kW] per cylinder; and the unit-injector fuel system used on the 3500 Series engines, which has 100 hp [74.6 kW] per cylinder.

This unit covers three different port and helix fuel-injection pumps, their governors, and the fuel-injection nozzles. The unit-injector system is covered in Unit 32, the sleeve-metering system is covered in Unit 36, and the pencil-type injector in Unit 27.

Components of Caterpillar Fuel-injection Pumps As mentioned previously, although all port- and helix-metering fuel-injection pumps operate on the same principle, they differ in their overall design, pump element arrangement, governor design, and adjustment.

The components which make up one of the Caterpillar Tractor Company's fuel-injection system is shown in Fig. 30-1. It should be noted here that the location and design of the transfer pump, priming pump, and the fuel filter housing vary according to engine design and/or application.

Hand Priming and Transfer-pump Flow When the operator unlocks the hand priming knob and pulls it upward, a low pressure is created in lines A, B, and C (Fig. 30-1). Atmospheric pressure forces fuel through the primary filter, past the check valves of the transfer pump and hand priming pump, and into the void created by the priming piston. As the pressure becomes equal in lines C and D, the check-valve spring closes the check valves. As the operator pushes the knob downward, the fuel is forced past the outlet check valve, through the secondary filter into line D, and through the fuel-inlet manifold, and then leaves the pump housing and flows into line E back to the fuel tank. This fuel flow primes the system and removes the entrapped air. The antisyphon block restricts the return flow so as to provide the specified manifold fuel pressure and prevent the system from draining when the engine is stopped.

When the engine is operating, the transfer-pump inlet side creates a low pressure in lines A and B. Fuel is forced into the transfer pump, and as the pump gears mesh, fuel is forced into line C through the inlet

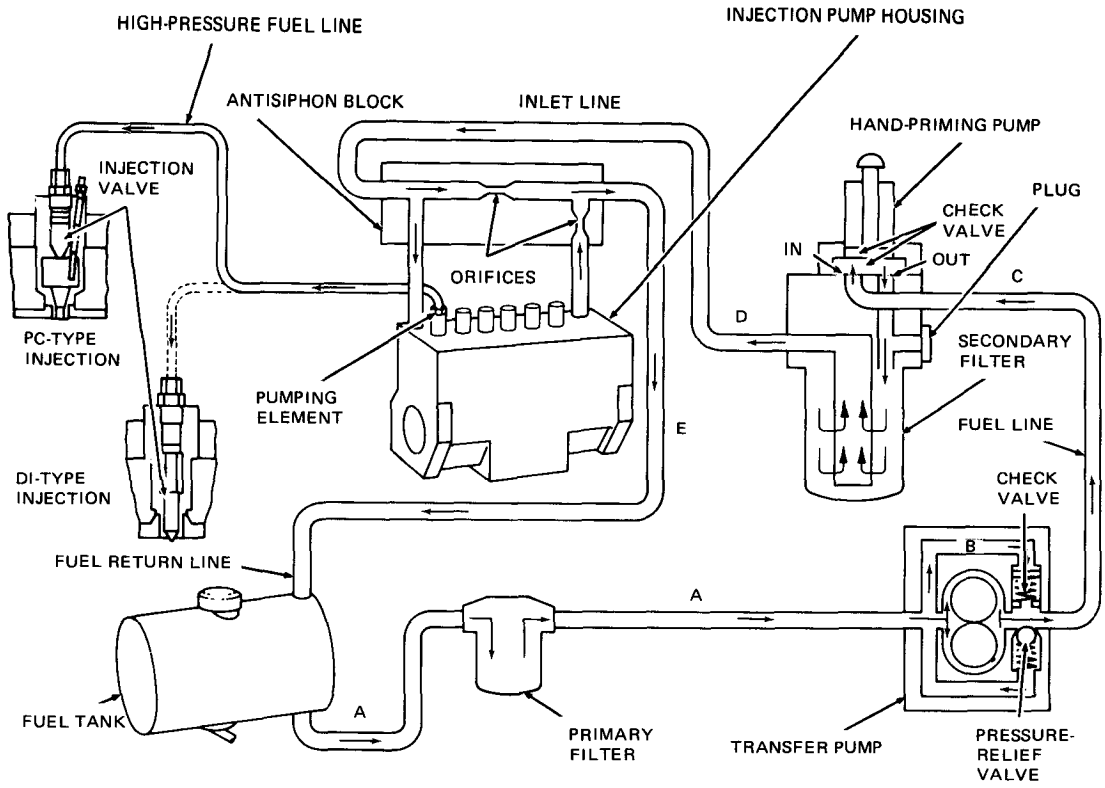


Fig. 30-1 Schematic view of one Caterpillar fuel-injection system. *(Caterpillar Tractor Co.)*

and outlet check valves in the hand primer, through the secondary filter. From this point on the fuel flow is the same as when using the hand primer.

Comparison between the Three-port and Helix Fuel-injection Pumps The oldest Caterpillar fuel-injection-pump design is the forged-body pump. These injection pumps have the individual pumping elements mounted on top of the housing (Fig. 30-2). The compact housing fuel-injection pumps are used on the 3400 Series engines, and as you can see (Fig. 30-3*a*), the pumping elements are located inside the pump housing, similar to the Robert Bosch, American Bosch, and CAV fuel-injection pumps. The barrel assembly is held in place by an externally threaded retainer bushing. These fuel-injection pumps are used in in-line and V design fuel pump housings. The fuel-injection pump shown in Fig. 30-3*b* has a flange-type barrel assembly which is very similar to the forged-body design. The flange-type and forged-body fuel-injection pumps are used in in-line fuel pump housings on the 300 Series engines.

All three pumping elements, although different in appearance, have like components and operate on the same principle. The fuel pump housing of the forged-body and compact-housing fuel pumps have one fuel manifold and the barrel has only one fuel-inlet port, whereas the flange-type pump housing has an inlet and a return manifold and, therefore, the barrels have two ports. The delivery valve of all three fuel-injection pump designs is a check valve having a displacement plunger.

The injection-pump plungers are of the constant-beginning and variable-ending designs and have the gear segment bolted to the plunger. The plungers have a second circumferential groove which is in line when the plunger is at TDC or BDC, with the inlet or spill port in the barrel. This allows the fuel used for lubrication to return through a passage to the inlet manifold (Fig. 30-3).

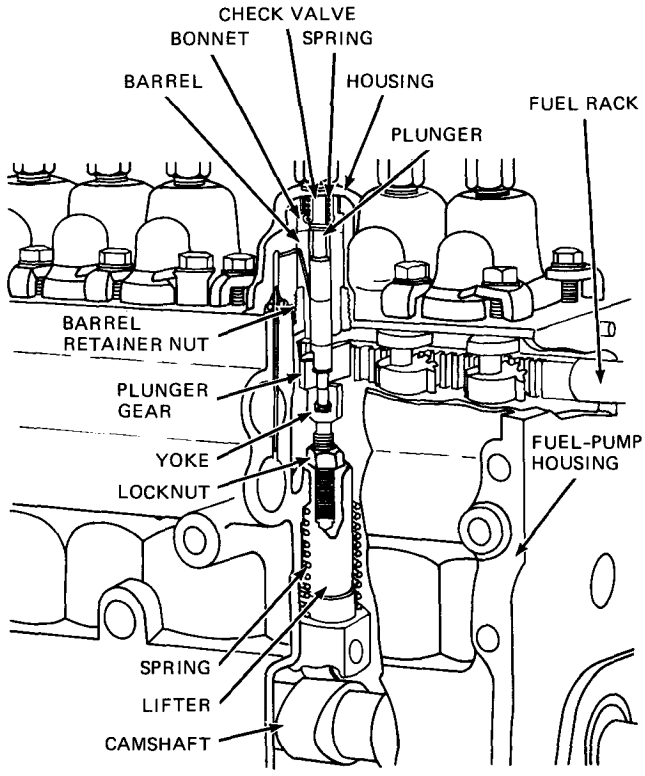


Fig. 30-2 Schematic view of a forged-body injection pump.

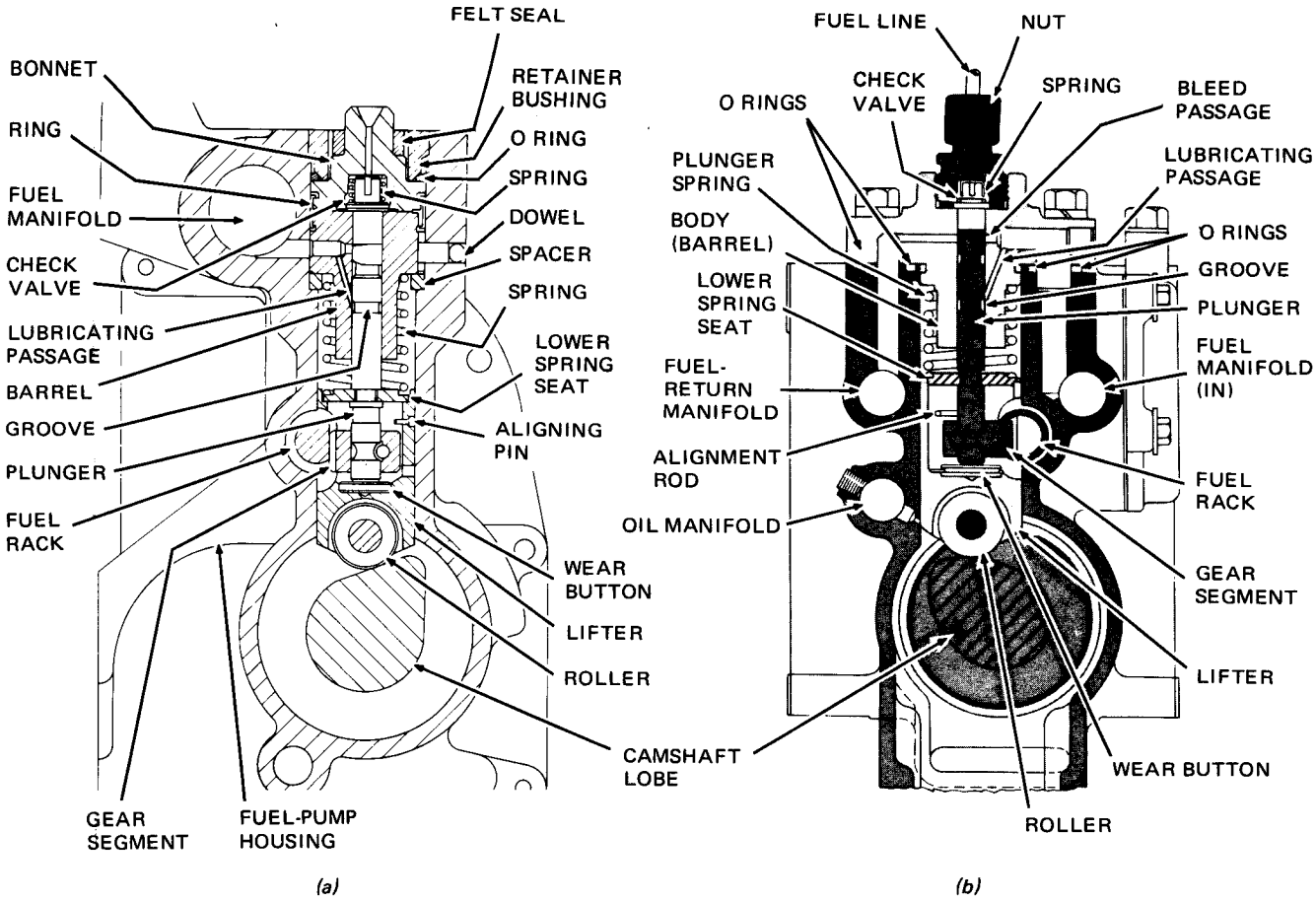


Fig. 30-3 Schematic view of (*a*) compact-housing and (*b*) flange-type fuel-injection pumps.

NOTE: Engines which have to operate under environmental restrictions use either a hydraulic or a mechanical timing unit to vary the beginning of injection.

The plungers of the forged-body pumping elements are hooked into a yoke which is screwed into the lifter tappet (Fig. 30-2). The plungers of the compact-housing fuel-injection pump have a lower circumferential groove to lock the lower spring seat (washer) to the plunger (Figs. 30-3). The plunger return spring is positioned between the barrel and the spring seat. This eliminates the need for a yoke arrangement since the plunger spring forces the plunger and the lifter assembly against the cam lobe. The lifter assembly is similar in design to the Simmins injection-pump lifter assembly using inner and outer rollers.

The camshafts on all Caterpillar fuel pumps are supported by bushings instead of roller or ball bearings. They are driven by either an offset tang coupling, a split coupling, a slip drive gear, or through the variable timing unit. When the pump element is installed and the retainer bushing torqued to specification, the barrel rests on the spacer, the plunger rests against the wear button, and the lifter rests against the camshaft lobe. The spacer's purpose is to position the plunger to the specified port closing position.

NOTE: Port closure is changed by varying the spacer thickness.

To position and hold the barrel inlet port to the inlet manifold, and to prevent the bonnet from rotating when the injection line nut is tightened, each dowel and bonnet has a machined groove in which a barrel pin rests. The square O ring between the bonnet and retainer bushing seals the assembly against fuel leakage. A felt seal is used to protect the assembly against dust, dirt, etc.

The flange-type fuel-injection pump is bolted to the fuel pump housing. The barrel and manifolds are sealed to the pump housing through O rings. To adjust the plunger height (port closure), the lifter assembly is changed with a lifter having a thicker or thinner wear button.

All fuel pumps are lubricated by engine oil which is connected through a tube to the lubrication passage. The oil lubricates the lifter, camshaft bearings, and the governor, and then through gravity drains back to the oil pan. The check valves of all Caterpillar injection pumps, though similar in design, differ in the seat diameter and the displacement plunger volume.

The fuel racks of the earlier designed fuel pumps have machined circular grooves whereas the newer pumps have teethlike grooves machined into the fuel rack.

NOTE: Fuel metering and injection is identical to a Bosch or CAV fuel-injection pump having a constant-beginning and variable-ending plunger (see Unit 29).

FORGED-BODY FUEL-INJECTION-PUMP SERVICE

Removing Fuel Pump There is nothing unusual in the removal procedure of a fuel pump whether it is mounted to the cylinder-block left-hand side or right-hand side. However, the procedure does change according to the type of drive coupling used. On V-type engines, fuel-injection-pump removal is arduous because the pump lies in the V between the cylinder heads.

To remove the injection pump having offset tang couplings or splined couplings, first remove the necessary fuel lines, throttle linkage, oil lines, and boost pressure air line, and then remove the housing mounting bolts. Lift the pump housing from the engine with a suitable hoist. Either coupling will then slide out of mesh.

A brief insight into the servicing of a 769B truck engine (split coupling) follows; however, *you are cautioned to refer directly to the Caterpillar service manual when actually removing this pump for service.* This pump uses a split drive coupling. To remove the pump, loosen the bolts and slide the coupling toward the timing-gear housing. Attach a hoist to the pump housing. Slide the adapter housing toward the timing-gear cover to clear the ferrules and the camshaft. Next, remove the mounting bolts and lift the pump housing from the engine.

Disassembling Forged-body Fuel-injection Pump *Never* attempt to disassemble a Caterpillar forged-body fuel-injection pump without reference to the service manual. However, the usual precleaning of the work area, unit, and tools precedes disassembly of *any* fuel-injection pump.

Here is a review of most of the steps to disassemble this pump. Mount the clean fuel pump housing in a swivel vise and remove the governor. Since the 769B engine has a servo-type governor, the rack limiter must first be removed (see Fig. 30-15 and Unit 25, "Governors"). Remove the cover and the pin which connects the governor to the control link. Then remove the bolts which hold the governor housing to the injection-pump housing. Remove the governor housing by working it loose from the dowel pins. Next, remove the bolts and clamps that hold the injection pump to the housing. Lift the pump housing from its dowels. Slide the plunger out of its yoke, and remove it as a unit from the housing (Fig. 30-4). (Do not let the plunger fall from its barrel.)

If it is difficult to remove the plunger from the yoke, then with a clean magnet lift the plunger out of the yoke and immediately insert it into the barrel. Use plastic caps and plugs to close off all openings.

CAUTION Do not manually lift the plunger since even the slightest dirt on the plunger will accelerate barrel and plunger wear.

To remove the camshaft, loosen the locknuts and screw out the yokes (see Fig. 30-5*a*). Use a 24NF ⅜-in bolt, 3 in long, to raise the lifters (see Fig. 30-5*b*). A large washer must be placed between the bolt head and the housing on which the bolt head can rest.

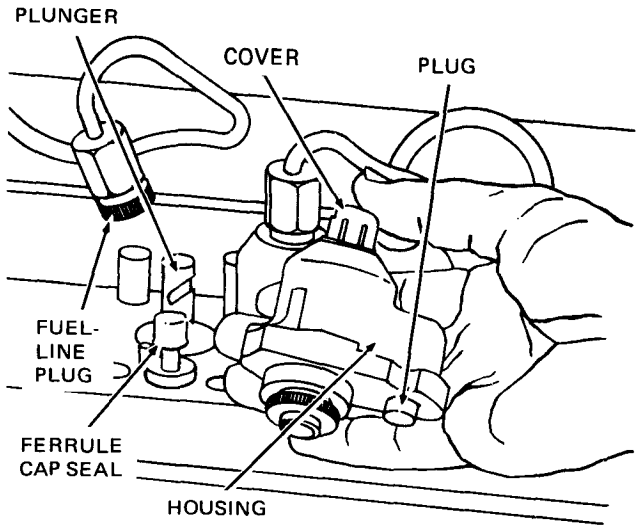


Fig. 30-4 Removing fuel-injection pump.

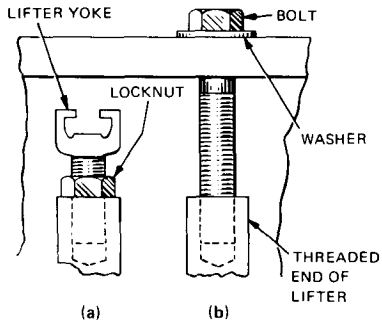


Fig. 30-5 (*a*) Removing lifter yoke, (*b*) raising lifters. *(Caterpillar Tractor Co.)*

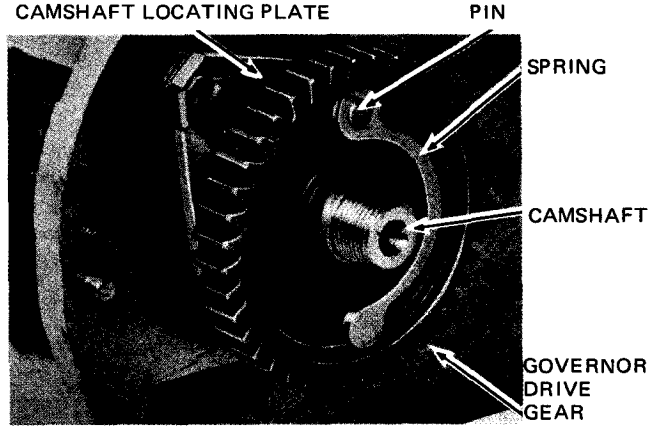


Fig. 30-6 View of governor drive gear.

Screw the bolt into each lifter to withdraw each one from the camshaft lobes.

To hold the camshaft when removing the drive-gear nut, place a piece of wood under a cam lobe near a bearing. When the nut is removed, lift off the plate, the spring, and the two pins, and slide off the drive gear (Fig. 30-6), but take note of the spring position since it is the connecting link from the camshaft to the governor drive gear. The governor drive gear can rotate about 33° without moving the camshaft. This assures a pulsationfree drive to the governor driven gear. Only two bolts need be removed from the locating plate when removing it in order to lift the cam-

shaft from the pump housing. Take care not to damage the camshaft bushings. If the lifters require servicing, remove the bolts, one by one, to release the lifter-spring tension and withdraw the lifters.

Inspecting the Forged-body-pump Components Check all the mounting surfaces for nicks and burrs and all the threaded holes for damage. Measure the camshaft and fuel-rack bushings for wear with an inside micrometer and a hole gauge, and then compare the measurement with the specification in the service manual. If the measurements indicate that the bushings should be replaced, push them out with a suitable adapter. When pressing the new bushings in place, make sure the oilholes are aligned and that the bushings are positioned in accordance with the service manual instructions.

Measure the camshaft-bearing journals, and then compare this measurement with the service manual specification. Check the cam lobes. If there is any sign of surface damage, the camshaft must be replaced.

The lifter body can be checked for wear by measuring its diameter. If the lifter roller shows any sign of rough spots or grooving, the assembly must be replaced. With a spring tester, measure the free length and test the energy of the lifter spring.

The Caterpillar service procedure for cleaning and checking the barrel and plunger or the delivery valve and spring is generally the same as that for similar components of the Bosch and CAV components (Fig. 30-7). However, the Caterpillar Tractor Company recommends measuring the length of the plunger to determine possible wear. If the measurement is not within specification or if the helix, plunger, or barrel is damaged, the barrel and plunger must be replaced (Fig. 30-8).

Always check the yoke. It should never be allowed to deteriorate to the extent shown in Fig. 30-7.

Reassembling Forged-body Pump Lubricate the lifter and its bore. Slide the spring over the lifter body, and place it on the bore. Screw the retracting bolt far enough into the lifter to raise it sufficiently to allow installation of the camshaft. Repeat this procedure with the remaining lifters.

Lubricate the bearings and camshaft-bearing surfaces. Slide the camshaft into position, and bolt it to the housing. Make certain the camshaft rotates freely and the end play is within the specified limit before resting the lifters on the camshaft. Screw the locknut onto the yoke. Screw the yoke into the lifter until the locknut bottoms against the lifter. Place the lubricated drive gear on the drive flange, and then install the dowel pins and spring. *(NOTE: The drive spring must "wind up" when driving the governor gear.)* (See Fig. 30-6.)

Place the plate washer and the locking plate over the end of the camshaft, and tighten the nut to specification. Before installing the pump elements, measure and then, if necessary, adjust the lifter height.

Pump Lifter Setting (Off-engine) Setting the lifter height to the recommended specification can be compared with timing and phasing, except that the measurement is made with a depth micrometer

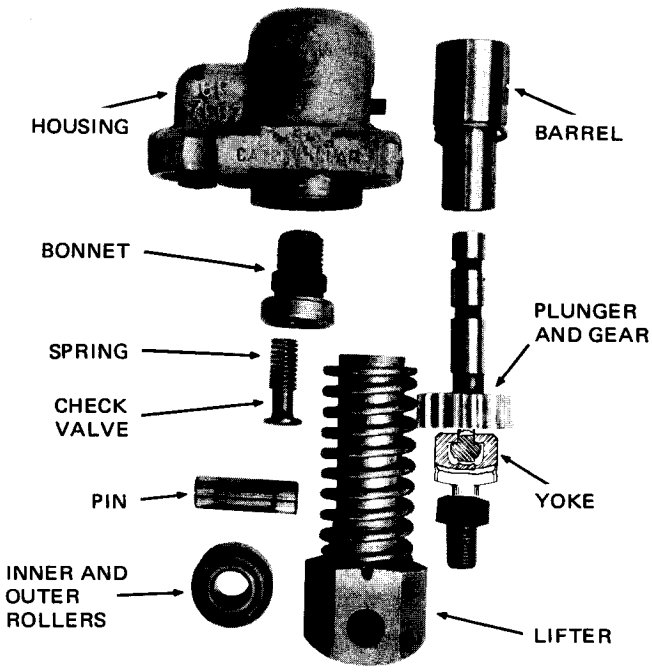


Fig. 30-7 Exploded view of forged-body fuel-injection pump.

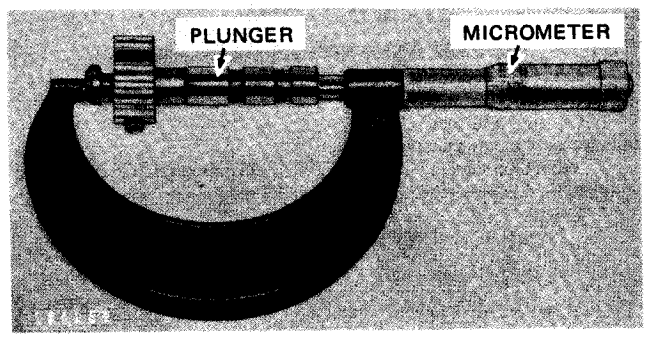


Fig. 30-8 Measuring plunger length. *(Caterpillar Tractor Co.)*

rather than by using the spill-timing method. To check or to adjust the lifter height, install the degree wheel onto the drive end of the camshaft and the pointer onto the housing as shown in Fig. 30-9. Refer to your service manual for lifter-height dimension and to Table 30-1. In this example the lifter-height dimension is 1.88 in ±0.002 in [47.78 mm ± 0.05 mm].

With the degree wheel and the pointer in place, rotate the degree wheel so that the ½° mark is aligned with the left-hand edge of the pointer. This brings No. 1 camshaft lobe and No. 1 lifter into position to be measured (and if necessary, adjusted). The No. 1 lifter is on the governor side of the pump housing, and the lifters continue (Nos. 2, 3, 4, 5, 6) toward the degree wheel.

Place the depth micrometer into the bore of the pump element. Make sure the surface of the housing is clean. Measure the distance from the surface of the housing to the yoke surface (*A* in Fig. 30-10). Using adjusting tools, raise or lower the yoke to bring the distance to specification, then lock the yoke with the locknut, and remeasure the lifter height. If it is within specification, turn the degree wheel to 300½°. This will bring No. 5 camshaft lobe and No. 5 lifter into position to be adjusted.

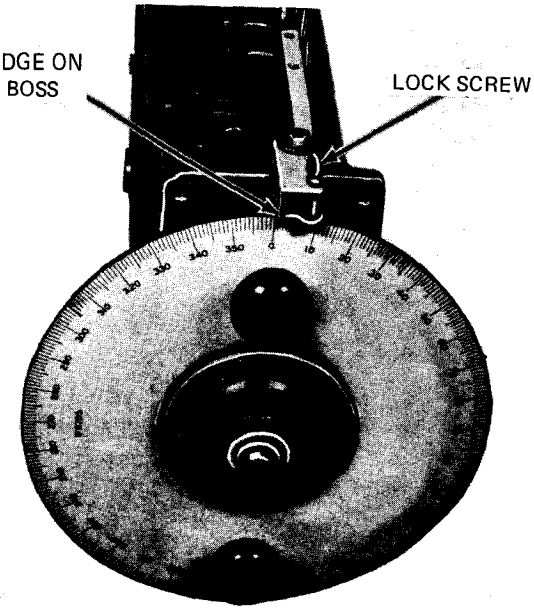


Fig. 30-9 Preparing for measuring lifter height (off-engine).

TABLE 30-1

LIFTER SETTING IN DEGREES (OFF-ENGINE)

Lifter number (numbered consecutively front to rear)	Timing plate degrees
1	½
2	120½
3	240½
4	60½
5	300½
6	180½

Measure, adjust, and recheck the measurements of No. 5 lifter, then proceed to the next lifter (No. 3) and so on, until all lifter heights are adjusted.

Pump Lifter Setting (On-engine) To check or adjust the lifter setting while the pump is installed to the engine it is necessary to position the injection-pump camshaft in order to measure the lifter height. The camshaft-lobe position is found through the timing marks on the flywheel or by screwing a timing bolt into the flywheel (Fig. 30-11).

The flywheel has four threaded holes, of which three align with the holes in the flywheel (Fig. 30-11). When the timing bolt is in No. 2 hole and is threaded into the flywheel the two pistons Nos. 1 and 6 are at precisely TDC (one piston is on compression and the other is starting its intake cycle). If the valves of No. 6 cylinder are open, No. 1 piston is on compression. The lifter of No. 1 injection pump is now ready to be measured, and if necessary, adjusted.

When No. 1 lifter is adjusted, remove the timing bolt. Turn the crankshaft 120°. Align the threaded bore in the flywheel with the No. 3 hole, and thread the timing bolt into the flywheel. The lifter of No. 5 injection pump is now in position to be measured (and if necessary, adjusted).

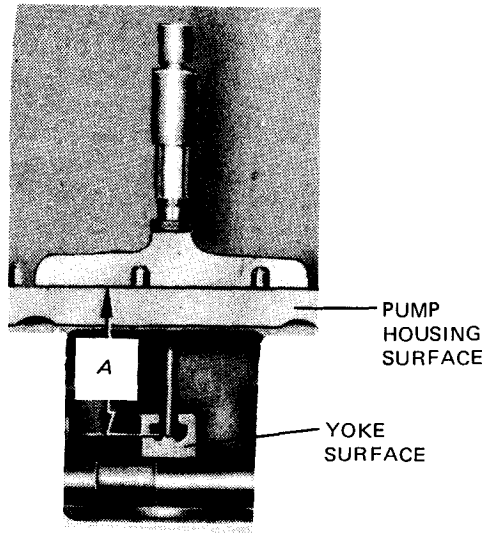


Fig. 30-10 Measuring lifter height. *(Caterpillar Tractor Co.)*

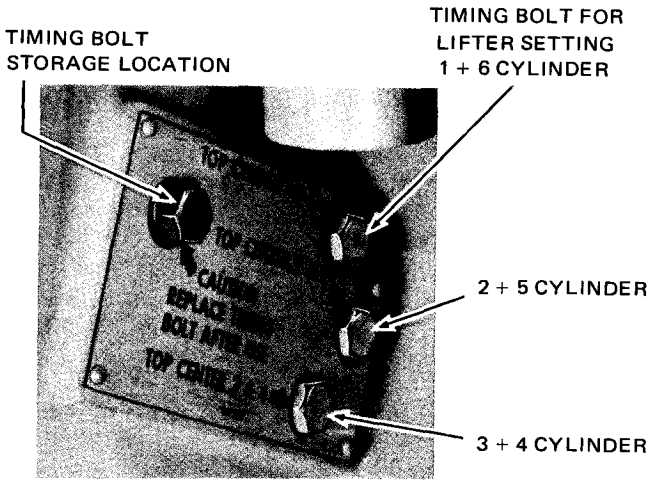


Fig. 30-11 Locating camshaft position by the timing bolt method. *(Caterpillar Tractor Co.)*

CAUTION If you overshoot the flywheel hole, turn the crankshaft at least 20° in the opposite direction, past the hole, then turn it back carefully to realign the hole. This will prevent gear lash.

Do not forget to replace the timing bolt in the No. 1 hole and to replace the three plugs.

NOTE: Remember that the lifter-height specifications for setting the lifters "on" engines always differ from the setting of those "off" engines, and vary with engine application.

Installing Forged-body Pump Before you install the fuel-injection pump, make certain that the housing surface is clean. Position the fuel rack so that its timing mark is in the center of the injection-pump housing bore. Remove the plunger from the barrel and, with a magnet, lower it into position; that is, position it with the lower part of the plunger hooked into the yoke, and the timing marks aligned (Fig. 30-12).

Next, install a new sealing ring. Use grease to hold it in the large recess of the injection-pump housing.

Using extreme care, slide the barrel over the plunger.

To position the pump housing, align the dowels with the holes in the pump housing. Install the clamp and hex bolts, and torque the bolts to specification. Then install the remaining injection pumps.

When you use the rack-setting gauge to check the rack travel, leave out one pump element.

Servicing Rack Limiter (Aneroid) First, remove the cover assembly, the locknut, and nut, and then withdraw the adjusting screw, retainer plate, diaphragm, spring, and shaft (see Fig. 30-13). Check each component very carefully for damage and/or wear. Measure and test the springs. (The diaphragm usually is replaced.) Check the bell crank and shaft, particularly where the adjusting screw contacts the bell crank.

When you reassemble the rack limiter, make sure the diaphragm fits smoothly between the plates and lies flat between the cover surface and the limiter housing surface, then tighten the screws. The rack limiter needs no spring preload adjustment. The spring is automatically correctly preloaded (adjusted) when the roller of the bell crank is positioned between the adjusting screw and the bushing, and the nut is torqued to specification.

Servicing Governor To service the governor, remove the cover, and slide out the cylinder and its blocks, the piston assembly, and the springs (see Fig. 30-14). Slide the thrust bearing and sleeve from the spindle. Then pull out the spindle assembly, governor weights, drive gear, and bearing. If there is any doubt about the serviceability of the control-lever assembly, remove them also.

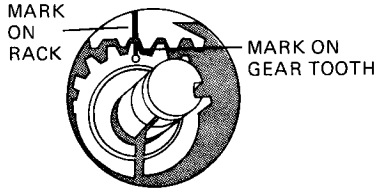


Fig. 30-12 View of plunger and fuel-rack timing marks. *(Caterpillar Tractor Co.)*

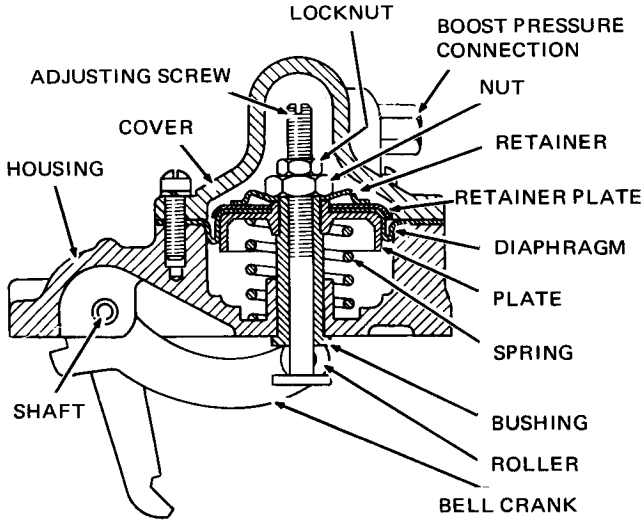


Fig. 30-13 Schematic view of rack limiter (fuel ratio control). *(Caterpillar Tractor Co.)*

The speed limiter used with this governor is shown in Fig. 30-15. It is a device which limits the travel of the control lever and as a result the engine speed, until the oil pressure of the engine is about 10 psi [68.95 kPa]. The oil pressure then forces the piston to retract against its spring force and the control lever and, therefore, the fuel rack is free to move to full-fuel position.

When you examine the governor components for wear, check particularly the governor weight assembly, the pins, rollers, spindle, drive gear, and bearing. Along with the thrust bearing and sleeve, these are the most vital components of the governor. If any are worn, they should be replaced.

Check the two speeder springs and measure their free length and energy. It should coincide with the length and energy of the same color code shown in the service manual.

Check the torque spring and spacer. Compare their thicknesses with the service manual specifications (torque spring group).

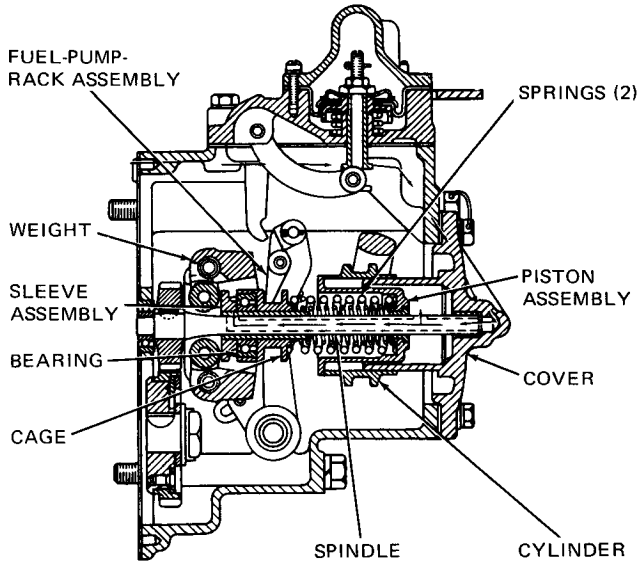


Fig. 30-14 Schematic view of the servo governor and rack limiter. *(Caterpillar Tractor Co.)*

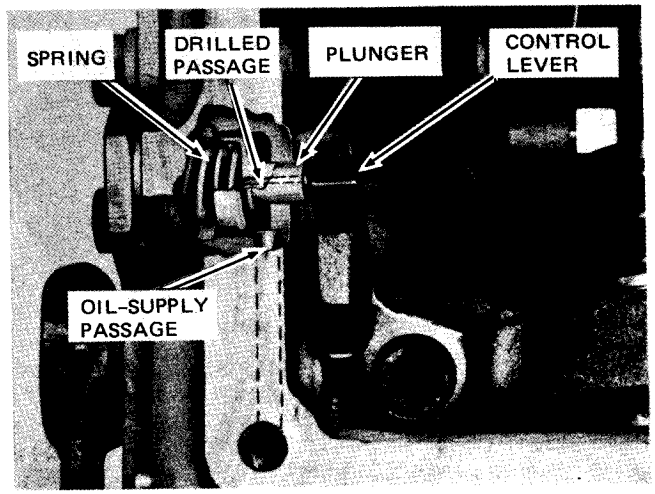


Fig. 30-15 Speed-limiter position when engine is operating. *(Caterpillar Tractor Co.)*

Make sure that the governor piston assembly and the cylinder are free of rough spots and grooves. (The piston must slide freely into the cylinders.) Check the grooves in which the blocks of the control lever are riding. The blocks must fit, without play, in the grooves and in the pins of the control lever.

Check the bushings, shaft, and pins of the rack-control lever for wear and make certain that the rack-setting adjusting screw is sufficiently loose so that it may be turned. Do no overlook the speed-limiter piston. It must move freely within its bore.

Reassembling Governor Wash all the components in clean fuel. Reassemble them in precisely the reverse order to that in which they were disassembled; however, leave off the rack-limiter housing, side cover, and speed limiter.

Place the governor housing onto the dowel pins of the fuel-pump housing. Mesh the drive and driven gears, and tap the governor housing into place. Tighten and lock the governor mounting bolts, and then connect the control link to the control-lever arm. Now position and tighten the rack-limiter housing to the governor housing.

Adjusting the Fuel Rack Using a Rack-setting Gauge The fuel rack can be adjusted before or after the pump is installed to the engine. Two methods are used to measure the travel: the rack-setting-gauge method and the dial-indicator method.

The outer circumference of the rack-setting gauge is inscribed with marks, from 0 to 0 (Fig. 30-16). The longer lines represent 0.100 in and the shorter lines represent 0.050 in. The inner dial face (which is connected to the gear segment) has two scales, each line representing 0.005 in. One scale is used when the control rack moves to the right, and the other scale is used when the control rack moves to the left in its travel to full-fuel position.

When using the rack-setting gauge, one fuel-injection pump must be removed and the rack-setting gauge installed so that the timing marks on the gear align with the fuel-rack marks, as shown in Fig. 30-12. Check this alignment through the gauge hole. When the marks are aligned, the dial should read 0.

To check the rack adjustment, loosen the locknut and turn the rack-limiter adjusting screw clockwise until the bell crank can no longer restrict the fuel-rack movement.

Remove the speed limiter to allow unrestricted rack travel. Place a feeler gauge, as thick as the spacer, say 0.100 in [2.54 mm], between the torque spring and the housing, to prevent the torque spring from bending during the adjustment. Now move the throttle to the full-fuel position. This action moves the fuel rack and the gauge dial, and bottoms the adjusting screw of the rack-control lever against the torque spring. When this position is reached, read the dial on the rack-setting gauge. Say the dial reads 1.230 in, as shown in Fig. 30-16*a*, but according to the service manual specification, the rack setting should be 0.475 in (Fig. 30-16*b*). You must move the fuel rack from 1.230 in to 0.475 in. To do this, loosen the locknut and turn the adjusting screw clockwise (Fig. 30-17) until the dial reading coincides with the specified value. Then tighten the locknut.

Adjusting Rack Limiter To adjust the rack limiter, remove the feeler gauge which was placed between the torque spring and the housing. During removal, the fuel rack will travel an additional 0.100 in toward full fuel. Recheck the dial reading because the torque spring will have become bent and will be resting against the housing. Loosen the locknut and turn the rack-limiter adjusting screws counterclockwise until the dial of the rack-setting gauge coincides with the setting specified in the service manual, and then lock the adjusting screw.

Recheck the adjustment by moving the throttle to the low-idle position and back again to the high-idle position. The dial reading should not have changed.

Adjusting Fuel Rack Using Dial Indicator When you use the dial-indicator method to adjust the fuel rack and the rack limiter, remove the speed-limiter piston and turn the rack-limiter adjusting screw clockwise until the bell crank no longer interferes with the rack movement. Move the fuel rack forward. Slide

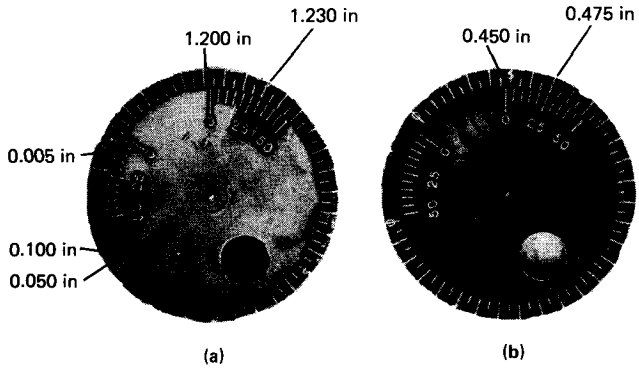


Fig. 30-16 Reading the rack-setting gauge. (*a*) Before fuel-rack adjustment. The 0 mark of the inner dial is just past the 1.200-in mark of the outer dial. The inner dial aligns with the outer dial at 0.030 in. The reading is 1.200 + 0.030 = 1.230 in. (*b*) After fuel-rack adjustment. The 0 mark of the inner dial is past the 0.450-in mark of the outer dial. The inner dial aligns with the outer dial at 0.025 in. The reading is 0.450 + 0.025 = 0.475 in.

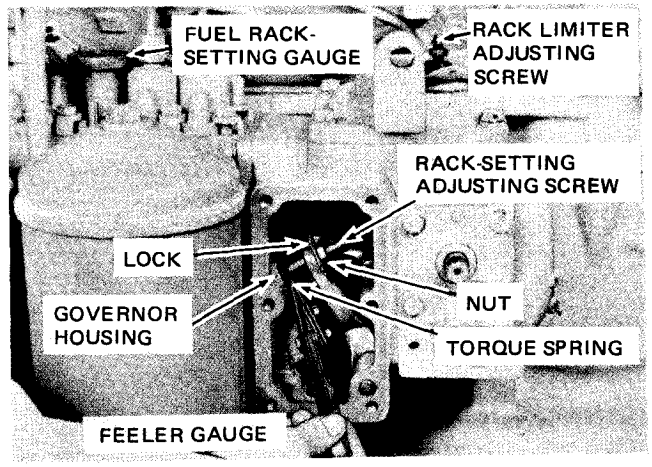


Fig. 30-17 Adjusting the fuel rack. *(Caterpillar Tractor Co.)*

the rack-centering gauge between the collar of the fuel rack and the housing. Position the throttle to the full-fuel position. This will hold the gauge in place.

Now, install the dial indicator as shown in Fig. 30-18, making certain that the adapter arm is in front of the fuel-rack collar. When in this position, zero the dial indicator and place a feeler gauge of 0.100 in [2.54 mm] between the torque spring and the housing. Remove the rack-centering gauge. When the gauge is removed, the fuel rack will move toward the full-fuel position until the adjusting screw of the rack control lever rests against the torque spring. The movement of the fuel rack moves the adapter arm, and this motion is transmitted to the dial indicator. The fuel-rack travel can now be read directly from the dial indicator.

Turn the rack-control-lever adjusting screw to obtain the specified rack travel of 0.475 in [12.06 mm]. To adjust the rack limiter, remove the feeler gauge, turn the rack-limiter adjusting screw counterclockwise until the dial indicator reaches the specified value, and then lock the adjusting screw.

NOTE: Always recheck adjustments.

Remove the rack-setting tools. Install the injection pump, cover, and speed limiter. Do not install the service meter at this time.

Installing Pump to Engine Before you install the pump to the engine, turn the injection-pump camshaft until the timing dowel slides into the camshaft. This correctly positions the camshaft for timing the pump to the engine. Install the assembled pump to the engine in exactly the reverse order of removal.

Position No. 1 piston on the compression stroke and install the timing bolt to the flywheel. (Make certain that No. 1 piston is on the compression stroke.) To take out the gear lash, slide the split coupling into position and tighten the bolts on the variable-timing shaft. Then turn the coupling toward you and tighten the bolts to the specified torque. The timing dowel should fit loosely in the injection-pump camshaft. Assuming that it does, remove the timing bolt from the flywheel, crank the engine 720°, and again install the timing bolt to the flywheel. In this position the timing dowel should slide into the camshaft without restriction. If it does, the injection pump is timed to 11° BTDC.

Spill-timing Caterpillar Pump When you use the spill-timing method to check the pump timing, remove the fuel-injection line from the precombustion chamber or direct-injection adapter of No. 1 cylinder. Remove the fuel line, nut, injection valve body, and the fuel nozzle. If the fuel pump has a return line, remove the line from the fuel pump and install a cap plug onto the outlet.

Bring No. 1 piston to TDC on the compression stroke. Install the dial-indicator adapter into the precombustion chamber, fingertight. Assemble and install a dial indicator with an extended contact point to the precombustion chamber (Fig. 30-19). Rotate the crankshaft counterclockwise to determine whether the dial has a minimum of 0.200-in [5.08-mm] travel distance. Turn the crankshaft slowly in a clockwise direction until the needle movement stops, that is, when the piston is in the TDC position. Zero the dial indicator by loosening the bezel lock, turn the bezel until the zero mark aligns with the dial needle, and then lock the bezel.

To recheck the TDC position, turn the crankshaft in a clockwise direction until the dial indicator reads 0.020 in [0.508 mm]. Mark this point on the flywheel or on the vibration damper. Turn the crankshaft counterclockwise until the dial indicator again reads 0.020 in [0.508 mm]. Mark this point on the flywheel or on

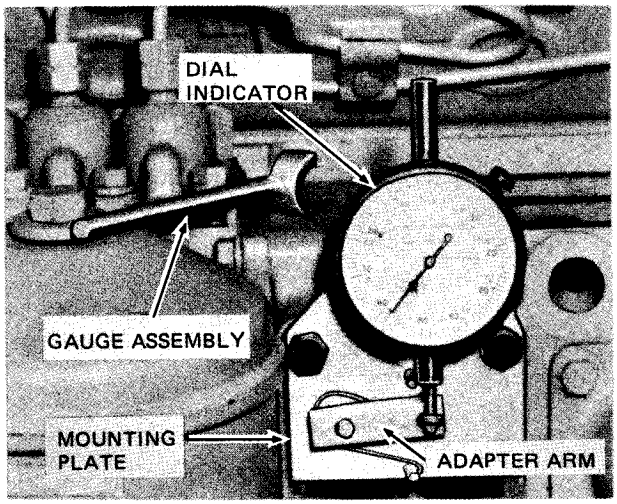


Fig. 30-18 Positioning the dial indicator for measuring fuel-rack travel. *(Caterpillar Tractor Co.)*

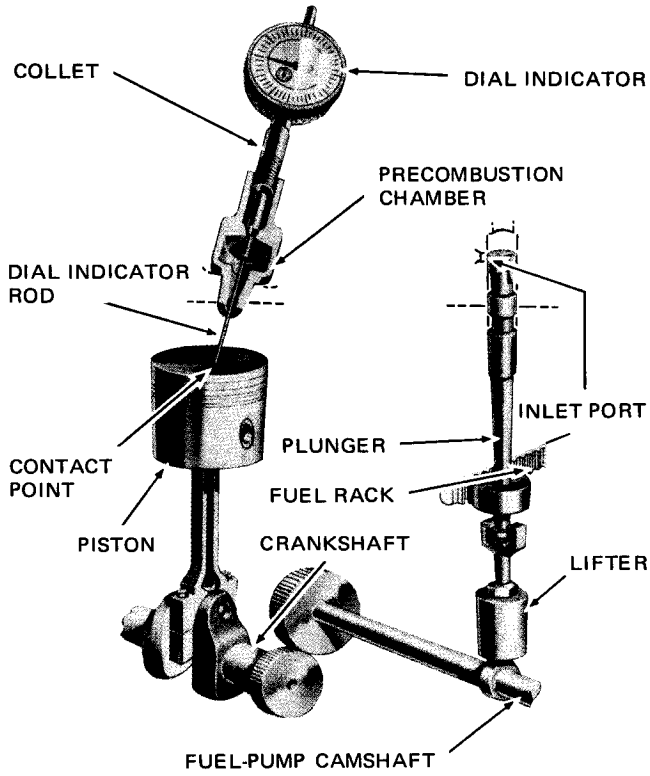


Fig. 30-19 Schematic view of measuring piston travel. *(Caterpillar Tractor Co.)*

the vibration damper. True TDC position is midway between these two marks. Correct your dial-indicator setting accordingly, if required.

When the TDC position is set on the dial indicator, connect a swan neck pipe to No. 1 injection-pump housing. Bring the fuel rack to the full-fuel position. Turn the crankshaft about 40° counterclockwise or until the dial indicator reaches the end of its travel. Pressurize the fuel manifold to a maximum of 15 psi [103.4 kPa]. Use a hand primer or pressurize the fuel tank (or use a special tank), and spill-time the engine for port closure.

Port closure for Caterpillar injection pumps generally is established when 6 to 12 drops/per minute leave the swan neck pipe. However, port closure for the Caterpillar D337 engine used on dump trucks is established when 12 to 30 drops per minute leave the swan neck pipe; therefore always refer to your service manual.

When you have determined the port closure, read the dial indicator. It should read, for this dump truck engine, 0.072 in [1.83 mm], which is equal to 11° BTDC (Table 30-2). The piston travel toward TDC position measured in thousandths of an inch [hundredths of a millimeter] and the conversion to degrees are shown in Table 30-2. However, since the stroke on engines differs, the piston travel varies in degree of crankshaft rotation. The travel is greater on an engine having a larger stroke, and smaller on an engine with a shorter stroke.

Fuel-injection-pump Camshaft Timing (D337 Engine) When the spill-timing has proven that port closure is too early or too late, the fuel pump camshaft must be adjusted in relation to the No. 1 piston. To do this, position the No. 1 piston on compression stroke and screw the engine timing bolt into the No. 2 flywheel hole (see Fig. 30-11). Remove the fuel pump timing pin from its storage place on the pump and drop it into the timing hole located close to the governor. If the timing pin head should come to rest against the fuel pump housing, the fuel pump camshaft is correctly timed to the engine but the plunger (lifter) height is not adjusted correctly. If the timing bolt head is not flush with the fuel pump housing, remove the cover from the front right-hand side to get access to the fuel pump drive gear. Loosen the eight cap screws that secure the drive gear to the drive shaft. Now, with a half-inch square drive, rotate the fuel pump drive shaft which rotates the fuel pump camshaft (see Fig. 30-20), until the fuel pump timing bolt enters the slot in the camshaft. Tighten three drive-gear cap screws fingertight, and remove the engine timing bolt; then rotate the crankshaft about 50° counterclockwise (viewed from the front of the engine), and then slowly clockwise, until the engine timing bolt can be screwed into the flywheel. This clockwise rotation causes the drive gear to slip, but with enough resistance to take the gear lash from the drive train. In this position tighten the drive-gear cap screws to the recommended torque.

To check the camshaft timing, remove both timing bolts, rotate the crankshaft 720°, and again install the engine timing bolt. When the camshaft timing is correct, the fuel pump camshaft timing bolt fits into the camshaft slot. If this is not the case, the above outlined procedure must be repeated until the fuel pump camshaft timing pin fits into the camshaft slot.

NOTE: The procedure just outlined above is also applicable to all fuel pump housings having a variable-timing unit.

Adjusting Low- and High-idle Speeds Replace all covers, fuel lines, and the necessary components which were removed to spill-time the injection pump. Start the engine. Check the operation of the speed limiter. Bring the engine up to operating temperature. Remove the cover to gain access to the adjusting screws. Set the throttle at high idle and turn the adjusting screw (which rests against the control lever) to achieve the recommended high-idle speed. Then move the throttle to the low-idle position. Turn the low-idle adjusting screw until the idling speed

TABLE 30-2

SERVICE MANUAL TIMING CHART FOR D337 ENGINE

Timing angle, degrees	in	mm
3.0		
3.5		
4.0		
5.0	0.015	0.38
5.5		
6.0	0.021	0.53
7.0	0.029	0.74
8.0	0.038	0.97
8.5		
9.0	0.047	1.19
9.5		
10.0	0.059	1.50
11.0	0.072	1.83
12.0	0.085	2.16
13.0	0.100	2.54
14.0	0.115	2.92
15.0	0.133	3.38

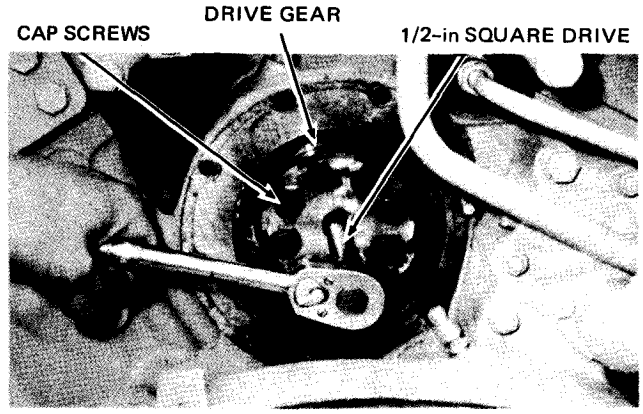


Fig. 30-20 View of fuel pump camshaft drive gear, rotating the fuel pump drive shaft and camshaft. *(Caterpillar Tractor Co.)*

meets the specification. Use a hand tachometer or a strobe light to measure the engine speed. Always cycle the engine to recheck adjustments.

COMPACT-HOUSING FUEL-INJECTION-PUMP SERVICE

The highlighted procedures which follow refer to the compact-housing fuel-injection pump used on a 3406 Engine (Fig. 30-21).

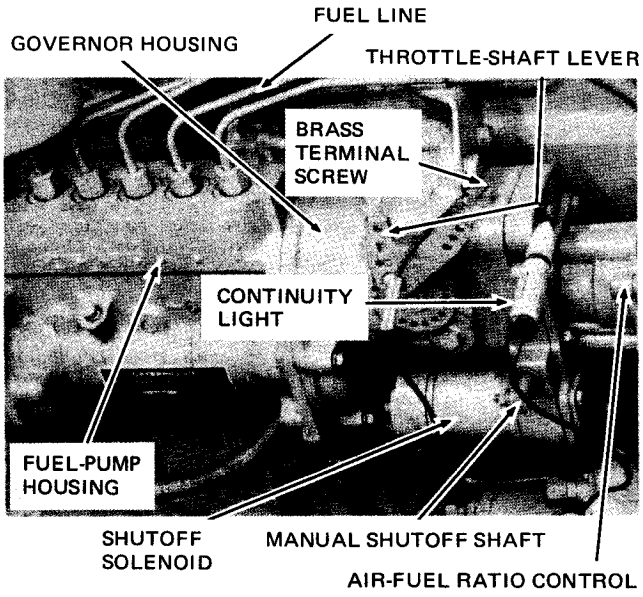


Fig. 30-21 View onto fuel pump with continuity light installed. *(Caterpillar Tractor Co.)*

Disassembling Compact-housing Pump After you have cleaned the injection pump, mount it in a holding fixture. Disconnect the fuel-ratio control by removing its mounting bolts and sliding out the adjusting bolt from the fuel-rack stop collar. Remove the cover, the high- and low-idle adjusting screws, the cover plate, and the electric shutoff. Then slide out the cover assembly.

Next, remove the stop collar and the bolts which hold the governor housing to the injection-pump housing. Lift off the governor housing. The governor-activating mechanism must then be removed. To remove it, take out the three bolts which hold the cylinder, move the assembly to the left, and slide the valve from the fuel rack (Fig. 30-22) (see Unit 25 for governor operation).

Dashpot Governor The dashpot governor (Fig. 30-22) is much the same in design and operation as the hydraulic governor shown in Fig. 25-14 in Unit 25, except that the sleeve bore is lengthened to accommodate the dashpot piston and spring, the dashpot spring rests between the piston and spring seat, and there is no spring inside the spring seat.

The purpose of the dashpot governor is to dampen the lower spring-seat movement and thus better control engine speed. To achieve this end, engine oil is directed into a small reservoir and from there, through passages, into the dashpot chamber. An adjusting screw controls the oil flow into the reservoir and another adjusting screw (dashpot) controls the oil flow from and into the dashpot chamber. Both adjusting screws (not shown in Fig. 30-22) are located beside the air-flow-ratio control. *[NOTE: If too little oil flows into the reservoir, the dashpot chamber will not have enough oil pressure and the governor will hunt be-*

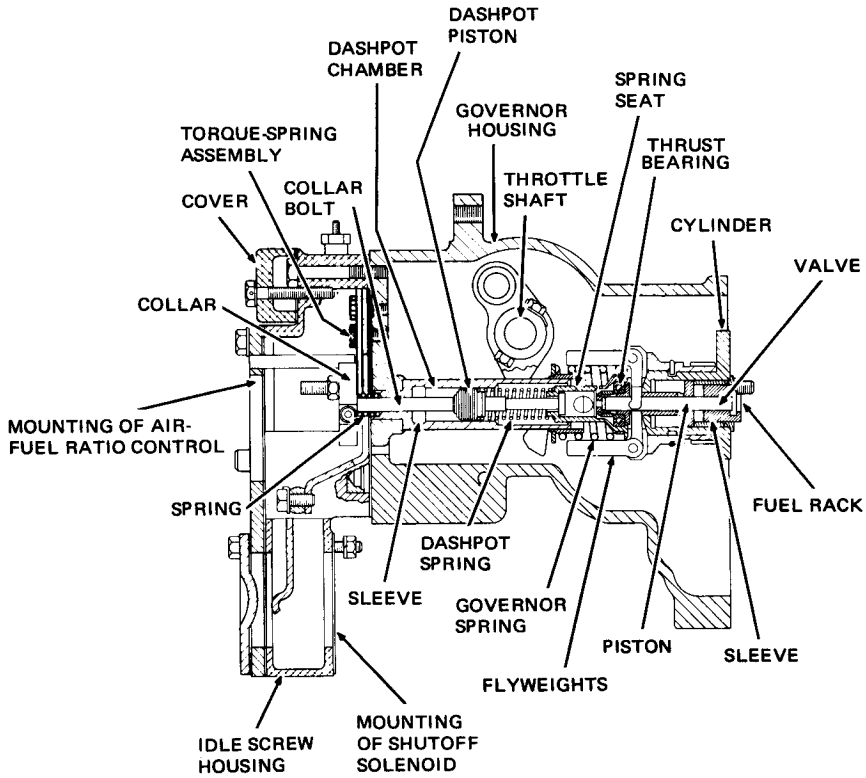


Fig. 30-22 Schematic view of dashpot governor. *(Caterpillar Tractor Co.)*

cause the lower spring seat has freedom to move. Too much oil flow into the reservoir fills the governor housing and restricts the movement of all governor components, thus reducing the governor effectiveness. If the dashpot screw is open too far, there will be less oil pressure in the dashpot chamber and the governor will also hunt. If the screw is closed too far, there will be a higher oil pressure within the chamber. Movement of the lower spring seat is then restricted and the governor action is sludgy. (For adjustment, see Dashpot Adjustment, further on in this unit.)]

SERVICING GOVERNOR When checking the components of the hydromechanical governor (otherwise known as the *hydraulic governor*) for serviceability, thoroughly check the valve, piston, sleeve, and cylinder. These components must be free of any surface damage. If it is necessary to clean their surfaces, use crocus cloth or tallow.

Check the end of the valve and the end of the piston which locks into the fuel rack. If there is any sign of wear, it must not exceed the specified maximum clearance.

Check the thrust bearing and washer. They must be free of any grooving. The weight assembly must show no pin or bearing wear.

Check the fingers of the flyweights. They should be round, that is, without flat spots. Replace the coned washer and the spring if wear is visible. Check the spring seat and also the bolt which is the connecting link to the shutoff lever. It should show no wear (Fig. 30-23).

Removing Compact-housing Fuel-injection Pump After you have removed the governor, remove the drive gear. The drive gear and the drive arrangement of this injection pump are slightly different from the forged-body design. The drive gear has two slots about ¾ in [19.5 mm] in length. It is held loosely to the camshaft by two cap screws and a sleeve is placed onto the cap screws, allowing the gear to move within the range of the slots and thereby reduce pulsation to the governor (Fig. 30-24).

With the special socket wrench, loosen the injection-pump retainer bushing about two full turns. Screw the extractor onto the bonnet. Press the extractor downward, but do *not* turn it while unscrewing, with your fingers, the retaining bushing.

Lift the fuel-injection pump straight upward without rotating it so that the grooves on the bonnet and barrel will clear the two dowel pins on the housing (Fig. 30-25). Remove the remaining injection pumps. Next, remove the fuel rack, and lift out the spacers and lifters. Place all three components (as a unit and in the order in which they were removed from the housing) into clean fuel oil. *(NOTE: Do not interchange the spacer or the lifter with the other pump elements as this may vary the lifter height.)*

Inspecting Compact-housing Camshaft and Lifters The checks and measurements for the compact-housing injection pump (that is, the camshaft and its bushings, the drive splines, and drive gear),

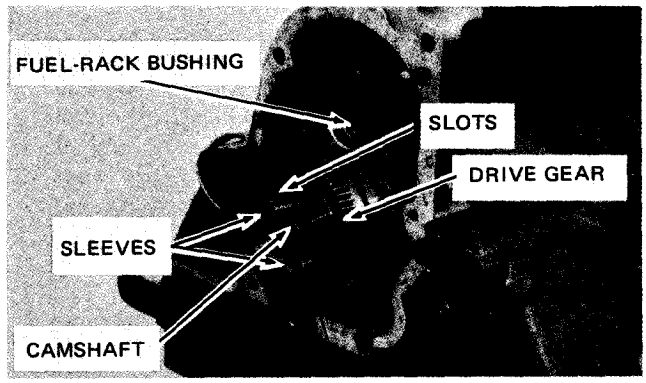


Fig. 30-24 View of governor drive gear arrangement. *(Caterpillar Tractor Co.)*

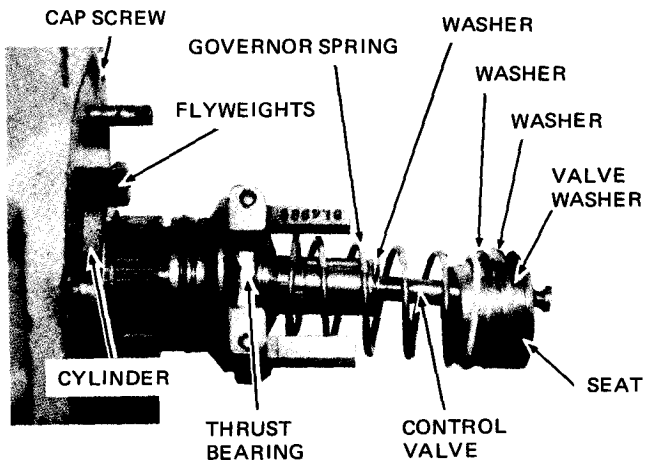


Fig. 30-23 Exploded view of governor. *(Caterpillar Tractor Co.)*

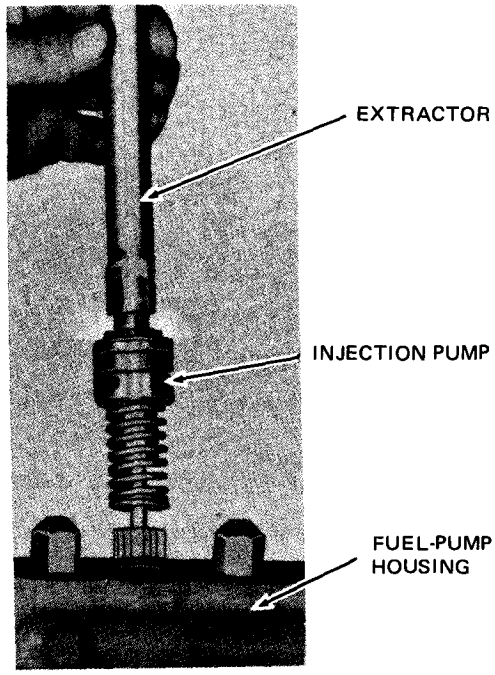


Fig. 30-25 Removing injection pump. *(Caterpillar Tractor Co.)*

do not differ from those of identical components in the forged-body injection pump. The lifter, however, should be checked for body, pin, and roller wear. Rough spots on the body surface or in the housing should be removed with 600-grit body paper. If the wear-washer is worn, the lifter must be replaced because either the port closure, the phase angle, or fuel metering is changed drastically.

NOTE: On the inside of some lifters is a very small alignment pin which is used to assist the plunger-gear-to-fuel-rack alignment.

Inspecting Injection Pump To remove the plunger, pull the plunger return spring from the barrel. Remove it and the spring seat from the plunger. Check the end of the plunger which contacts the wear washer. If worn, the assembly must be replaced (Fig. 30-26).

Measure the length of the plunger. If the plunger is shorter than specified or if the gear shows wear, the assembly must be replaced. Replacement is necessary because delivery (injection) begins later if the plunger is shorter. When the gear is worn, the plunger can rotate on its own, and this causes a constant variation in the fuel delivery.

If the assembly is reusable, clean the barrel and plunger assembly with tallow. Lap the bonnet, barrel, and check-valve surface to ensure effective sealing.

The fuel-rack teeth must show no wear and the rack must slide freely within its bushings but without excessive play. When in doubt, measure the bushings and the fuel rack and compare the measurements with those specified in the service manual.

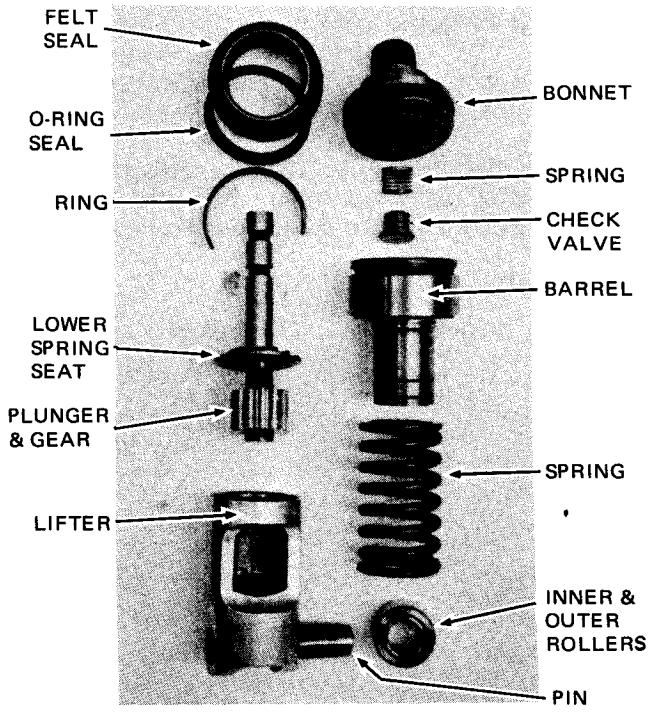


Fig. 30-26 Exploded view of a compact-housing fuel-injection pump.

Inspecting Pump Housing Check the threaded holes for damage. Do not forget to check the pump housing for nicks and burrs. Check especially the shoulder on which the spacer rests because if damaged it can cause an incorrect lifter-height adjustment. Check for damaged locating dowel pins. Using an inside micrometer, measure the camshaft bushing for wear, and compare with service manual specifications.

Installing Camshaft and Lifters Wash the pump housing in clean fuel and dry it with compressed air. Lubricate the bushings and camshaft journals. Install the camshaft into the housing. Install the camshaft locating plate and bolt it to the fuel pump housing. Place the drive gear into the camshaft, and the sleeves into the gear slots. Place two cap screws through the lock-plate holes and screw them into the camshaft (Fig. 30-24).

CAUTION Do not damage the bushings during installation.

With the camshaft in place, lubricate the lifters and their bores. Return each lifter to its bore so that the lifter roller rests against the camshaft lobe. Then place each spacer on the shoulder of the bore. Make certain the lifters rest on the cam lobes before you install the fuel rack, or else the lifter may be damaged when inserting the fuel rack.

Measuring Fuel Pump Timing Dimension Mount the degree wheel (timing plate) to the camshaft and the pointer to the housing. Turn the degree wheel (in a counterclockwise rotation) so that 355° on the wheel aligns with the left-hand edge of the pointer. This brings the No.1 lifter into position to be measured. See Table 30-3 for the timing-plate setting in degrees.

Make certain that the lifter rests firmly on the cam lobe before placing the 2-in [50.8-mm] gauge block on top of the spacer. Use a depth micrometer with a 4- to 5-in [101.6- to 127.0-mm] rod, and measure the distance from the surface of the gauge block to the wear washer of the lifter (Fig. 30-27). The micrometer should read, in this case, 4.394 in ±0.002 in [111.61 mm ±0.05 mm] (see Fig. 30-28). If the micrometer reading is higher, say by 0.004 in [0.101 mm], remove the spacer, measure its thickness, and select a spacer which is 0.004 in [0.101 mm] thinner to give the recommended lifter height.

TABLE 30-3

LIFTER SETTING CHART (OFF ENGINE)

Lifter number (shown beside each pump hole)	Turn timing plate counterclockwise to (degrees)	
	PC, degrees	DI, degrees
1	355	346
4	295	286
2	235	226
6	175	166
3	115	106
5	55	46

When the No. 1 lifter is within specification, turn the degree wheel in a counterclockwise rotation so that 295° on the wheel aligns with the left-hand edge of the pointer. This positions the No 4 lifter. Measure (and, if necessary, change) the spacer to bring the No. 4 lifter within specification. Then measure and adjust the remaining lifters.

To check the fuel-injection-pump timing while the pump is installed to the engine, follow the same procedure outlined previously. However, the fuel pump camshaft timing pin is placed in the outside hole below the No. 3 fuel-injection pump.

Installing Fuel-injection Pumps Wash all the components of each injection pump in clean fuel. Place the spring seat in the groove of the plunger. Put the spring on the plunger. Carefully slide the plunger into the barrel and the spring over the barrel *(NOTE: The plunger must turn freely.)*

Next, place the check-valve spring and the valve into the bore of the bonnet. Position the barrel assembly on the bonnet. Clip the ring in the grooves of the barrel and the bonnet (see Fig. 30-28). Place a new O ring, then the retainer bushing, on the bonnet and then screw the extracter onto the bonnet. Before you install the injection pumps, the fuel rack must be centered. This can be done in two ways: (1) by measuring the distance (on this pump 0.156 in [3.96 mm]) that the fuel rack protrudes from the housing face, or (2) by fastening the pointer used for measuring the degree angle to the fuel-pump housing and pushing the fuel rack into the pointer cavity. When the fuel rack is centered, turn the camshaft so that the injection-pump lifter being installed is on the base circle of the cam lobe. Align the slots of the bonnet and barrel with the slot of the gear segment (Fig. 30-28). Install the assembly into its bore. The barrel and the bonnet slots should engage smoothly with the dowel pins. The gear segment should engage smoothly with the fuel rack.

CAUTION Do not exert force. Unnecessary force will damage the gear segment and the fuel rack or will break pieces from the dowel pins.

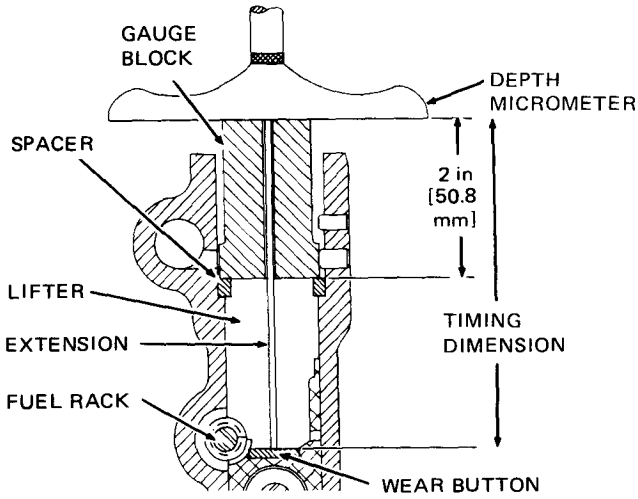


Fig. 30-27 Measuring timing dimension. *(Caterpillar Tractor Co.)*

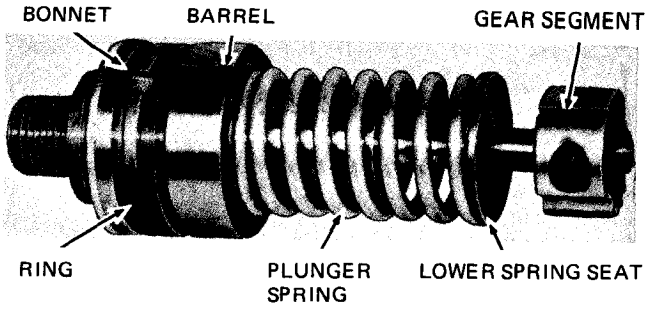


Fig. 30-28 Showing alignment of slots and gear. *(Caterpillar Tractor Co.)*

With the assembly in position, press the extractor downward, locate the square O ring, and begin hand-tightening the retainer bushing until two threads protrude from the housing surface. Remove the extracter and tighten the bushing to 150 lb·ft [203.2 N·m]. Install the remaining injection pumps.

Measuring piston travel and spill-timing on a compact-housing pump is performed in the steps previously outline for the forged-body pump; however, the specifications are different. See the applicable service manual.

Installing Governor Wash all the governor components in clean fuel and dry them with compressed air. Lubricate the components before reinstalling them. Carefully place the the sleeve and the sealing ring into the cylinder and the valve into the piston. Hook the piston into the fuel tank. Make sure that the thrust bearing and spring are positioned properly, and that the coned side of the disk spring faces to the rear, before installing the governor housing. Install the rack collar to the bolt, but make sure that the screw is in the bolt groove before tightening it. Install the torque-spring assembly in the order shown in Fig. 30-29. Do not install the spacer plate, speed limiter, or fuel-ratio control at this time.

NOTE: The more recently designed fuel pumps do not use a speed limiter.

Fuel-rack Setting with Rack-setting Gauge On the earlier designed fuel pumps, the fuel-rack setting can be made with the rack-setting gauge. To

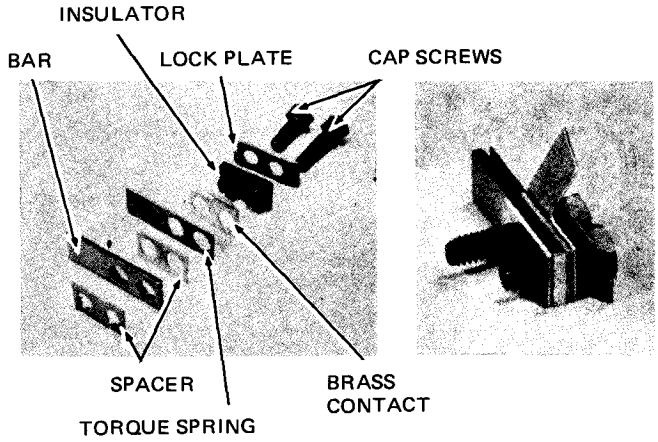


Fig. 30-29 Exploded and assembled view of torque-spring assembly.

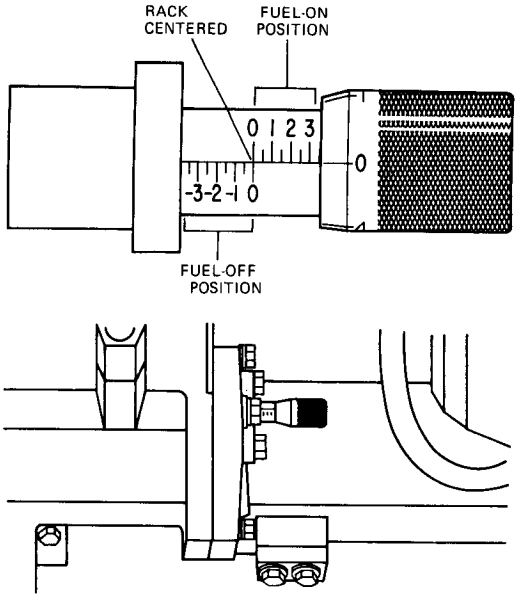


Fig. 30-30 Schematic view of rack-setting gauge installed showing various rack position readings.

do this, install the rack-setting gauge over the front end of the fuel rack. Set the gauge to the specification recommended in the rack-setting information section of the service manual (Fig. 30-30). Now, move the throttle to the full-fuel position. The rack collar should barely contact the torque spring. If the torque spring becomes compressed or if the collar does not contact the torque spring, loosen the locknut and turn the adjusting screw until the collar just touches the torque spring. Then lock the screw. Now turn the rack-setting gauge slightly in a clockwise direction to reduce the rack travel. If the rack collar instantly moves away from the torque spring, the setting is correct (Fig. 30-22).

Fuel-rack Setting with Dial Indicator The dial-indicator method of measuring and adjusting fuel-rack travel is more precise than the rack-setting-gauge method. The dial-indicator method can also be applied to the earlier designed fuel pumps. Another advantage is that the fuel-rack travel can be measured with the engine in either the running or the stopped position, or with the pump removed from the engine.

To use the dial-indicator method, install the gauge shown in Fig. 30-31. This indirectly places one end

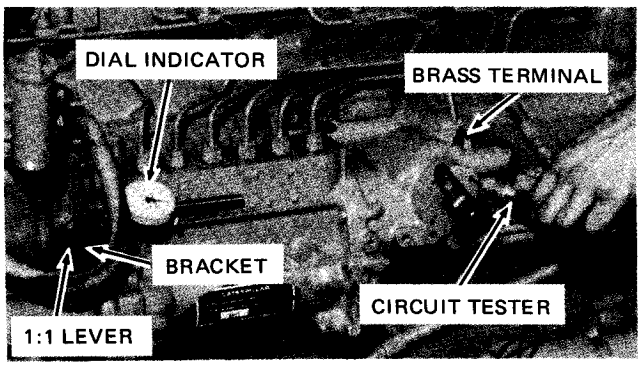


Fig. 30-31 Fuel-rack-setting tool installed. *(Caterpillar Tractor Co.)*

of the 1:1 lever onto the fuel rack and the other end onto the dial-indicator pointer. Move the throttle lever to the fuel-off position, place the spacer (which is part of the rack-setting tool group) over the rod that makes contact with the fuel rack, and hold it in place while zeroing the dial indicator; then remove the spacer.

To determine the exact moment when the rack collar contacts the torque spring, connect one lead of the circuit tester to the insulated terminal; connect the second lead to an effective ground. After the test instruments are installed, move the throttle lever to the full-fuel position. The light should glow brightly. If it does not, loosen the locknut and turn the adjusting screw in the collar (Fig. 30-22) until the light becomes bright. Then move the throttle in the opposite direction until the light goes out. Again, (very slowly) move the throttle to the full-fuel position until the light barely glows. This indicates that the rack collar has just contacted the torque spring. At this point read the rack travel directly from the dial indicator. If necessary, continue to reset the adjusting screw until the dial indicator shows the correct setting while the light glows faintly.

Fuel-ratio Control—Tests and Adjustments The fuel-ratio control coordinates the movement of the fuel rack with the inlet-manifold boost pressure to reduce exhaust smoke during acceleration. When the fuel-ratio-control valve is serviced, it must be checked and tested before being reinstalled to the governor. (See Unit 26, "Antipollution Control Devices," for operation.)

To test this valve, connect an air line with a pressure regulator to the inlet port of the chamber (see Fig. 30-32). Apply 5 psi [34.5 kPa]. This should cause the diaphragm and bolt to move. Apply 16 to 20 psi [110.3 to 137.9 kPa]. This should then cause the diaphragm to bottom onto the housing and the bolt to move fully outward.

To check the chamber for air leakage increase the pressure to 35 psi [241.3 kPa], then close off the air supply and check the pressure drop. The pressure drop should not exceed 2 psi [13.8 kPa], within 10

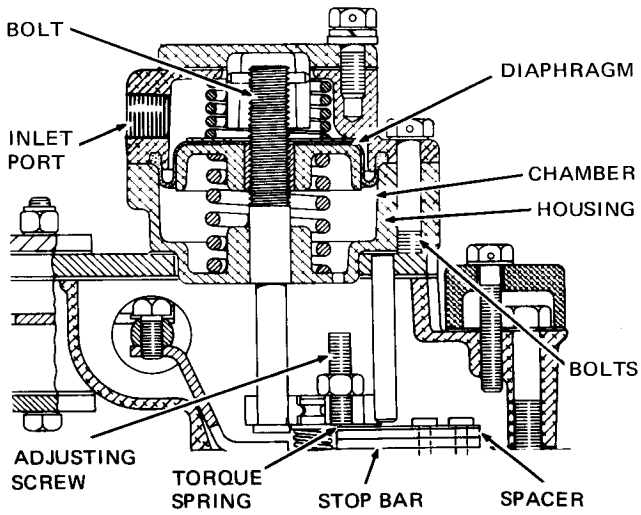


Fig. 30-32 Schematic view of an earlier-design fuel ratio control.

seconds. If the fuel-ratio control does not pass these two tests, it must be reserviced.

Fuel-ratio Control—Installation and Adjustment Move the throttle lever to the fuel-off position. Slide the bolt into the rack collar notch. Install and tighten the hex bolts to specification. Connect the circuit tester as previously outlined. Move the throttle to the full-fuel position; the test light should glow brightly. If it does not, turn the valve (using the cover) clockwise until it does; then slowly turn it counterclockwise until the light barely glows. In this position, place an aligning mark on the cover and the housing. (See service manual for fuel-ratio-control setting.)

Assuming that the fuel-ratio-control setting is 0.020 in [0.508 mm], you must then retract the fuel rack by that amount. To make this reduction, turn the cover three holes from the alignment mark, counterclockwise. (The distance from hole to hole is equal to 0.008 in [0.20 mm] of rack travel.)

NOTE: When the cover holes do not align with the threaded bores, turn the valve cover to align the next hole to reduce rack travel. In this case the reduction is 0.004 in [0.010 mm]. One complete turn of the cover is equal to 0.050 in [1.27 mm].

When the air-fuel-ratio control is adjusted, install the bolts that hold the cover and the speed limiter, if used, and then install the injection pump to the engine. (See Air-fuel-ratio-control Adjustment when Fuel Pump is Installed to Engine, below).

Variable-timing and Drive Shaft When the fuel-injection pump is serviced, the variable-timing and drive shaft must also be serviced since it is the drive link between the timing gear and the pump camshaft. Any malfunction in the variable-timing device will decrease the engine performance.

The 3400 Series engines use a mechanical variable-timing device similar in design to the Robert Bosch mechanical timing device (see Fig. 30-33). Its drive gear is supported by the flange and held thereto by a retainer ring. Machined-out grooves in the gear fit loosely over the counterweights. The counterweight grooves rest in slides and these slides are positioned on dowel pins fastened to the flange. The dowel pins are offset and the machined-out grooves in the gear are slightly angled. A large-coil spring and a small-coil spring are located in the counterweight slots. When assembled, the gear flange holds the springs compressed and the counterweights are forced toward the bore center. The variable timing is held to the fuel pump drive shaft by the flange through a retainer and four cap screws.

OPERATION When the engine operates at low-idle speed, the drive gear's rotating speed is not high enough to move the counterweights outward against the spring force. As the engine rpm increases, the counterweights start to move outward and at 1100 engine rpm they have reached their outward limit. The outward movement of the counterweights changes the alignment between the drive gear and flange because of the off-center dowels and the angled slots in the gear. This causes the flange, drive shaft, and fuel-pump camshaft to move 4° (on precombustion chamber engines), and 2½° (on direct engines), in the direction in which the drive gear rotates, thus advancing the beginning of injection.

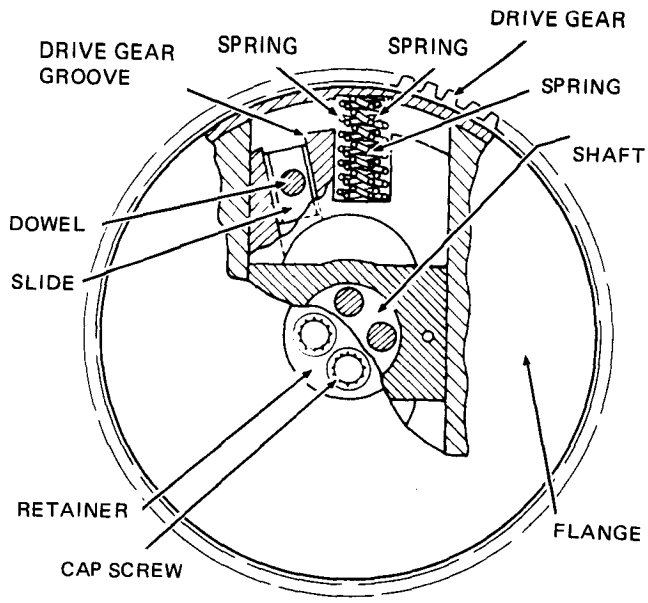


Fig. 30-33 Schematic view of automatic advance.

SERVICING When servicing the automatic timing advance, check the flange stub shaft, and the gear bore, for wear. Check the slides, dowels, grooves, and slots for burrs and grooving, as this will increase friction and alter the beginning of advance. Measure the springs' lengths; if any are not within specification, replace them. Also, if the springs are bent or show erosion, replace them.

The fuel pump drive shaft is supported in its housing by ball bearings and the right-hand side is splined into the fuel pump camshaft. The drive shaft not only serves as the link between the drive gear and fuel pump camshaft, but also as the drive for the tachometer.

Installing Fuel Pump to Engine Position the No. 1 piston on compression stroke so that the timing bolt can be threaded into the flywheel, or position the crankshaft as outlined in the service manual.

Install the timing pin into the fuel pump camshaft. Align the splines of the fuel pump camshaft with the splines of the drive shaft and slide the camshaft splines into the drive-shaft splines until the mounting flange of the fuel pump bottoms against the drive-shaft housing. From this point on the camshaft, timing procedure is identical to the procedure outlined previously in this unit in the material on checking camshaft timing.

High- and Low-idle Adjustment To adjust the engine's high- and low-idle speed, bring the engine up to its operating temperature and then remove the cover (Fig. 30-34). Position the throttle to the low-idle position. Turn the low-idling adjusting screw until the strobe light or hand tachometer indicates the rec-

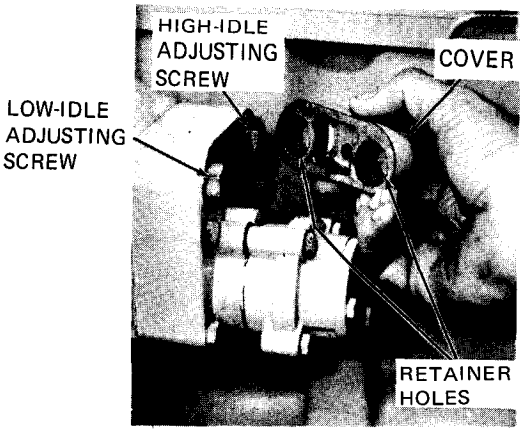


Fig. 30-34 View of low- and high-idle adjusting screws.

ommended speed. Then move the throttle to the full-fuel position and turn the high-idle screw until the engine speed is up to specification.

If the exhaust smoke is excessive when accelerating the engine, check the operation of the variable timing, using a injection-timing tool (see Unit 53, "Troubleshooting and Tuneup") and check the dashpot adjustment.

CAUTION Make certain you have checked the air-intake system and the turbocharger boost pressure before adjusting the air-fuel-ratio control.

Air-fuel-ratio-control Adjustment when Fuel Pump is Installed to Engine To check the air-fuel-ratio-control adjustment when the fuel pump is installed to the engine, connect the dial indicator and the circuit tester to the fuel pump as shown in Fig. 30-31. Start the engine and bring it to operating temperature, then quickly move the fuel rack to the full-fuel position while reading the dial indicator. It should agree with the air-fuel rack-setting specification. *(NOTE: You must read the dial indicator quickly because the maximim fuel-rack travel is only indicated for a moment.)* If the dial-indicator reading does not correspond to the air-fuel rack-setting specification, remove the cover bolts and then, with the cover, turn the valve, one hole at a time, clockwise to increase or counterclockwise to decrease the rack travel. When the adjustment is correct, replace the cover.

Dashpot Adjustment With the engine at operating temperature, turn the reservoir adjusting screw (located below the air-fuel-ratio control) three to four turns counterclockwise, as this will clean the orifice. Turn the screw clockwise until seated and then open it one-quarter to one-half a turn to give the correct flow into the reservoir. Repeat this procedure with the dashpot-chamber adjusting screw located on the left-hand side of the air-fuel-ratio control, but open the adjusting screw three-quarters to one turn.

V-type Compact-housing Fuel Pump There are some very significant differences between the in-line and the V-type compact-housing fuel pumps (Fig. 30-35). For example, referring to the V-type pump, note the following: (1) The fuel pump is located in the V between the cylinder heads. (2) The fuel pump housing is of the V design, having either four or six fuel-injection pumps in each bank. (3) Each bank has its own fuel manifold and its own fuel rack. (4) The plungers have a pressure-relief passage below the helix. (5) The (low-pressure) inlet elbow has a damper to reduce shock pressure caused from the injection pump during spillback (end of injection). (6) There is a restricter orifice positioned in the return line to create the desired inlet manifold pressure. (7) The governor is bolted vertically to the fuel pump housing and is driven through a bevel gear set. The crown gear is bolted to the fuel pump camshaft and the pinion is fastened to the governor drive shaft. (8) To link the fuel racks with the governor, the bell crank lever engages with the lever in the fuel pump housing

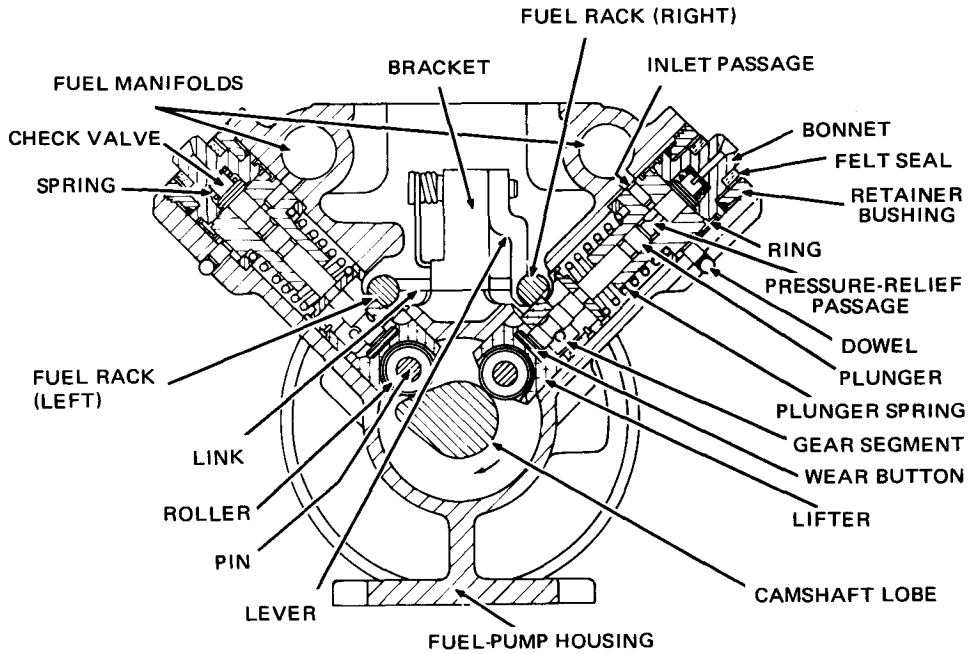


Fig. 30-35 Schematic view of a V-type compact-housing fuel pump. *(Caterpillar Tractor Co.)*

and the lever is connected loosely with the link. The link ends rest in the groove of the left- and right-hand fuel rack (Fig. 30-36). (9) Some engine applications use a torque-spring arrangement, others have a fixed stop bar. (10) The governors use a rack limiter. (11) The fuel transfer pump is driven through a helical gear from the crown gear. (12) The transfer-pump drive shaft drives the service meter and/or tachometer drive. (13) The fuel racks are centered through a centering pin. (14) The variable timing has three springs in each counterweight slot (Fig. 30-33).

CHECKS AND ADJUSTMENTS (V-TYPE PUMP) The following checking, measuring, and adjusting procedures are comparable to the in-line compact-housing fuel pump: (1) Checking the lifter height (timing dimension). (2) Checking and adjusting camshaft timing. (3) Measuring piston travel. (4) Removing and installing the injection pump (however, a rack centering pin is used). (5) Using a timing bolt to locate TDC of No. 1 plunger. (6) Using a dial indicator to measure rack travel. (7) Adjusting rack travel with the same screw in the collar. (8) Adjusting high idle, low idle, air-fuel-ratio control, and dashpot governor.

Flange-type Injection Pump Fuel pumps with flange-type injection pumps are in-line pumps and are used on the 300 Series engine. The fuel pumps, being located about 2 feet (ft) [0.61 meter (m)] below the top of the aftercooler between the cylinder heads, are very cumbersome to service (Fig. 30-37).

Some of the features of a flange-type low-pressure fuel system are that the (six) fuel filters are placed in series into the filter housing. Fuel from the transfer pump (when the engine is operating), or from the hand primer (when priming the system), flows through the transfer pump, then flows to and through the pressure-relief valve, and from there flows into the filter housing. The fuel flows from the outside to the inside of each filter and then to the fuel pump manifold. The hand primer as well as the pressure-relief valve are bolted to the fuel filter housing.

The fuel-pump camshaft is driven through a speed-sensitive hydraulic variable-timing unit. The drive gear is driven through the idler gear of the rear timing-gear train. The camshaft drive gear is held, through the clamping force of the retainer and cap screws to the variable-timing shaft assembly, and the left-hand power piston is spline fitted into the camshaft splines.

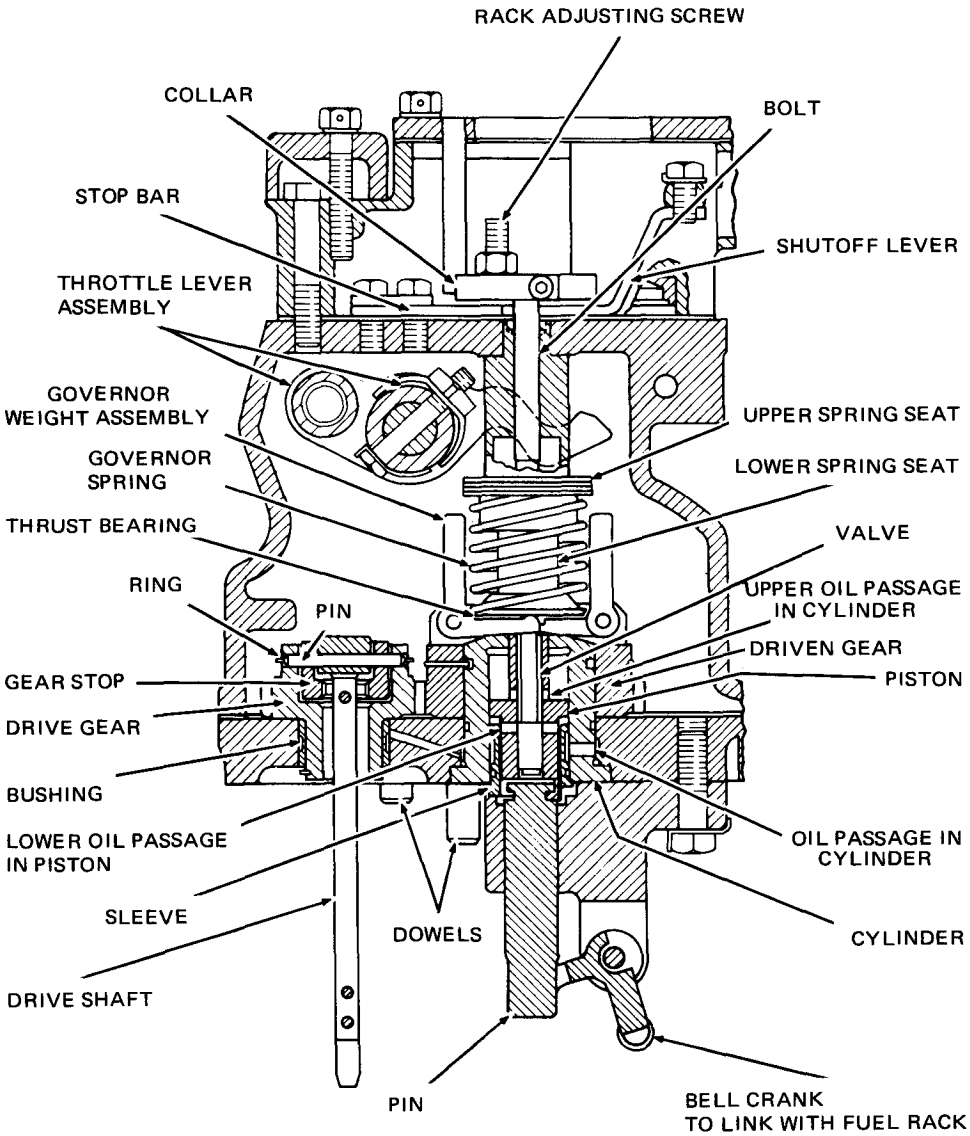


Fig. 30-36 Schematic view of hydromechanical governor used on 3400 Series engine. *(Caterpillar Tractor Co.)*

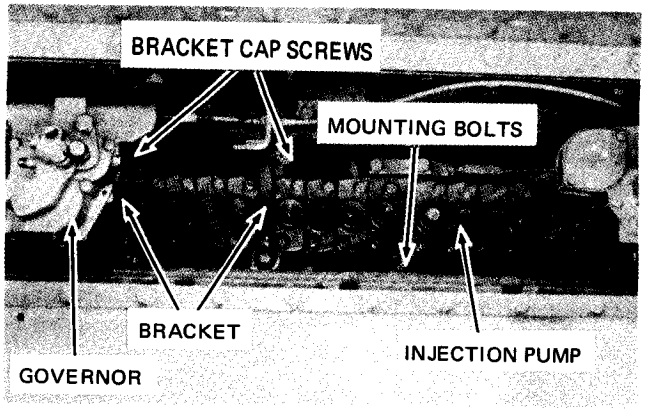


Fig. 30-37 Top view of a 12-cylinder fuel pump. *(Caterpillar Tractor Co.)*

The fuel-pump camshaft is cast with a bevel gear located at the first camshaft bearing. The bevel gear is in mesh with the pinion gear attached to the governor drive shaft. The transfer pump is bolted to the front end of the fuel-pump housing and is driven by the camshaft through a square coupling or helical gear. The governor used is the same as that on the 3400 series engine except that the pin assembly is connected to a bell crank and the other end of the bell crank rests in the fuel-rack slot (Fig. 30-36).

Measuring Fuel Pump Timing and Lifter Setting The procedure to check the timing on a flange-type fuel pump is precisely the same as that for a compact-housing fuel pump, but the specifications, of course, are different. You can use a timing light, or position No. 1 piston on compression stroke to TDC and then position the timing pin into the camshaft, or follow the spill-timing method.

Measuring the lifter height is also similar; however, when changing the lifter height (phase angle) of the injection pump, and the lifter dimension is above or below specification, you must exchange the lifter for one having a greater or smaller dimension (see Fig. 30-38*b*). The measurement is taken from the wear bottom to the outside of the roller. Five different lifter sizes are available to bring the injection-pump plunger to the correct height.

Components of Variable-timing Drive The components of the speed-sensing variable-timing drive are shown in Fig. 30-39. As illustrated, the drive gear is bolted to the right-hand side of the shaft assembly. The shaft assembly is held in the fuel-pump housing by a plate. The power piston has straight splines on one end. These straight splines mesh with the straight splines of the camshaft. On the other end, the power piston has helical splines that mesh with the helical splines in the shaft assembly.

The control-valve spring and the control valve are positioned over the power-piston rod. The piston rod is connected to the followup rod by a pin. The power-piston return spring is situated between the bore in the shaft assembly and the spring seat. The seat is held to the followup rod by the cap nut. The two flyweights are fastened through pins to the drive-shaft assembly and the fingers of the weights rest in the groove of the control valve.

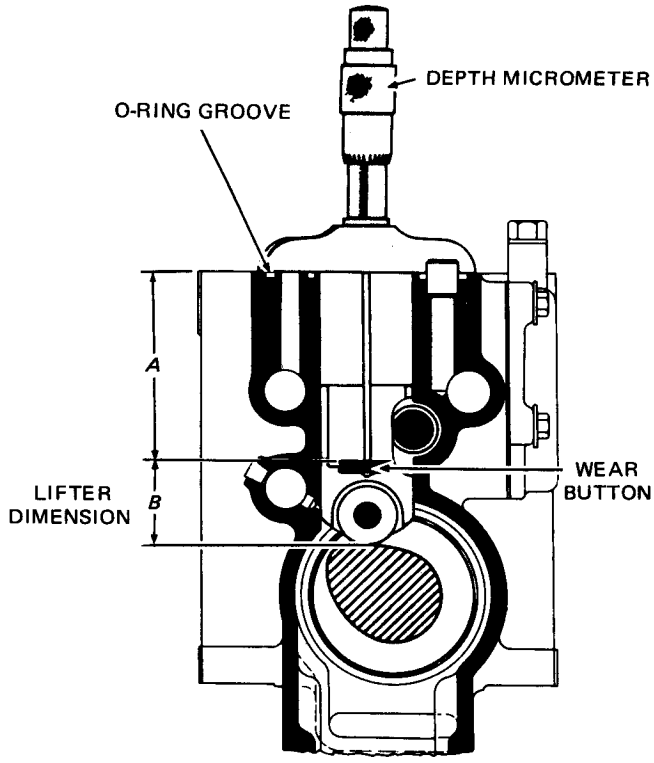


Fig. 30-38 Measuring lifter height using depth micrometer. *(Caterpillar Tractor Co.)*

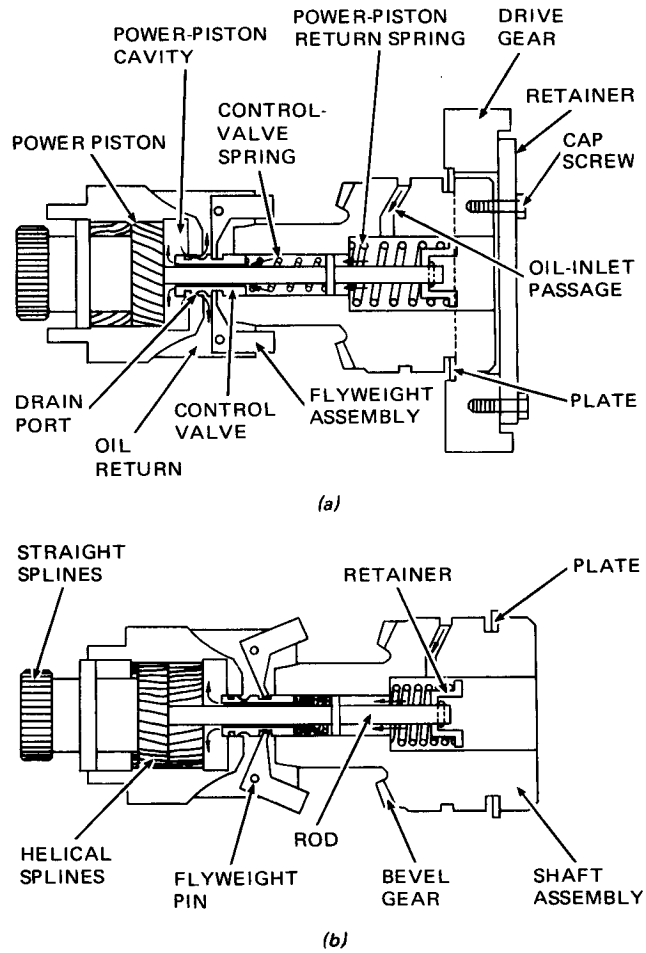


Fig. 30-39 Schematic view of hydraulic variable-timing unit. *(Caterpillar Tractor Co.)*

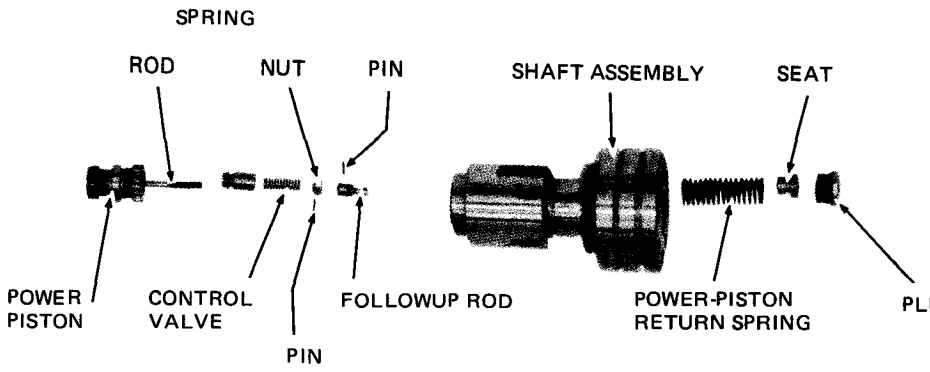


Fig. 30-40 Exploded view of variable-timing unit. *(Caterpillar Tractor Co.)*

VARIABLE-TIMING-DRIVE OPERATION When the engine is running (at idle speed), oil from the lubrication system is supplied to the front support bushing. From here it enters the inlet passage, flows through the control valve into the power-piston chamber, and then out through the drain port. This occurs because the flyweight force at this speed is lower than the spring force of the control valve (see Fig. 30-39).

As the engine speed increases, the flyweight force increases, moving the control valve to the right in Fig. 30-39*b*, so that the drain annulus opening is reduced. Consequently, pressure in the power-piston chamber increases. The power piston is moved to the left, against its spring force. Because of the helical splines, the outward movement of the piston turns the camshaft slightly, in the same direction as the variable-timing drive gear.

The camshaft advances in relation to the drive-shaft assembly. The outward movement of the power piston has now increased the control-valve spring force. This moves the control valve and increases the return annulus opening. As soon as the power-piston return-spring force and the flyweight forces balance, the oil pressure in the power-piston chamber is constant. As the engine speed increases, the camshaft advances correspondingly until the power-piston flange butts against the camshaft. The spring and weight force and the helical spline govern the advance curve.

At any constant speed above 1150 rpm, the camshaft maintains its full advance position.

NOTE: The amount of advance varies between engines and is between 8 and 11°.

SERVICING VARIABLE-TIMING UNIT Start by positioning the No. 1 piston on compression stroke so that the flyweight timing mark aligns with the pointer. Install the fuel pump camshaft timing pin into the camshaft slot.

Remove the variable-timing drive from the engine by removing the gear cover cap screws, the cover, and the retainer cap screws. Lift the retainer from the gear and the gear from the shaft assembly, and lift out the variable-timing assembly.

To disassemble the unit, unscrew the plug from the followup rod and remove the spring seat and spring. Press out the flyweight pins and remove the flyweights. Slide the power piston with the control valve, control-valve spring, and followup rod from the shaft assembly. Remove the pin which holds the followup rod to the power-piston rod. Loosen and remove the adjusting nut and slide the control-valve spring and valve from the rod (Fig. 30-40). When checking the components for serviceability, check the flyweight bores for wear and the weight fingers for flat spots. Check the control valve and its cylinder for scoring or excessive wear. Replace the control-valve spring and piston return spring. Check the straight and helical splines of the power piston, drive shaft, and camshaft. The splines must mesh smoothly. Reassemble the variable-timing unit in precisely the reverse order of disassembly.

Before inserting the power piston onto the shaft assembly, the control-valve spring must be adjusted. To do this, turn the adjusting nut so that the distance between the face of the nut and the center of the followup pin is as specified, for example, 0.156 $\pm$0.010 in [3.96 $\pm$ 0.25 mm].

INSTALLING VARIABLE-TIMING UNIT Assume the crankshaft was not rotated and that the flywheel timing mark is aligned with the pointer: Install the variable-timing unit in precisely the reverse procedure of disassembly, and then time the camshaft fuel pump to the engine. From this point on the camshaft timing procedure is the same as outlined earlier in this unit in the material on checking camshaft timing.

Next, use the timing light to check the operation of the timing unit.

FUEL-RACK SETTING To check or measure the fuel-rack travel, you need the Caterpillar rack-setting tool group, that is, a special dial indicator having a small revolution counter and a conventional dial face, a long extension, and adapter, a long rod, and contact point. To perform an adjustment or check, first center the fuel rack by installing the timing pin into the fuel-rack slot and removing the air-fuel-ratio-control valve. Assemble the extension, adapter, rod, and dial indicator. Remove the plug located at the right-hand side of the fifth fuel-injection pump and screw the extension into this hole. This brings the dial-indicator rod end in contact with the 1-to-1 lever (see Fig. 30-41). Raise or lower the adapter so as to bring the revolution counter hand to zero, then zero the large dial indicator by rotating the bezel. Connect one lead of the circuit tester to the brass terminal and the other to ground. Now remove the fuel-rack timing pin and place the throttle into full-fuel position and then gently push downward on the exposed dial-indicator stem. This moves the 1-to-1 lever downward, the fuel rack to the right, and the bell crank, pin, valve, bolt, and

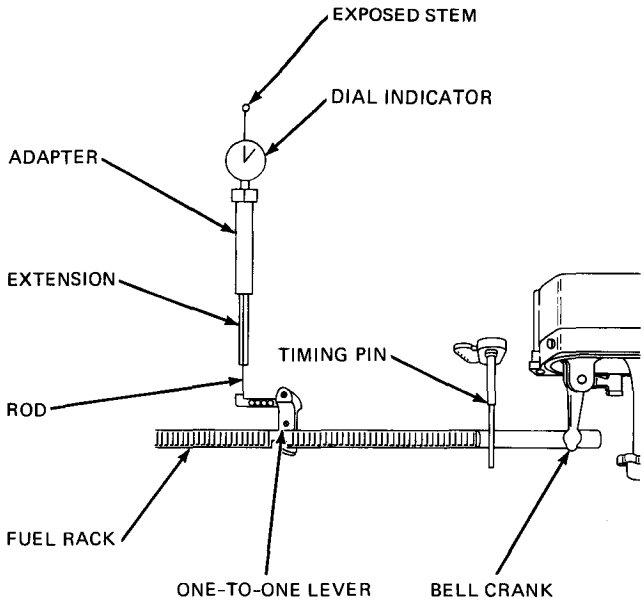


Fig. 30-41 Schematic view of tools installed to measure fuel-rack travel.

collar downward. Push downward until the circuit tester bulb barely glows and read (from the small dial) the revolutions, and (from the outside dial) the thousandths of an inch measurement. If an adjustment is needed, loosen the locknut and with an Allen wrench turn the adjusting screw until the dial-indicator reading conforms with the rack-setting specification. Lock the adjustment, reinstall the air-fuel-ratio control, and adjust it as previously outlined to the specification given in the rack-setting information guide.

Since the governor is the same as that used on the compact-housing fuel pumps, the high- and low-idle adjustment is also the same and will, therefore, not be repeated here.

Precombustion Chamber, Adapter, and Fuel Nozzles The Caterpillar 3400 Series engines are designed as precombustion-chamber or direct-injection engines. The 3300 and the 300 Series engines are designed only as precombustion-chamber engines, and the 3200 Series engines are designed only as direct-injection engines and use pencil-type injectors.

When the engine is built as a precombustion-chamber engine, an outward-opening capsule-type nozzle is used, and when the engine is built as a direct-injection engine, a capsule-type needle-valve injection nozzle is used (Fig. 30-42).

The precombustion chamber or the adapter is screwed into the cylinder head and is sealed on the lower end with a copper-alloy gasket and on the upper end with an O ring. *(NOTE: Glow plugs are used only with precombustion chamber.)*

PRECOMBUSTION-CHAMBER OR ADAPTER REMOVAL AND INSTALLATION If it is necessary to remove the precombustion chamber or the adapter, the cooling system must be drained, and on overhead-camshaft engines the camshaft housing must be removed, as must the glow plug if one is used. (Precise instructions are outlined in your service manual.) After removing the valve cover, remove the injection line and cover its openings. Remove the nut and lift, from the precombustion chamber or the adapter, the body and nozzle. Insert the specially splined wrench into the fine spline of the precombustion chamber or adapter. Loosen the precombustion chamber, or adapter, and unscrew it. If the interior or exterior of the chamber, or adapter, is not damaged by corrosion or oxidation, glass-bead the assembly to ensure adequate cooling. The chamber or adapter interiors must be cleaned thoroughly with compressed air before it is reinstalled. Coat the O ring and groove and the chamfered portion of the cylinder head with the recommended grease (or soap). Apply an antiseize compound to the threads and, with grease, attach a new gasket to the bottom of the chamber or adapter.

Thread the precombustion chamber or adapter into the cylinder head and tighten it to 150 lb·ft [200.2 N·m]. If a glow plug is used, make certain it is posi-

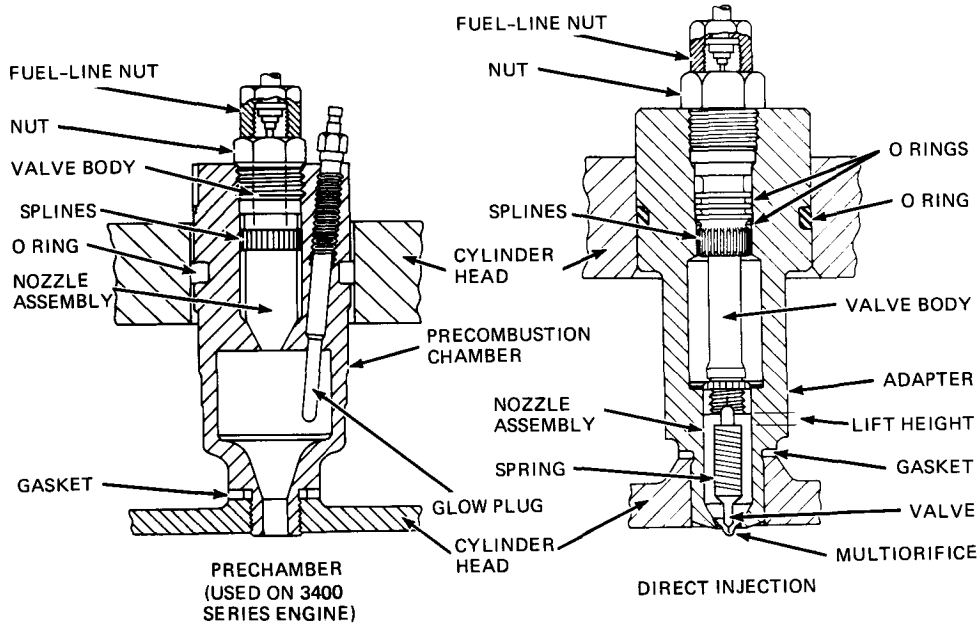


Fig. 30-42 Schematic view of precombustion chamber and adapter assembly installed.

tioned in the "go" range. If positioned in the "no-go" range, the rocker arm will damage the glow plug. To change its position, change the gasket (which is identified by a letter) according to the service manual specifications.

NOZZLE-VALVE FUNCTION (PRECOMBUSTION CHAMBER) The fuel-injection valve is a capsule-type nozzle. It consists of the components shown in Fig. 30-43.

When the fuel pressure in the area above the valve seat rises, force is exerted on the valve and, when the force becomes higher than the spring force, the valve opens outward (toward the orifice). Fuel is sprayed into the precombustion chamber until the injection-pump plunger opens the inlet port. The pressure in the injection line quickly decreases the valve-spring and fuel pressure force seats the valve. As a result of the displacement plunger on the check valve, a predetermined pressure is maintained within the injection line and the area above the valve.

NOZZLE-VALVE FUNCTION (DIRECT INJECTION) The nozzle used on direct-injection engines is also a capsule-type nozzle similar to a Detroit Diesel spray-tip design. It consists of a threaded collar, a screen and screen support plate, a valve-spring guide, a valve pressure spring, a needle valve, a valve seat with orifices, and a pressure chamber.

When the fuel pressure increases in the pressure chamber, the force on the needle valve increases, and when it becomes greater than the pressure spring force, the needle valve lifts off its seat. Fuel is then sprayed through multiorifices onto the piston crown. As the injection-pump plunger ends injection, the spring and fuel pressure force seats the valve.

SERVICING AND TESTING NOZZLES If when inspecting the precombustion chamber or the direct-injection nozzle you find that the screen or the seating area of the nozzle is damaged, or the orifices are plugged, the nozzle must be replaced. However, if the orifice of a precombustion chamber is plugged up with carbon, it can be cleaned with a drill having the same dimension as the orifice. When the surface near or around the orifice is damaged, it can be lapped to restore the orifice's roundness and to make the surface corners sharp again. This is the only service possible on a precombustion chamber capsule nozzle.

To test a capsule-type nozzle, mount it to an injector tester (Fig. 30-44). Check the opening pressure, spray pattern, and valve leakage [see Unit 27, "Fuel-injection Nozzle and Holders (Injectors)].

PRECOMBUSTION-CHAMBER NOZZLE TESTING The opening pressure for used precombustion-chamber nozzles should not be lower than 400 psi [2758 kPa] or higher than 750 psi [5171.2 kPa]. New nozzle opening pressure lies between 685 to 750 psi [4723.0 to 5171.2 kPa]. The spray pattern must have a solid cone and be in line with the valve. A new nozzle should show no wetness at the orifice when pressurized to 450 psi [3102.7 kPa]. The pressure drop (valve leakage) after pressurizing the nozzle to 300 psi [2068.5 kPa] must not, after 30 seconds, exceed 200 psi [1379 kPa]; if it does, the nozzle must be replaced.

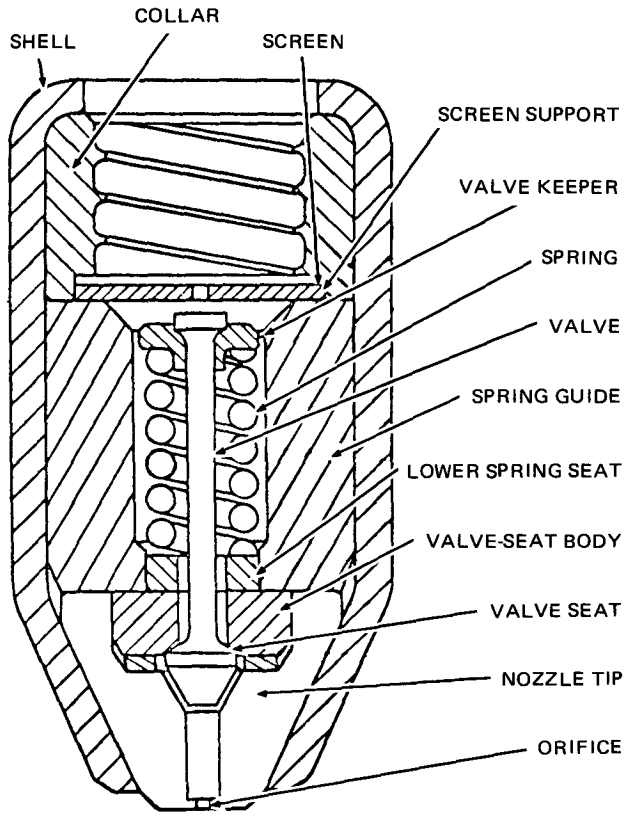


Fig. 30-43 Schematic view of precombustion chamber nozzle.

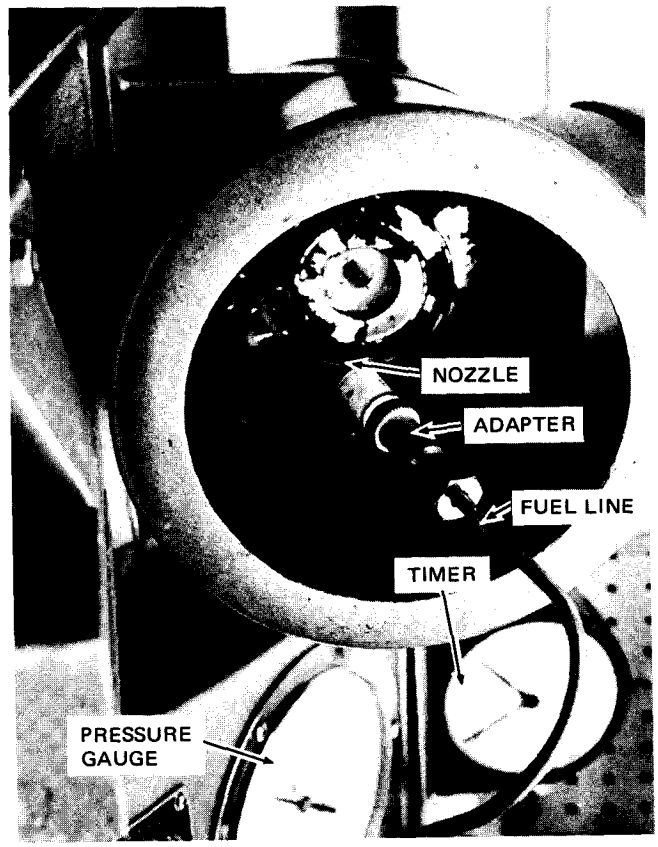


Fig. 30-44 View of nozzle testing.

DIRECT-INJECTION NOZZLE TESTING The opening pressure for used nozzles should not be lower than 2400 psi [16,548 kPa] or higher than 3100 psi [21,374.5 kPa]. Opening pressure for new nozzles is between 2900 to 3100 psi [19,995.5 to 21,374.5 kPa]. The pressure drop (valve leakage) after pressurizing the nozzle to 2200 psi [15,169 kPa], must, after 30 seconds, be at least 200 psi [1379 kPa] to assure lubrication, but must not exceed 1800 psi [12,411 kPa]. The nozzle may show some wetness when pressurized to 2200 psi [15,169 kPa] but should not drip. The spray from the nozzle holes must be equally spaced and have the same pattern, otherwise the nozzle must be replaced.

INSTALLING CAPSULE-TYPE NOZZLE Screw the nozzle fingertight to the valve body. Check to make certain the nozzle seat in the precombustion chamber or adapter is clean. Install the O ring onto the direct-injection valve body and lubricate it with soap, then insert the assembly into the precombustion chamber or adapter. The fine valve body splines should engage smoothly with the splines in the precombustion chamber or adapter. Tighten the nut to the specified torque, but do not overtorque it as this could cause nozzle leakage. Conversely, undertorquing could cause combustion leakage and, therefore, insufficiently cool the nozzle.

Questions

1. List the most significant differences between the Caterpillar fuel-injection system and the Detroit Diesel fuel-injection system.
2. List the difference in construction between a forged-body injection pump and a compact-housing injection pump.
3. List the differences in construction between a compact-housing and a flange-type fuel-injection pump.
4. What checks and measurements must be taken (when servicing) to properly check out the pump housing of a forged-body fuel pump?
5. What problems would arise if a new pump element were used with a worn yoke?
6. How could the engine timing and phase angle be affected if the micrometer accuracy were out plus 0.010 in [0.25 mm]?
7. Why is it important to zero the rack before installing the injection pump?
8. What is the purpose of a speed limiter?
9. Refer to Fig. 30-17. Draw a rack-setting gauge which indicates 0.115 in.
10. Outline the procedure to check the timing of a 3400 Series engine when using the spill method. (Port closing is at, say, 11° BTDC.)
11. What precautions are necessary when removing a compact-housing fuel-injection-pump element?
12. Why is it necessary to measure the plunger length of the fuel-injection pump?
13. What preliminary steps must be taken before measuring the lifter height of a compact-housing injection pump?
14. Explain the operation of the mechanical timing unit from the point when the advance begins.
15. When setting or adjusting the fuel rack, why should you place (between the torque spring and stop plate) a feeler gauge the same thickness as that of the spacer?
16. Why is it recommended to adjust the fuel-ratio control to the next hole reducing the rack travel, rather than to the next hole increasing the rack travel?
17. What is the advantage of the variable-timing drive with regard to engine performance?
18. Which parts of the precombustion chamber require detailed inspection?
19. Outline the mechanical and hydraulic action of a precombustion-chamber nozzle from beginning to the end of injection.
20. Which checks and what service can be made on a precombustion-chamber nozzle after it has been removed from the engine?

UNIT 31 - DETROIT DIESEL FUEL-INJECTION SYSTEM

COMPONENTS OF DETROIT DIESEL FUEL-INJECTION SYSTEM

The two- and four-cycle Detroit Diesel fuel-injection systems (Figs. 31-1 and 31-2) are comparable to the port and helix fuel-injection systems covered in Units 29 and 30. The differences which exist occur within the unit injector and the control linkages to the governor.

The main advantages of a unit injection fuel system are: (1) It has a constant injection pressure of about 1800 psi [12,411 kPa], (2) during injection the spray pattern is even and the droplet size nearly uniform, (3) it has no high-pressure fuel line which could alter the flow rate to the unit injectors, (4) the fuel-injection pump and the fuel-injection nozzle comprise one unit.

Additional positive features of the unit-injection fuel system include the following: Each injector control rack (fuel rack) is snugly fitted to a rack-control lever which can be adjusted independently to the injector control tube to permit a uniform adjustment of all injector racks (Fig. 31-3); the injector control tube is

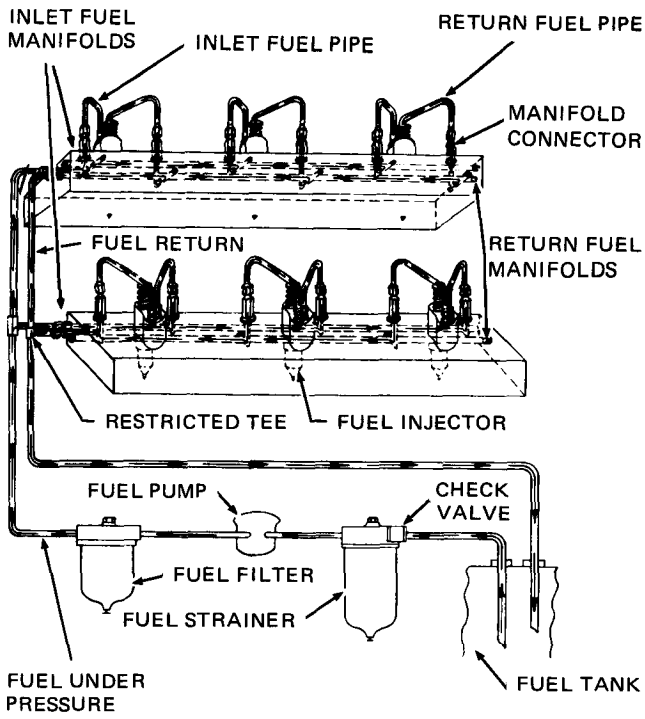


Fig. 31-1 Schematic view of a typical two-cycle Detroit Diesel fuel-injection system.

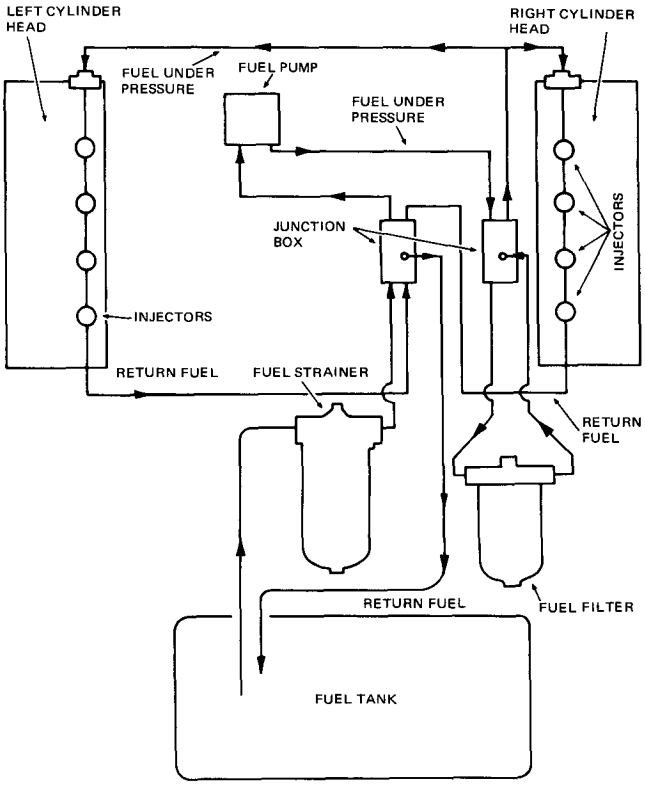


Fig. 31-2 Schematic view of a typical four-cycle Detroit Diesel fuel-injection system.

connected to the governor by the fuel rod; and the unit injector is held in its injector tube by the injector clamps or by its flange clamp. The follower (including the plunger), unlike the port and helix injection pumps previously outlined, is indirectly actuated. The follower actuation on the 149 Detroit Diesel unit, however, varies from 53, 71, and 92 Series engines and the Fuel Pincher (four-cycle) (Fig. 31-4).

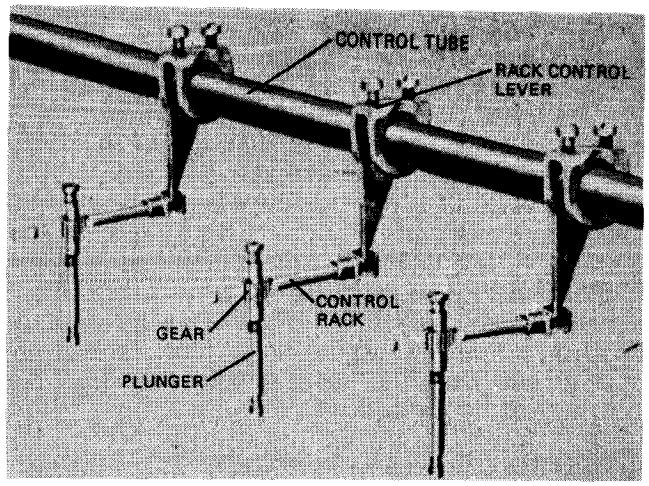


Fig. 31-3 View of the components that link the governor with the plungers.

The low-pressure side of a Detroit Diesel fuel-injection system (that is, the fuel tank, primary filter, transfer pump, and secondary filter) is comparatively similar to any other fuel-injection system. The fuel-inlet and return manifold passages of the 53, 71, and 92 Series engines are integral parts of the cylinder head, whereas the fuel manifold of the 149 Series engine is bolted to the cylinder heads. The manifold has internal inlet and return passages which are connected (through tubings) to the unit injectors.

Fuel Flow (Two-cycle System) Refer back to Fig. 31-1. Fuel from the positive displacement gear-type pump is forced through the secondary filter into the inlet manifold. A manifold connector is screwed into the cylinder head to connect the inlet manifold with the inlet fuel pipe at one end, while the other end of the fuel pipe is connected with the injector filter cap. Fuel flows through the unit injector, which cools, lubricates, and maintains a low pressure within the injector and also removes air (when present). Fuel flows through the outlet filter cap, through the return fuel pipe and manifold connector and into the return

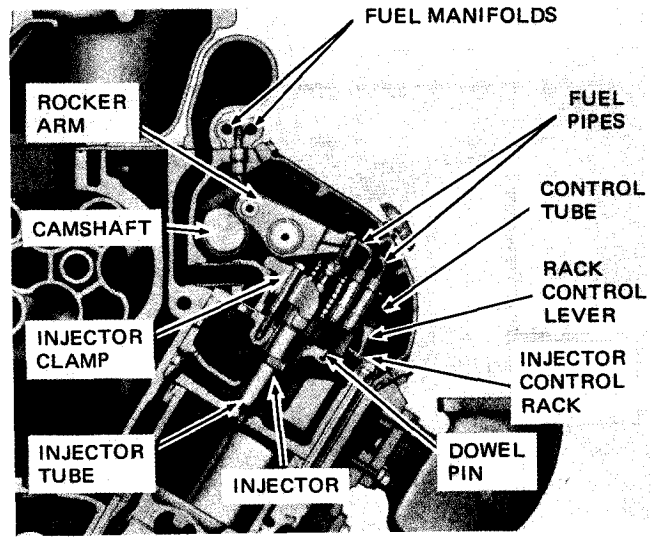


Fig. 31-4 Cross-sectional view of a 149 injector mechanism. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

manifold. The outlet manifold has a restricted orifice. Its purpose is to restrict the return flow to raise the manifold pressure to the required specification. The pressure-relief valve in the fuel (transfer) pump prevents the pressure from exceeding specification.

Fuel Flow (Four-cycle System) Refer back to Fig. 31-2. You will see the main differences between the fuel flow of a two-cycle injector system and a four-cycle Detroit Diesel fuel system. In a two-cycle system (1) junction blocks are used to connect and distribute the fuel flow, (2) the cylinder heads have only one fuel manifold, (3) the injector tube has been modified (shortened), and (4) the unit injectors are directly connected to the fuel manifold. (See Fuel Pincher injector, Fig. 31-9*b*.)

Fuel Pump Testing and Service To check the efficiency of the fuel (transfer) pump, first refer to the appropriate service manual in regard to the engine and its fuel pump test specifications. Assume in this case your engine is a 71 T. Connect a pressure gauge to the inlet manifold. Disconnect the return line at a convenient place and hold the opening end over a measuring container. Start the engine and run it at 1800 rpm. The manifold pressure when using a 0.055-in [1.397-mm] orifice should be 50 to 60 psi [344.7 to 413.7 kPa] and the spillback should be 0.6 gal (U.S.)/min [2.27 L/min].

If the fuel pressure or the fuel spillback is lower than specified, check the fuel filter and the relief valve. If the filter and the relief valve are not defective, the trouble is in the fuel pump. Remove the fuel pump from the engine and cap all fuel line openings. At the same time check the drive-coupling fork, and if it is damaged or worn, replace it.

Disassembling Fuel Pump Clean the pump externally and secure it in a soft-jaw vise before removing the cover. Take care not to damage the mating surfaces of the body or the cover.

Next, remove the drive shaft and gear and the driven shaft and gear (see Fig. 31-5). Remove the relief-valve assembly. Use a suitable puller to remove the seals.

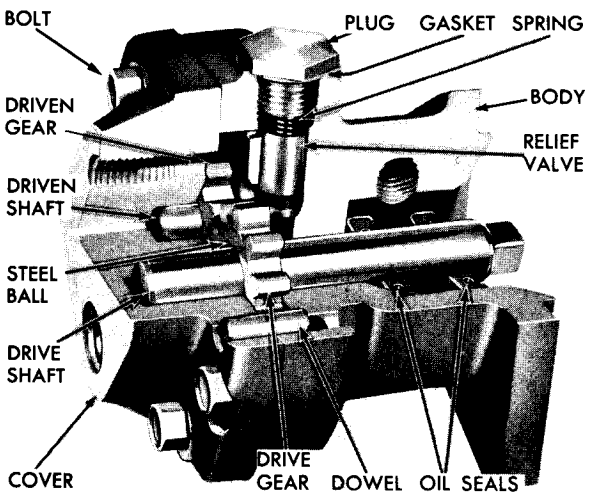


Fig. 31-5 Cutaway view of the fuel pump. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

Inspecting Fuel Pump Clean all components with fuel. Check the shafts, with the body, and the bearing bores in the body and cover for scoring and wear. If the gears are worn, scored, or damaged, they must be replaced. The mating surfaces must be free of any nicks and burrs. Check the body flange and seal bores for damaged surfaces. When necessary, lap the surfaces to a smooth finish since no gasket is used to seal against fuel leaks or pressure loss. If either the body or cover surface is damaged beyond refinishing, it must be replaced. If either the relief valve or relief-valve bore is pitted or corroded, the valve must be replaced. Always replace the relief-valve spring and the seals.

Reassembling Fuel Pump Lubricate the seal lips and the seal case. Using the correct seal driver, install the seal. Always check your service manual for correct seal direction and position, because on standard fuel pumps the seal lip faces toward the flange end, whereas on high-lift fuel pumps the lip seals are installed back to back.

If you are not using Detroit Diesel installation tools, take care that you do not insert the seals so deep that they cover the drain holes.

Press the gears onto their shafts until they are centered with the slot facing the pump cover.

NOTE: Do not press the drive gear from the square end on the shaft. This will damage the gear and shaft seal surface.

Lubricate the gears, shafts, and seals. Carefully install the drive shaft, taking care that the seals are not damaged. Install the driven gear and shaft. Place the pump cover on the dowel pins and install the cover bolts. Tighten the bolts alternately to the recommended torque. Check and make certain that the drive shaft rotates freely when turned by hand.

NOTE: Detroit Diesel engines use left- or right-hand rotation fuel pumps depending on the engine rotation. Make certain when you install a replacement fuel pump that it has the correct rotation.

Locating Misfiring Unit Injector To locate a faulty or misfiring injector of a two- or four-cycle engine, remove the valve cover, start the engine, and force each injector follower down so that the injector cannot meter and inject fuel. The sound of the engine should change as each follower is held down. When the engine sound does not change, you have located the faulty injector.

Removing Unit Injector Assume you have to remove a unit injector from a 149 Series engine. Start by removing the valve cover. Disconnect the fuel-inlet and fuel-outlet pipes from the injector and loosen both fitting nuts on the fuel manifold. Slide a hose over the pipe to avoid fuel spillage onto the cylinder head. Instantly cover inlet and outlet filter caps and place caps on fuel pipe openings. *(NOTE: When removing a Fuel Pincher injector, the fuel manifold must be drained prior to removing the injector.)* Remove

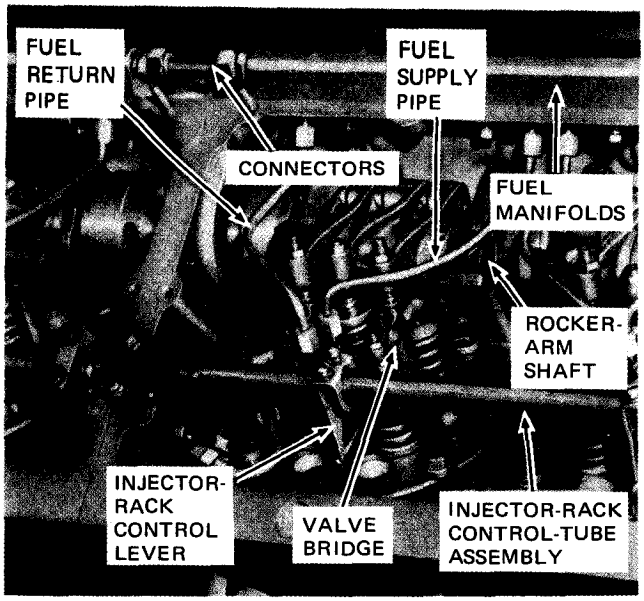


Fig. 31-6 Top view of 149 injector and valve mechanism. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

the two bolts which hold the rocker-arm shaft to the camshaft-bearing caps. Lift the rocker-arm assembly from the cylinder head and lift the two exhaust-valve bridges from their bridge guides. Loosen the inner and outer control-lever adjusting screw (newer engines have only one screw and locknut), and slide it away from the injector control rack (Figs. 31-4 and 31-6). Remove the injector clamp. Lift the injector from its sleeve using an injector bar, when necessary, to break the injector loose.

Types of Unit Injectors Detroit Diesel 53, 71, 92, and 149 Series engines have the same unit-injector design but the components vary in size. The unit-injector design for the Fuel Pincher is slightly different. The function of the unit injector is to time injection, meter fuel in relation to load and speed, and to pressurize and atomize the fuel.

Since the power output for a specific engine and its emissions is, to a large extent, governed by the plunger and spray-tip design, many different plunger designs are used. The three basic types are shown in Fig. 31-7. When advanced injection is required, the plunger has a variable beginning and a constant end of injection (Fig. 31-7*a*). When advanced and retarded injection is required, the plunger has a variable beginning and variable ending. *[NOTE: Both helices are right-hand-spiraled; however, the upper helix has a wider advance curve for greater fuel delivery than the lower helix (Fig. 31-7b).]* The 50-50-type plunger is also of the variable-beginning and -ending design; however, the upper helix has a right-hand spiral and the lower helix a left-hand one. This increases the fuel delivery and advances injection (Fig. 31-7*c*).

The fuel-injection pumps mentioned earlier have nameplates which identify design, dimension, construction, etc. This is also true of the Detroit Diesel unit injector. Each engine (even within the same series) may use a different number of spray holes, different spray hole sizes, angles, plunger sizes, and helix design. Some information is engraved on the identification tag which is pressed into the recess of the injector body and some is written on the nut and plunger and on the spray tip.

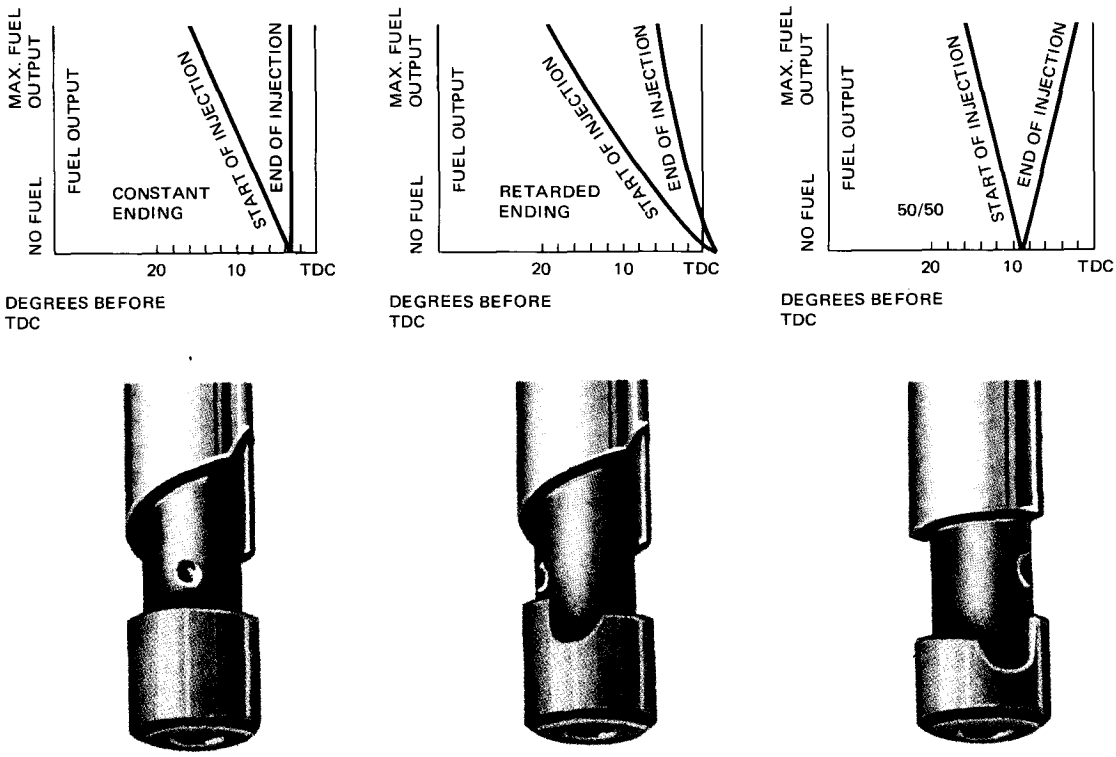


Fig. 31-7 Plunger designs: (*a*) variable beginning, constant ending; (*b*) variable beginning, variable ending, retarded type; (*c*) variable beginning, variable ending, 50/50 type.

The letter and number on the plunger identifies the plunger design. For example, an N on the plunger identifies it as a plunger having a helix design of constant beginning and variable ending, whereas a C on the plunger identifies it as a plunger having a variable-beginning and variable-ending helix design.

The number 70 refers to the test specification fuel output in cubic millimeters (mm^3) per thousand strokes. For example, a C70 unit injector can have a variation of 71 mm^3 to 75 mm^3 maximum per thousand strokes.

In order to identify the unit injector, the same letter and number on its identification tag are shown on the plunger.

The three numbers engraved on the spray tip identify the number of spray holes, the size of the holes, and the spray-hole angle.

Unit-injector Construction Two unit injectors are shown in Fig. 31-8 and Fig. 31-9. They are the Fuel Pincher unit injector and a unit injector used for the 51, 71, and 92 Series engines. *(NOTE: The 149 Series unit injector is identical to the one shown in Fig. 31-8, except that its components are larger.)* Each has a follower and a follower return spring held to the injector body by the stop pin. The stop pin, when installed, rests with its end in the groove of the follower to prevent it from rotating. The plunger hooks to the follower. The upper part of the plunger has a machined flat surface on which the gear is fitted. The control rack is supported in the injector body and meshes with the gear. The bushing (the barrel) has a lower and upper port. It also has another fuel passage, near the top, which allows the fuel that was used to lubricate the bushing and plunger to return into the area between the bushing and spill deflector. The bushing is positioned by one dowel pin to the injector body and, in conjunction with the gear retainer, holds the gear in position. Inlet and outlet filter caps are screwed into the injector body to hold the wire-mesh filter in place. On the Fuel Pincher unit injector: (1) The filters are located in the injector nut, (2) the injector nut has two seal rings which are used to seal the fuel manifold with the injector, and (3) the injector clamp is located between the body and the follower spring (see Fig. 31-9).

Up to this point, the construction is similar to an in-line fuel-injection pump. The features now change because the fuel-injector nozzle is located directly below the bushing.

The needle-valve assembly is stacked onto the bushing in the following order: check valve, check valve cage, spring, spring seat, spring cage, and spray tip. Inside the spray tip is the needle valve and inside the spring cage are the spring seat and the valve spring. The nut holds the assemblies and the bushings to the injector body. An O ring is used to seal the nut to the body. The locating dowel positions the injector to the cylinder head and on the Fuel Pincher it is positioned by the clamp.

Cycle with Plunger in No-fuel Position The pumping and metering principles of the Detroit Diesel unit injector are similar to any helix-metering fuel-injection pump except that the Detroit Diesel bushings have two offset ports (Figs. 31-8 and 31-9). The Detroit Diesel unit-injector plunger has a center hole and a cross-drilled hole (Figs. 31-7 and 31-8).

Most plungers used for the 53, 71, 92, and 149 Series engines and the Fuel Pincher are of the variable-beginning and variable-ending design.

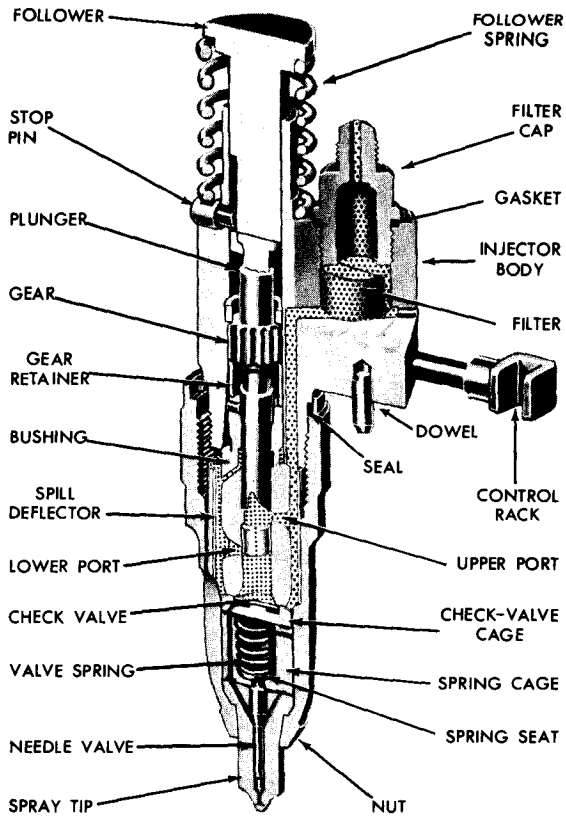


Fig. 31-8 Sectional view of a unit injector (53, 71, and 92 Series).

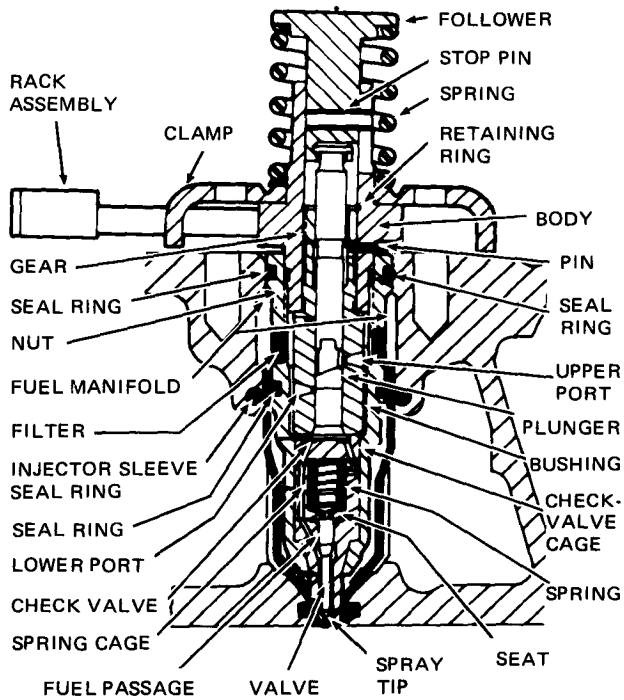


Fig. 31-9 Sectional view of a unit injector installed (Fuel Pincher).

When the governor is moved to no-fuel position, it moves the control rack as well as the gear and the plunger, and thereby brings the plunger into a position where no fuel can be pressurized (Fig. 31-10*a*). This occurs because the upper helix has a machined cutout recess which allows the upper port to stay open over a longer period of time and to close just before the lower port is opened.

When the engine is cranked over, the fuel pump provides fuel, under pressure, to the cavities within the injector. When the engine camshaft is on its base circle, the injector follower spring has moved the follower and the plunger upward, thereby opening the upper and lower ports. Fuel then pressurizes the helix area, below the plunger, the spring cage area, and the spray tip. The valve spring holds the needle valve on its seat, stopping fuel from entering the combustion chamber. As the engine camshaft rotates, the pivoting rocker arm forces the injector follower and the plunger downward, closing the lower port. The fuel displaced by the downward-moving plunger leaves via the center- and cross-drilled holes out of the upper port and through passages within the injector to the outlet filter, filter cap, fuel pipe, outlet manifold, and restricted orifice, and into the fuel tank. (On the Fuel Pincher the fuel returns to the fuel manifold.) Just before the upper port closes, the lower port opens, allowing fuel to leave the lower port until the plunger movement stops, that is, as the engine camshaft moves from the lift flank to the cam nose. Further rotation of the camshaft allows the plunger to move upward. Fuel at fuel pump pressure then fills the area voided by the retracting plunger, first through the lower port, then the upper port, and then both.

Metering and Injection The metering principle of the Detroit Diesel unit injector is the same as that of any other fuel-injection pump with a helix-designed plunger of variable-beginning and variable-ending design. The governor spring and the weight force of the governor determine the plunger position and thereby change the effective stroke. When the control tube is moved by the governor, the rack-control lever moves the control rack, rotating the gear and the plunger. This rotation changes the upper-helix position in relation to the upper port, and the lower helix in relation to the lower port (variable ending). Assume, for instance, that the plunger is at half fuel; when it moves downward, it closes the lower port. Fuel displaced by the plunger flows through the center- and cross-drilled holes and out of the upper port, until the upper port is closed by the plunger helix (Fig. 31-10*b*).

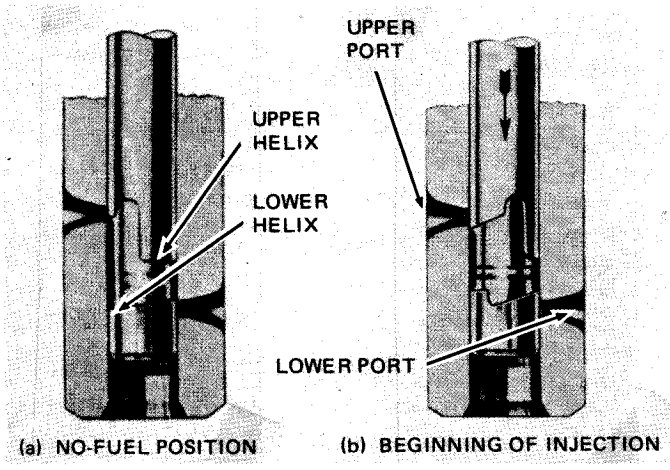


Fig. 31-10 View of plunger position.

From this point on, pressure rises rapidly in the area below the plunger, helix, spring cage, and spray-tip area. The fuel pressure acting on the pressure taper on the needle valve increases and as the force of the fuel pressure becomes higher than spring force (around 3000 psi [20,685 kPa] the needle valve lifts off its seat and its upper shoulder comes to rest against the spring cage (needle lift). Fuel is sprayed in a predetermined pattern and angle into the combustion chamber until the lower helix opens the lower port, ending injection. The fuel at high pressure spills back out of the lower port, against the deflector sleeve. This reduces the pressure in the return passage within the injector. At the same time the lift force on the needle valve is reduced and the spring force quickly seats the needle valve. The check valve below the bushing is a safety check valve to prevent combustion gases from entering the fuel passages in case the seat of the needle valve leaks.

Testing Unit Injector Prior to Servicing Most fuel-injection service shops do not test the injectors prior to servicing unless it is to assist the mechanic in troubleshooting. Although servicing is not very difficult, it is extremely important that diesel mechanics pay particular attention to area and component cleanliness and follow service manual instructions exactly. Often, injector failure arises from improper tolerances, dirt and dust, faulty installation, or careless workmanship. To ensure good workmanship, the special servicing tools should be used.

SERVICING THE UNIT INJECTOR

Disassembling Unit Injector Clean the exterior of the unit injector. Mount it in a holding fixture and remove the filter caps. Inspect the threads and flared ends of the caps and discard the filters and gaskets. On the offset injector only one inlet filter is used. If the threads or the seats are damaged, also discard the filter cap. To withdraw the stop pin, push the follower slightly down with one hand and with pliers in the other hand, turn the stop pin 90° and withdraw it. On the Fuel Pincher unit injector, push the follower down, rotate it counterclockwise to align the relief slot with the roll pin, and then withdraw the follower (Fig. 31-11).

Tilt the vise about 145° to withdraw the follower, follower spring, and plunger. Place the plunger in clean fuel and the follower and spring in a separate container. Tilt the vise a full 180° and, using a deep socket to loosen the injector nut, unscrew and remove the nut. Take care not to displace the spray tip and valve components in the process! Separately remove the spray tip (taking care not to lose the needle valve), spring cage, spring seat, spring, check-valve cage and check valve (see Fig. 31-12). Place the components in individual containers. If the spray tip adheres

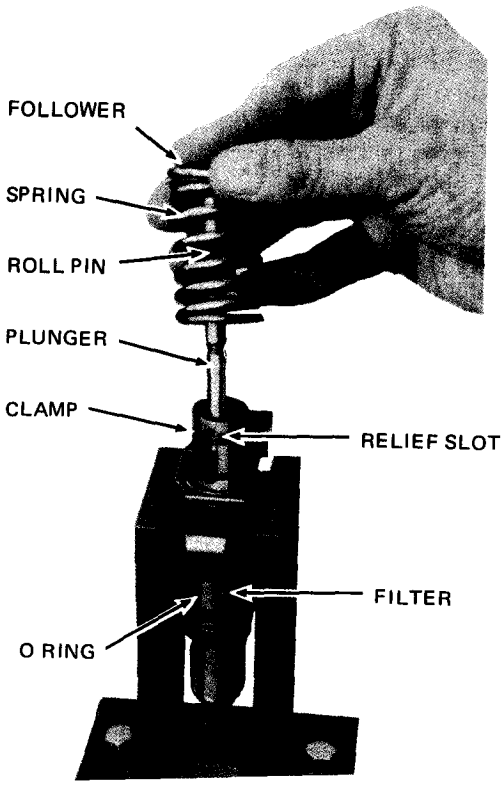


Fig. 31-11 Removing or installing follower, follower spring, and plunger (Fuel Pincher).

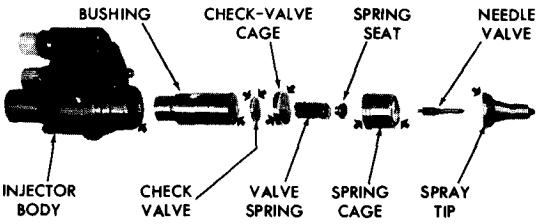


Fig. 31-12 Exploded view of spray-tip components. (Arrows show the lapped surfaces.) *(Detroit Diesel Allison, Division of General Motors Corporation.)*

to the nut so that it cannot be removed by finger force, support the nut on a wooden block and drive the tip through the nut using a small tube with the inner bore resting on the face of the tip. Remove the bushing, insert the plunger, and place the assembly in clean fuel. Tilt the vise to remove the gear container and the gear and place them in separate containers also. Finally, remove the control rack.

Cleaning and Inspecting Components Clean all individual parts separately using solvent, fuel, etc., as shop facilities dictate.

INJECTOR BODY Inspect the threads of the fuel-filter cap and the nut. Check the dowel pin. Resurface the ring face with a reamer by using a straight flute reamer to remove any nicks and burrs from the bore (Fig. 31-13). *(NOTE: Turn the reamer only in a clockwise direction to prevent damaging the flutes.)*

Check the contact surface of the bushing and if necessary, lap it to ensure a leakfree seal between the injector body and the bushing. Wash the injector body in clean fuel and place it in the assembly rack.

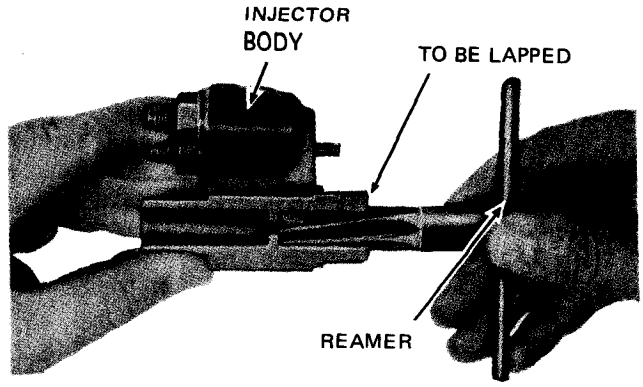


Fig. 31-13 Cleaning injector body ring.

INJECTOR NUT Inspect the threads for damage and the O-ring groove and the sealing surface of the nut for corrosion. If any of these is defective, the nut must be replaced. Use the carbon-removing tool to clean the spray-tip seat (Fig. 31-14). (Refer to the service manual for the correct tool type.) Failure to remove any carbon may cause the spray tip to misalign, may result in inadequate sealing (fuel leaks) between the tip and the spring cage, or may cause inadequate compression sealing between the nut and the injector tube. On the Fuel Pincher injector, replace the fuel filters.

BUSHING AND PLUNGER Insufficient fuel, dirty fuel, or plugged or choked spray-tip holes often cause score marks on the injector bushing and plunger (Fig. 31-15). Inspect the plunger and bushing; use a mag-

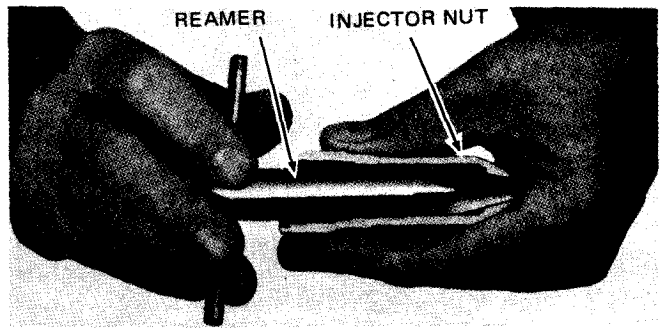


Fig. 31-14 Cleaning the injector-nut spray-tip seat. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

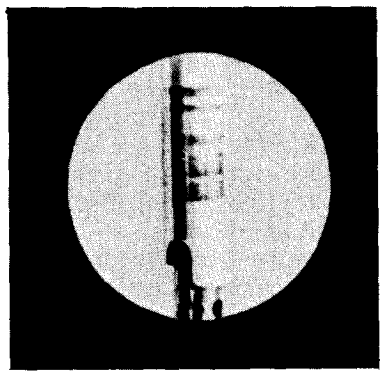


Fig. 31-15 Score marks on a plunger caused by one or more plugged spray holes. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

nifying glass to check for scoring or chipping at the ports and helices. Check the flat surface on which the gear slides. When the surface cannot be made smooth with an oil stone, the assembly must be replaced. Check the ports in the bushing for carbon deposits, restriction, or damage. If the sealing surface of the bushing (which fits against the injector body) is damaged, the bushing assembly must be replaced. A faulty sealing surface causes fuel leakage and allows the fuel to leave the injector body at the control rack and contaminate the crankcase oil.

To clean the bushing and plunger, apply a moderate amount of mutton tallow to the plunger. Insert the plunger into the bushing. Gently move the plunger back and forth to remove wax or deposits from the bushing and plunger. Before cleaning the assembly, lap the lower seats (Fig. 31-12), thoroughly clean the components, and then check for plunger freeness within the bushing. Keep the assembly, as a unit, in clean fuel until used.

DEFLECTORS When the deflector is out-of-round, pitted, or corroded, it must be replaced. If sharp edges or burrs are present, they should be removed with a 600-grit oil stone.

INJECTOR FOLLOWER SPRING Check the follower spring for corrosion and straightness. Measure the free length; it should be 1.504 in [38.20 mm], and the spring wire used should be 0.142 in [3.606 mm]. With a spring tester, test the spring compression. When compressed to 1.028 in [26.111 mm], it should read 70 lb [31.75 kg]. Do not use a spring which has less energy. It will affect metering because of the slower return action of the plunger.

FOLLOWER Check the contact surface of the rocker arm. If this area is slightly worn, lap it or use a valve grinder to restore the follower surface.

CAUTION Do not remove more than 0.005 in [0.125 mm] of surface.

Measure the follower length using a micrometer or the special dial tester. The follower length should be within 0.005 in [0.127 mm] of 1.650 in [41.91 mm]. If it is not, the follower must be replaced as it would otherwise adversely affect the beginning of injection.

SPRAY TIP The cleaning and service procedure for a unit-injector spray-tip assembly is the same as that for a multihole fuel-injection nozzle. However, before you clean and service any components, measure them with a micrometer. The spray-tip shoulder should not be less than 0.199 in [5.054 mm] thick. The gauge check valve must not be less than 0.163 in [4.140 mm]. The valve spring cage must not be less than 0.602 in [15.290 mm]. The check valve not less than 0.022 in [0.559 mm].

If the spray-tip seat is only slightly damaged, the use of a polishing stick and polishing compound is recommended to restore the seat surface.

CAUTION Do not smear the compound onto the lapped surface of the upper needle valve because this will increase the tolerance and may cause metered fuel to leak off, preventing it from being injected.

Check the freeness of the needle valve and valve lift in the same manner as that for a multihole or pintle-type nozzle valve (Fig. 31-16).

Check all other valve assembly components and lap the surface of those which are damaged (see Fig. 31-12). As a general rule, the valve spring should be replaced.

CONTROL RACK AND GEAR Check the control-rack-bearing surface and the teeth for damage, corrosion, and wear. Replace if necessary. Check the gear teeth for damage and the bore for roughness and wear.

Testing Needle-valve Spray Pattern and Opening Pressure After the components are lapped and cleaned, assemble them (in sequence as shown from left to right in Fig. 31-12) into the tip test adaptor, or onto a dummy injector body and bushing. Tighten the nut to 85 lb·ft [115 N·m] torque, maximum. Place the protection shield over the assembly and then operate the hand pump of the tester until all air is removed from the assembly. Open the gauge valve slightly and operate the hand pump rapidly with even strokes (about 40 strokes per minute) to simulate the valve action during engine operation. Observe and record the opening pressure on the gauge. The opening pressure should be within 2200 to 3200 psi [15,169 to 22,064 kPa]; otherwise the valve spring must be replaced. However, an even opening pressure within 50 psi [344.7 kPa] of 3000 psi [20,685 kPa] is recommended for rebuilt unit injectors. To check the spray pattern, close the gauge valve and then operate the hand pump once every second with a sharp, even stroke. The spray pattern should be without distortion and without visible unatomized fuel. Each pattern should be evenly spaced from the other. Observe the chatter of the needle valve.

To check the needle-valve seat for leakage, raise

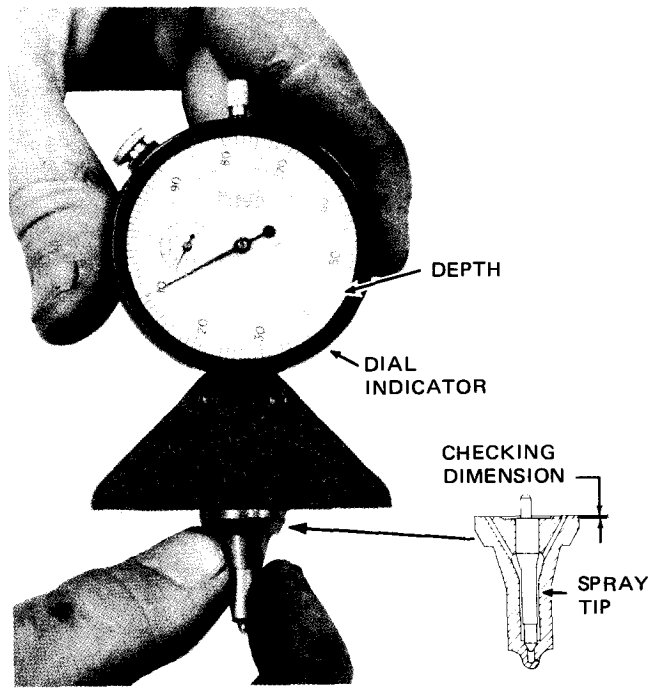


Fig. 31-16 Measuring needle-valve lift. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

the pressure to 1500 psi [10,342.5 kPa] and maintain this pressure for about 15 seconds. Although the spray tip should remain dry, a slight wetness is allowable. Next, check the spray tip for back leakage to ensure needle-valve lubrication. It must be within the specified limit; otherwise too much metered fuel could be lost. To make this test, bring the pressure to 1500 psi [10,342.5 kPa] and time the pressure drop. The maximum allowable pressure drop within 5 seconds is 500 psi [3447.5 kPa]. If the pressure drop is higher, the spray tip must be replaced.

Reassembling Unit Injector Before you reassemble the unit injector, all components must be thoroughly cleaned, serviced, tested, and measured. Pay particular attention to the following points during reassembly:

1. Use compressed air to remove fuel from the filter openings.
2. Install the filter(s) with the slotted end upward.
3. Use new gaskets and tighten the filter cap to the specified torque.
4. Slide the control rack in place so that the drill marks are visible (*A* in Fig. 31-17). Place the gear in the injector body with its drill mark aligned between the two marks on the control rack (*B* in Fig. 31-17).
5. Place the gear retainer on top of the gear.
6. Position the bushing dowel pins over the slot and position the bushing to the injector body.
7. Assemble the valve and spray tip on the bushing in the following order: spill deflector, seal ring, check valve, check-valve cage, valve spring, spring seat, spring cage, and spray-tip assembly.
8. Carefully guide the nut over the stacked assembly and hand-tighten the nut while turning the spray tip. When the spray tip cannot be hand-rotated any further, use a torque wrench and deep socket to tighten the nut to 85 lb·ft [115 N·m].
9. Position the stop pin so that the tighter wound end of the follower spring, when placed over the injector body, rests on the flat side of the stop pin.
10. On Fuel Pincher unit injectors, place the clamp onto the body and the spring onto the clamp.
11. Hook the plunger head into the follower. Align the follower slot with the stop pin and align the flat side of the plunger with the gear.
12. Guide, but do not force, the plunger through the gear and into the bushing.
13. With the plunger in position, push the follower downward and at the same time force the stop pin in place.
14. On the Fuel Pincher, align the roll (spring) pin in the follower with the release slot in the body. Then press downward on the follower, rotate it clockwise until the pin contacts the guide slot, and then release the force from the follower.
15. Remove the injector from the vise. Bring the control rack to the full-fuel position and check the rack-to-plunger timing. The flat side of the plunger must be visible through the hole in the injector body.
16. Next, place the unit injector in the concentricity gauge. Adjust the dial gauge to zero. Slowly turn the injector 360° and observe the dial movement. If the total spray-tip runout is more than 0.008 in [0.2 mm], loosen the injector nut, reposition the spray tip, retorque the nut, and recheck the spray-tip concentricity (Fig. 31-18). If the spray tip is more than 0.008 in [0.2 mm] out of concentricity, it could cause the needle valve to stick and/or allow combustion gases to pass by the injector, or cause reduced injector cooling.

Testing Serviced Unit Injector

RACK FREENESS TEST To check the rack freeness to ensure smooth plunger movement, install the injector in the injector tester, and then force the follower downward. Move the control rack back and forth. A free rack indicates that the internal components of the injectors are free from damage and contamination.

HIGH-PRESSURE TEST With the injector installed, connect the test head connection to the filter caps by

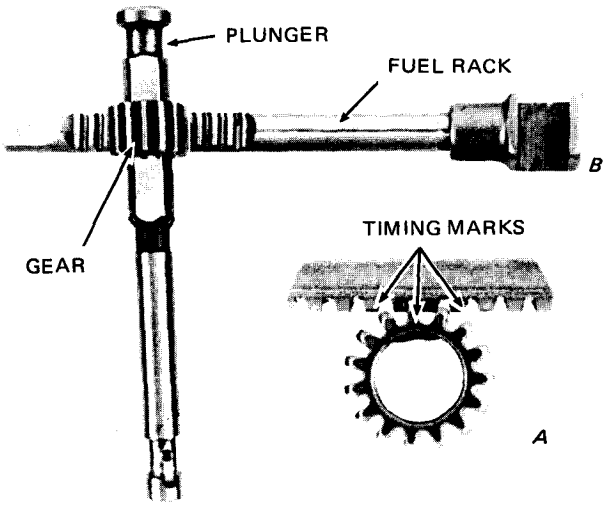


Fig. 31-17 Correct gear and control rack position. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

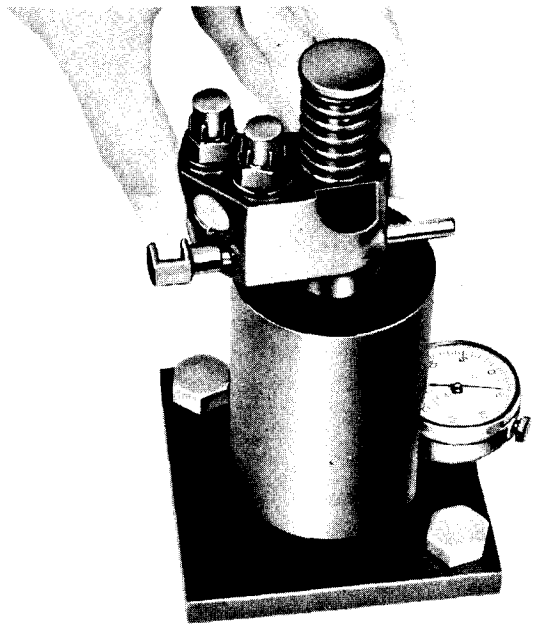


Fig. 31-18 Checking spray-tip concentricity. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

rotating the eccentric lobes. This forces the head connection against the filter caps. Operate the hand pump to pressurize the injector. Maintain a maximum pressure of about 2000 psi [13,790 kPa]. Blow the injector dry, and then check for leaks at the filter cap, nut seal, and control rack. A slight fuel seepage at the control rack, because of the higher pressure, is permissible, but there must be no fuel leakage. If leakage occurs, it is an indication that the bushing-to-injector body is not sealing well.

VALVE-HOLDING PRESSURE TEST Pressurize the injector to 700 psi [4826.5 kPa] and time the pressure drop. A pressure drop of 250 to 400 psi [1723.7 to 2758 kPa] should show on the gauge after a time lapse of not more than 15 seconds. A higher pressure drop indicates the lapped surfaces are not seating properly, or the plunger-to-bushing assembly has a high leakby. It could also mean that the needle valve to spray tip has too much leakby. This would have shown up had the needle-valve leakoff previously been tested. In any event, if a higher pressure drop occurs, the injector must be reserviced.

The spray pattern and valve-holding test should be repeated as a precautionary measure.

FUEL OUTPUT TEST When the unit injector has successfully passed all other checks and tests, install it to a fuel flow calibrator or to a comparator.

When using the comparator to check the fuel output, make certain the injector is positioned properly and the handwheel has been tightly secured to the adapter. Always use the recommended test fuel. Make certain that the test-stand filters are clean so that they do not restrict the fuel flow and that the test-stand fuel pressure is not too low.

Set the counter to 1000 strokes. Push the injector control rack to the no-fuel position. Switch on the motor which drives the camshaft and the fuel-transport pump.

When the fuel lines show no sign of air, push the control rack to the full-fuel position and hold it in this position. Press the fuel flow "start" button to direct fuel into the vial. At the same time the counter will start totaling the injection strokes and will automatically stop the flow into the vial after 1000 strokes. Take the vial calibration reading and record it. Dump the fuel from the vial by turning the vial changer. Reset the counter and repeat the fuel output tests. Take a second reading; it should be within specification. For example, it can vary from 51 to 61 mm^3 for a C60 unit injector.

NOTE: Both fuel and water are attracted to the vial sides, thus forming a concave meniscus (crescent-shaped surface). Take your readings at the lowest point of the fluid surface (Fig. 31-19).

Installing Unit Injector To ensure good sealing, and cooling, and to prevent distorting the spray tip, the injector tube must be cleaned before the injector is placed in the tube. Use the injector bezel tube reamer and coat the flutes with grease to pick up residual carbon, etc., while reaming. Turn the reamer in a right-hand direction to remove the carbon deposits from the tube. Do not use an injector nut reamer because it can remove metal and place the spray tip too far into the combustion chamber.

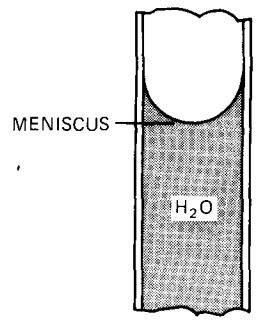


Fig. 31-19 Correct fuel level reading. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

Clean the tube thoroughly. Remove the spray-tip protection cap, and place the injector into the injector tube. Align the locating pin with the hole in the cylinder head and push the injector into position. Position the rack-control lever in the control rack. Install the injector clamp, washer, and bolt. Tighten the bolt to the recommended torque. After each injector is torqued into position, check the freeness of the control rack. Place the valve bridges over the bridge guides. Make certain they are positioned properly, then swing the rocker-arm assembly into position.

Install and torque the rocker-arm-shaft bolts to the recommended torque. Make certain the valve bridges are not dislodged during this procedure.

Remove the protection cap from the filter cap and fuel connector as you install each individual fuel pipe. Torque all fuel pipe connections to the recommended torque to prevent leakage, twisting, or damage to the pipes.

When all fuel pipes are installed, attach a hand pump to the inlet manifold, and pump clean fuel through the injectors. When the manifolds and injectors are free of air, plug the return line, pressurize the system to 150 psi [1034.2 kPa], and then check for fuel leakage at the connection.

To install the unit injector to a Fuel Pincher engine, clean the injector tube as outlined above, then install the two O rings onto the injector nut and thoroughly lubricate them. Position the injector into the injector tube, align the injector clamp, and tighten the two 6-mm bolts within 7 to 9 lb·ft [10 to 12 N·m] (see Fig. 31-9).

Engine Tuneup Before a customer takes possession of a new engine, or one that has just been rebuilt, it must be given a tuneup, or tuneup check, and it should be checked again after about 100 to 150 hours of operation. A tuneup is also essential when the cylinder head, blower, governor, or injector have been serviced, or when the engine performance is not satisfactory even though the engine is in good mechanical condition.

An engine tuneup should be made after the coolant system, the lubrication system, the drive belts, and the fuel filters have been checked and the engine has been found mechanically sound. Tuneup involves a series of checks and adjustments to bring the components to the recommended specification. The ef-

fectiveness of an engine tuneup may be unsatisfactory unless the recommended procedure sequence is followed. The Detroit Diesel tuneup sequence is as follows:

1. Adjust valve bridge
2. Adjust exhaust valves (or, on a Fuel Pincher, also the intake valves)
3. Time injectors
4. Adjust governor gap
5. Adjust injector racks
6. Adjust no-load speed
7. Adjust idle speed
8. Adjust buffer screw
9. Adjust throttle-delay mechanism

Valve Bridge Adjustment The 71, 92, and 149 Series engines utilize valve bridges. Valve bridge adjustment is required only after the cylinder head has been serviced, or when the valve bridge has been damaged, worn, or a new one installed.

To make the adjustment, remove all the fuel pipes and use plastic caps to cover all openings. (Take all the precautions outlined under Removing Unit Injector.)

Start with the cylinders where the exhaust valves are closed, and remove the rocker-arm shaft-retainer bolts from the cylinder head, and then swing the assembly away from the valves. Do not force the rocker arms over center.

Remove one valve bridge at a time. Place it in a vise to loosen the locknut and then place the bridge as shown in Fig. 31-20, turning the adjusting screw until it just touches the top of the valve stem. Add about one-eighth of a turn to compensate for thread looseness. Hold the bridge in a vise, and hold the adjusting screw with a screwdriver while torquing the locknut. Install the valve bridge on the bridge guide from which it was removed and place a 0.0015-in [0.0381-mm] feeler gauge stock under each end of the valve bridge. When you press down on the valve bridge, the pull on each feeler gauge must be equal. Next, adjust the second bridge. Do not interchange valve bridges after they have been adjusted. Repeat the procedure with the other valve bridges.

Reinstall the rocker-arm assembly and fuel pipes, then crank the engine over until three other sets of exhaust valves are closed. Then repeat the bridge adjustment steps.

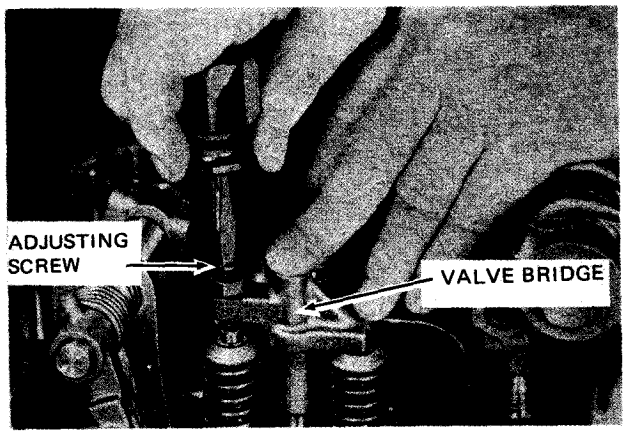


Fig. 31-20 Valve bridge adjustment. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

Valve Adjustment Crank the engine over. Make sure the governor is in the stop position when you bring No. 1 cylinder to TDC, that is, when the injector pushrod has moved upward, depressing the injector follower spring.

Select the feeler gauge thickness designed for cold-setting the exhaust valves. When possible, use a go–no-go gauge. For the 71 Series engine with two exhaust valves, or the Fuel Pincher which has one exhaust valve and one intake valve, slide the feeler gauge between the rocker arm and the valve stem. The adjustment is made by loosening the locknut and turning the pushrod until the feeler gauge has a slight drag when pulled and pushed between the surfaces. Then tighten the locknut and recheck the clearance. The intake and exhaust valve adjustment for the Fuel Pincher Series is made by loosening the locknut and turning the adjusting screw in the end of the rocker arm located over the pushrods (Fig. 31-21).

For four-valve cylinder-head engines, the adjustment is made in a similar manner, except that the feeler gauge is placed between the rocker arm and the pallet surface of the valve bridge.

The adjustment of the exhaust valves on the 149 Series engine is made by turning the adjusting screw in the end of the rocker arm to obtain proper clearance between the pallet of the valve bridge and the valve bottom of the adjusting screw (Fig. 31-22).

For the 53 Series engines, the adjustment is made in the same manner as for the 71 Series, except that the feeler gauge is placed between one valve stem and the surface of the pivot-mounted valve bridge.

After each adjustment, mark the cylinder so that you can keep track of the valves which have been

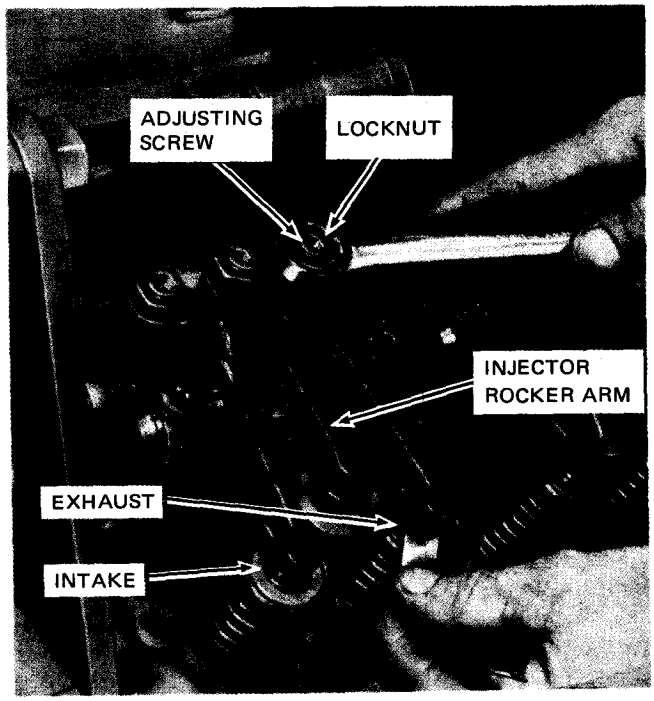


Fig. 31-21 Adjusting valve clearance (Fuel Pincher).

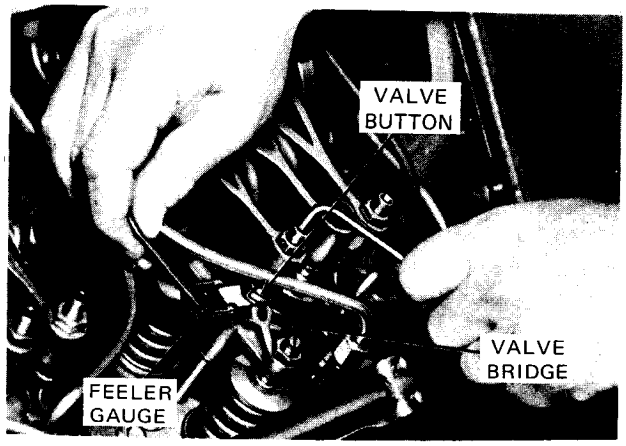


Fig. 31-22 Checking valve clearance (V149). *(Detroit Diesel Allison, Division of General Motors Corporation.)*

adjusted. Assume you have a 6-71 engine, with a firing order of 1-5-3-6-2-4. You can adjust the exhaust valve of Nos. 1, 5, and 4 cylinders and the injector timing of Nos. 3, 6, and 2 cylinders when No. 1 cylinder is at TDC.

Injector Adjustment (Phasing) To ensure that each injector is timed correctly with regard to piston position, the height of the injector follower must be adjusted in relation to the injector body. Timing gauges of various dimensions are used. For example, when using a timing dimension of 1.484 in [37.69 mm], the beginning of injection is retarded, allowing the piston to reach a higher position within the cylinder before injection begins. This is essential because the plunger has to travel a further 0.024 in [0.6 mm] before it closes the upper bushing port.

To check the injector timing or to make an adjustment, select the recommended timing tool and place its small end in the hole provided in the injector body (Fig. 31-23). You can start with either the No. 3, 6, or 2 injector. The timing is correct when the flat end of the gauge wipes off the oil from the top of the follower. If it does not, then adjust the pushrod in the same manner as you adjust the exhaust valve pushrod, until the proper follower height is obtained. Next, hold the pushrods while tightening the locknut to maintain the adjustment. Always recheck new adjustments and, when correct, mark the injector to identify that it has been adjusted.

After the exhaust valves and the injector adjustments have been made, turn the crankshaft 180° to bring the No. 6 cylinder to TDC. You can now adjust the exhaust valves of Nos. 6, 3, and 2 cylinders and the injector timing of Nos. 1, 5, and 4 cylinders.

It is slightly more time-consuming to check and/or adjust the injector timing on a Fuel Pincher, and a specially designed gauge must be used. The injector timing can be checked when the cam follower is on the base circle or when the cam follower is on TDC. Start the injector checks and adjustments by adjusting the timing gauge on the master block for base circle timing. Adjust and lock the gauge in this position. Loosen No. 1 injector adjusting screw so that two threads are showing. Then rotate the crankshaft (by hand) until No. 1 injector just begins its down travel. In this position you can adjust Nos. 3, 4, 6,

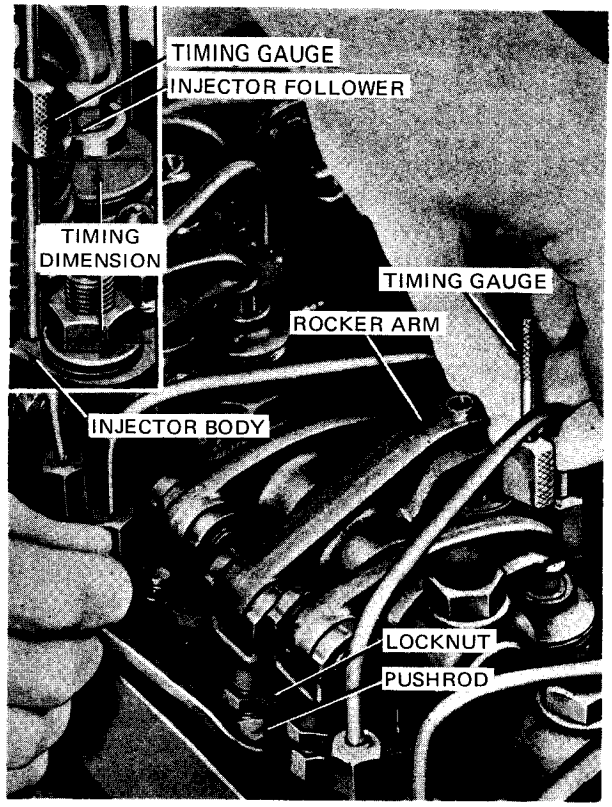


Fig. 31-23 Checking injector timing. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

and 8 injectors. Place the timing gauge onto the No. 3 injector so that the pins lock into the follower spring, then adjust the injector to the specification given on the valve cover identification plate (Fig. 31-24). Repeat this procedure with Nos. 4, 6, and 8 injectors and adjust them to specification. Then rotate the crankshaft about 360° until No. 6 injector follower just starts to move downward. Now you can adjust Nos. 1, 2, 5, and 7 injectors to the specification written on the valve cover.

The procedure to follow after the exhaust valves are adjusted and the injectors are timed depends on whether the engine has been running before, or whether it is a new or a rebuilt engine, and on the

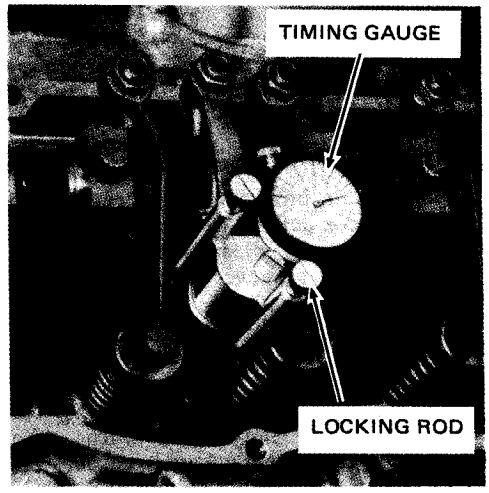


Fig. 31-24 Setting injector timing height (Fuel Pincher).

type of governor used. Assuming the engine was rebuilt and a limited-speed governor (double-weight) is on the engine, then the next step would be to position the rack-control lever of the No. 1 cylinder.

Positioning Individual Rack-control Levers To ensure that each injector control rack has maximum fuel output while the engine is running at full load, back out the idle-speed adjusting screw about ½ in [12.7 mm] beyond the locknut and back out the buffer screw about ⅝ in [15.87 mm]. Remove any linkage attached to the governor speed control and shutoff levers or which are connected to the fuel control tube.

NOTE: For governors having a yield link, attach a C clamp to prevent the yield link spring from altering the yield link length while adjusting the injector-rack control levers. (See Unit 25, "Governors.")

Loosen all inner and outer injector-rack lever-adjusting screws. Hold the speed control lever with light finger pressure in the maximum fuel position. Then turn the inner adjusting screw clockwise on the No. 1 injector-rack-control lever until you feel a step-up in effort, and a light movement of the control tube. Next, turn the outer adjusting screw clockwise until it bottoms lightly on the control tube, then alternately tighten both adjusting screws (Fig. 31-25). This should place the No. 1 injector in the full-fuel position. To determine if it is in this position, use a screwdriver or your fingertips and press down on the injector control rack. If the injector control rack returns with a springing action to its original position, but does not move the speed control lever, the control rack is probably correctly placed in relation to the full-fuel and governor positions. If the rack does not return to its original position, it is too loose. Loosen the outer adjusting screw and tighten the inner adjusting screw to get the proper control-rack action. When the control lever has moved or the clevis pin which connects the fuel rod with the fuel-control-tube lever has become too tight, back off the inner adjusting screw and slightly tighten the outer adjusting screw.

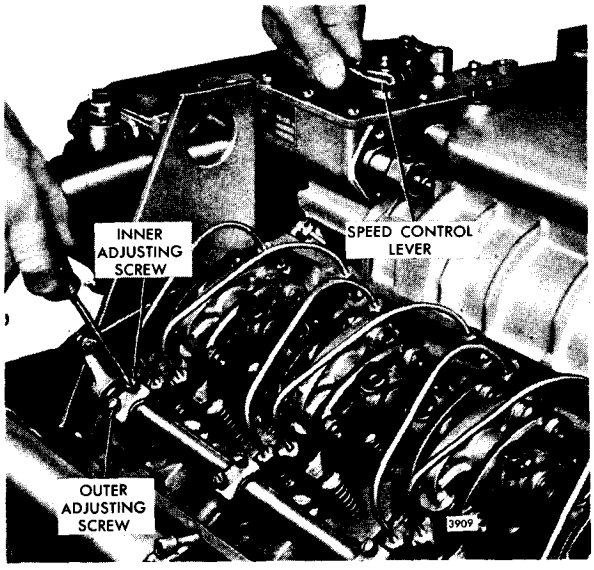


Fig. 31-25 Adjusting the injector rack control lever on a V53 engine. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

If you are working on a V engine, remove the clevis pin from the fuel rod of the right-hand cylinder bank before adjusting the No. 1 injector control rack on the left-hand cylinder bank. When the No. 1 injector control rack is adjusted, remove the clevis pin from the left-hand side and place the pin in the fuel rod and control-tube lever to connect the right-hand cylinder bank with the governor. Then adjust the injector control rack of the No. 1 injector. When the fuel control racks of both No. 1 left- and right-cylinder bank injectors are evenly adjusted, the left-hand cylinder bank's clevis pin should slide in place smoothly and both pins should drag equally when moving them within their bores.

This adjustment procedure must be followed precisely; otherwise one cylinder bank receives less injector-control-rack travel than the other, and consequently one cylinder bank receives less fuel.

Positioning Other Control Racks After the No. 1 injector is adjusted, remove the clevis pin or pins (when working on a V engine) and manually hold the injector-control-tube lever so that the No. 1 injector control rack is in the full-fuel position. In this position, adjust the No. 2 control lever so that the No. 2 control rack is in the full-fuel position and is as equally responsive as that of the No. 1 control rack.

NOTE: Do not adjust the No. 1 injector control rack again.

Adjust the remaining control racks and make certain that all racks have equal resilience (bounce-back). When reconnecting the fuel rod to the control tube, the clevis pin must slide in without restriction. Position the valve cover(s) and make certain that all tools are removed from the engine before it is started. Warm the engine up to the operating temperature, 160° to 185°F [71° to 85°C].

Governor Adjustment Detroit Diesel engines have six different types of governors, each with its own adjustment peculiarity. Select the appropriate service manual outlining tuneup procedure when adjusting the governor.

To adjust an engine having a limited-speed governor (double-weight), start the engine and bring it to operating temperature, then stop the engine. Disconnect the throttle linkage. Remove the two attaching bolts, then remove the governor high-speed spring-retainer cover. Back out the buffer screw if you have not already done so. Start the engine and adjust the idling speed to that recommended on the unit option plate. (The option plate is attached to one valve cover. It lists precise information about engine design, additional equipment used, and recommended idle and high-idle speeds.) Then stop the engine. Remove the governor cover and lever assembly.

On in-line engines remove the fuel rod from the differential lever and the injector-control-tube lever. On V engines the fuel rod need not be removed. Hold the control-tube lever in one hand, start the engine, and manually control the engine speed with the con-

trol-tube lever. On V-type engines, control the engine speed by controlling the differential lever.

With the engine at 1100 to 1300 rpm, check the governor gap by placing a 0.0015-in [0.0381-mm] feeler gauge between the low-speed spring cap and the high-speed spring plunger. If the gap is correct, there will be a slight drag on the feeler gauge (Fig. 31-26). When adjustment is necessary, stop the engine and turn the gap adjusting screw to obtain the proper drag.

To recheck the gap setting, run the engine between 800 and 1000 rpm and force the gap closed with a screwdriver. When the setting is correct, the gap closing movement can be seen.

Another method of rechecking gap setting is to place a drop of oil on the gap area, and then slowly raise the rpm so that you can see the gap close. However, there must be no mistake in the gap setting because this would affect the injector-control-rack adjustment. When gap setting is completed, stop the engine; replace the fuel rod and the governor cover. Do not reconnect the throttle linkage to the speed control lever at this time.

Readjusting Exhaust Valve, Timing, and Rack-control Levers When the governor gap has been adjusted, you must check and/or readjust the exhaust valve, the injector timing, and the position of the rack-control levers.

Adjusting Maximum and Idle Speeds (Limiting-speed Governor) With the engine at operating temperature, loosen the locknut and back off the high-speed spring retainer approximately five turns (Fig. 31-27). Start the engine and move the speed control lever to maximum-speed position, using a strobe light or hand tachometer to measure the rpm.

The maximum engine speed should not exceed the recommended no-load speed shown on the unit option plate. Turn the high-speed spring retainer until the engine runs at recommended no-load speed, and then tighten the locknut. Reduce the engine speed. Again bring the speed control lever to the full-fuel position, and recheck the maximum no-load speed.

To adjust the idling speed, bring the speed control lever to the idle position and turn the idling-speed adjusting screw until the engine runs about 15 rpm below the idling speed shown on the unit option plate. The engine should operate smoothly without hesitation and without a change in engine rpm. If it does not, all previous adjustments must be rechecked.

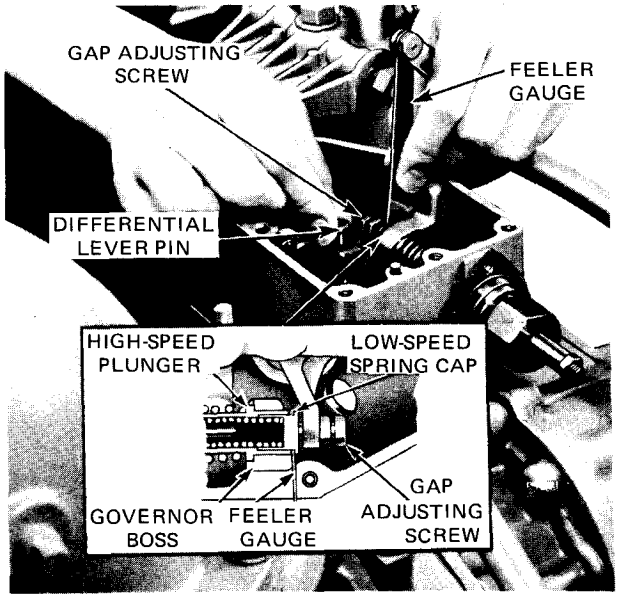


Fig. 31-26 Adjusting the governor gap. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

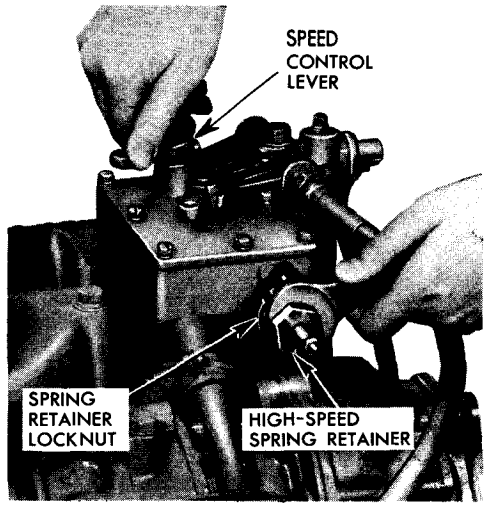


Fig. 31-27 Adjusting the high-idle speed. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

Buffer Screw Adjustment With the engine at idling speed, turn the buffer screw as shown in Fig. 31-28 until it contacts the differential lever to raise the idling speed to that recommended on the option plate. Do not use the buffer screw adjustment to smooth out engine operation or to raise the idling speed. Always recheck the maximum no-load speed. If it has increased more than 25 rpm, back off the buffer screw until the speed increase is less than 25 rpm of the no-load high-idle speed.

Throttle-delay Mechanism Some Detroit Diesel engines use a throttle-delay mechanism to reduce exhaust smoke during acceleration. This device—a piston which is part of a rocker-arm bracket—is connected over a link with the throttle-delay lever which is bolted to the injector control tube (Fig. 31-29).

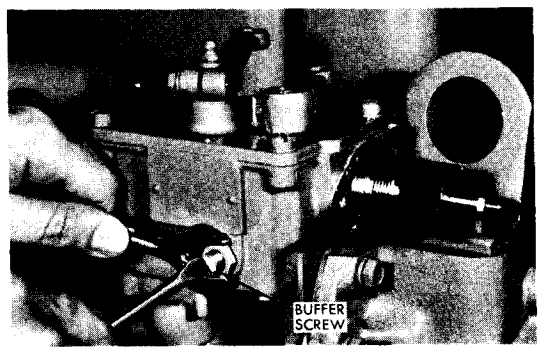


Fig. 31-28 Adjusting the buffer screw. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

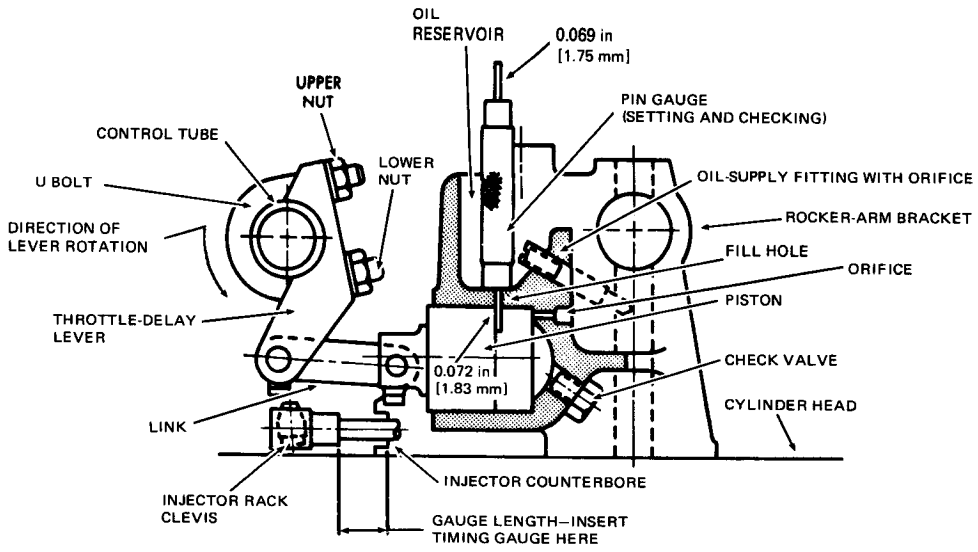


Fig. 31-29 Throttle-delay cylinder with the injector rack in the full-fuel position. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

Operation of Throttle-delay Mechanism When the engine is running, oil is supplied from the rocker-arm bracket through a supply plug to the reservoir. However, the plug has a restriction orifice to reduce the oil flow into the reservoir. When the injector rack is in the full-fuel position, the injector tube has moved the throttle-delay lever, the link, and the piston to the right. With this action the piston blocks the oil opening in the reservoir. As the control rack is moved to the no-fuel left-hand position, the check valve opens and air can enter the delay cylinder allowing the piston, and therefore the injector tube, to move freely to the left. As the piston uncovers the reservoir fill hole, oil enters the cylinder and air is displaced through the orifice above the check valve.

The governor, the fuel rod, and the yield lever are permitted full accelerator travel because of a special yield lever and spring assembly instead of the standard injector-control-tube lever (Fig. 31-30*a*).

As the governor is moved to the full-fuel position, the yield lever spring transmits the motion from the governor to the injector tube onto the throttle-delay piston. However, the injector tube, due to the restriction of the throttle-delay mechanism, does not rotate in proportion to the yield lever. This increases the spring force and the force is transmitted onto the injector tube and delay piston. The delay piston forces the oil through the orifice and slowly the injector tube rotates until it butts against the yield lever stop.

When a yield link is used in the governor (Fig. 31-30*b*) instead of a solid link, it permits the governor also to react to load and speed changes.

When the throttle is placed in the full-fuel position, the throttle-delay piston restricts the movement of the injector tube. This causes the yield link ends to slide apart. The yield link's spring force then pulls the link ends together and semirotates the operating lever. The lever movement is transmitted to the fuel rod, injector tube, and delay piston, forcing the piston inward until the yield link is fully retracted.

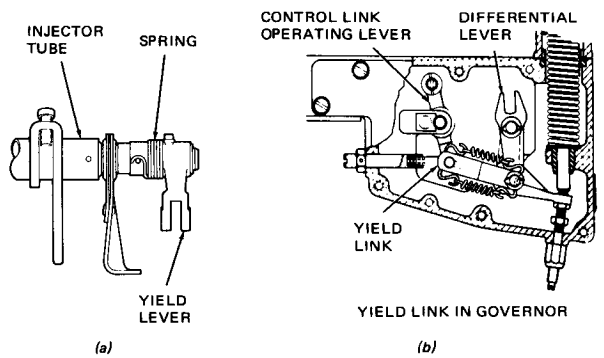


Fig. 31-30 View of (*a*) yield lever and spring assembly, (*b*) yield link in governor. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

Throttle-delay Adjustment After you have made all other adjustments, the throttle-delay mechanism must be adjusted. There are two throttle-delay mechanisms: (1) the current model, which has a 5/16-in [7.938-mm] fill hole and (2) the previous model, which has a 1/4-in [6.35-mm] fill hole. The adjustment procedure varies somewhat, but with either model first stop the engine and then loosen the U-bolt nut. To adjust the earlier type, place the timing gauge (0.454 in [11.532-mm] in length) between the injector body and the shoulder on the injector rack. Apply a slight pressure to the injector tube in the direction of the full-fuel position and then tighten the U-bolt nuts so that the delay piston is flush with the edge of the throttle-delay cylinder. Remove the tool. Check the freeness of the injector tube.

On the current model proceed as follows: Position the timing gauge (see specific engine manual) and insert the larger diameter of the pin gauge as shown in Fig. 31-29. Place the throttle in the full-fuel position and then tighten the U-bolt nuts so that the timing gauge is snug and the delay piston rests against the pin gauge. To check your adjustment, remove the timing gauge and pin gauge and attempt to reinstall the pin gauge into the cylinder bore. It should not go in. If it does not, reverse the pin gauge and insert the smaller-diameter rod into the cylinder. If the adjustment is correct, the smaller-diameter rod should enter the cylinder without restriction.

Start the engine and check the oil supply, the action of the yield lever or the yield link, the check valve,

and the combination air-and-oil bleed orifice (see section on engine run-in, Unit 3).

Questions

1. Why is an outlet restriction fitting required in the return line of a Detroit Diesel fuel-injection system?
2. If the restriction fitting orifices were greater than specified, how would it affect engine performance?
3. What would occur if the fuel pump seals were installed backward?
4. Outline two procedures (other than those mentioned in this textbook) to locate a misfiring injector.
5. Explain how to remove a unit injector which is seized in the injector sleeve.
6. What does the engraved number on the nozzle tip signify?
7. Why aren't the spray angles of all nozzles equal?
8. List the differences in the metering and pumping principles between a unit injector pump and a Bosch injector pump.
9. Explain the effects of each of the three basic plunger designs on engine performance.
10. List the components of an N-type injector in their order of reassembly.
11. Why must the plunger-follower be within specified limits?
12. If the needle lift height of an N-type nozzle were greater than maximum specification, how would it affect the spray pattern and fuel flow?
13. What causes the rack on a unit injector to lose its freeness?
14. When working on a V engine, explain how to check and adjust the injector, adjust No. 1 injector control levers, and check and adjust the governor gap.
15. Assume that an engine continues to run rough at idle even after you have increased (with a buffer screw) the idle speed by 60 rpm. What further steps (or repeated steps) must you take?
16. What would result if the orifice in the throttle-delay piston were clogged?

UNIT 32 • CATERPILLAR UNIT-INJECTOR FUEL-INJECTION SYSTEM

To increase engine power and keep abreast of industrial needs, Caterpillar Tractor Co. has developed the 3500 Series engine, comparable to the Cummins KTA 2300 and 3067 models and the Detroit 149TI Series engines. These engines are manufactured in three models, namely, the 3508, 3512, and 3516. Optimum engine performance is achieved through a unit-injector fuel-injection system very similar to the 149 Series Detroit Diesel unit-injector fuel-injection system covered in Unit 31. As you have now learned, unit-injector systems have no high-fuel pressure lines; a variable timing has been built in by changing the helix design. Furthermore, these engines have a high injection pressure and an even injection pressure and, therefore, a near uniform spray pattern during injection. The 3500 Series engine injection pressure is the same as that for the Detroit Diesel, that is, around 1600 psi [11,032 kPa]. Engine displacement on the Caterpillar 3512 and 3516 models is higher than the 12V and 16V 149TI Detroit Diesel engines, and the Cummins KTA 2300 or the 3067. (See Table 32-1.)

Low-pressure System Components When examining Fig. 32-1, which shows the low-pressure fuel system of a 3512 engine, you will notice the fuel flow is much like that of the 149 Series Detroit Diesel. The low-pressure fuel system consists of the fuel transfer pump, fuel pressure regulators, fuel filters, hand primer, left- and right-hand fuel manifolds, unit injectors, and the necessary tubes and fittings.

The fuel transfer pump is an external gear pump. It is bolted to the right-hand side of the engine and is driven by the engine lubrication pump. It has built-in pressure-relief and check valves. The pressure-relief valve opens should the pressure within the inlet fuel manifolds exceed 75 psi [517.1 kPa]. Fuel is then directed through passages to the inlet side of the transfer pump. The check valve allows fuel to be drawn past the valve when the hand priming pump piston is pulled out (to the right). It is closed by the fuel pressure when the piston is pushed inward (to the left) as the fuel is forced into the low-pressure side for priming the system.

TABLE 32-1

Model	Displacement, in³ [L]	Horsepower	Kilowatts
12V—149 TI	1792 [29.39]	890–1200	663.9– 895
12V—KTA 2300	2300 [37.72]	1050–1200	783.3– 895
12V—3512	3158 [51.8]	1055–1200	787.0– 895
16V—149TI	2389 [39.18]	1080–1600	805.6–1193
16V—KTA 3067	3067 [50.3]	1250–1600	932.5–1193
16V—3516	4211 [69.0]	1200–1600	895.2–1193

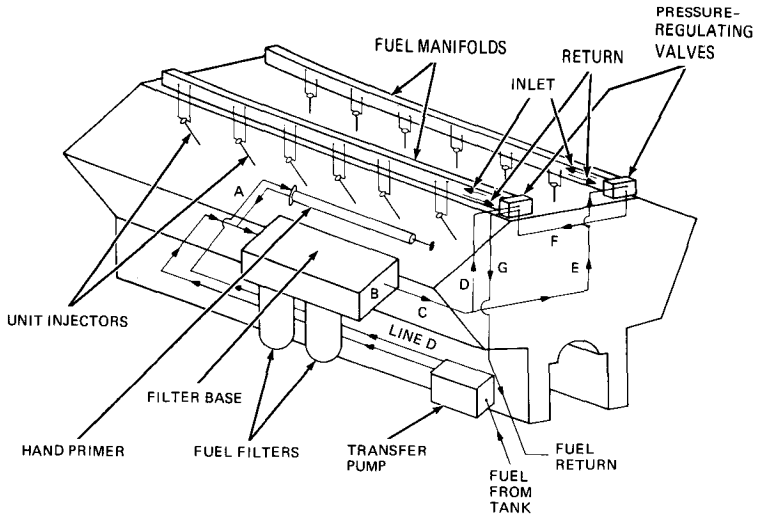


Fig. 32-1 Schematic view of low-pressure fuel flow. *(Caterpillar Tractor Co.)*

Spin-on-type fuel filters are screwed onto the three-sectional filter base which has internal passages designed to allow one filter to be changed at a time without stopping the engine, and to pump priming fuel through the filters. Each inlet connection has a fuel strainer for final fuel filtering. The piston-type hand priming pump is fastened to the filter base, and its pumping chamber is bolted to the priming pump adapter. The adapter is bolted to the right-hand side of the filter base.

The left- and right-hand fuel manifolds consist of three individual manifold sections (Fig. 32-2). Each manifold section has an inlet and return rifle-drilled passage connected through pipe fittings to the adjacent manifold section. The pressure regulators are bolted to the front section of each manifold to which inlet lines E and D are connected. A crossover line F connects the outlet manifold of the left-hand pressure regulator to the right-hand regulator, and the fuel line G directs fuel from the right-hand pressure regulator back to the fuel tank. The inlet fuel-manifold passage is the top passage in the manifolds and is connected to the front inlets of the cylinder heads through tubes and fittings. The lower manifold passage is connected to the rear outlets of the cylinder heads.

Each cylinder head is cast with inlet and outlet passages leading to the injector bore. The bore diameter is slightly enlarged at the section between the lower- and second-injector O rings (see Fig. 32-3).

The 3500 Series unit injectors are about the same in dimension as the Detroit 149 Series and similar in design to a Fuel Pincher unit injector. The inlet and outlet fuel passages are sealed by O rings to prevent fuel from entering the combustion chamber, or into the area above the cylinder head to prevent oil dilution.

Fuel Flow Hand Priming After the cylinder head, fuel manifold, injectors, etc., have been serviced, the fuel system must be primed. To do this, unlock the

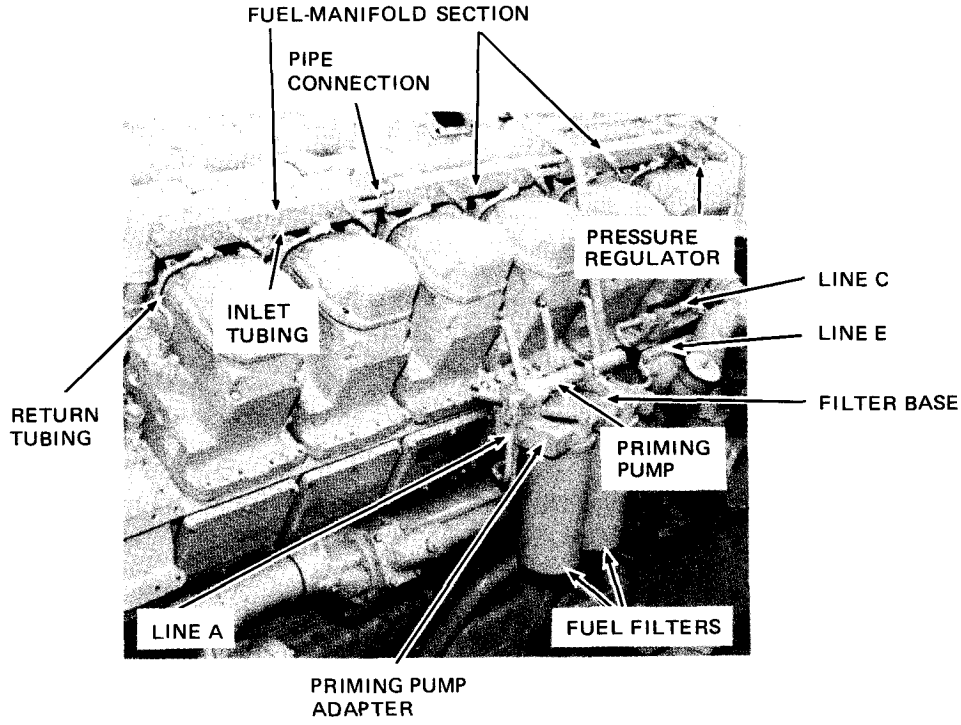


Fig. 32-2 View onto the right-hand side of a 3512 Series engine. *(Caterpillar Tractor Co.)*

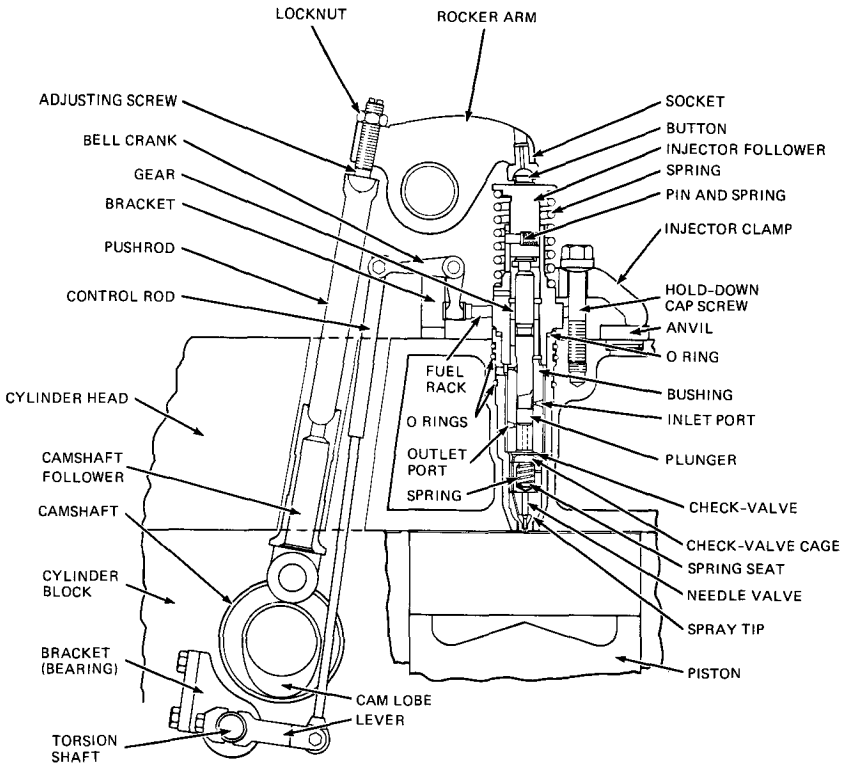


Fig. 32-3 Schematic view of unit injector and operating linkage. *(Caterpillar Tractor Co.)*

hand primer knob and move it back and forth. As the piston moves outward a low pressure is created. Fuel then flows from the fuel tank into the fuel transfer pump, passes by the check valve, and flows into line A and into the void created by the piston. As the piston is pushed inward, the fuel pressure closes the check valve and fuel then flows into the priming pump adapter passage, through the filter base passages and the filters back to the filter base, and through passages to the outlet fitting B. From there fuel flows into line C where it is T'd off to lines D and E, into the pressure regulator, and through the regulator passages into the left- and right-hand inlet fuel manifold passages. The fuel then flows from these passages through the strainers, through the inlet tubings and fittings, into the cylinder head passages, and into the fuel chambers formed in the injector bore between the O rings and the injector sleeve walls.

When the injector is in the metering cycle, the fuel flows into the bushing inlet port, into the helix area below the plunger, and out of the outlet port into the cylinder-head outlet passages, into the connecting tubings and fittings, and into the fuel manifold outlet passage. As the fuel pressure increases to 35 psi [241.3 kPa], it opens the check valve. Fuel then passes from the left-hand pressure regulator to the right-hand one, over line F, and from there back to the fuel tank. This fuel flow removes any trapped air and primes the injection system.

Fuel Flow when Engine Is Operating When the engine is operating, the fuel transfer pump creates a low pressure at its inlet side. This forces fuel from the fuel tank into the transfer pump. As the pump gears mesh, the fuel is forced out of the transfer pump into line A, then into the filter base. From this point on, the fuel flow is in the pattern outlined above when using the hand primer.

Injector Design Unlike the Detroit Diesel unit injector, the Caterpillar unit-injector body has no filter caps. The injector follower is held to the injector body only by a spring-loaded pin, whereas the Detroit Diesel units require a pin and a retainer. The Detroit Diesel unit injectors have no outer sealing rings or inlet or outlet openings on the injector nut, whereas the Caterpillar unit injectors have. Nevertheless, from the point of view of the components, you will see that, apart from the foregoing, Detroit and Caterpillar unit injectors have much in common (see Fig. 32-3).

Two major differences between Detroit and Caterpillar unit injectors are in the fuel control linkage and the fuel-rack full-fuel position. On the Caterpillar engine the full-fuel position is achieved when the fuel rack is fully pulled out, whereas on the Detroit Diesel unit injector it is achieved when the fuel rack is pushed in. The fuel flow through the injector and the metering, as well as the injection, is much the same as that of a Detroit Diesel unit having a variable-beginning and a variable-ending plunger design (see Unit 31), and is, therefore, not repeated here.

Injection-operating Mechanism The Caterpillar injection mechanism is much the same as the 53, 71, 92, or the Fuel Pincher engines, apart from the follower design and the fact that the rocker arms use a socket and button to reduce injector-follower wear and side thrust (Fig. 32-3).

Fuel Control Mechanism The Caterpillar fuel control mechanism (Fig. 32-4) is considerably different from that on the Detroit Diesel engines. The bell crank which links each fuel rack with the control rod is pivot-fastened to the bracket which is bolted to the cylinder head. A ball socket is fastened to each bell-crank lever end. One ball socket rests in the fuel racks and the other is attached in the spring-loaded control

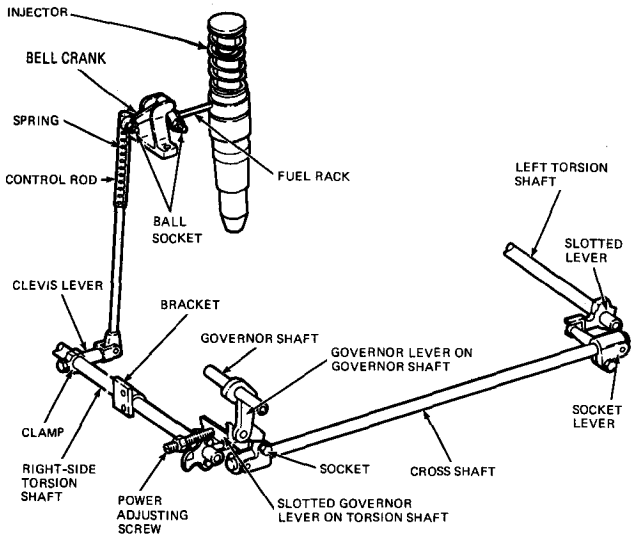


Fig. 32-4 Schematic view of the fuel control mechanism. *(Caterpillar Tractor Co.)*

rod ends. Clevis levers are pinned to the other end of the control rods. The levers are fastened, through a clamp and a screw, to the two-piece (left- and right-hand) torsion shafts. The torsion shafts are located below the camshafts. Each torsion shaft is supported by three brackets, two of which are bolted to the inspection-opening side walls and one of which is bolted to the front of the cylinder block. To link the left- and right-hand torsion shafts together, a slotted lever is fastened to each front end. The ball sockets of the cross-shaft levers rest in the slotted levers. The levers are bolted to the cross shaft. To link the governor shaft to the torsion shafts, the slotted governor lever is fastened to the right-hand torsion shaft. The ball sockets of the governor shaft lever rest in the slotted governor levers. The governor shaft is connected, through levers, with the governor terminal shaft. The standard governor used on the 3512 engine is the Woodward UG-8L governor (see Unit 25). For generator sets and for marine auxiliary engines, the Woodward 2500 or UG-8D governor is used.

Fuel Control Operation Any rotating motion from the governor terminal shaft semirotates the governor shaft and its lever. This motion is transmitted through the lever ball socket to the slotted governor lever on the right-hand torsion shaft, causing it also to semirotate. The movement is again transmitted through the clevis levers, onto the control rods, which semirotate the bell cranks, causing the fuel racks to move in or out of the unit injectors. The semirotation of the right-hand torsional shaft is transmitted over the cross shaft and onto the left-hand torsion shaft, which then semirotates and moves the left-hand fuel rack in or out of the unit injectors. Should a fuel rack become stuck for any reason, the governor or the remaining injector fuel racks will not be affected because the bell-crank end of the malfunctioning fuel rack can move in the spring-loaded control rod.

Injector Replacement When the engine runs rough because of misfiring, underfueling, or overfueling of one or more injectors, the misfiring cylinder can be located by the method outlined in Unit 31 for locating a faulty injector, or as follows: Measure the individual exhaust port temperatures, using a touch pyrometer (see Unit 53). If one or more cylinders have a lower temperature than the average exhaust temperature, this indicates incomplete combustion. A higher temperature indicates overfueling. When the faulty injector is known, remove the valve cover and the two cap screws that hold the rocker-arm shaft, and remove the rocker-arm shaft with the three rocker arms. Lift the inlet and exhaust valve bridges from their guide stems and remove the inlet and exhaust valve pushrod (Fig. 32-5).

To disconnect the control rod from the bell crank, remove the self-locking nut and washer. Remove the two cap screws that hold the bell-crank bracket to the cylinder head, and lift the assembly from it. Make certain that the bell-crank socket slides with ease from the fuel rack. Now remove the injector hold-down-clamp cap screw, and by using two injector bars, pull the injector from its bore.

Thoroughly clean the injector bore and the injector nut seat. Remove the replacement injector from its packing. Visually check it for external damage and verify that the fuel rack falls through its own weight from and into the injector body. Next, install three new O rings into the injector nut grooves but make certain that they are not twisted. Lubricate the O rings and the injector bore. Insert the injector straight into the bore and with the palm of your hand push it firmly into place. Should the injector fail to seat, remove it and check the O rings for damage. When the injector is in position, place the clamp onto the injector and the other end onto the anvil. Tighten the cap screw to the recommended torque and then again check the freeness of the fuel rack. If the fuel rack sticks, it is an indication that the injector bore was not properly cleaned, that the O rings were damaged during installation, that the hold-down clamp was not correctly positioned, or that the cap screw was overtorqued.

The next step is to check and adjust the plunger height.

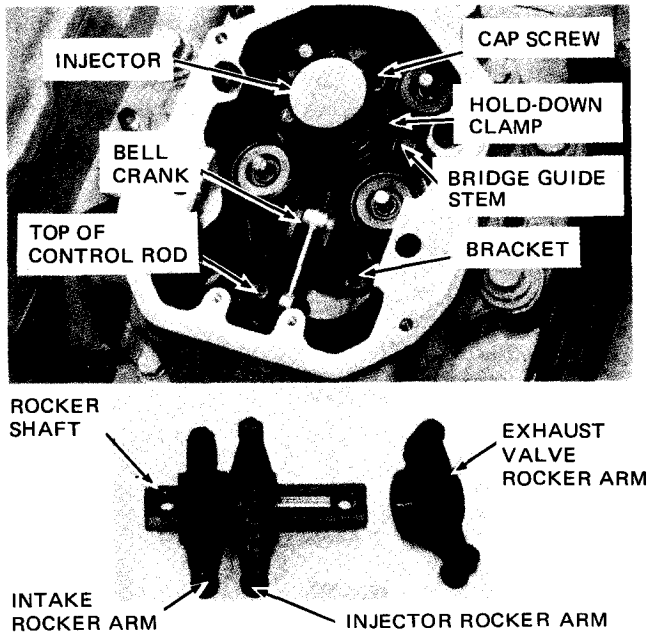


Fig. 32-5 Top view of one cylinder head. *(Caterpillar Tractor Co.)*

Injection-pump Plunger Timing To measure the follower-to-injector body height, that is, timing the injector plunger, you need the special timing tool similar in design to the tool used for the Fuel Pincher. It consists of a calibration gauge, a dial indicator and contact stem, and a timing fixture. In addition you need a special engine turning tool.

First, remove the small cover located on the right-hand front side of the flywheel housing to rotate the crankshaft. Install the turning tool, attach a ½-inch drive ratchet wrench to it, and turn the ratchet wrench to rotate the crankshaft until the piston on which the injector is to be timed is on compression stroke, that is, when the exhaust and intake valves are closed and the injector pushrod follower is on its base circle. Now set the dial indicator onto the timing fixture and zero the dial. Loosen the injector pushrod locknut and, with a screwdriver, turn the adjusting screw several turns counterclockwise. Place the timing fixture's horizontal extension onto the injector follower and its stem onto the injector body (Fig. 32-6). Next, turn the adjusting screw clockwise until the dial indicator reads zero. Hold the adjusting screw while locking the adjustment and torquing the nut to specification. After the nut is torqued, check the injector adjustment. *(NOTE: All injector intake and exhaust valves can also be adjusted with one crankshaft revolution as outlined in Unit 31 for the Detroit Diesel fuel system.)*

Injector Synchronization *Injector synchronization* is the procedure of adjusting all fuel racks to the same specific position. To do this, you need the synchronizing gauge, which is a U-shaped metal precisely 0.50 in [12.7 mm] in length, attached to a rod. To synchronize the injectors, remove the cover located at the left-hand side of the governor and use the longer cap screw (synchronizing pin) without the washer, screwing it tight into the hole left from the power adjusting screw (Fig. 32-7). Now position the throttle to full fuel. This action brings the synchronizing pin against the governor-lever fuel stop's surface. Hold it in this position while adjusting the fuel rack. Place the open side of the U-shaped synchronizing gauge onto the fuel rack between the injector body and step shoulder of the fuel rack. If the gauge does not fit between these points, use a screwdriver and turn the adjusting screw (located in the end of the control rod) counterclockwise, one click at a time, until the gauge fits snug. If the gauge fit is too loose, turn the adjusting screw clockwise, also one click at a time, until it fits snug. Then remove the gauge, semirotate the bell crank several times, and again position the gauge (and if necessary, readjust). Make certain the adjustment is made as perfectly as possible as this setting not only increases or decreases the fuel output, but also varies the beginning of injection. Repeat this procedure with the remaining 11 injectors.

Power Setting *Power setting* is the governor-to-fuel rack adjustment to assure maximum fuel at maximum torque. To check and/or make an adjustment, install the dial indicator as shown in Fig. 32-7. Remove the synchronizing pin, move the throttle to full-fuel position, and zero the dial indicator. This action assures that the flat surface (fuel stop) on the slotted governor lever rests against the end of the power adjusting screw. Take the power setting reading directly from the dial gauge and compare it with the power specification setting written on the engine information plate. If the reading is higher or lower than specified, loosen the locknut and turn the power adjusting screw clockwise to increase (or counterclockwise to reduce) the dial-indicator reading to the given specification. When the adjustment is made, replace all components (use new gaskets) and torque the bolts and nuts or screws to the specified torque.

Startup Procedure The Caterpillar Tractor Company recommends the following startup procedure whenever work has been performed on the injector or governor, or when the engine is started for the first time. *(NOTE: This procedure can apply to all types of engines.)*

1. Disconnect the turbochargers from the air inlet system.
2. Position two employees near the inlets, each with a piece of steel plate large enough to completely cover the inlets.
3. If the engine starts to run too fast, or runs out of control, the steel plates should be put against the turbocharger air inlets. This will cut off the air supply to the engine and the engine will stop. (See Unit 25, "Governors," for adjustments to the UG-8L governor.)

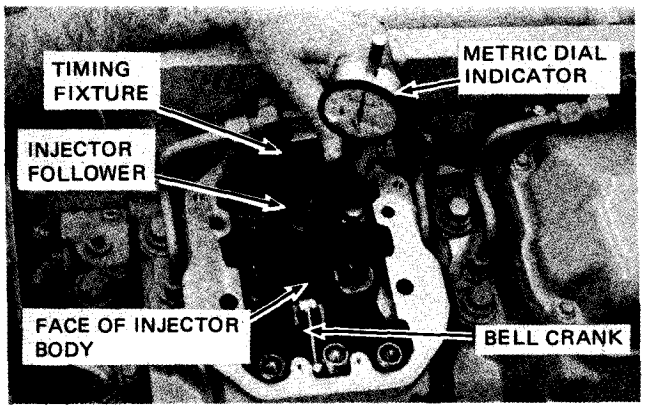


Fig. 32-6 View onto cylinder-head unit-injector timing tool in position. *(Caterpillar Tractor Co.)*

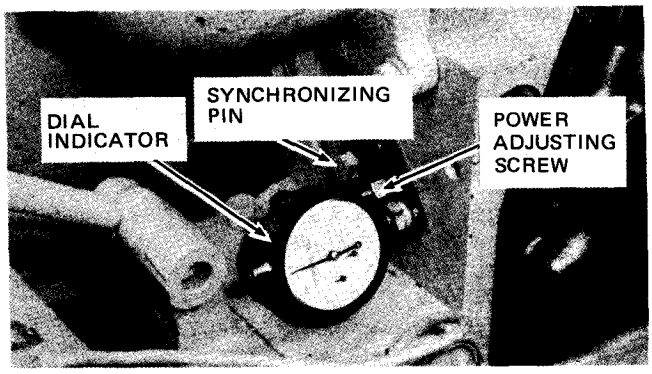


Fig. 32-7 Tool installed to check power setting.

Questions

1. List six differences between the low-pressure fuel system of the Caterpillar 3512 engine and the Detroit Diesel engine shown in Fig. 31-1.
2. How is the inlet manifold pressure controlled?
3. Explain the fuel flow when priming a Caterpillar 3512 engine.
4. List the four most significant differences between a Caterpillar unit injector and a Detroit Diesel unit injector.
5. List (in sequence) the components which move the fuel control rack.
6. Outline the procedure to replace a unit injector.
7. Outline the procedure to (*a*) time an injector and (*b*) synchronize an injector.
8. Why, in your opinion, should you apply the Caterpillar recommended startup procedure to all engines?

UNIT 33 • CUMMINS FUEL-INJECTION SYSTEM

The basic components of the Cummins PT fuel-injection system are shown schematically in Fig. 33-1 [PT (type G) AFC style pump]. Superficially, this injection system appears to be the same as any other. In actual operating principles, however, the metering and injection operations differ considerably from others. To begin with, this system has a fuel pump instead of the regular injection pump. Injection is accomplished through a series of mechanical and hydraulic actions in the injector and the injector activating mechanism. The Cummins PT fuel-injection system is based on pressure and time and utilizes fixed openings (orifices) in the injectors and variable openings in the fuel pump.

The metering principle is based on the laws of hydraulics. It is commonly known that: (1) An increase in flow volume increases the pressure proportionately; (2) pressure is created by restricting the flow (adjustable restriction in the governor or the regulator); (3) when a liquid flows through an orifice the volume and pressure decrease; (4) when the time is extended to allow the liquid to flow through the orifice, the volume increases.

Basic Fuel Flow Although oversimplified, the basic fuel flow of a Cummins engine can be explained as follows: As the crankshaft is rotated to start the engine, the gear pump within the PT fuel pump creates a low pressure, and atmospheric pressure then forces fuel from the fuel tank through the filters, into the gear pump, and it is pumped through the system. Restrictions within the system cause the fuel pressure to rise and the PT fuel pump is now controlling the fuel flow and the fuel pressure. The fuel is directed through a tube into the inlet manifold of the first cylinder head. *(NOTE: The cylinder fuel manifolds are interconnected through a fuel crossover connector, and the inlet manifold of the last cylinder head is closed off.)* Some fuel flows from the inlet fuel manifold through the injectors where it is metered while the excessive fuel flows into the return manifold and back to the fuel tank. Injection on Cummins engines is based on the same principle as Detroit Diesel engines.

As with other fuel-injection systems, the nameplate on Cummins fuel pumps, and the numbering system on the injectors, give the information required for their servicing. For example, the nameplate used on a V 1710 engine indicates:

0236	3170	0045455 C
L	30006036	69990

These numbers and letters identify the pump application, design, and adjustment procedure. For instance:

1. The first set of numbers, 0236, indicates the engine model which, in turn, tells you the injectors, pistons, and camshaft to be used.
2. The next set of numbers, 3170, is the basic fuel pump code number.

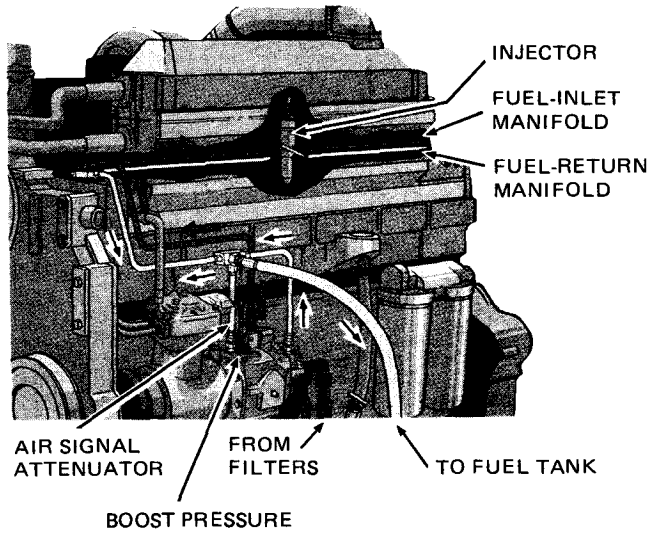


Fig. 33-1 Schematic view of Cummins (in-line engine) fuel-injection system. *(Cummins Engine Company, Inc.)*

3. The next set of numbers is the fuel pump series, and the letter "C" indicates the latest code division.
4. The letter "L" or "R" indicates clockwise or counterclockwise rotation.
5. The next set of numbers is the fuel pump assembly number.
6. The last set of numbers is the engine builder's shop order number.

PT FUEL PUMPS

PTR, PTG, PTG-AFC, and PTH Pumps, Their Components, and Their Purpose Cummins Engine Co., Inc., builds four basic PT fuel pumps, namely, types R, G, AFC, and H. The PTR fuel pump controls the pressure through a regulator (R). The PTG fuel pump controls the fuel pressure through the governor (G). The PTG-AFC is a PTG fuel pump with an internal air-fuel control (AFC). The PTH is a modified PTG-AFC fuel pump having a variable-speed governor and a high-capacity gear pump. This pump is used exclusively on the KTA 3067 engine and is modified, internally, to compensate for the high fuel flow.

Externally, these four Cummins fuel pumps look alike, but the internal construction, the fuel flow, and the method of pressure control are quite different. The PTR pump has a return line and the current PTG fuel pumps have a bleed line connected to the return manifold fuel line. The bleed line prevents excessive fuel temperature within the pump when the throttle is closed and the gear pump speed (engine speed) is high because of downhill operation. The special check valve (in the return line fittings) opens when the fuel pressure overcomes the spring force. This action permits excessive fuel to flow to the reservoir but prevents it from flowing on reverse flow.

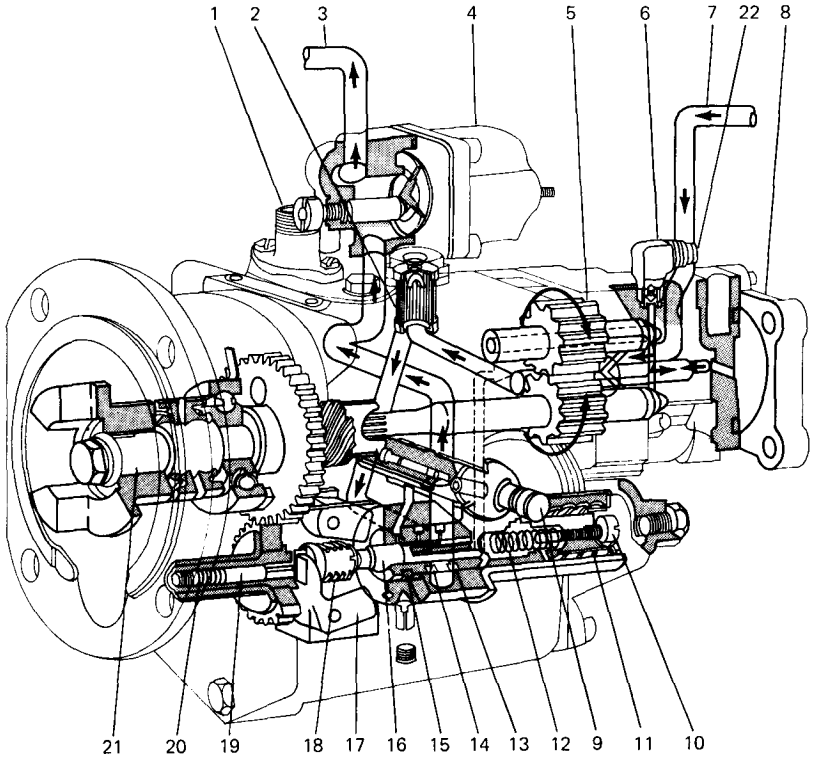
As previously mentioned, the PTR fuel pump is only used on special engines; therefore it will be compared only briefly with the PTG pump.

Each of these fuel pumps uses a combined mechanical-electrical activation shutdown valve to stop the fuel flow to the injectors (see Fig. 33-2). The positive-displacement-type gear pump is driven directly by the main shaft to pump fuel through the fuel-injection system. The steel diaphragm-type pulsation damper smooths out pressure variations created by the gear pump. The opening in the throttle shaft controls the fuel flow and therefore engine speed above idle by increasing or decreasing the throttle opening. This increases or decreases fuel flow to the injector to meet operating requirements under varying load and speed conditions.

The throttle shafts of both fuel pumps vary with pump code. The throttle shafts used with PTG, AFC, and H fuel pumps have restriction plungers so that small pressure adjustments can be made (Fig. 33-3). The governor weight (flyweight) assembly is driven at increased speed from the gear on the main shaft. The governor plunger drive tang is held firm between the governor weight fingers by the idle spring plunger, which is forced onto the governor barrel by the governor spring pack.

The governor plunger, the weight carrier, the idle plunger, and the governor spring vary, depending on the pump type and fuel pump code (Fig. 33-4). The governor plungers of the PTG, PTH, and AFC pumps are center-drilled and have two cross-drilled holes of various sizes. The governor plungers of the PTR pump have only a single machined-out groove. PTG, AFC, and PTH pumps use a weight-assist plunger, and some, in addition, use a torque spring.

PTR Fuel Flow and Pressure Regulation A schematic illustration of the PTR fuel flow is shown in



1. Tachometer shaft
2. Filter screen
3. Fuel to injectors
4. Shutdown valve
5. Gear pump
6. Check-valve elbow
7. Fuel from tank
8. Pulsation damper
9. Throttle shaft
10. Idle adjusting screw
11. High-speed spring
12. Idle spring
13. Gear-pump pressure
14. Fuel-manifold pressure
15. Idle fuel pressure
16. Governor plunger
17. Governor weights
18. Torque spring
19. Weight-assist plunger
20. Weight-assist spring
21. Main shaft
22. Bleed line

Fig. 33-2 PTG fuel pump. (The arrows show the fuel flow.) *(Cummins Engine Company, Inc.)*

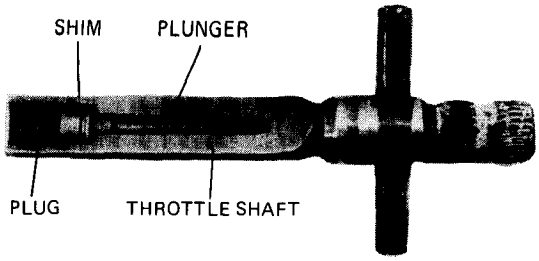


Fig. 33-3 Cutaway view of the throttle shaft assembly.

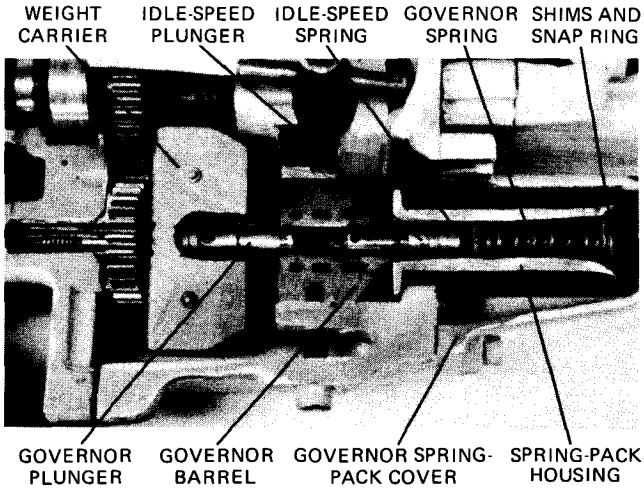


Fig. 33-4 Sectional view of a limiting governor.

Fig. 33-5. When the engine is running at idle speed, fuel under pressure is instantly available to the injector because the throttle is never fully closed. Also, a second passage is always open, thus keeping fuel lines and injectors filled with fuel. The fuel lubricates and cools the injectors, removes air, and assures quick acceleration. The governor weight force and spring force position the governor plunger to allow idle fuel to pass to the injectors. The pressure regulator plunger, when forced to the right (in Fig. 33-5) by fuel pressure, opens the first bypass holes, thus reducing the fuel pressure. As the throttle is rotated, its opening increases, allowing additional fuel to flow to the governor and injectors. As engine speed increases, the gear pump and fuel pressure also increase. This increased fuel pressure moves the plunger in the pressure regulator further to the right, uncovering the first adjusting holes and allowing more fuel to bypass. With increased engine speed, the fuel pressure exerts an even greater force on the plunger. The torque holes are then uncovered, and the pressure is again reduced.

The increased engine speed (from idle) increases the weight force causing the governor plunger to move against the high-idle spring in such a position that fuel is no longer restricted by the plunger. If the engine speed increases above high idle, the weight force moves the plunger even further to the right. This reduces the fuel flow to the injectors because another passage to the inlet side of the gear pump is opened. Should the engine speed increase even further, the fuel flow to the injectors shuts off (Fig. 33-6) and, at the same time, the fuel pressure increases, exerting a greater force on the pressure regulator plunger. The plunger then opens the recirculating passage (dump holes) and returns fuel to the reservoir.

If it is necessary to increase or decrease the fuel pressure in order to come within specified pressure, shims must be added or removed from behind the pressure regulator spring.

PTG Fuel Flow and Pressure Regulation

When the engine is cranked over or is idling, fuel under pressure is readily available to the injector. This is because fuel from the gear pump has already traveled through the filter screen, the governor, the throttle shaft, and the shutdown valve into the inlet fuel manifold. The idle spring plunger rests against the governor plunger, preventing fuel from bypassing and causing the fuel flow and pressure to increase.

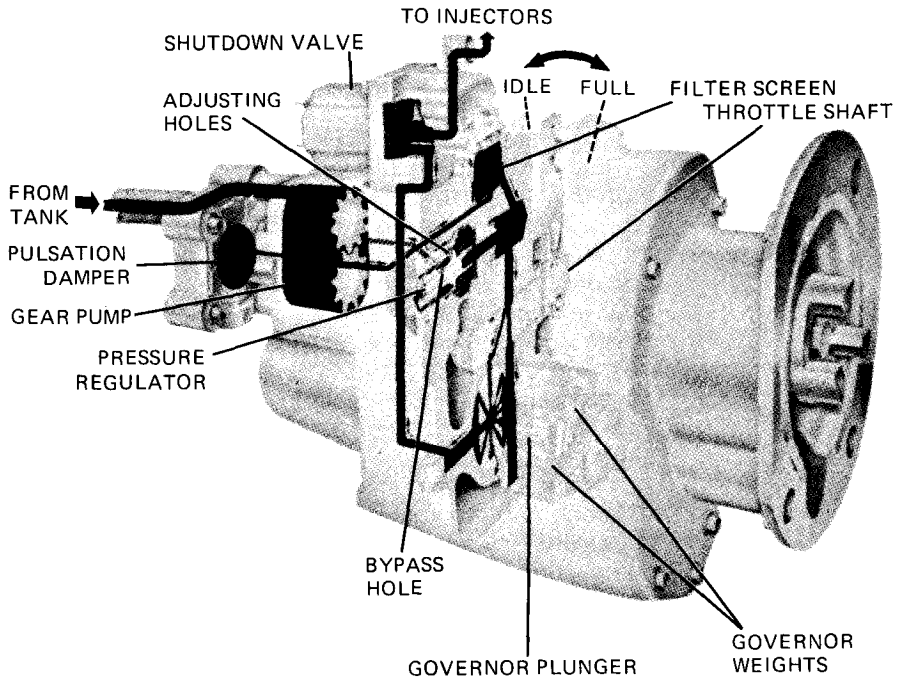


Fig. 33-5 Cutaway view of the PTR fuel pump showing the fuel flow. *(Cummins Engine Company, Inc.)*

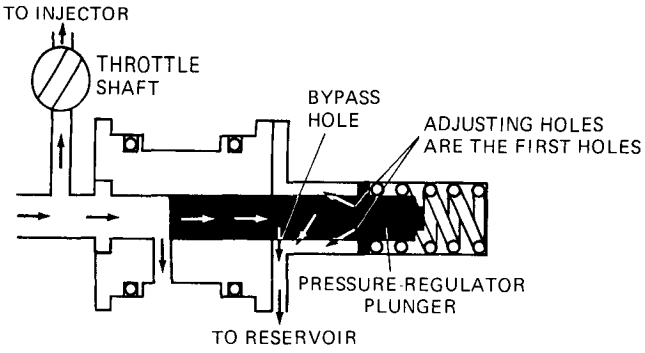


Fig. 33-6 PTR pressure regulator action during downhill operation (throttle closed). (Arrows show the fuel flow.) *(Cummins Engine Company, Inc.)*

The governor plunger position (in its barrel) is achieved by the idle spring force at the right-hand side and the governor force at the left-hand side. The fuel then flows through the center-drilled passage of the governor plunger to the idle spring plunger, thus forcing the idle spring plunger away from the governor plunger. Fuel then escapes into the pump housing thereby reducing the fuel pressure (Figs. 33-2 and 33-7). At the same time, fuel passes around the governor plunger and enters the idle speed passage, bypassing the throttle.

The throttle in the PTG and PTH fuel pumps is never closed. A small amount of fuel always passes through (throttle leakage). Fuel that passes through the idle speed passage, as well as throttle leakage, supplies fuel to the injectors.

Idle spring plungers of different sizes are used to control the amount of fuel to the injectors. A plunger codified with a high number has a larger surface area (greater force) than one with a lower number. Consequently, the fuel pressure acting on a high-numbered plunger (large area) extends its distance further from the governor plunger than that acting on one having a lower number. This allows more fuel to escape (bypass) into the pump housing, causing a reduction in the fuel pressure (Fig. 33-8).

To increase engine torque (fuel pressure) at low speed, a weight-assist plunger and spring are used. This spring forces the weight-assist plunger against the governor plunger, as indicated in Fig. 33-9. The governor weight force and weight-assist plunger

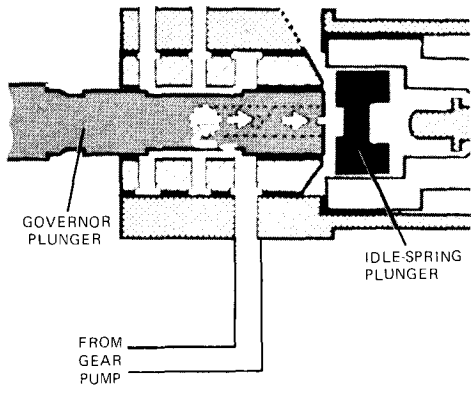


Fig. 33-7 PTG idle spring plunger operation. (Arrows show the fuel flow.) *(Cummins Engine Company, Inc.)*

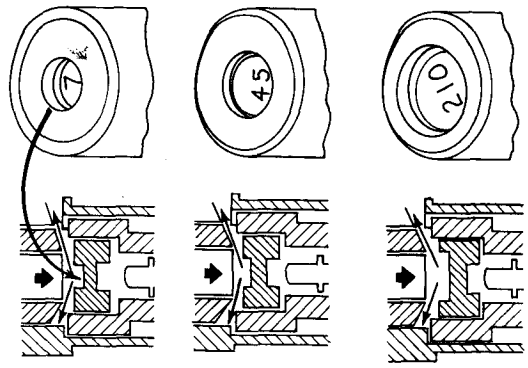


Fig. 33-8 PTG idle spring plungers of different sizes for various fuel bypasses. *(Cummins Engine Company, Inc.)*

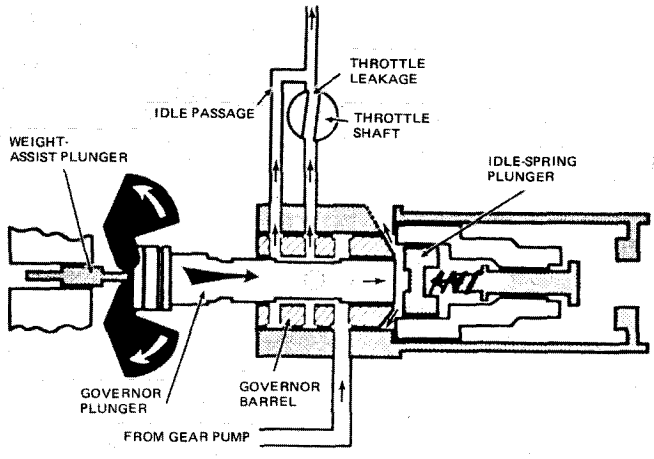


Fig. 33-9 Governor position at idle speed, showing the action of the weight-assist plunger. *(Cummins Engine Company, Inc.)*

spring force the governor plunger against the idle spring plunger so that less fuel is bypassed and the fuel pressure is increased. Shims are used to extend or reduce the effective range of the weight-assist plunger. The idle speed is adjusted through the idle-speed adjusting screw, by increasing or decreasing the idle-speed spring force which, in turn, alters the force on the idle spring plunger and the amount of fuel bypass.

The limited-speed governor controls idle speed, high-idle speed, and torque rise. The throttle position controls engine rpm between idle and high idle. If the engine speed increases, because of downhill operation, the weight force increases, causing the governor plunger to close the fuel passage to the throttle shaft. At the same time, however, it opens another passage, allowing the fuel to pass into the pump housing and back to the inlet side of the gear pump. This results in a reduction of engine speed regardless of throttle position.

A standard pump can be adapted to suit many different engines by varying the governor weight force, the governor spring force, or the idle-speed plunger to change the fuel pressure. The fuel pump code number indicates the specified combination for the correct fuel pressure and high-idle speed. However, if the high-idle speed is above or below the

specified rpm, shims can be used to increase or decrease the spring force. This, of course, increases or decreases fuel pressure because more or less fuel is bypassed at the idle spring plunger. To increase the torque rise, a torque control spring is placed on the governor plunger. This modifies the weight force and the amount of fuel bypass. A specified combination may produce a 20 percent torque rise.

PTG-AFC Fuel Pump versus PTG Fuel Pump

Most Cummins engines are turbocharged and use a PTG fuel pump in conjunction with a separately mounted aneroid (see Unit 26). The PTG-AFC fuel pump is a modification of the PTG, having an integral air-fuel control. It is designed to improve fuel economy, lower emissions, and increase engine power, and is tamperproof.

To allow space for a new air-fuel control valve, the tachometer drive assembly has been relocated in the front cover. The air-fuel control valve is located in the area previously designed for the tachometer assembly. The throttle shaft has been redesigned and is a sealed unit. The adjustment of the restriction plunger within the throttle shaft is now made with an adjusting screw (instead of shims) and the adjusting screw is then permanently sealed. The throttle leakage adjustment and throttle shaft travel are still made with front and rear adjusting screws, but the adjusting screws are covered by a plate on which there is an inscription warning against tampering (Fig. 33-10).

The air-fuel control-valve plunger and its fuel passage are in series with the throttle shaft and shutoff valve. The no-air fuel passage is parallel to the fuel outlet passage and always allows fuel to flow into this passage. The no-air adjusting screw of the air-fuel valve is located behind the throttle shaft plate. (No-air relates to "no boost pressure" fuel flow.) A flow valve (check valve) is screwed into the AFC cover. Its function is to prevent fuel from flowing into the intake manifold in event the AFC bellows are ruptured and/or the fuel drain hose is restricted or damaged.

An engine which is to be used where a noise control law is enforced is additionally equipped with an *air signal attenuator* (ASA). This valve reduces noise and exhaust smoke by controlling the fuel flow from the AFC cavity and slowing down the movement of

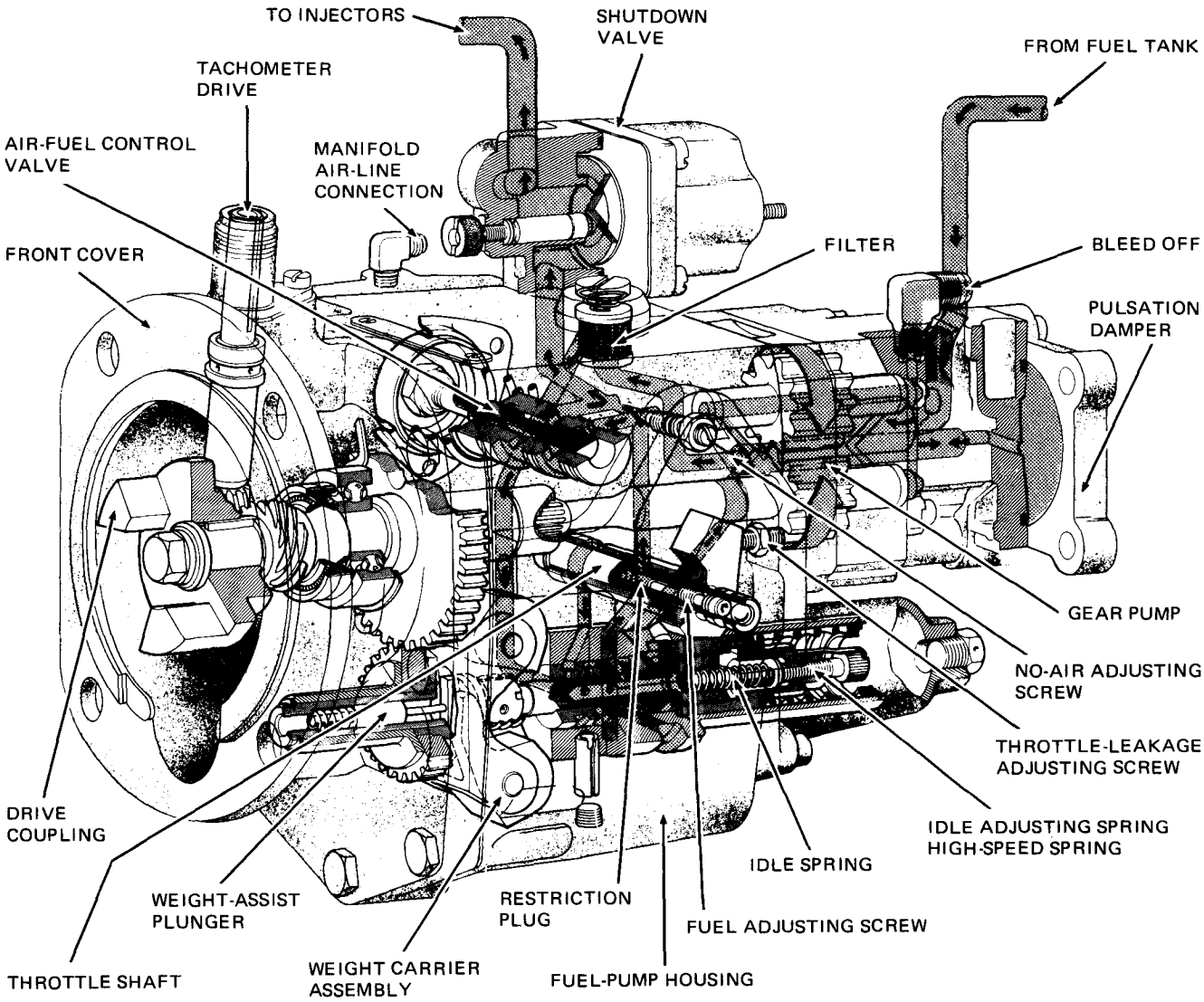


Fig. 33-10 Schematic view of PTG (limiting-speed governor) AFC fuel pump and fuel flow.

the AFC plunger during rapid engine acceleration. The valve has a check valve and a restricted orifice of 0.025 in [0.64 mm] over which a screen is located. It is screwed into the top of the fuel pump housing and its return line is connected to the fuel tank. The check valve prevents air and/or fuel from entering the housing, and the filter screen prevents dirt from entering the orifice.

NOTE: When an ASA valve is used, the AFC plunger has a center-drilled passage and a spring is positioned between the barrel and housing bore (see Fig. 33-11).

PTG-AFC Fuel Flow The fuel flow and pressure control to the point of the air-fuel control valve is identical to that of the older-type PTG fuel pump.

At idle speed or during starting, the boost pressure is low or nonexistent. This causes the AFC spring force to move the AFC plunger to the left, blocking the fuel supply (from the throttle) to the shutoff valve and fuel then passes by the no-air valve and into the outlet passage. As the engine rpm increases, the turbocharger boost pressure increases and this pressure reacts on the AFC piston and bellows. As the boost pressure increases, the force on the piston and bellows increases, and when the force exceeds the AFC spring force, the AFC bellows, piston, and plunger are forced to the left. The AFC plunger position allows additional fuel to flow over the crossover passage into the outlet passage. When the engine operates at wide-open throttle and maximum load, the AFC plunger moves into position to prevent the crossover passage from restricting the fuel flow. Under any other operating condition, the plunger (because of reduced boost pressure) restricts or fully closes the fuel flow at the crossover passage (Fig. 33-12).

The AFC plunger is designed to provide a fuel flow and pressure in proportion to the boost pressure of the turbocharger, and by changing the AFC spring rate, the no-air screw adjustment and/or the AFC plunger adjustment, the fuel pressure curve can be precisioned to the proven optimum engine performance, yet stay within the legal emission limit.

PT-type AFC-VS PTG fuel pumps with variable-speed (VS) governors have a special main pump housing in which the VS governor is located (see Fig. 33-13). The VS governor is driven over an idler gear

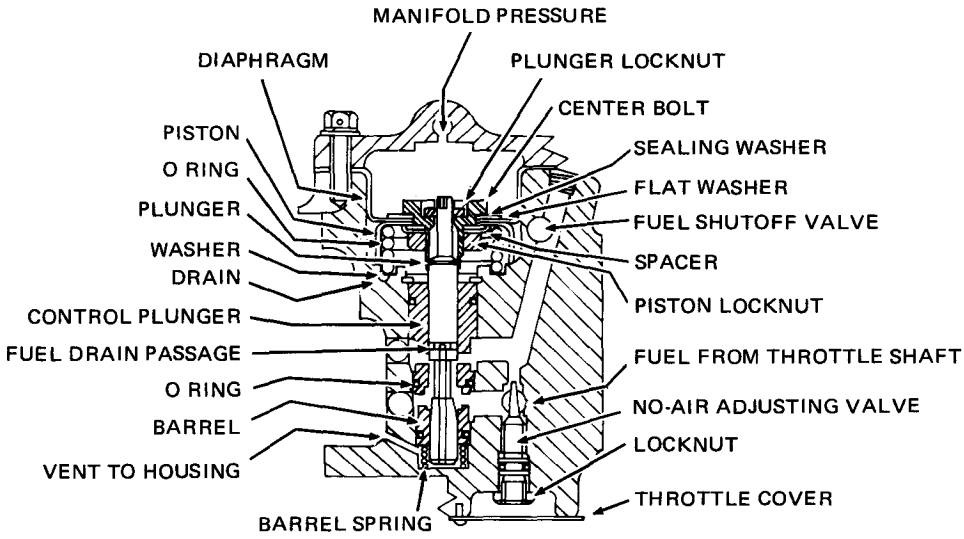


Fig. 33-11 Sectional view of AFC with maximum boost pressure applied.

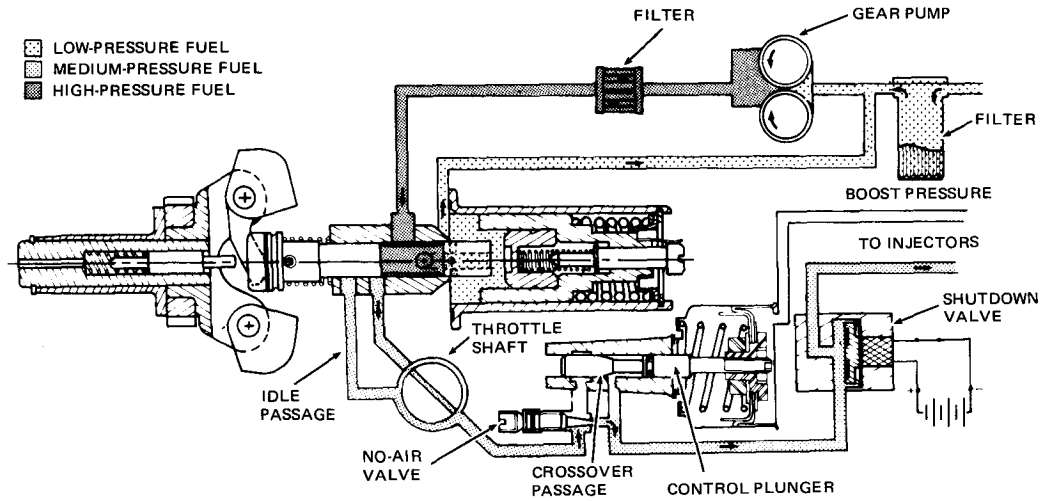
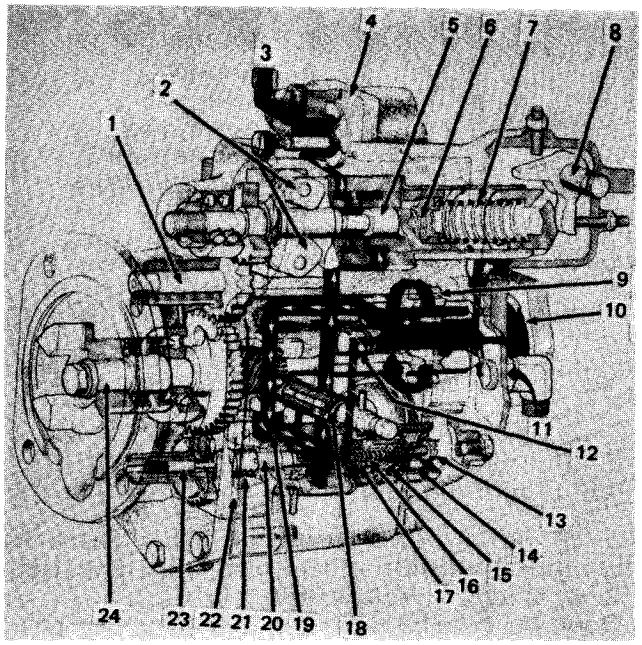


Fig. 33-12 Schematic view of fuel flow during high idle.



1. Idle gear and shaft
2. VS governor weights
3. Fuel to injectors
4. Shutoff valve
5. VS governor plunger
6. VS idle spring
7. VS high-speed spring
8. VS throttle shaft
9. Gear pump
10. Pulsation damper
11. Fuel from filter
12. Pressure regulator valve
13. Idle adjustment screw
14. Spring spacer
15. High-speed spring
16. Idle spring
17. Idle spring plunger
18. Throttle shaft
19. Filter screen
20. Governor plunger
21. Torque spring
22. Governor weights
23. Governor assist plunger
24. Main shaft

Fig. 33-13 Schematic view of PTG (VS governor) AFC fuel pump and fuel flow.

at twice the speed of the main shaft. The shutoff valve and fuel filter are relocated and a housing pressure valve is added. The pressure valve is located in the passage from the housing leading to the inlet side of the gear pump. The check valve assures a fuel housing pressure of about 6 psi [41.67 kPa] and prevents air from entering the fuel pump. Commonly a single lever control is used with the throttle linkage connected to the VS throttle lever, and the PTG throttle is set to a fixed 28° opening. The PTG governor cutoff rpm is set 0.5 percent higher than that of the VS governor. Throttle leakage is made on the VS governor by adding or removing shims, the idle-speed adjustment is made by the rear adjusting screw, and high-idle speed adjustment is made by the governor's top-rear adjusting screw. The fuel flow to the injector (engine rpm) is controlled by the VS governor plunger position in regard to its idle- and operating-speed ports.

Removing Fuel Pump from Engine Do not waste time removing the fuel pump from the engine unless you are certain that it is the fuel pump that is causing the problem. Nevertheless, the removal or installation of a PT fuel pump is a simple operation because the fuel pump is driven through a coupling from the compressor drive or fuel pump drive. Timing or phasing is unnecessary because the fuel pump controls only the fuel pressure and flow.

Before you remove the fuel lines and the throttle connection, clean the surrounding area thoroughly. Cap the hose and pump openings immediately to prevent contaminants from entering. Finally, loosen and remove the fuel pump mounting bolts, and then lift the pump from the engine. Use a circular starter-type wrench to facilitate removal.

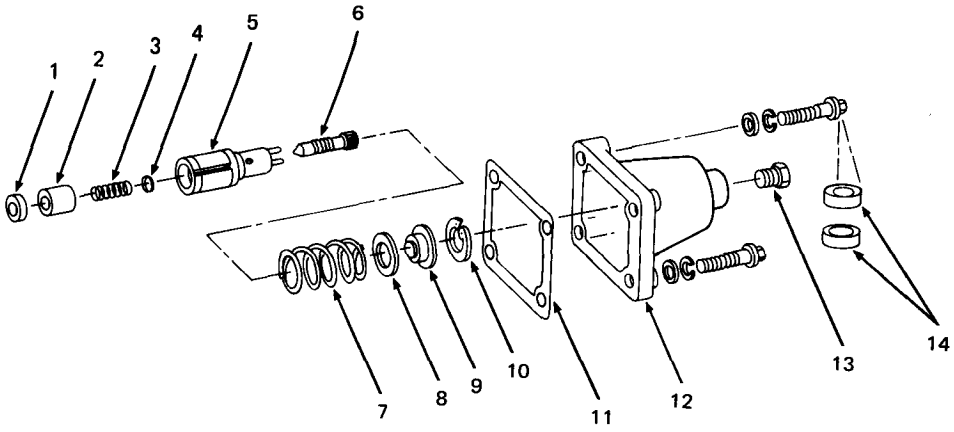
PTG-AFC Fuel Pump Disassembly and Service Thoroughly clean the exterior of the fuel pump before mounting it to a swivel vise. You can then start the disassembly procedure from the drive shaft side or from the gear pump side, or by removing the shutdown valve from the pump housing and then the filter. To remove the filter, first remove the cap and seal, and lift out the components as follows: spring, screen, and magnet. *(NOTE: Flat washers are used between the lock washers and aluminum components to prevent the lock washers from cutting into the soft metal.)*

AFC Control To remove the AFC, start by removing the flow valve from the AFC cover and then remove the cover. Carefully loosen the bellows from their seating surfaces and pull the bellows, piston, and plunger assembly from the AFC barrel.

If the bellows are punctured or damaged, the plunger and/or barrel shows wear or scratches or corrosion, or the spring is damaged or shows corrosion, the air-fuel control must be serviced. Start by loosening the jam nut and screw out the plunger from the center bolt. Lift off the bellows and piston, remove the barrel retainer rings from the housing, and with a puller, remove the barrel (and if applicable the barrel spring).

Remove the bolts from the front cover and use a soft-face hammer to tap the cover loose from its two dowels. Slide the assembly from the housing and then remove the governor plunger. Handle the plunger with care because any small nicks will make it unusable. Remove the weight-assist plunger, shims, and spring from the bore of the weight assembly. Remove the throttle retainer and drive screws holding the cover plate, then carefully slide the throttle out of its bore. Loosen the locknut and withdraw the no-air fuel adjusting screw. If the tachometer drive requires servicing, remove its cover screws and carefully drive the assembly from inside the fuel pump housing, using a brass punch. Next, remove the check-valve elbow from the gear pump, then the pulsation damper, and the gear pump mounting screws. Use a soft-face hammer to lightly tap the gear pump loose from its dowels, then pull the pump from the housing.

To remove the governor spring pack assembly, remove the mounting screws of the spring pack cover and then lift it off. Remove the retainer ring which holds the spring pack in the spring housing. Lift out the shims, spacer, and high-speed spring from the housing. Then remove the idle-speed plunger guide, washer, idle-speed spring, and idle spring plunger (Fig. 33-14). *(NOTE: Some fuel pumps use an adapter.)*



1. Adapter
2. Idle spring plunger
3. Idle spring
4. Washer
5. Guide and clip
6. Adjustment screw
7. High-speed spring
8. Shim
9. Retainer
10. Retaining ring
11. Gasket
12. Cover
13. Plug
14. Seal

Fig. 33-14 Limiting-speed governor components.

At this time do not remove the drive shaft bushings, the throttle sleeve, or the governor barrel because these may not require replacement. First, wash the housing using a suitable cleaning method, then inspect the above-mentioned components for wear. If the governor weight shaft is loose in its bushings, or if the gear backlash between the drive gear and the drive shaft gear is more than 0.009 in [0.23 mm], the front plate must be serviced.

Remove the weight-assist plunger, spring, and shims, if not previously done, and heat the cover in an oven to about 300°F [149°C]. Use a suitable puller to remove the weight carrier assembly. If the snap ring pulls away from the shaft, it will leave the bushing in the front cover. You must then remove the bushing with an internal engaging puller.

If the drive bearing is worn or damaged, remove the snap ring and the fuel pump drive-coupling retainer screw and washer. Screw a 3/8-in 24-hex screw into the drive shaft and place the cover on the press. Press out the drive gear assembly, and then press out the drive shaft oil seal.

Fuel Pump Inspection and Service Inspect the pump housing for cracks, worn or damaged threads, studs, and threaded holes. When necessary, refinish the mounting surfaces of the front cover, shutdown valve, and governor spring pack cover.

GOVERNOR BARREL AND PLUNGER If the governor plunger is worn but the governor barrel is reusable, replace the plunger with one that is a class or two larger. Lap it to the old barrel with fine-grit lapping compound. Make sure that the replacement plunger has the same part number as the discarded plunger.

If the replacement plunger is the largest size (No. 7) and is still too loose in the barrel, or if the governor barrel is damaged, the barrel must be replaced. To remove it from the housing, first withdraw the dowel using a wire hook and then heat the housing in an oven to 300°F [149°C]. This prevents damage to the pump housing while it is being pressed out. Before you press the new barrel into the housing, measure the barrel bore. It must be 0.002 in [0.05 mm] smaller in diameter than the new barrel. Next scribe the centerline of the fuel passage on the governor barrel and the pump housing to ensure precise alignment and thereby an unrestricted fuel flow (Fig. 33-15). This is also a convenient time to check the spring pack housing to determine if it is worn sufficiently to require replacement.

Heat the housing again and place the lubricated barrel with the chamfered edge on the bore so that the locating pinhole is at the bottom and the scribe lines are aligned. Press the barrel into its bore until it rests fully against the spring pack housing. The barrel retaining pinhole must now align. Install the spring dowel with its slot facing the front of the housing. If the governor plunger appears reusable, make sure that the thrust washer and the stop sleeve are not worn. If it is not reusable, remove the retainer pin and the governor plunger drive, and press the stop sleeve from the plunger.

NOTE: If a torque spring is used, rotate it lightly when removing it from the governor plunger to prevent stretching.

When you do the reassembly, the two notches on the stop plate must face toward the barrel, and the chamfered side of the stop plate must be next to the drive.

There must be a clearance between the plunger driver and thrust washer of at least 0.002 in (or not greater than 0.005 in) [0.05 to 0.127 mm]. Make sure that you install the specified torque spring. This specification information can be obtained from the pump calibration data.

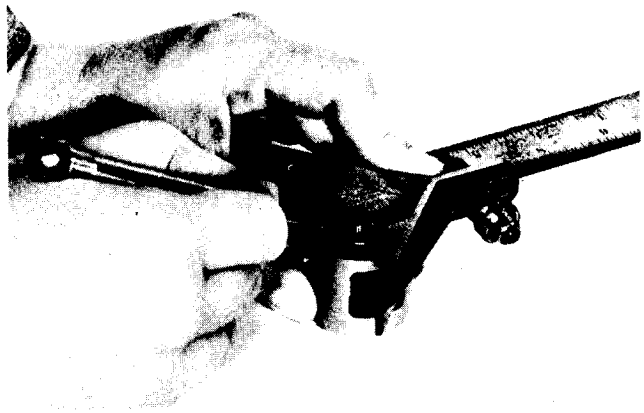


Fig. 33-15 Scribing the fuel passage centerline on the governor barrel. *(Cummins Engine Company, Inc.)*

THROTTLE SHAFT If the throttle shaft or the throttle shaft sleeve shows wear, a new shaft with a higher class number must be lapped to the throttle shaft sleeve. However, when the sleeve is worn beyond a No. 5 shaft size, the housing assembly must be replaced.

Be certain that the housing, the throttle sleeve, and the governor barrel are free of all lapping compound.

TACHOMETER DRIVE If the tachometer drive requires servicing, remove the oil seal and press the shaft from the drive gear and bushing. Check the tachometer shaft for wear. If it is reusable, place the new bushing on the shaft so that the chamfered end faces the drive gear. Press the gear onto the shaft until the clearance is less than 0.005 in [0.127 mm] but the bushing still turns freely on its shaft (see Fig. 33-16).

WEIGHT RETAINER To service the weight retainer, first remove the snap ring and slide the governor carrier bushing from the carrier shaft, then press the governor gear from the shaft. If there is any damage or wear on the weights or pins, the weight carrier must be replaced as a unit. The number on the replacement weight carrier must correspond with the fuel pump's code number.

When you reassemble the unit, press the new weight assembly onto the gear, making certain that you do not damage the weights or pins. Slide the new governor carrier bushing onto the carrier shaft and position the snap ring.

When you press the front and inner seals into the front cover, be sure that the lip of the front seal faces toward the drive coupling and the lip of the inner seal faces toward the inside of the fuel pump. To prevent damaging the seals, use a seal protecting sleeve when pressing the drive shaft assembly into the front cover. When it is in place, install the snap rings, and the drive-coupling key, and then press the drive coupling into position. During installation of the drive coupling, support the drive shaft assembly with the governor drive gear. Heat the front cover in an oven. Coat the external area of the governor carrier bushing with a heat-resistant lubricant. Press the assembly (while meshing the gears) into its bore until the bushing fits firmly against the housing.

If used, install the shims, spring, and weight-assist plunger into the governor weight carrier shaft. Then measure the plunger protrusion, as shown in Fig. 33-17, or use a depth micrometer and subtract the weight-carrier-to-plunger dimension from the weight-carrier-to-housing-face dimension. Add or remove shims to achieve specified protrusion.

Gear Pump Service Disassemble the gear pump by removing the six remaining Allen head screws. To remove the end cover from the pump body, screw two long screws into the body and drive the body against them to separate the unit (the pump body and cover). Inspect the gears and shaft for wear. Measure the gear width and compare it with the specifications. If the gears or shafts are worn or scored, they must be replaced. If the gear body is damaged, or the wear marks pass 3 o'clock, or the cast-iron bearings are worn, the body must be replaced. If the end-cover surface is rough or damaged, it may have to be resurfaced by lapping. If gears or body were lapped to restore proper running clearance, make sure that they are flush with the body surface. Measure the height of the gear pocket and the width of the gears. When you press new gears onto the shaft, heat the gear first and coat the shaft with a heat-resistant lubricant to prevent scoring the shaft. Make certain that each gear is positioned at the specified distance from the end of the shafts.

When you reassemble the gear pump, be sure to correctly position the notches that indicate pump rotation (see Fig. 33-18).

Lubricate the components and slide the shafts into the cover. Place a new 0.002-in [0.05-mm] gasket onto the cover and place the cover on the body. Align the holes and secure the pump assembly through its dowel before tightening the Allen head screws to the specified torque.

NOTE: The pump must turn freely with finger force. If the fuel pump uses a cooling feature, install it at this point.

Pulsation Damper Remove the remaining Allen screws and separate the cover from the housing (Fig.

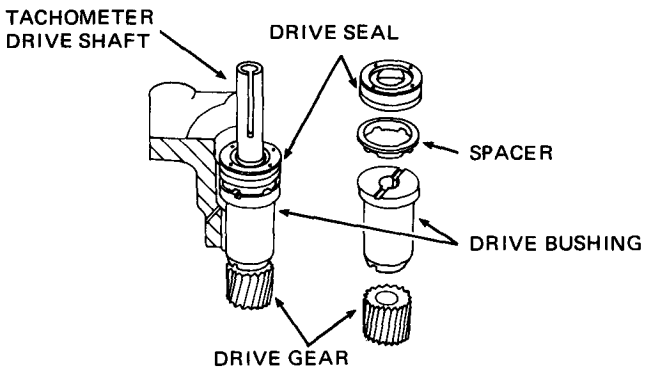


Fig. 33-16 Tachometer drive components. *(Cummins Engine Company, Inc.)*

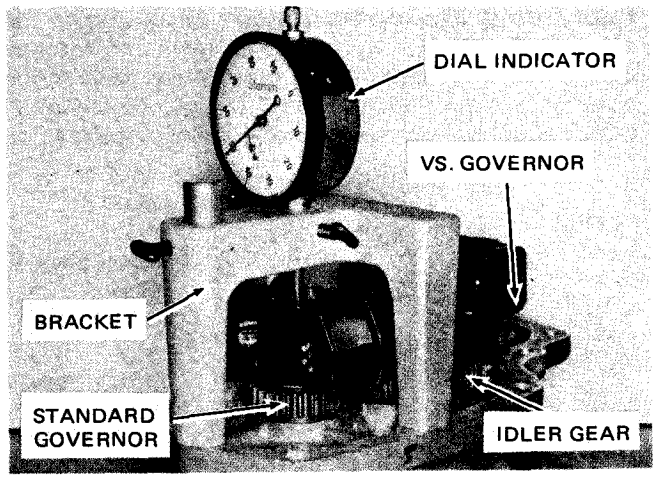


Fig. 33-17 Measuring weight-assist protrusion (VS governor).

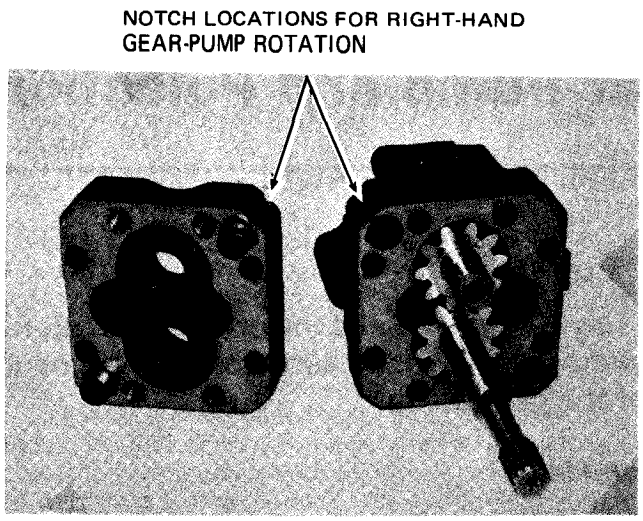


Fig. 33-18 Notch locations for right-hand gear pump rotation.

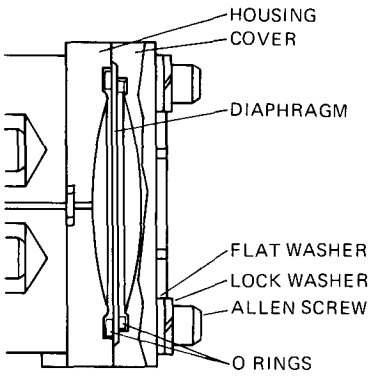


Fig. 33-19 Sectional view of the pulsation damper. *(Cummins Engine Company, Inc.)*

33-19). Clean the housing and the cover and, when necessary, lap their surfaces. Check the diaphragm. If it is bent, twisted, or corroded, replace it. When reassembling the damper, coat the new O rings with grease and place them in the grooves. Place the lubricated diaphragm in position and then affix the housing to the cover. Do not forget to place flat washers between the housing and the lock washer before tightening the Allen screws to the specified torque.

Fuel Pump Shutdown Valve Disassemble the valve by first removing the four screws and the coil from the valve housing. Next remove the parts in the order shown from left to right in Fig. 33-20. Clean all parts except the coil with mineral spirit. Wipe the coil clean, and with an ohmmeter measure the coil resistance; compare the reading with the specifications. Inspect the valve and seat for wear, bonding failure, and corrosion. Replace all O rings. When you reassemble the valve, install a new O ring on the override shaft, lubricate it, and screw the shaft into the housing until it bottoms. Then set the depth micrometer to specification. Measure the distance from the face of the housing to the tip of the shaft. Adjust the shaft until its tip contacts the spindle of the micrometer. Press the knob onto the shaft until it is flush with the valve housing. Lubricate the housing O ring and place it in its groove. Place the valve into the housing (rubber side first), and then place the spring washer on the valve with the concave side up, and with the washer piloted around the valve boss. Place the fuel shield on the valve housing. Tighten the screws to the specified torque.

Reassembling Fuel Pump Start your reassembly procedure by pressing the tachometer drive gear into its bore. Reassemble the other components in the order shown from bottom to top in Fig. 33-16. Install the gasket and tachometer drive cover to the fuel pump housing. Next, install the filter screen. Position the seal and spring, and then tighten the cover to the specified torque. Select the specified idle spring plunger and high-idle-speed spring according to the fuel pump's code number. Assemble the parts as shown in Fig. 33-4. Install the spring-pack cover. Place a new gasket on the fuel pump housing. Install the gear pump and pulsation damper. Tighten the Allen screws to the recommended torque. Install the fuel inlet and cooling fitting using a Teflon sealing tape. Be certain that you have the specified throttle shaft. When a restrictive plunger is used, install enough shims so that the plunger restricts half the throttle opening. Next, tighten the plug to the recommended torque (Fig. 33-3). Lubricate and install a new throttle shaft O ring using a protection sleeve. Slide the throttle plate over the shaft and insert the lubricated throttle shaft into the sleeve and position the snap ring. The throttle shaft, which uses an adjusting screw, must be adjusted so that the restriction plunger does not restrict the throttle opening. If not done previously, install the throttle lever. *(NOTE: The counterbore of the throttle passage on PTG and AFC throttle shafts must face downward, whereas on torque convertor governors and PTR fuel pumps the throttle shafts must face upward.)*

Lubricate the governor plunger, but make certain that it is numbered according to specification before

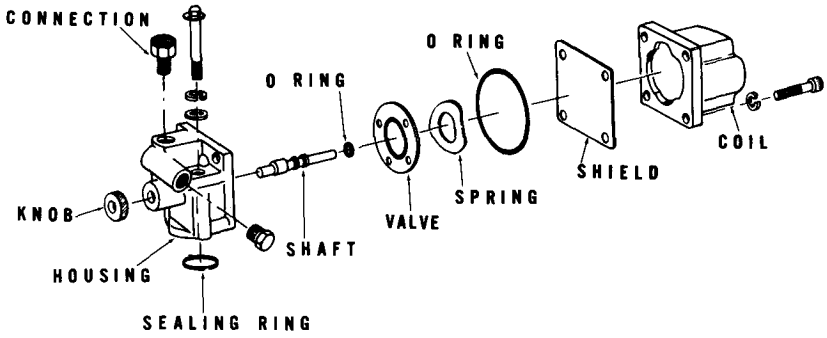


Fig. 33-20 Components of the fuel pump shutdown valve. *(Cummins Engine Company, Inc.)*

sliding it into its barrel. Place a new gasket on the fuel pump housing. Install the weight assist (shims, spring, and plunger) into the carrier shaft. Lubricate the drive shaft and bushing. If an AFC valve is used, lubricate the no-air valve O ring and install it onto the valve. Screw the no-air valve, fingertight, into its bore until it is seated and then place the jam nut onto the valve. If no AFC valve is used, install a plug and torque it to specification. Rotate the weights and plunger drive tang to horizontal position. Now, carefully slide the front cover onto the fuel pump housing while meshing the tachometer gears. Engage the tang with the weight finger, then torque the mounting bolts to specification.

Lubricate the AFC barrel and O rings, then install the O rings. On fuel pumps using an ASA, install the small spring in the bore cavity, then the AFC barrel. Force it downward and then install the barrel retainer (Fig. 33-21). Select the specified AFC spring and place the shim and spring into position. Assemble the center bolt, plunger jam nut, sealing washer, bellows, flat washer, piston, and piston jam nut. Screw the plunger into the center bolt and finger-tighten the piston jam nut. Carefully install the plunger and at the same time push the bellows down between the piston and housing. Align the bellow holes to the cover holes. Next, install the cover and bolts and tighten them fingertight.

Calibrating PTG-AFC Fuel Pump Mount the fuel pump to the test stand as outlined in the service manual. Make sure that you use the recommended test oil. Fill the gear pump and pump housing with test oil before connecting the pump inlet and the cooling bleed line to the test stand. Lubricate the tachometer gear, and remove the AFC cover and replace it with the plunger adjusting plate. Attach an air line having a regulator and a mercury manometer to the plate (Fig. 33-24). Select the calibration card codified on the pump nameplate. Adjust the throttle to the full open position so that the port in the throttle shaft is indexed (in line) with the fuel passage in the throttle sleeve.

NOTE: On AFC fuel pumps, the rear throttle adjusting screw is for throttle leakage adjustment and the front is for throttle travel adjustment.

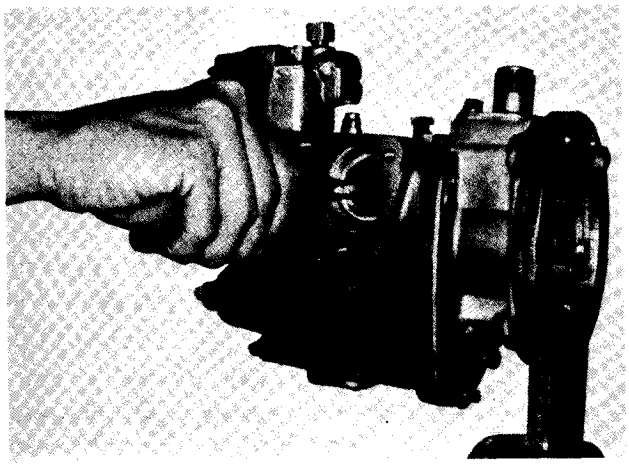


Fig. 33-21 Installing AFC barrel retaining ring.

Manually turn the knob of the shutdown valve clockwise to fully open the valve. Switch on the fuel heater. Open the main flow valve. Then close the idle and leakage valves. Select the correct pump rotation and operate the fuel pump between 800 and 1000 rpm. To prevent damage to the gear pump, make certain that it promptly pumps fuel. Operate the fuel pump at this speed until the test oil is at 90°F [32.2°C]. During this time check for external fuel leaks and for air bubbles in the flowmeter. Seal any leaks in the connections before the continuous warm-up period. Cummins Engine Company recommends adjusting the vacuum valves so that the gear pump draws 8 inHg [20.32 cmHg] during the warm-up period.

NOTE: If you cannot obtain the specified vacuum, check that (1) the test-stand filters are clean; (2) there are no restrictions in the inlet lines; (3) the main shaft seal, the throttle shaft seal, and the tachometer drive seal do not leak.

When the test fuel reaches the recommended temperature, operate the fuel pump at the rated rpm. Apply a pressure of 24.5 psi (50 inHg) [1270 mmHg] onto the AFC. Adjust the vacuum valve to get 7 inHg [17.78 cmHg] and adjust the main flow valve until the flow is equal to the calibration sheet data. If the flow cannot be obtained, check the cutoff rpm and check to see if you have the correct governor spring and idle spring plunger number.

Setting Governor Cutout rpm To check governor cutout rpm, hold the throttle in the full-fuel position, open the fuel pressure valve, and then increase the pump rpm while observing the manifold pressure and vacuum gauges. The rpm at which the pressure just begins to fall should coincide with the specified governor cutout rpm (see fuel pump calibration data sheet).

If the cutout rpm is lower than specified, add shims between the governor spring and retainer; if the cutout rpm is too high, remove shims (Fig. 33-4). If the flow volume is high or low but the cutoff rpm is correct, check the color code of the governor spring and the number on the idle spring plunger.

NOTE: Before retesting the governor cutout rpm (after an adjustment), make certain that the flowmeter shows no air bubbles.

Adjusting Throttle Leakage (Limiting-speed Governor) Operate the fuel pump at rated speed, move the throttle toward the gear pump, and hold it firmly against its stop. Next, fully open the leakage valve and close the main flow control valve, then check the throttle leakage rate indicated by the small flowmeter. *(NOTE: Do not operate the pump under this condition any longer than is absolutely necessary.)*

The throttle leakage flow rate must coincide with the Cummins fuel pump calibration sheet. If the flow rate is not within specification, turn the rear throttle adjusting screw in clockwise or counterclockwise rotation to bring it within specification (Fig. 33-22), and then lock the adjustment.

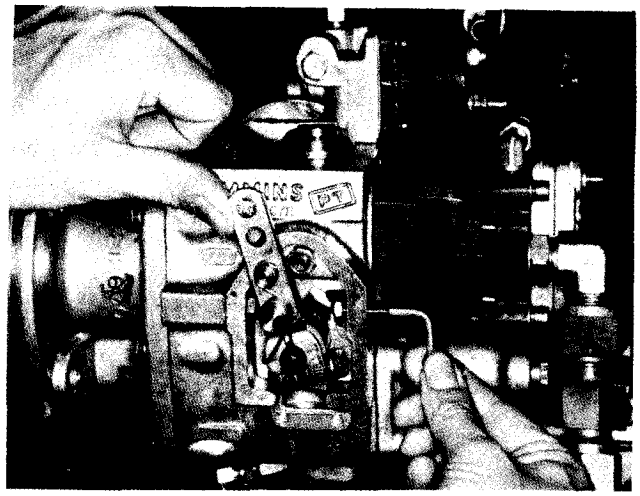


Fig. 33-22 Adjusting throttle leakage.

NOTE: This adjustment is very important because it affects the deceleration time of the engine. Do not forget to tighten the locknut.

Idle-speed Adjustment Stop the test-stand motor. Remove the plug from the governor cover. Place a short piece of rubber hose onto the screwdriver shank, insert the screwdriver into the governor-cover plug hole, and then use the rubber hose to seal the hole (Fig. 33-23). Close the main flow valve. Close the leakage valve, open the idle valve, and hold the throttle shaft firmly in idle position. Next, operate the fuel pump at the rpm recommended on the Cummins fuel pump calibration sheet. The fuel-manifold pressure gauge should indicate the recommended pressure. If the pressure is too low, turn the idle adjusting screw, with the screwdriver, in clockwise rotation to increase the fuel pressure. If the fuel pressure is too high, turn the idle adjusting screw in counterclockwise rotation to decrease the fuel pressure. When adjusted, remove the screwdriver and install the plug.

Adjusting Fuel-manifold Pressure with Internal Throttle Shaft Plunger Adjust the throttle lever to 28° from the idle stop position, using the throttle lever templet, and lock the adjustment with the front throttle screw. Place the throttle at the full-fuel position. Close the idle valve, open the main flow valve, and then operate the fuel pump at the rated speed indicated by the Cummins fuel pump calibration sheet (under the heading "Manifold psi rpm"). Adjust the fuel flowmeter according to the fuel-flow calibration data and then check the pressure on the fuel-manifold pressure gauge.

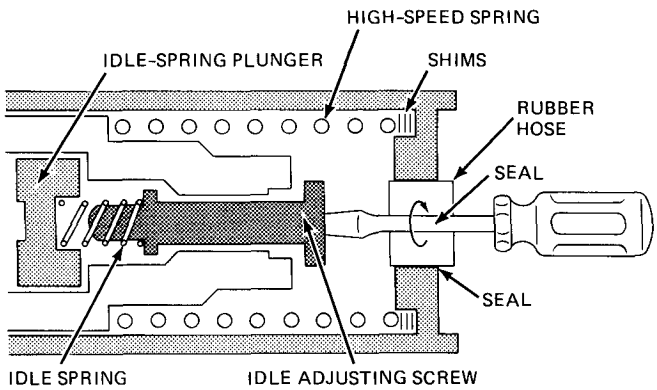


Fig. 33-23 Schematic view of adjusting the idle-speed pressure. *(Cummins Engine Company, Inc.)*

NOTE: Adjust the vacuum control valve so that the vacuum gauge reads 8 inHg [20.32 cmHg] during the test.

If the pressure is not within specification, use an Allen wrench and rotate the adjustment screw at the end of the throttle shaft to achieve the specified pressure, or, when shims are used for adjustment, stop the test-stand motor and remove the throttle shaft. Add shims to increase manifold fuel pressure or remove shims to decrease the pressure as required.

CAUTION After each adjustment, reset flow and vacuum control readings to the specified values before retesting.

If the throttle shaft has no restriction plunger, the manifold fuel pressure can be adjusted by turning the rear throttle stop screw clockwise. This will reduce the opening of the throttle shaft and thereby reduce the fuel flow. The correct manifold psi and rpm is outlined in the Cummins fuel pump calibration sheet.

Compare with checkpoint pressure given in the fuel pump calibration sheet. Operate the pump at rated speed. Be sure that the fuel flow is set to specified value. Now, reduce speed to that specified under checkpoint 1 in the Cummins fuel pump calibration sheet.

Check the manifold pressure gauge reading. The checkpoint pressure should be within the specified tolerance. If the readings are not within specification, check the torque spring to make sure it is properly seated. If a spring or shim is used, it must meet specification.

Weight-assist Pressure Check If the fuel pump uses a weight assist, run the fuel pump at specified rpm and check the fuel-manifold pressure. It should be as specified in the calibration data. If the pressure is low, add shims behind the weight-assist plunger. To decrease pressure remove shims (see Fig. 33-4).

NOTE: If shims are added or removed behind the weight-assist plunger, the entire pump calibration must be rechecked.

AFC Testing and Adjusting To test the AFC valve, first connect the air line hoses and valves as recommended in the manual *Rebuilding and Calibration Instruction.* Place the throttle in the full-fuel position and operate the fuel pump at the AFC Test Code calibration revolutions (1600 rpm). Apply 50 inHg [127 cmHg] onto the bellows and close the idle and leakoff flow valves. Open the main flow valve and adjust it to the flow and pressure value of the Code, for example, 65 psi at 200 pounds per hour (lb/h) [448.2 kPa at 90.72 kilograms per hour (kg/h)]. If not previously done, screw the no-air valve onto its seat. Now remove the air pressure from the bellows and you will notice that the flow and pressure fall to zero. Next, gradually increase the air pressure to specifi-

cation (8 inHg [20.32 cmHg]) and then check the fuel pressure. If the fuel pressure and flow are too high or too low, remove the air pressure from the bellows. Use the AFC plunger adjusting tool to loosen the plunger locknut. Turn the plunger clockwise or counterclockwise to adjust the fuel pressure to specification, for example, 65 psi ± 2 psi [448.2 kPa ± 13.7 kPa] (Fig. 33-24). After the locknut is tightened, retest the AFC fuel pressure. When the pressure is adjusted to specification, torque the locknut. Lower the air pressure to zero, then with a screwdriver turn the no-air valve adjustment screw to obtain the specified pressure and flow, for example, 65 psi and 215 lb/h [448.2 kPa and 97.5 kg/h] (Fig. 33-25). When all adjustments are completed, retest the fuel pump. Remove the adjusting tool, install and lockwire the AFC cover, and install the throttle cover.

Installing PTG Fuel Pump to Engine Before you install the fuel pump, check the buffer or the spline coupling for wear or damage. Fill the gear pump and the pump housing with clean fuel. Then, using a new gasket, install the fuel pump to the mounting flange. Connect the inlet and return fuel lines to the fuel pump. Connect the fuel supply line from the fuel-pump shutdown valve to the cylinder head(s). Connect the AFC. Connect the electrical wire to the terminal of the fuel pump shutdown valve.

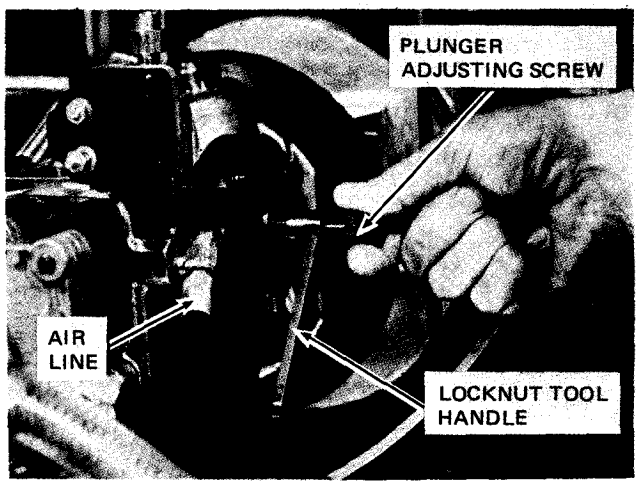


Fig. 33-24 Adjusting AFC plunger.

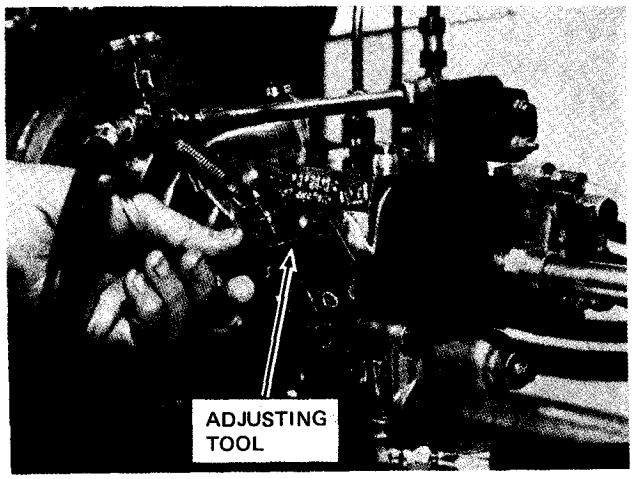


Fig. 33-25 Adjusting no-air needle valve.

Start the engine and bring it up to operating temperature. Then check the idle speed and, when necessary, adjust the idle-speed screw. Check the high-idle speed. You may need to add or remove shims to come within specification.

PT FUEL INJECTORS

Fuel injection on Cummins diesel engines is accomplished through a series of mechanical actions of the injector activating mechanism and through mechanical and hydraulic action within the injector. The camshaft with its eccentric injector cam rotates at half the engine speed. The camshaft rotary motion is changed into reciprocating motion by the cam follower riding on the injector cam. This moves the push tube, causing the rocker lever to pivot and force the plunger down (see Fig. 33-26).

PT injectors are simple but precision-built units which meter, time, and inject fuel into the combustion chamber. The beginning of injection is controlled by the camshaft and the quantity of fuel metered (into the spray cup) depends on pressure and time. The injector code number is located on the adapter (see Fig. 33-27). The first three numbers indicate the flow volume. The second set of numbers indicate the number of cup holes, the hole size, and the spray angle. The inscription on the plunger identifies the plunger class size.

The PTD injector has, in addition, a letter stamped on the adapter; for example, "A" indicates 80 percent flow. On top of the adapter is the assembly number and on the spray cup the part number, the month, and the year it was machined. The inscription on the older spray cup indicates the number of holes, the size, and hole angle, and the letter identifies where it was manufactured.

Basic Components and Operating Principles of PTB, PTC, and PTD Fuel Injectors These three types of injectors are similar in basic construction and operate according to the same metering

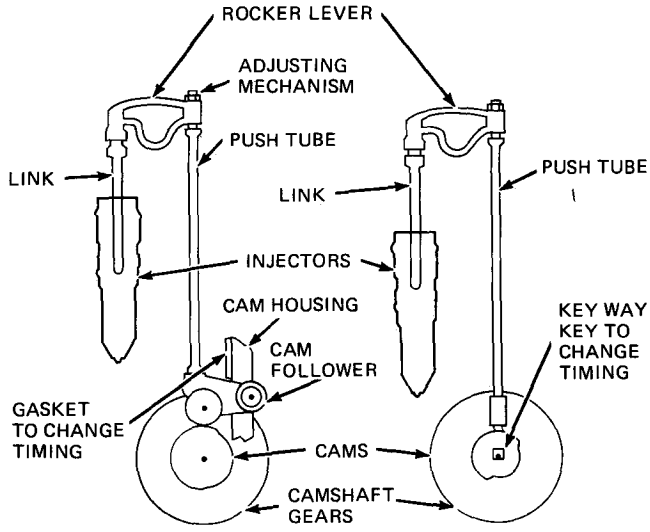


Fig. 33-26 Injector-activating mechanism. *(Cummins Engine Company, Inc.)*

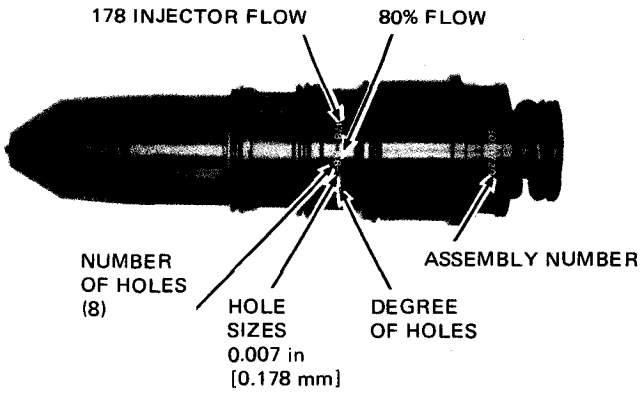


Fig. 33-27 Injector code number (type D) location: (1) 178 injector flow, (2) 80 percent flow, (3) 8—number of holes, (4) 7—size of holes (0.007), (5) 17—degree of holes, (6) assembly number.

injection principle (see Fig. 33-28). They are cylindrical and are positioned in the injector sleeve. The injector sleeve is located in the cylinder head and the injector is held by either a mounting plate or yoke. O rings separate and seal the inlet and drain (return) fuel manifolds: the lower manifold is the inlet, the upper manifold is the drain. Since the PTD top stop injector has come into extensive use in recent years, it will be examined in detail in this section.

Two types of PTD injectors are used: one with a 5/16-in [7.94-mm] plunger and one with a 3/8-in [9.53-mm] plunger. The PTD injectors are actually modified type B and C injectors which, through component design changes, provide more interchangeability among those components which are subject to wear.

The PTD injector consists of seven parts: an adapter, a barrel, a plunger, a plunger link, a spring, a spray cup, and a spray-cup retainer.

The B- and C-type injectors, unlike the D type, are manufactured with the adapter (body) and the barrel as one piece.

The PTD top stop injector, to the right in Fig. 33-28c, provides a positive stop; that means that the plunger is limited in its upward travel resulting in better injector lubrication and less wear. In addition, the injector mechanism is not under strain (it is unloaded) and oil can flow into the balls, sockets, rocker arm, and follower areas.

PTD Adapter and Barrel The adapter has three external O-ring grooves by which the O rings seal and separate the inlet manifold from the drain manifold. It has an inlet opening (in which the balance (adjustable) orifice is threaded), and an outlet opening. Internal fuel passages connect the inlet and outlet ports with the fuel passages in the barrel and the manifolds. Two dowel pins (in the adapter) are used to position the barrel to the adapter. The barrel is short, allowing the plunger to be fitted more closely. It is made of hard-wearing resistant material, is lap-fitted to the plunger, and contains the ball check valve and a fixed metering orifice.

PTD Plunger The plunger is bonded to the coupling, and the tip diameter is narrowed and "fixed," regardless of plunger class (Fig. 33-29). The plunger diameter increases with plunger class size but the seat area remains the same, so the amount of fuel metered does not change. The tapered plunger seat is lapped to the cup. To cool the injector during the combustion and exhaust stroke, a fuel groove is cut around the lower part of the plunger which connects the inlet fuel to the drain passage when the plunger is seated against the cup.

Cup and Retainer The cup is lapped to the plunger seat. The spray holes assure good atomization and the spray-hole angle assures precise droplet distribution over the area required for combustion.

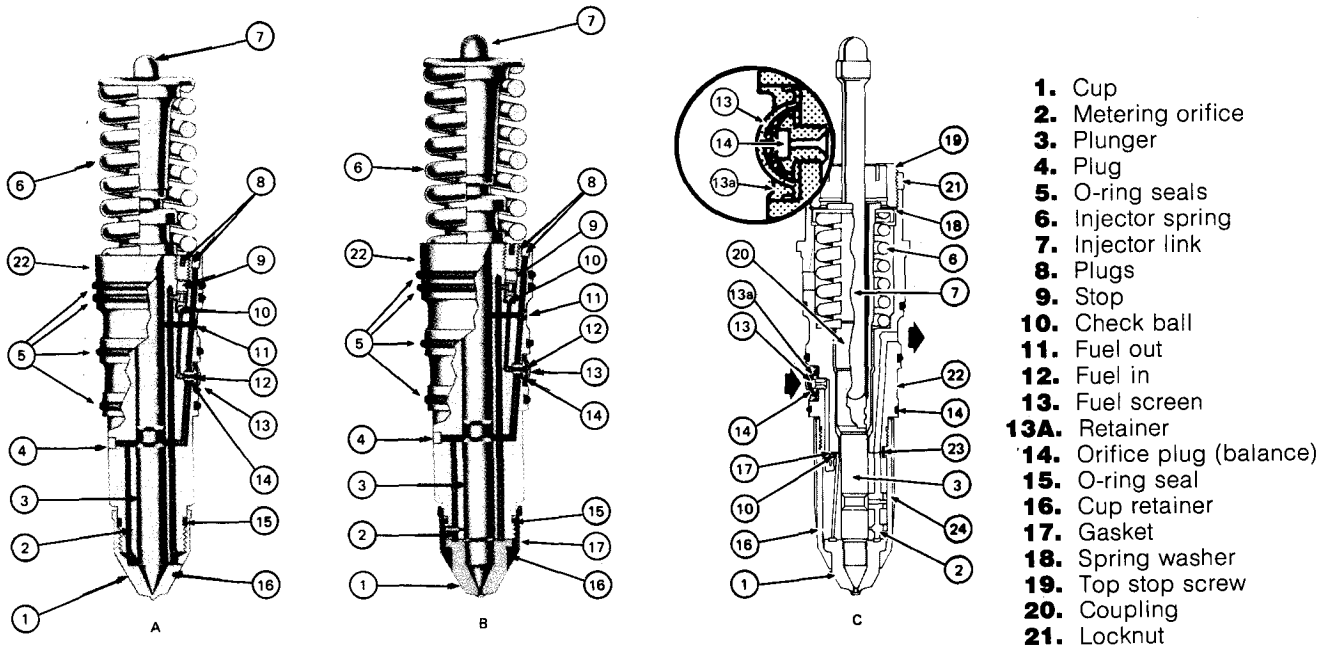


Fig. 33-28 Sectional view of cylindrical PT injectors: A—type PTB; B—type PTC; C—type PTD top stop. *Note:* The barrel is of the direct-fuel-feed design. See Fig. 33-34 for standard barrel design.

1. Cup
2. Metering orifice
3. Plunger
4. Plug
5. O-ring seals
6. Injector spring
7. Injector link
8. Plugs
9. Stop
10. Check ball
11. Fuel out
12. Fuel in
13. Fuel screen
13A. Retainer
14. Orifice plug (balance)
15. O-ring seal
16. Cup retainer
17. Gasket
18. Spring washer
19. Top stop screw
20. Coupling
21. Locknut
22. Adaptor
23. Spiral pin
24. Barrel

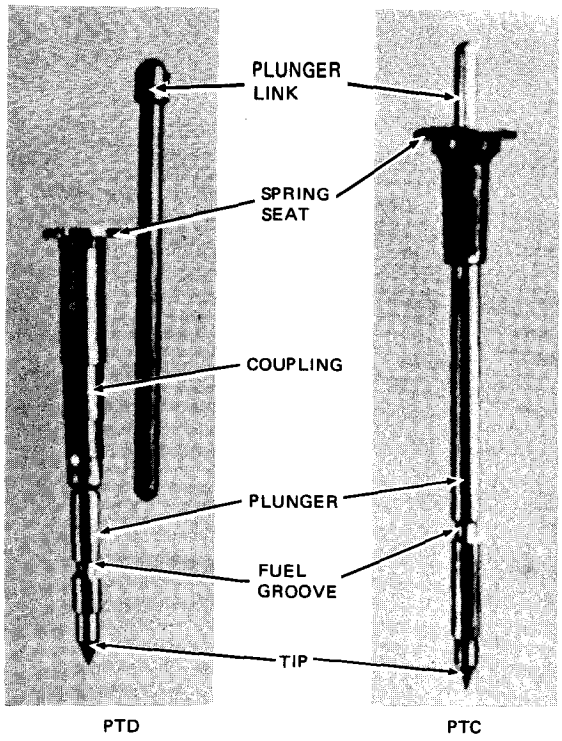


Fig. 33-29 Comparison of PTD and PTC plungers. *(Cummins Engine Company, Inc.)*

The retainer nut holds the cup and the barrel to the adapter (Fig. 33-30). *(NOTE: No seals or gaskets are used.)*

The plunger tip clearance (sac volume) of the newer cup shown in Fig. 33-31 is reduced, thereby leaving less fuel in the cup after injection. Consequently fuel "drip" (or boil out) into the combustion area during metering and combustion is minimized, resulting in a cleaner burning engine.

Plunger Spring and Link The plunger spring which is positioned between the adapter and the coupling forces the plunger upward. The plunger ring rests in the socket of the coupling and the rocker-arm adjusting screw. The long link lessens wear and reduces side thrust on the plunger and barrel because it can follow the arc of the rocker arm. The components of the PTD top stop injector are identical to those of the PTD with the exception that the adapter

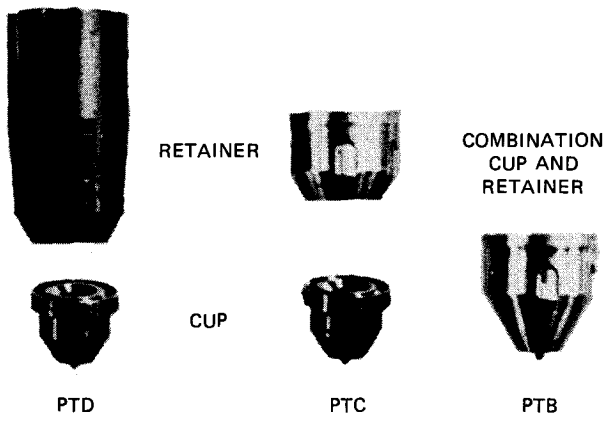


Fig. 33-30 Comparison of PTD, PTC, and PTB spray cups and retainers. *(Cummins Engine Company, Inc.)*

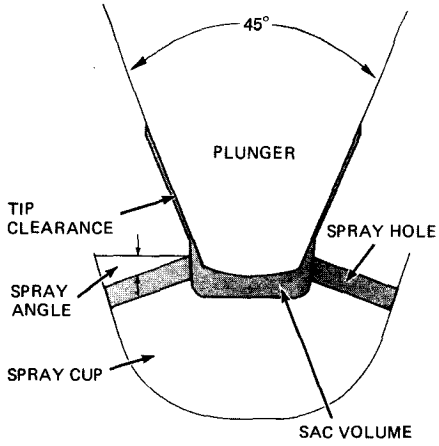


Fig. 33-31 Schematic view of spray-cup design.

is longer to accommodate the top stop, that is, the spring washer, locknut, and top stop screw.

Comparison of PTC and PTD Injectors

1. The adapter and barrel of the PTC are one unit, whereas on the PTD they are separate units.
2. The PTC check valve is located in the top part of the injector body, but it is in the barrel of the PTD.
3. The PTC injector has four O rings and the PTD has three.
4. The metering orifice of the PTC is threaded into the lower end of the injector body and is interchangeable. The metering orifice of the PTD injector is in the barrel and is fixed.
5. The PTC plunger is longer and is one piece whereas the PTD plunger is a two-piece unit.
6. The PTC retainer is shorter than the PTD and uses an O-ring seal.
7. The PTC plunger spring is longer but the link is shorter than the PTD.
8. The PTC differs from the PTD in that the diameter of its plunger is equal from the top to the tip, and the cup and the retainer are one piece.

Fuel Flow and Metering through a PTD Injector A simplified schematic diagram of the PTD-injector fuel flow is shown in Fig. 33-32. The actual relationship between the camshaft actuating mechanism and the injector is shown in Fig. 33-33.

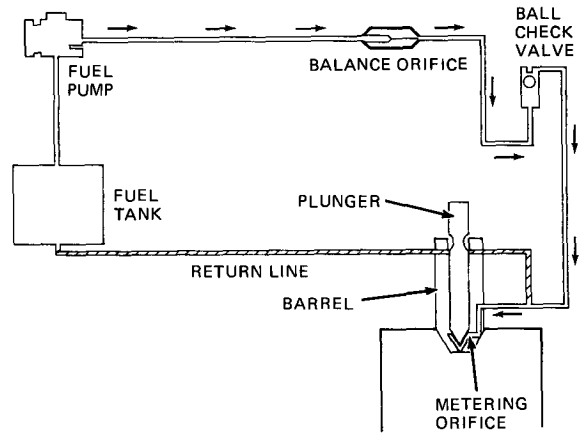
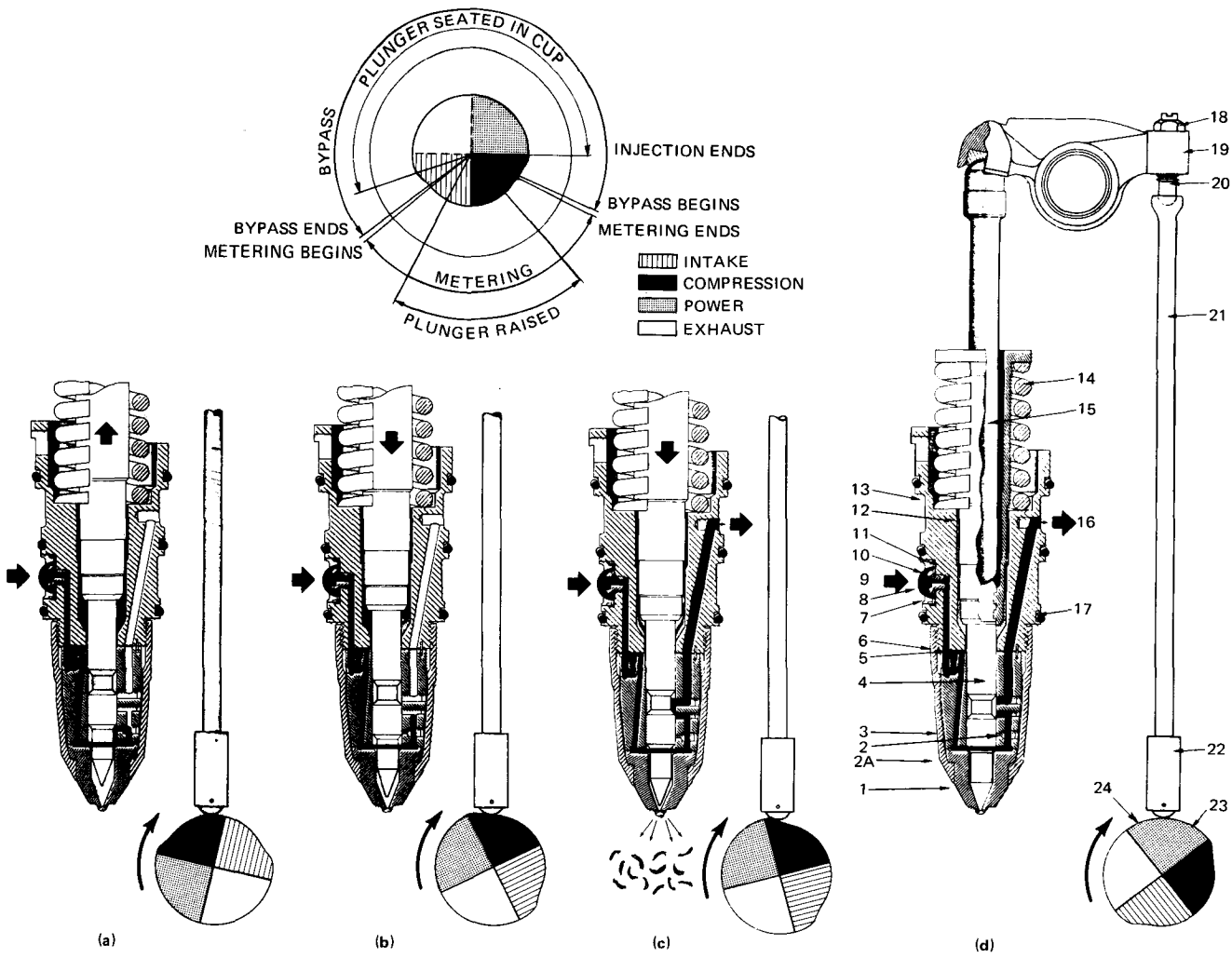


Fig. 33-32 Schematic diagram of PTD injector fuel flow. (The shaded area shows the fuel flow when the plunger is seated.) *(Cummins Engine Company, Inc.)*



1. Cup
2. Metering orifice
2A. Cup retainer
3. Barrel
4. Plunger
5. Ball check valve
6. Gasket
7. Clip
8. Screen
9. Fuel in
10. Balance orifice
11. Orifice gasket
12. Coupling
13. Adapter
14. Spring
15. Link
16. Drain outlet
17. O ring
18. Nut
19. Rocker lever
20. Adjusting screw
21. Push tube
22. Cam follower
23. Cam lobe
24. Injector ramp

Fig. 33-33 Relation of camshaft rotation during metering and injection: (*a*) metering, (*b*) preinjection, (c) injection, (*d*) purging. *(Cummins Engine Company, Inc.)*

Late in the intake cycle of the compression stroke, the rotating injector cam lobe allows the follower roller to move from the outer base circle onto the retraction ramp and then onto the inner base circle. At the same time the injector spring lifts the plunger and pivots the rocker lever, forcing the pushrod and the follower roller down. The plunger then passes by and thereby uncovers the metering orifice, and simultaneously the plunger blocks the return fuel flow. Fuel under pressure from the PTG fuel pump, and under throttle-shaft flow control, enters the injector adapter, flows through the balance orifice and around the ball check valve, through the metering orifice, and into the cup. The follower roller remains on the inner base circle during the compression stroke to approximately 19° before TDC (Fig. 33-33*a*). At this point the injector ramp lifts the roller. This action lifts the follower and the push tube, pivots the rocker lever, and forces the plunger downward. The downward movement of the plunger closes the metering orifices and opens the drain outlet. Fuel under pressure which was metered by the throttle, balance orifice, and metering orifice is trapped in the cup (Fig. 33-33*b*). However, the amount of metered fuel which is in the cup depends on the time the metering orifice is open (which is proportional to engine speed).

As the plunger moves downward, the fuel pressure in the cup increases until fuel is forced through the spray holes into the combustion chamber (Fig. 33-33c). Injection ends when the plunger is seated against the cup, that is, when the cam follower roller reaches the nose of the outer base circle (Fig. 33-33*d*). The plunger remains on the cup seat during the power stroke, exhaust stroke, and most of the intake stroke. The check ball is used to isolate hydraulic pulsation between the injectors and inlet manifold.

DIRECT-FUEL-FEED INJECTOR Automotive engines which are subjected to long downhill motoring or long engine brake operation may be affected with carbon buildup on the plunger. This takes place when the injector plunger is up and combustion air enters the cup. As the plunger moves downward, the air cannot escape because of the ball check and therefore fuel remains at the metering orifice. On the next metering cycle a very small amount of fuel is metered and forced into the cup and it is this fuel that causes the carbon buildup. To overcome this problem, Cummins Engine Company modified the injector barrel (see Fig. 33-34). You will notice that: (1) The metering orifice is located in the fuel-inlet side, and (2) a vent drilling is connected to the fuel drain. Consequently, the air and some fuel can now flow on the downstroke of the injector plunger, to the fuel drain, via the metering orifice and supply drilling in the barrel.

Metering Function As illustrated in Fig. 33-33, it is the position of the camshaft cam which determines when metering and injection will take place. The engine speed determines how long the metering orifice is open. The governor determines the fuel pressure in the manifold, and the throttle determines the fuel flow through the throttle's opening. The balance orifice size governs the amount of fuel that will enter the injector. It also provides a means for matching the flow for a set of injectors for a given engine so that, regardless of any difference in the machining process or metering orifice, each injector will deliver a specified amount of fuel. The balance orifice also standardizes a single-model injector body for many different engines.

The metering orifice is the last point where the fuel is metered. It is replaceable in the type C and the type B injectors, unlike the metering orifice in the type D barrel, which is fixed. In the type D injector, the fuel flow for a given set of injectors is changed through the balance orifice. Different engines, however, may require larger or smaller metering orifices; therefore, the barrel and plunger must be changed to suit the engine's application.

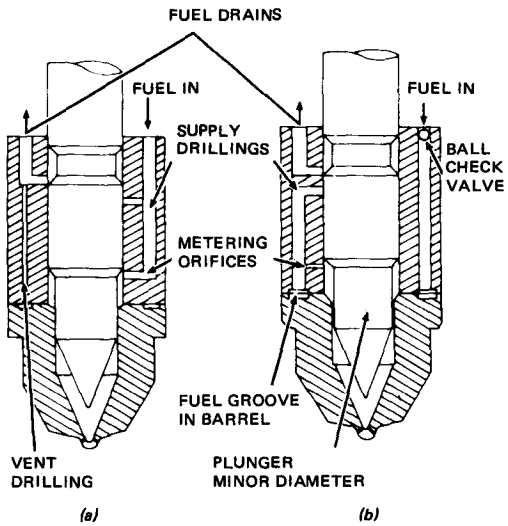


Fig. 33-34 Schematic view of (*a*) standard barrel and (*b*) direct-fuel-feed barrel.

Other Factors Affecting Metering There are other factors which affect metering and injection in addition to time, pressure, and orifice size. For instance, if the injector adjustment is incorrect, say too tight, the push tube exerts an abnormal amount of pressure on the entire injection mechanism and on the injector (Fig. 33-35). Of still more importance is the fact that the cam contacts the cam follower earlier and the plunger descends too low in the barrel, resulting in reduced metering time (reduced fuel per cycle) and early injection.

Loose adjustment has the opposite effect. It causes a loose plunger-to-cup seat, gives more time for metering (more fuel per cycle), and the cam must rotate several more degrees before it has any effect on plunger movement, resulting in late injection. The loosely seated plunger can allow hot combustion gases to enter the cup. This can cause a buildup of carbon which will reduce the size of the spray holes and the metering orifice (Fig. 33-36). Reduced spray-

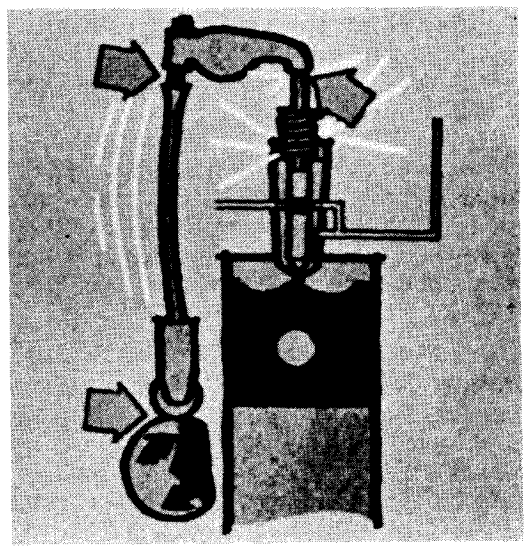


Fig. 33-35 Injector adjustment too tight. *(Cummins Engine Company, Inc.)*

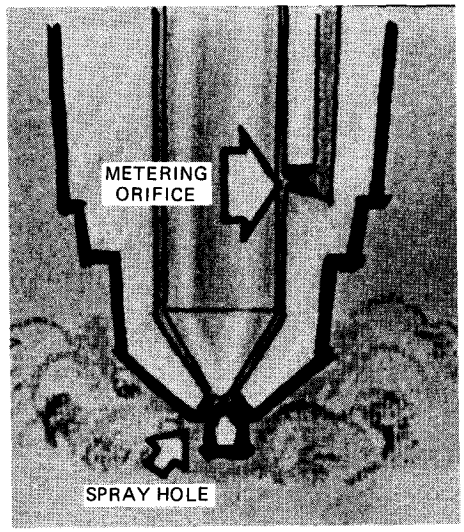


Fig. 33-36 Carbon and varnish buildup caused by loose adjustment. *(Cummins Engine Company, Inc.)*

hole size will cause early ignition and will accelerate wear of the injection mechanism. Enlarged spray-hole size increases fuel droplet size and causes early injection and incomplete combustion.

INJECTOR SERVICE

To locate a misfiring Cummins injector, remove the valve cover and run the engine at the rpm where the misfiring is most noticeable. Hold one injector at a time on its seat to prevent it from metering, and listen for a change of engine sound. If the cylinder has been misfiring, there will be *no* noticeable difference in the sound and operation of the engine. The faulty injector is then located.

To remove the injector for service, loosen the injector-adjusting-screw locknut and back out the adjusting screw. Push the rocker lever down (against the plunger spring) and swing the push tube from under the adjusting screw. Then tilt the rocker lever away from the injector. Remove the injector link, the injector hold-down bolts, and the hold-down clamp.

NOTE: Different types of hold-down clamps are used for different engine models.

To remove an injector with the hold-down clamp shown in Fig. 33-37, thread a 3/8-in 17-hex screw into the threaded clamp hole and swing the clamp from its normal position. Turn the hex bolt down to lift the injector from its seat, and then lift the injector from its bore.

Disassembling PTD Injector Some service shops recommend that the injector be given a preliminary cleaning in solvent and the injector then be tested to determine the plunger-to-barrel leakage. Others suggest disassembling the injector without testing it.

In any event, remove the plunger link and place the injector into the top stop setting fixture. Loosen the locknut and turn the top stop screw from the adapter.

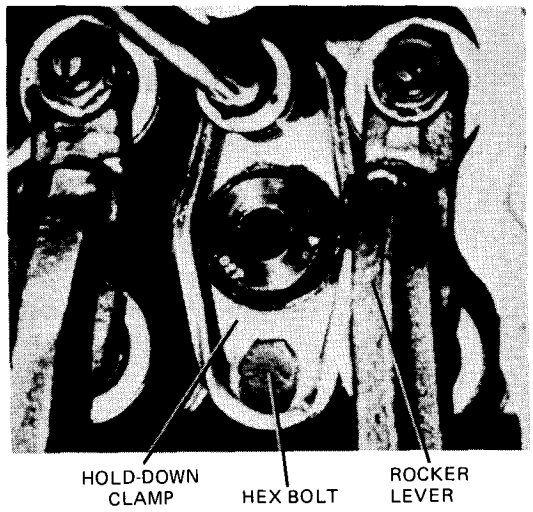


Fig. 33-37 Injector hold-down clamp. *(Cummins Engine Company, Inc.)*

Remove the injector from the fixture and lift the spring washer, spring, and plunger from the adapter. Place them upright on a clean work bench and remove the spring from the plunger. Remove the O rings and the screen retainer and screen from the adapter. Insert the injector into the loading fixture, place the special cup retainer wrench onto the retainer, and swing the holding fixture onto the flat of the adapter. Activate the air cylinder to hold the injector in place. Now loosen the cup retainer. Remove the injector from the loading fixture. Hold it upside down and remove the retainer and then the cup (Fig. 33-38). Remove the barrel from the adapter dowels and then remove the check valve ball from the barrel (Fig. 33-39).

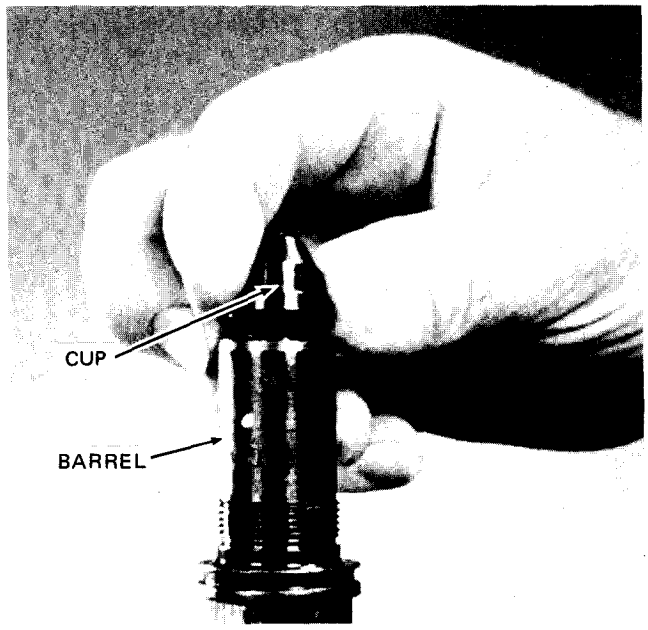


Fig. 33-38 Removing the cup by hand. *(Cummins Engine Company, Inc.)*

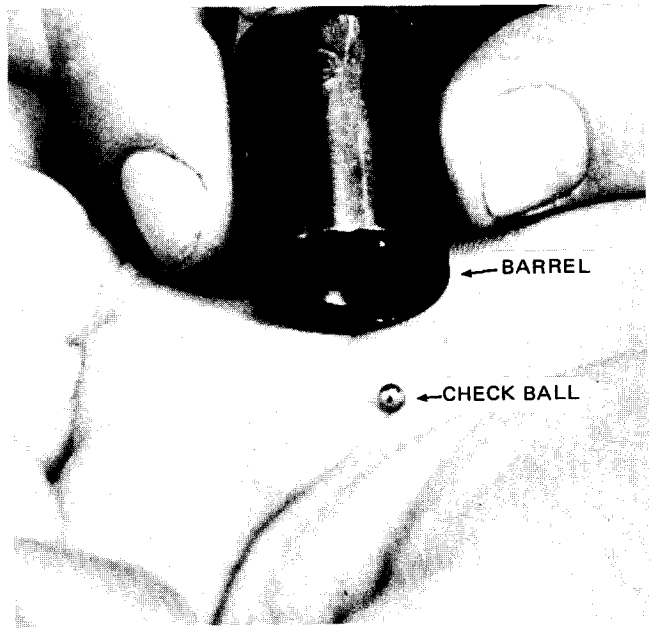


Fig. 33-39 Removing the check-valve ball from the barrel. *(Cummins Engine Company, Inc.)*

NOTE: It is usually necessary to lap both ends of the barrel, the spray-cup seat, and sometimes the adapter, before the components can be cleaned.

Clean all parts in a sonic cleaner (see Unit 49, "Shop Tools") or use a suitable cleaning tank. Some service shops additionally clean the spray cup by soaking it in Everite acid.

NOTE: Do not interchange the plunger and barrel. Always slide the barrel onto the plunger immediately after they are cleaned to prevent a mixup of parts.

Inspecting PTD Injector

PLUNGER SPRING AND LINK Check the plunger spring for excessive wear and damage. Check the squareness of the spring, measure its overall length, and test its energy on a spring tester. If either measurement is not within specification, or if the spring is bent, the spring must be replaced. Examine both ends of the plunger link for wear and damage and replace the link if either end is worn.

PLUNGER Check the plunger-to-coupling bond for cracks and tightness of fit, as shown in Fig. 33-40. If the plunger cannot be twisted in the coupling by hand, the unit is acceptable. When there is noticeable wear or fretting on the spring contact area of the coupling flange, or the link-to-plunger coupling seat is excessively worn, the plunger and the barrel must be replaced.

Check the plunger closely for scuffed or scored surfaces. (A shiny surface at the top of the lapped plunger area or on the opposite side at the bottom of the plunger is acceptable because this is a normal result of rocker-lever thrust.) A plunger can be reused if no surface damage is visible and if the plunger seat continuously covers 40 percent of the cup seating area. However, the injector must pass the injector leakage test.

BARREL Check the barrel surface at both ends for flatness. If necessary, lap the surfaces. With a strong magnifying glass, check the fuel passages and orifices for damage and wear. If the metering orifice is damaged, the plunger and barrel must be replaced. Shine a light into the barrel and check for evidence of metal seizure or unusual wear (Fig. 33-41). Make certain you check the check-valve ball seat and plugs for tightness. When necessary, lap the check-valve ball seat.

SPRAY CUP If the spray-cup holes are damaged, elongated, eroded, or heat-scored, the cup must be replaced. It must also be replaced or the plunger must be lapped to the cup if the cup seat pattern is uneven, or if it is damaged because of carbon buildup. If the cup surface at the barrel area has a broken seat pattern or burrs, lap the surface on No. 320 aluminum oxide cloth and finish it using crocus cloth.

ADAPTER AND RETAINER Visually inspect the adapter at the O-ring area for nicks and burrs and for damaged top stop and retainer threads. Check the balance orifice for damage or restriction. Make certain both fuel passages are clean.

Check the internal threads of the retainer and the cup seating flange. They must be free from corrosion, nicks and burrs. Check the outside cone area. It must be damagefree. (Imperfect cone-seat area can cause improper injector-to-sleeve sealing.)

Reassembling PTD Injector After all parts have been serviced and the replacement parts (or the old ones) have been checked and correspond with the injector code number, reclean them and then start the reassembly. Place the adapter spiral pin into the barrel (roll pins are no longer used), then drop the ball check valve on its barrel seat and place a new gasket onto the adapter. Make certain that all holes match. *(NOTE: Only the 5/16-in [7.94-mm] injectors require a gasket.)*

Position the adapter on the barrel. Align the spiral pins with the holes in the barrel and guide them into place. Take care not to damage the gasket (Fig. 33-42), if used. Place the cup on the barrel and screw

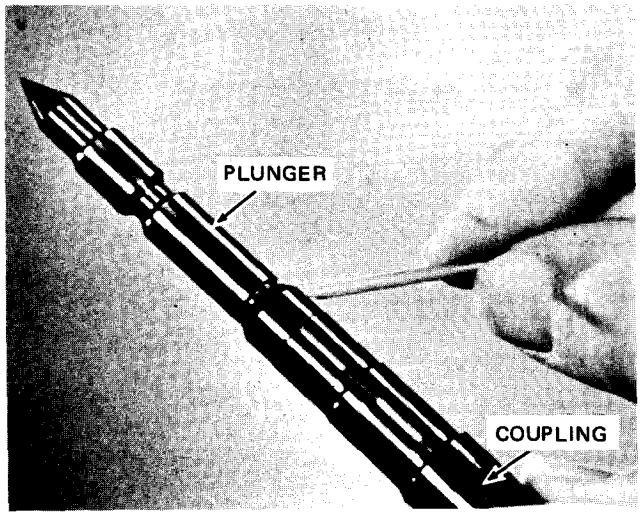


Fig. 33-40 Checking the plunger-to-coupling bond for cracks and tightness. *(Cummins Engine Company, Inc.)*

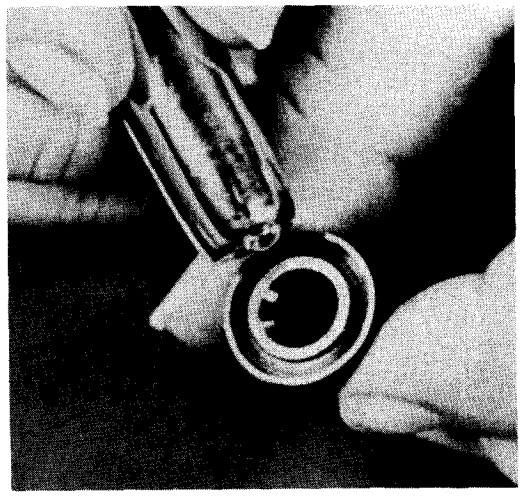


Fig. 33-41 Checking the metering orifice and cup seating area using a flashlight. *(Cummins Engine Company, Inc.)*

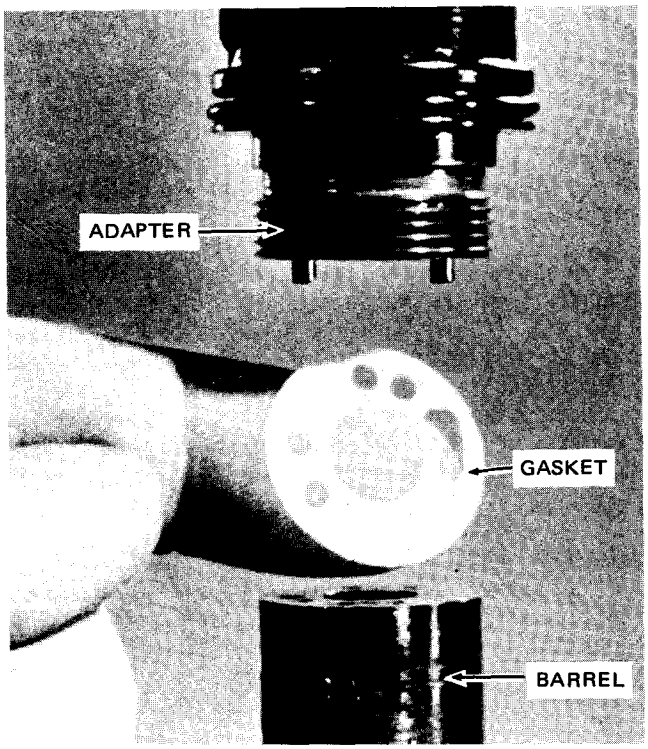


Fig. 33-42 Assembling the barrel to the adapter. *(Cummins Engine Company, Inc.)*

the well-lubricated retainer fingertight to the adapter, and then loosen the retainer about one-quarter turn. Immerse the injector plunger in test oil and slide it into the barrel (without the spring). Install the assembly into the holding fixture as shown in Fig. 33-43. Torque the adjusting stud to specification or activate the air cylinder. This installation procedure ensures plunger-to-cup alignment. Use a crowfoot wrench, installed to the torque wrench, to tighten the retainer to the specified torque.

To check plunger-to-cup alignment, remove the injector from the loading fixture, remove the plunger, and dip the plunger in clean fuel. Hold the injector vertically and allow a few drops of fuel into the barrel. Insert the plunger about ½ in [12.7 mm] into the barrel, and then quickly force the plunger firmly against the cup seat (Fig. 33-44). Turn the injector upside down (cup up). The plunger should be free enough to drop out because of its own weight or when the injector is lifted quickly. If the plunger does not slide out, repeat the test. Should it once more fail to drop out, the injector must be checked on a plunger-sticking checking tool. This tool measures the effort required to rotate the plunger within the injector assembly. If the plunger also fails this test (or if this test tool is not available), the injector must be disassembled, reassembled, and retested.

After successful test results, remove the plunger, and install the spring retainer, spring, and plunger into the adapter. Install the new O rings into the proper grooves and the new fuel-inlet screen and retainer clip.

Plunger-to-barrel and Plunger-to-cup Leakage Tests Install the injector to the plunger-to-barrel leakage tester in the manner recommended in the *Cummins* manual *Service Rebuilding and Calibration Instructions.* For example, install the injector into the adapter so that you can see the balance orifice alignment through the burnishing tool hole. Then install and tighten the locating screw. Install and tighten the plug into the inlet of the adapter pot. Connect the pressure line to the drain passage of the adapter pot.

Select the specified spacer and place it on the adapter. Position the extension tool on the plunger coupling. Then place the assembly in the leakage tester to perform the barrel-to-plunger leakage test and then the plunger-to-cup leakage test. *(NOTE: If the plunger-to-barrel leakage exceeds specification, the assembly must be replaced. If the plunger-to-cup leakage exceeds specification, the injector must be disassembled and the plunger lapped to the cup.)*

Check-valve Leakage Test If the plunger-to-barrel leakage is within specification, the ball check valve must then be checked for leakage. To make this test, connect the pressure line to the drain passage of the adapter pot. Remove the plug from the inlet, hold the assembly vertically, and press the plunger firmly onto its seat. Apply about 150 psi [1034.2 kPa] pressure to the injector. At this pressure no fuel should leak from the balance orifice.

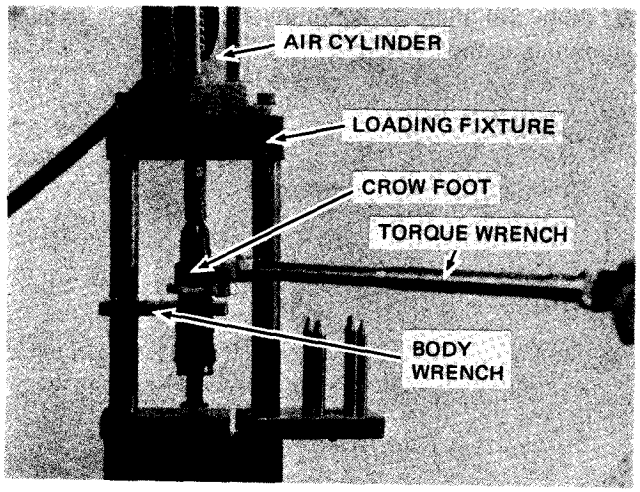


Fig. 33-43 Torquing the cup retainer.

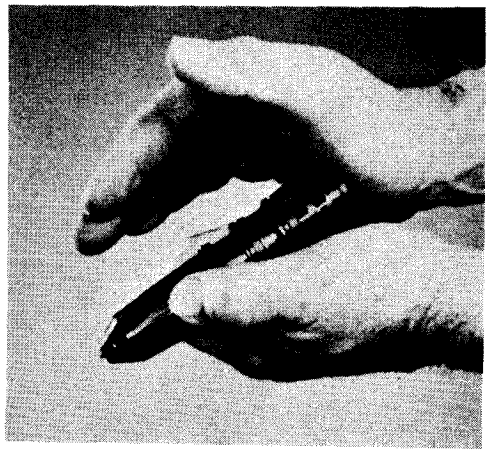


Fig. 33-44 Preparing to make a plunger drop test. *(Cummins Engine Company, Inc.)*

Spray-pattern Test When an injector has passed each of the above tests, remove the plunger and spring assembly from the injector and plug the plunger bore with the correct size plug. (Make certain the plunger is protected from dirt or damage when removed.)

Select the correct seat spacer (according to the cup and specified seat) to obtain the correct spray angle. Then remove the plug and install the adapter to the spray-pattern tester (Fig. 33-45). Next, select a target ring that corresponds with the spray-cup holes. Pressurize the adapter according to recommendations in the shop manual since this pressure varies with orifice size. Rotate the target ring so that one injection stream obviously hits the center of the No. 1 (enlarged) window. Closely check each of the other injection streams. Their spray must be confined to the inside of the window.

NOTE: The spray pattern (the cup) is acceptable if no more than one injection stream exceeds its target by the area of the No. 1 (enlarged) window.

CAUTION When forcing fuel from the spray-cup holes, be sure to keep hands and body out of the spray stream to prevent injury.

After the spray-pattern test has been made, remove the adapter from the tester. Make certain the plunger is clean before you slide the plunger (with its spring) into the injector body.

Calibrating and Testing PTD Top Stop Injector Before you install the injector to the calibrating test stand (Fig. 33-46), make certain that the test fuel meets the Cummins' specification, that the fuel level is as specified, and that the correct cam is installed.

Calibrating Test Stand Index the timing marks to bring the cam in TDC position. Make sure that adequate air is supplied to the test stand. Place the load cell in the test stand (open the air valve to clamp it in place).

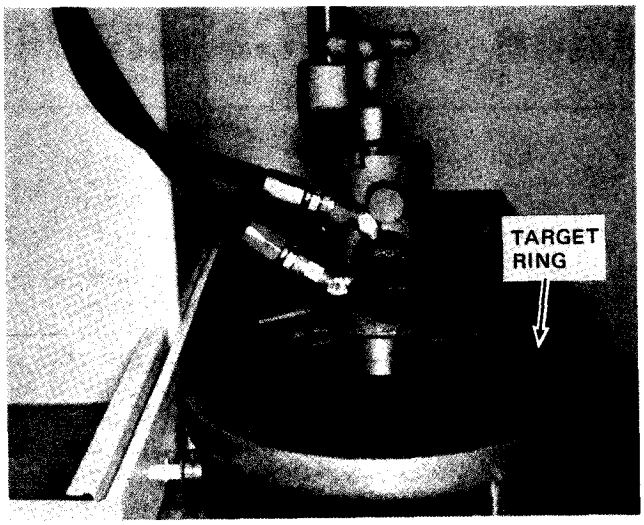


Fig. 33-45 Checking the spray pattern on an injector spray tester. *(Cummins Engine Company, Inc.)*

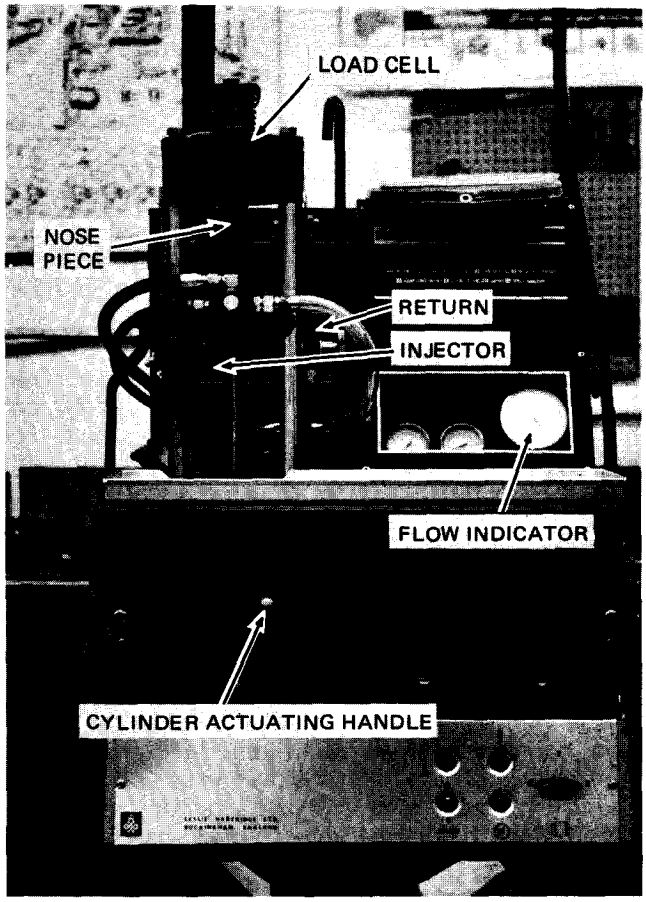


Fig. 33-46 View of calibrating test stand.

NOTE: Check the shop manual to determine if an orifice is required in the nose piece.

Adjust the air pressure until the load cell dial is within the marked black band, that is, 380 psi + 10 psi [2620.1 kPa + 68.9 kPa], then lock the adjusting screw with the locknut.

Calibrating Test Stand with Master Injector Select the recommended test-stand adapter, position the master injector and lock it in place with the set screw. Fit the specified orifice into the nose piece. Select the specified stem extension and place it on the injector link. Open the air valve to clamp the injector in place. Make certain the injector link and the extension are positioned properly before you switch on the test-stand motor. Shortly after the motor is switched on, you should hear the injection and see fuel in the drain line. At this time, adjust the fuel pressure to 120 psi [827.4 kPa] and set the counter to 1000 strokes. When the test fuel temperature is about 90°F [32.2°C], press the counter button to record the fuel delivery. Read the fuel delivery. Then dump the fuel from the vial and repeat the test several times to assure constant delivery. If, for example, the delivery of the master injector is 2 mm^3 less than specified [132 mm^3], do not change the fuel pressure. Instead, increase the counter setting to come within the fuel delivery. A change of seven to eight strokes on the counter setting varies the delivery by 1 mm^3.

Repeat the test and adjust the counter as necessary to obtain 132-mm^3 delivery at a pressure of 120 psi

[827.4 kPa]. Make three delivery tests. Reclamp the master injector, and then make three more delivery tests to assure maximum accuracy of test-stand adjustment.

Flow-testing PTD Injector Flow-testing an injector means to compare its performance and make any necessary adjustments to reconcile the performance with that of the master injector. Master injectors are precisely calibrated on Hartridge equipment at the factory, by the Cummins Engine Company. Do not misuse your master injector.

When flow-testing a PTD injector, select the correct adapter and stem extension. Fit the specified orifice into the test-stand nose piece. Install and clamp the injector to the test stand. Mount the burnishing tool to the carrier block. *[NOTE: Check the test-stand instructions in regard to fuel pressure and the stroke percentage (indicated by a letter on the plunger coupling).]* Run through a test cycle and check the delivery against the test specification. If the delivery is too high, install a smaller balance orifice. If the delivery is too low, turn the burnishing tool knob until you can feel the needle enter the orifice. Lock the needle shaft to the large knob by turning the small knob counterclockwise, then turn the large knob clockwise until you feel positive contact. Continue turning the large knob clockwise according to the amount to be burnished (refer to your shop manual). (See Fig. 33-47.)

NOTE: Take extreme care during the first burnishing operation because the initial reading may be false due to foreign matter or slight burrs in the balance orifice. Then remove the burnishing tool and run through a test cycle to check your fuel delivery.

Top Stop Injector Setting When the injector is calibrated, screw the top stop screw into the adapter and the locknut onto the top stop screw. Install the injector into the top stop fixture (Fig. 33-48), adjust the cup seat and tighten it to 100 in·lb [11.1 N·m] torque. Position the dial-indicator extension onto the plunger coupling flange and, with the handle, force

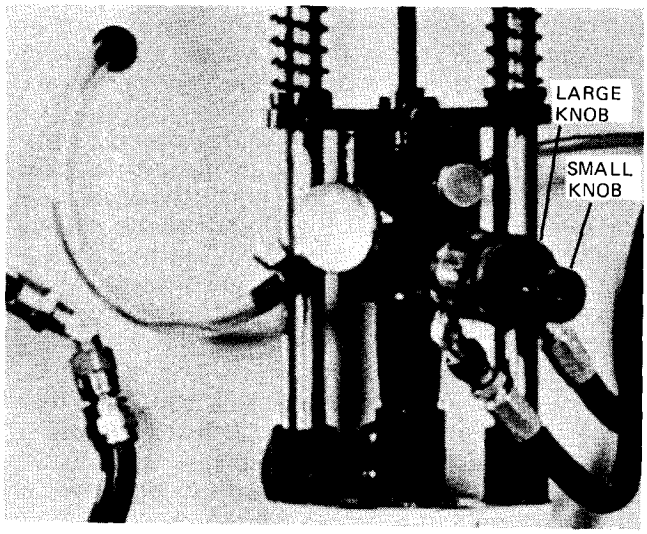


Fig. 33-47 Burnishing tool (installed). *(Cummins Engine Company, Inc.)*

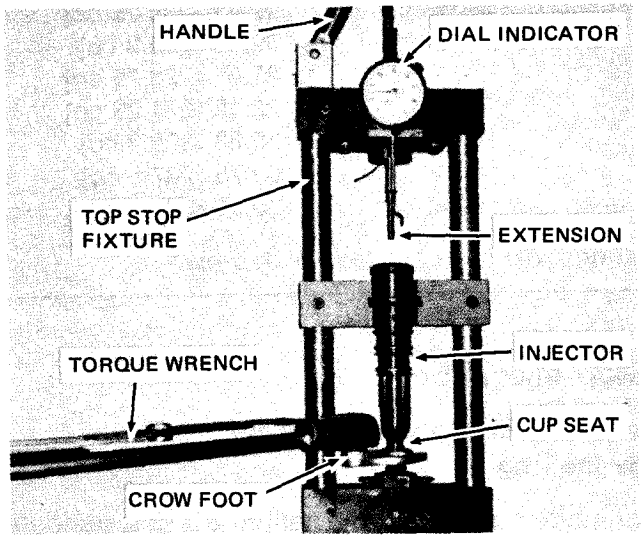


Fig. 33-48 Torquing cup seat.

the plunger onto the cup seat, then set the dial indicator at zero. Now, slowly release the force from the plunger and note the dial indicator reading. It should read, for instance, 0.222 in ± 0.0005 in [5.638 ± 0.0127 mm]. Adjust the top stop screw to achieve the specified plunger travel, and lock the adjustment with the locknut. Recheck the adjustment after the locknut is torqued to specification.

INSTALLING INJECTOR AND MAKING INJECTOR ADJUSTMENT Before you install the injector make certain that the injector sleeve is clean and that the O rings are well lubricated. *(NOTE: On K-type engines place the seal seat into position and do not use a hammer or any other tool to force the injector into the sleeve. Guide the injector into the sleeve and with a quick push, seat it against its sleeve seat. Should it fail to bottom, remove the injector and check the O ring(s) for damage. Do not force it onto its seat as this may cause O-ring damage and consequently a fuel leak.)*

When the injector hold-down bolts are torqued to specification, turn the crankshaft until the valve set mark correctly aligns with the pointer.

Tighten the injector adjusting screw until it bottoms in the push-tube socket, but make certain the adjusting screw turns freely. Tighten the injector adjusting screw about 10 in·lb [1.1 N·m] above the specified torque to force out any fuel which may be present in the cup. Loosen the adjusting screw and retorque it to specification. Then, while holding the adjusting screw, tighten the locknut (Fig. 33-49).

Injector Adjustment with Dial-indicator Method A very efficient and effective method of adjusting the injectors is with a dial indicator. It is recommended, however, only when the engine has an instructional decal or when the free plunger travel is not greater than 0.205 in [5.20 mm]. This method prevents torque errors due to thread friction and thread looseness because the injector plunger travel is premeasured. It also provides uniform beginning of injection, improved fuel economy, better emission control and, because of improved plunger seating, longer injection life.

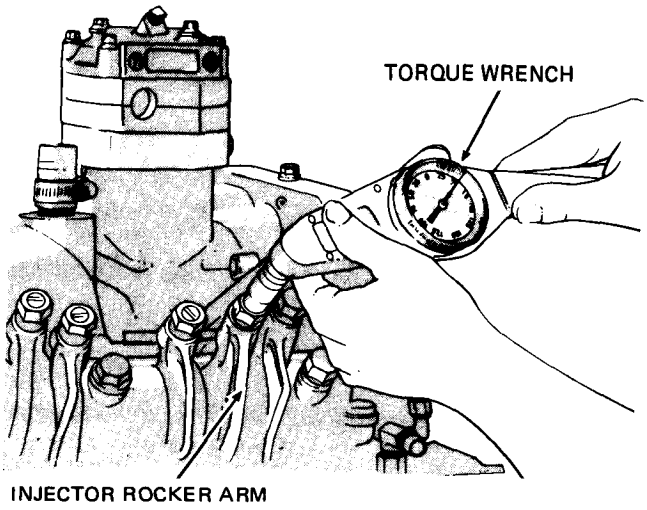


Fig. 33-49 Adjusting injector plunger. *(Cummins Engine Company, Inc.)*

CHECKING INJECTOR PLUNGER FREE TRAVEL Except as outlined above, the plunger free travel of all injectors must be measured first. To do this, install the dial indicator with the dial-indicator extension resting on the top of the plunger coupling.

Position the dial indicator so that it is at the middle of its total travel, as shown in Fig. 33-50. Loosen the injector-adjusting-screw locknut. Turn the adjusting screw 1½ turns counterclockwise and retighten the locknut. Next, turn the crankshaft and note when the dial indicator reaches its lowest and highest readings. The difference between these readings equals the total plunger travel. Check all injector plunger free travel. When all are within specification, use the dial-indicator method to adjust the injectors.

Injector Adjustment Turn the crankshaft until one of the timing marks aligns with the pointer on the cylinder block. Table 33-1 shows the old and new pulley adjustment marks and identifies which injector and valves can be adjusted when in the "A," "B," or "C" position. But remember, when the engine is at the valve set mark "A" (or "1-6" on an old engine), then Nos. 1 and 6 cylinders are 90° ATDC; Nos. 5 and 2 cylinders are 30° BTDC; and Nos. 3 and 4 cylinders are 150° BTDC. However, only one cylinder (either No. 5 or 2) is on the compression stroke, and only one injector (either No. 3 or 4) is metering. When No. 5 piston is on the compression stroke, both valves (intake and exhaust) are closed and the injector of No. 3 cylinder is metering because No. 3 cylinder follows No. 5 cylinder in the firing order.

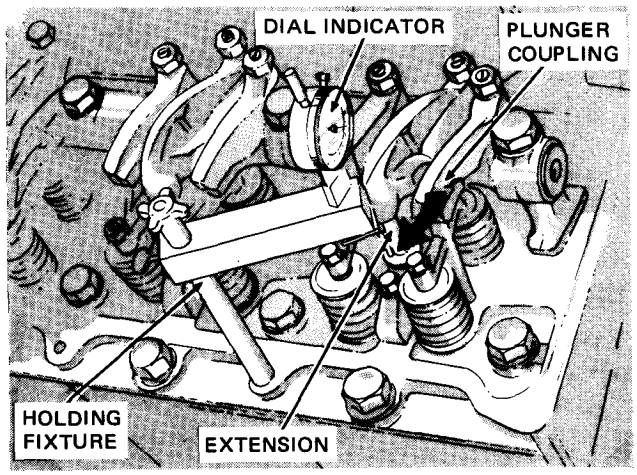


Fig. 33-50 Dial indicator installed. Extension resting on the plunger coupling.

TABLE 33-1

INJECTOR AND VALVE SET POSITION

Bar direction	In pulley position	Set injector	Cylinder valve
Start	A or 1-6 CS	3	5
Adv. to	B or 2-5 VS	6	3
Adv. to	C or 3-4 VS	2	6
Adv. to	A or 1-6 VS	4	2
Adv. to	B or 2-5 VS	1	4
Adv. to	C or 3-4 VS	5	1

Position the dial indicator as explained above, under Checking Injector Plunger Free Travel. Next, place the rocker-lever actuating tool on the injector rocker lever and, with a box-end wrench, rotate the tool to force the plunger onto its cup. This action squeezes the fuel from the cup.

Repeat this action several times but be careful when you release the force from the rocker lever not to damage the dial indicator. Again force the plunger onto its seat and hold it there while zeroing the dial indicator. (Check the zero setting several times.)

Slowly allow the plunger to rise, and read the plunger travel on the dial. When the plunger travel is not within specification, loosen the locknut and turn the adjusting screw until the specified reading is obtained. Then tighten the locknut to the specified torque.

NOTE: The locknut must be torqued to specification before you take the dial reading. The plunger travel must always be rechecked after an adjustment is made and after the locknut is torqued to specification.

Another important advantage of the dial-indicator method over the torque method is that it does not place a strain on the rocker-lever train and thus makes it possible for the intake and exhaust valves to be adjusted more accurately.

TOP STOP INJECTOR ADJUSTMENT The top stop injector is adjusted so that there is zero clearance between all injector train components. These checks and/or adjustments are made at the same timing mark when an injector adjustment is performed.

When the piston is set at its timing mark, loosen the injector-adjusting-screw locknut and tighten the adjusting screw until the backlash is removed from the injector train. Tighten the screw one additional turn to force the oil from between the clearances of the components. Next, back off the screw until the spring washer contacts the top stop screw. Now, with a torque wrench, tighten the adjusting screw to 6 in·lb [0.68 N·m] torque and lock the adjustment with the locknut. The injector link under this condition should

be barely turnable with your fingers if the zero adjustment is correct.

Mechanical Variable Timing Some Cummins engines operating in California and all NTC 475 hp engines have a mechanical variable injector timing to keep within the emission requirements. The mechanical variable timing (MVT) device consists of the components shown in Fig. 33-51. With no air applied to the piston, the engine timing is in retarded mode. If air is applied to the piston, the piston assembly and rack are forced upward. This action rotates the pinion, follower shafts, and the injector cam followers. Because the cam followers are fastened off-center (eccentric) to the shaft, they move to the right, thereby causing early cam contact with the cam followers, resulting in advance injection. To actuate all cam followers, the shafts are splined together. To control the airflow to and from the air piston with precision timing, a pressure switch is positioned in the discharge side of the fuel pump pressure line and a solenoid-operated air valve is attached to the lower part of the air cylinder housing.

When the engine is operating at 0 to 25 percent of load, the fuel pressure is low and the pressure switch is closed, energizing the solenoid. Air is then directed onto the piston, resulting in an advance injection. When the engine load increases, the fuel pressure increases in proportion, causing the switch to open. The solenoid is de-energized, the air valve is opened, and air flows through an orifice into the lower part of the MVT. The piston spring now forces the piston assembly and rack downward, rotating the cam follower shafts and cam followers to the retard position. The restrictor orifice in the return line reduces the return airflow, slowing down the cam followers' movement from the advance to the retard position.

For adjustment and/or checks of engine timing, the engine timing tool is used. For changing the injector timing only, the spacer length can be changed (see Fig. 33-51). A larger spacer increases the difference between the advance and retard position but also increases the retardation and reduces advance. A shorter spacer decreases the difference between advance and retard position and reduces retardation and increases advance.

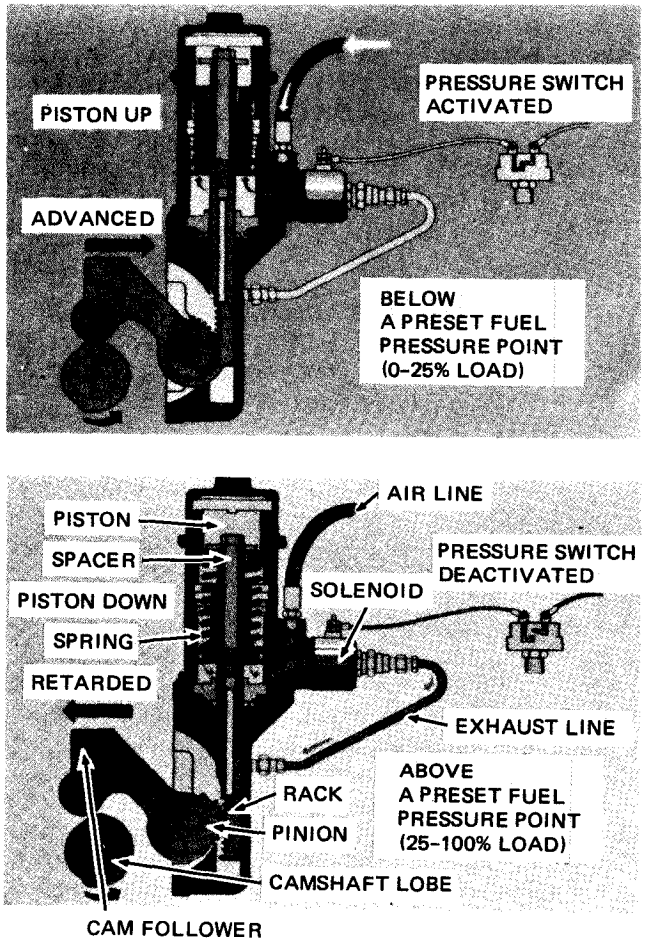


Fig. 33-51 Schematic view of mechanical variable timing (MVT).

ENGINE TIMING It is well known that precise engine timing is essential to assure rated power and proper engine performance. Engine timing is necessary after any service work has been done on the timing gears, camshafts, or followers or when the push tubes have been replaced. This is necessary because the relation between the push-tube travel and the piston travel may have changed.

To obtain precise engine timing, you must measure both the push tube and the piston travel. The timing is changed by changing the camshaft key or by altering the gasket thickness of the cam follower housing which changes the relation between the cam lobe and followers.

To check engine timing, remove the rocker housing and the injector specified in the service manual. Install the timing tool so that it rests in the injector sleeve with one dial-indicator extension resting on the piston and the other dial-indicator extension resting in the injector push tube. Tighten the timing tool, using the injector mounting bolt hole and the special holding fixture (Fig. 33-52). Then turn the crankshaft in the direction of engine rotation. Bring the piston having the installed timing tool to TDC on compression stroke (if not previously done). At the point of

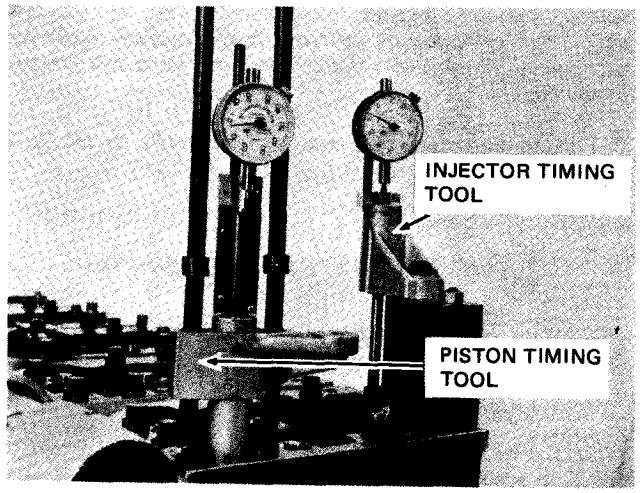


Fig. 33-52 Engine timing tools installed to a K engine.

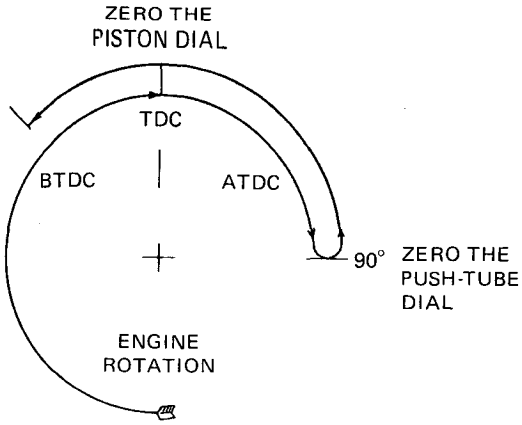


Fig. 33-53 Crankshaft rotation and position for setting the dial indicator to zero. *(Cummins Engine Company, Inc.)*

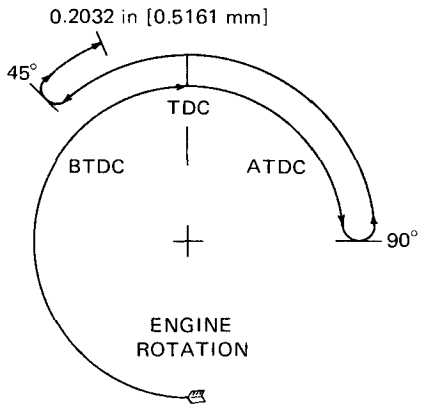


Fig. 33-54 Crankshaft rotation and position for checking injector timing. *(Cummins Engine Company, Inc.)*

maximum piston travel, zero the dial (above the piston). Continue to turn the crankshaft to the 90° ATDC position, and zero the dial indicator above the push tube (Fig. 33-53). Then turn the crankshaft 135° in the opposite direction, that is, to 45° BTDC. Again, turn the crankshaft slowly in the direction of engine rotation until the dial indicator above the piston reads the specified piston travel (Fig. 33-54).

NOTE: Both indicators should move in the same direction when the piston is on its proper stroke.

Assume you have to check the timing on a KT (A)1150 engine. The specifications for this engine are as follows:

- Piston travel: 0.2032 in [5.156 mm]
- Push-tube travel: 0.108 ± 0.002 in [2.743 mm ± 0.050 mm]

When the dial indicator above the piston reads 0.0032 in [0.0812 mm] before zero, this is actually 0.2032 in BTDC, since the indicator hand has gone around twice as the crankshaft was moved to 45° BTDC. In this position read the dial indicator above the push tube. It must be 0.108 in ± 0.002 in [2.743 mm ± 0.050 mm]. If it is not, the camshaft key must be changed or a gasket or gaskets must be added or removed from between the cam follower housing and cylinder block.

If the push-tube travel is greater, the engine timing is retarded, and if it is lower, the timing is advanced. Add gaskets to advance timing, and remove them to retard the timing. *(NOTE: The timing procedure must be performed on each cylinder head.)*

Questions

1. List the major differences between the PT fuel-injection system and a helix-metering system in regard to their injection principles and their metering principles.
2. List the components which control the fuel pressure in a PTG fuel pump.
3. Which component controls the engine speed between the idle and high idle (limiting-speed governor)?
4. Explain how the governor components limit the high idle and the low idle.
5. How would engine performance be affected if the throttle shaft were worn or if the throttle shaft O ring allowed air into the fuel pump?
6. How would engine performance be affected if the gear pump were worn?
7. Which components must be adjusted to alter the cutoff rpm? (Assume the fuel pump is on the test stand.)
8. How would engine performance be affected if the throttle leakage were lower than specified?
9. Explain how to adjust throttle leakage.
10. When decreasing manifold pressure by less than 10 psi, why should you *not* use the rear throttle screw?
11. List the major differences between PTD injector and an American Bosch injector.
12. List the differences between a PTD injector and a PTC injector. What advantages, if any, has the PTD injector over the PTC injector?
13. Outline the fuel flow through a PTD injector when metering, and after injection has ended.
14. List four factors which govern the quantity of fuel which enters the spray cup?
15. Which components in the PTD injector are used to change the fuel metering?
16. Outline in detail the injector installation procedure.
17. Outline the torque method and the dial/indicator method to adjust an injector.
18. When using the dial-indicator method to adjust the injector (say of No. 1 cylinder), in what position is the No. 1 piston?
19. If an injector had been adjusted too loosely, how would engine performance be affected and how would the injector unit be affected?
20. What advantage, or advantages, has the top stop injector over a PTD injector?

UNIT 34 - STANADYNE DIESEL SYSTEMS' AND DPA DISTRIBUTOR-TYPE FUEL-INJECTION PUMPS

The Stanadyne, Inc., (formerly Roosa Master) diesel systems' and the CAV Limited, London, or DPA, distributor-type injection pumps are described as "opposed plunger, inlet-metering distributor-type pumps." They use only one metering valve to meter the fuel, either two or four opposed plungers to pump the fuel, and only one component, the distributor rotor, to distribute the metered fuel out through the hydraulic head to the engine. The distributor pumps are of the variable-beginning and constant-ending type for delivery and have a fuel-delivery capacity for installation on engines of 10 to 40 hp [18.7 to 30 kW] per cylinder.

Although the distributor-type injection pumps of these two companies operate on the same principle, there are differences in component construction in governor design, in accessories used, and minor differences between pump models.

The nameplates on the Stanadyne diesel systems' and DPA distributor-type injection pumps, as with other pumps, contain abbreviated information required for servicing. For example, a Stanadyne diesel system DM nameplate may be designated "DM 2 6 33 JN 2580." These letters and figures correlate with the pump series, plungers, cylinders, etc., as follows:

1. DM—M model of D series (distributor) pump
2. 2—Number of plungers (two- or four-plunger version)
3. 6—Number of cylinders (two, three, four, six, or eight)
4. 33—Abbreviation of plunger size from 25 (0.250 in) to 39 (0.390 in) [6.35 to 9.91 mm]
5. JN—Accesory code; special accesories added such as aneroid, electrical shutoff, etc.
6. 2580—Specification number used for parts and test specification

Components and Their Function Stanadyne diesel systems' and DPA distributor-type injection pumps are shown in Figs. 34-1 and 34-2. Although these pumps differ externally, a careful comparison of the pictures will reveal that the working components (metering valves, head, rotors, and governors) are similar. An exception is the DPA injection pump which uses a hydraulic governor. (CAV no longer produces this type of governor.)

Both companies use for their injection pumps an aluminum-alloy housing which contains the following major operating components: drive shaft, distributor rotor, transfer-pump blades, pumping plungers, internal cam ring, hydraulic head, end plate, transfer pump, pressure regulator assembly, governor, automatic advance, and metering valve.

DRIVE SHAFT The drive shaft, supported by a bushing or ball bearing, engages with the distributor rotor through a tang or through splines. The drive shaft oil seals are not always identical in design and are not always located in the same position. Nevertheless, the lip of the forward seal faces forward to prevent engine oil from entering the pump. The rear seal lip faces the pump and retains fuel.

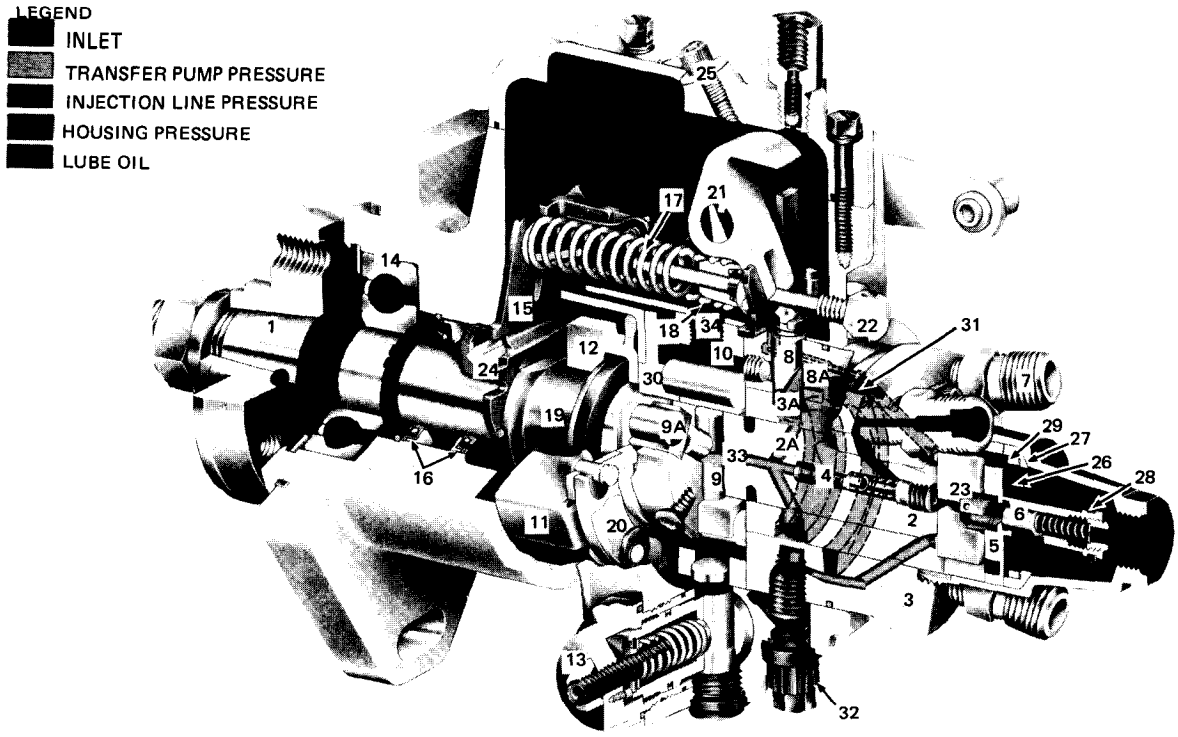
DISTRIBUTOR ROTOR The distributor rotor is lapfitted to the hydraulic head and the governor weight retainer assembly is fastened to its drive end (Fig. 34-3). Also in the drive end are two pumping plungers (or two sets of pumping plungers) which move in opposite directions within a tranverse bore. The outer end of each plunger rests against a guide shoe which is guided in the rotor slots. A roller rests in each guide shoe to reduce friction and side thrust. The outward movement of the roller shoes is limited by a leaf spring or, when four plungers are used, by two leaf springs (Stanadyne diesel systems' fuel-injection pumps) or by the adjusting plate (CAV fuel-injection pumps). A radial passage or passages in the rotor connects the pumping chamber with the radial hole or with a number of holes (equal to the number of cylinders) and with the charging passage and ports in the hydraulic head. *(NOTE: The pumping chamber is actually the space between the two or four pumping plungers.)*

A center-drilled passage from the pumping chamber leads to the discharge port. Stanadyne diesel systems' and some DPA fuel-injection pumps have a delivery valve within this passage (Fig. 34-1).

On the other end of the distributor rotor, vane slots are machined for the transfer-pump blades of the positive displacement vane-type pump. On some DPA pumps, the transfer-pump rotor is threaded into the distributor rotor.

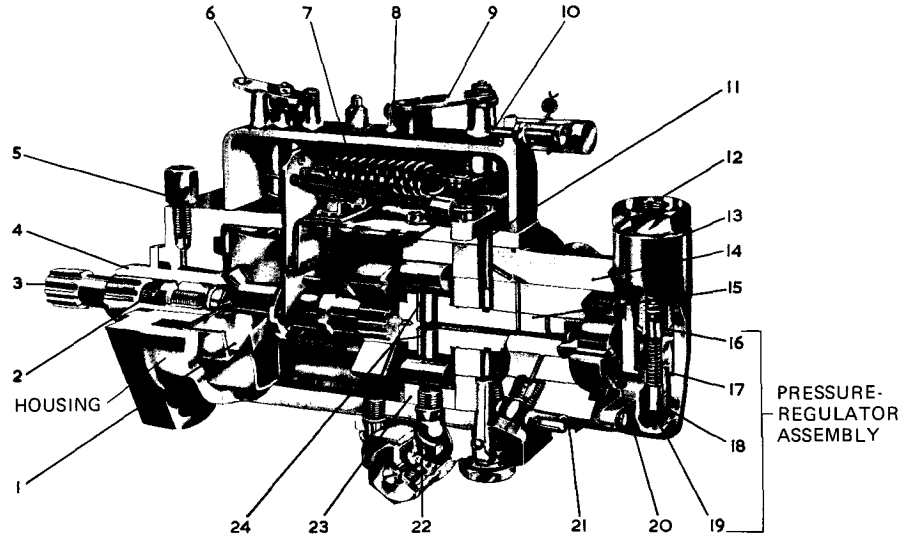
CAM RING The circular (cam) ring surrounds the base of the rotor and is located over the shoes and rollers. The number of internal cam lobes always coincides with the number of cylinders regardless of the number of pumping plungers. The cam ring performs two tasks: (1) It simultaneously forces the plungers toward each other to cause fuel to be pumped, and (2) it can be rotated back and forth about the rotor to vary the beginning of inward movement of the plungers (beginning of injection).

HYDRAULIC HEAD The hydraulic head is machined with bores and passages which allow fuel to flow to and from a specific point, that is, from the transfer pump to the metering valve, from the metering valve



1. Drive shaft
2. Distributor rotor
2A. Indexed charging ports
3. Hydraulic head
3A. Metering valve helix
4. Delivery valve
5. Regulator assembly
6. Pressure regulator
7. Discharge fitting
8. Metering valve
8A. Fuel inlet
9. Pumping plungers
9A. Roller and shoe
10. Internal cam ring
11. Governor
12. Governor weights
13. Advance
14. Drive shaft bearing or bushing
15. Governor arm
16. Seals
17. Governor spring
18. Idle spring
19. Sleeve
20. Governor retainer assembly
21. Throttle shaft lever
22. Guide stud
23. Transfer-pump blades
24. Governor-arm pivot shaft
25. High-idle adjusting screw (not shown)
26. Screen retainer ring
27. End cap
28. Screen
29. Pressure plate
30. Right-hand retainer hub
31. Air vent passage
32. Head locating screw
33. Pumping chamber
34. Housing

Fig. 34-1 Sectional view of a Stanadyne diesel systems' DM-type fuel-injection pump. *(Stanadyne Diesel Systems.)*



1. Governor weights
2. Drive-hub securing screw
3. Drive shaft
4. Drive hub
5. Back lead connection
6. Shutoff lever
7. Governor spring
8. Idle stop
9. Control lever
10. Maximum-speed stop
11. Metering valve
12. Fuel inlet
13. End-plate assembly
14. Hydraulic head
15. Distributor rotor
16. Nylon filter
17. Regulating valve sleeve
18. Regulating piston
19. Priming spring
20. Transfer pump
21. To injector
22. Automatic advance
23. Internal cam ring
24. Pumping plungers

Fig. 34-2 Main components of a DPA fuel-injection pump. *(CAV Limited.)*

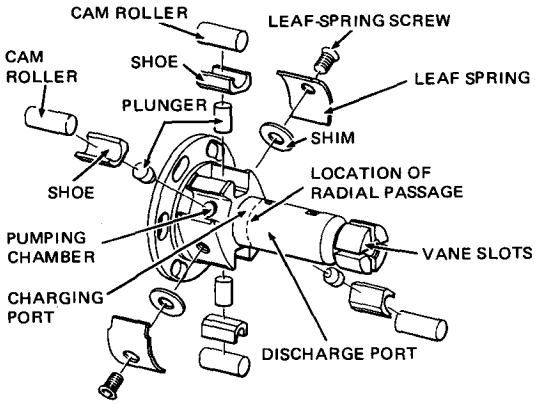


Fig. 34-3 Rotor assembly (Stanadyne diesel systems' DM4). *(Stanadyne Diesel Systems.)*

to the charging ports, from the discharging ports to the discharge fittings, and from the metering valve to the automatic advance (or the transfer pump to the advance). (See Figs. 34-1 and 34-2.)

END PLATE The end plate of the DPA, DB, or DC Stanadyne diesel systems' injection pumps absorbs the end thrust. It is the housing for the pressure regulator and covers the rear of the rotor and the hydraulic head (Fig. 34-2). The end-plate design and the pressure regulator components' design vary among companies and models. On the DM and DB2 (Fig. 34-8), the end thrust is taken by the face of the pressure regulator assembly, pressure plate, and rotor retainers.

AUTOMATIC ADVANCE Although automatic advance components vary somewhat in design, all models use fuel pressure to move the piston and the advance pin, and thereby the cam ring (Figs. 34-4 and 34-17). Fuel to the advance piston comes from the metering valve or directly from the transfer pump, depending on pump model.

GOVERNORS The governor weight retainer may be permanently fixed to the rotor drive end, or may be splined through a tang slot, or it may be splined or bolted to the rotor drive end. The weight retainer may be of solid composition or it may utilize a cushioning device so as to isolate engine vibration and pulsation entering the pump via the drive shaft from affecting the fuel metering mechanism (Fig. 34-5).

The weights are slide-fitted in the weight retainer pocket and are shaped to pivot on the outer edge. The weights are fitted in the thrust sleeve through their machined grooves.

One end of the governor control arm rests against the thrust sleeve and the other end is connected to the governor spring and to the metering valve through a linkage hook. The control lever is connected to the shutoff lever and the fulcrum lever is connected to the governor spring (Fig. 34-14).

Fuel Flow (Tank and Transfer Pump) When the drive shaft rotates, the transfer-pump blades in the slots of the rotor rotate within the liner (Fig. 34-6*a*). The liner is eccentric from the axis of the rotor and the rotation of the blade increases the volume

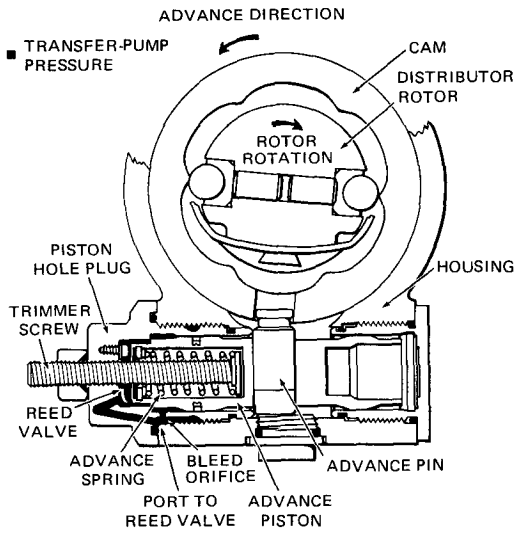


Fig. 34-4 Sectional view of the automatic advance. *(Stanadyne Diesel Systems.)*

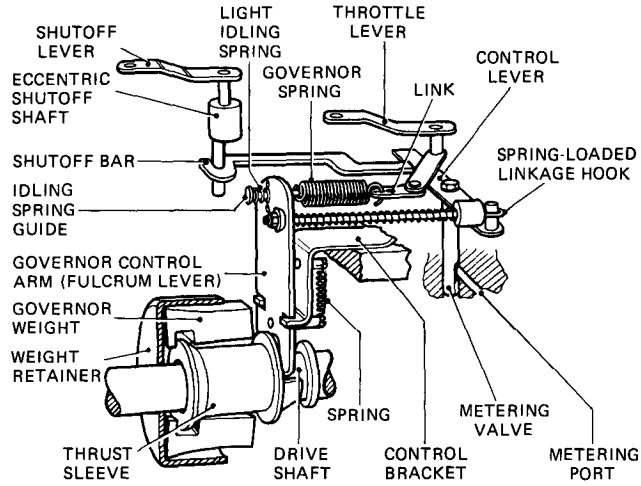


Fig. 34-5 Governor components of a DPA fuel-injection pump. *(CAV Limited.)*

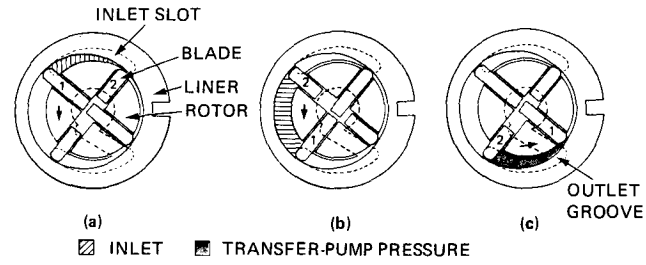


Fig. 34-6 Schematic illustration of transfer-pump operation (model DM): (*a*) beginning of charging, (*b*) maximum charge, (*c*) discharging. *(Stanadyne Diesel Systems.)*

between the blades and the liner, creating a low pressure (Fig. 34-6*b*). Atmospheric or supply pump pressure forces fuel from the tank through the filters, through the inlet filter screen, and around the pressure regulator assembly to the inlet side of the transfer pump. As the blades are forced to retract (through the liner), the volume between the blades and the liner is reduced (Fig. 34-6*c*). Fuel is then forced into the rotor retainer to the pressure regulator and into the passages in the hydraulic head.

The fuel flow of Stanadyne diesel systems' DM and DB2 models differs slightly. If flows through the screen and through the inlet side opening of the regulator assembly flange, into the pocket of the transfer pump. Fuel under pressure is forced past the rotor retainer and into a passage on the rotor, leading to the passage in the hydraulic head. This fuel flow arrangement thoroughly lubricates the rotor and prevents it from seizing.

Pressure Regulator Operation The pressure regulator controls the fuel pressure by maintaining a definite relationship between the fuel pressure and the engine speed. Although all pressure regulator components are not identical, their function remains the same, that is, to control maximum pressure. As the pump speed increases, it increases the amount of fuel pumped and, therefore, the fuel pressure, until its force on the piston becomes greater than the spring force, thus causing the piston to uncover the regulator slot. (Fig. 34-7). Fuel is then directed through the slot to the inlet side of the transfer pump. Should the pressure rise beyond the regulator slot's reducing capacity, the increased pressure then moves the piston still further, thus uncovering the high-pressure-relief slot (Stanadyne diesel systems' DM and DB2).

Some pressure regulators include a compensating device for fuel viscosity changes. This device is a thin plate with an orifice located in the adjusting plug. When the fuel is cold, very little fuel passes by the regulator piston and the small amount that does bypass flows through the orifice back into the inlet side of the transfer pump. Consequently, only the regulating spring force acts on the right-hand side of the regulating piston. If the fuel temperature increases, so does the leakage past the piston, thus placing an additional force on the right-hand side of the regulator piston. A greater fuel pressure, therefore, is required to open the regulator slot. Regardless of the fuel temperature, only a fixed flow passes through the orifice.

Charging and Metering (Model DM) When the engine is being cranked over or when it is running, fuel at transfer-pump pressure passes into a passage behind the transfer-pump rotor and then through a connecting passage in the hydraulic head, to the head locating screw, and to the automatic advance (Fig. 34-8), where the fuel flow is stopped. This forces the fuel into the hydraulic head passage located before the head locating screw. The passage on the rotor is connected through a restricted air vent passage to the pump housing governor compartment. This air vent passage serves two purposes: (1) It fills the injection-pump housing with fuel which is used to lubricate and to cool the injection-pump components (excessive fuel is returned to the fuel tank via the return line), and (2) when air has entered the transfer pump, it is carried off with the fuel and does not enter the charging passage in the hydraulic head.

The fuel flow of a DC or DB injection pump differs slightly in that fuel at transfer-pump pressure leaves the outlet port and flows through a passage in the hydraulic head toward the top of the head and then flows through the air vent passage into the pump-housing governor compartment.

NOTE: The transfer-pump rotors of DC, DB, or DPA pumps are not as well lubricated as those in DM and DB2 injection pumps.

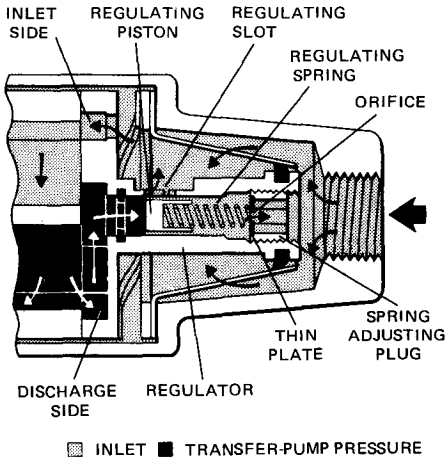
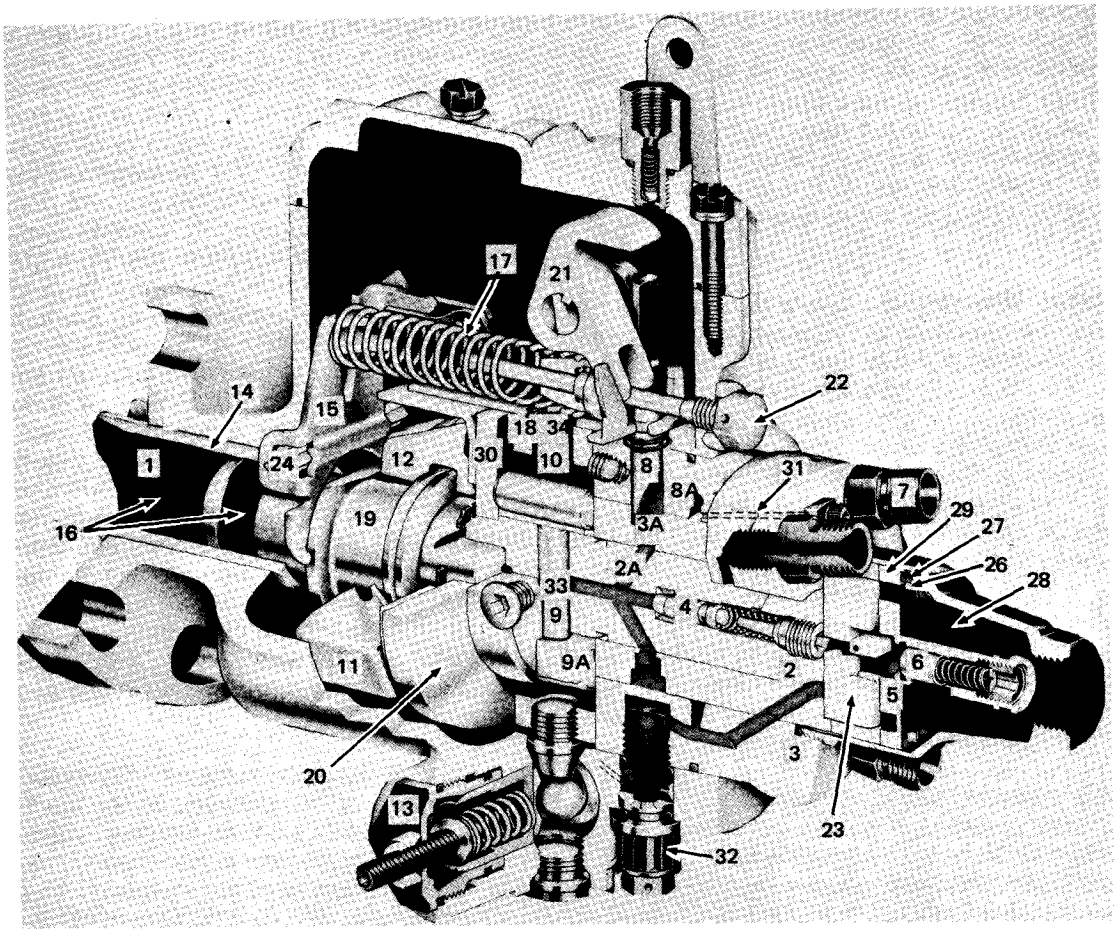


Fig. 34-7 DM pressure regulator components and fuel flow. *(Stanadyne Diesel Systems.)*

In CAV and Stanadyne diesel systems' distributor-type injection pumps, a drilled passage on the top of the hydraulic head connects with the metering valve. Engine requirements and governor action then dictate the amount of fuel that flows past the metering valve and into the charging passage. The number of charging ports in the passage equals the number of cylinders. When the two charging ports in the rotor register with two of the charging ports in the charging passage, fuel under charging pressure passes into the chamber formed by the opposed pumping plungers. The amount of fuel flow to, and therefore the outward movement of the plungers, is governed by: (1) the opening of the metering valve, (2) the time available to charge the pumping chambers, and (3) the transfer pressure. The adjustable leaf spring(s) (Stanadyne diesel systems) or the eccentric adjusting plates (DPA) limit the outward travel of the roller shoes and consequently the maximum separation of the plungers. (See Fig. 34-9.) This is what controls the maximum fuel level of the pump.

Fuel that passes into the slots or into the small grooves on the rotor (located on each side of one of the charging ports) lubricates the cam rollers and the rotor. This fuel and the fuel from the air vent fills the entire pump, lubricating the components within the pump and absorbing heat. It then returns through the housing pressure regulator (on some models) and then through the return line to the fuel tank.

Discharging (Injection) Fuel Flow As the rotor continues to revolve, the charging ports of the rotor pass out of registry with the charging port in the hydraulic head. For a very short interval fuel is trapped in the pumping chamber since the discharge port has not yet come into registry with the discharging port in the hydraulic head. Immediately before the cam rollers contact the cam lobes, the discharge ports come into registry with each other and, as the rollers force the plungers inward (toward each other),



1. Drive shaft
2. Distributor rotor
2A. Indexed charging ports
3. Hydraulic head
3A. Metering valve helix
4. Delivery valve
5. Regulator assembly
6. Pressure regulator
7. Discharge fitting
8. Metering valve
8A. Fuel inlet
9. Pumping plungers
9A. Roller and shoe
10. Internal cam ring
11. Governor
12. Governor weights
13. Advance
14. Drive shaft bearing or bushing
15. Governor arm
16. Seals
17. Governor spring
18. Idle spring
19. Sleeve
20. Governor retainer assembly
21. Throttle shaft lever
22. Guide stud
23. Transfer-pump blades
24. Governor-arm pivot shaft
25. High-idle adjusting screw
26. Screen retainer ring
27. End cap
28. Screen
29. Pressure plate
30. Right-hand retainer hub
31. Air vent passage
32. Head locating screw
33. Pumping chamber
34. Housing pressure regulator

Fig. 34-8 Sectional view of a Stanadyne diesel systems' DB2-type fuel-injection pump (charging). *(Stanadyne Diesel Systems.)*

fuel is discharged from the pumping chamber (Fig. 34-10). Some injection pumps have a delivery valve in the discharge passage while others use a cam relief (cam retraction) to reduce the pressure in the discharge line for sharp injection cutoff, to prevent secondary injection, and to prevent nozzle dribble. The cam retraction takes place just before the discharge port comes out of registry. The DPA injection-pump fuel flows from the metering valve to a single passage in the hydraulic head and then to the charging port. The number of rotor charging ports coincides with the number of cylinders in the engine (Fig. 34-11).

Delivery-valve Action The delivery valve is a check valve with a displacement plunger. It operates on the same principle as the check valve on the Caterpillar injection pump and it serves the same purpose. It pressurizes the delivery-valve spring chamber for a quicker beginning of injection (Fig. 34-12*a*) and quickly reduces the injection line pressure when the cam rollers pass the crescent of the cam and the plunger begins to move outward, ending injection (Fig. 34-12*b*).

Residual injection line pressure is achieved by the delivery valve or through the cam retraction, but it is maintained by the rotor as the discharge ports come out of registry.

Automatic Advance Action Nearly all DPA and Standadyne diesel systems' injection pumps use a simple automatic speed advance mechanism which controls movement of the cam ring. The device is hydraulic/mechanical and uses transfer pressure, which varies with speed, to move a piston against spring force. The piston is linked to the cam ring by

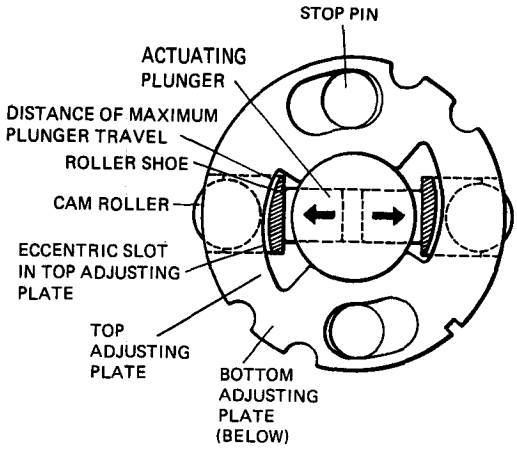


Fig. 34-9 Maximum fuel adjustment components on the rotor assembly. *(CAV Limited.)*

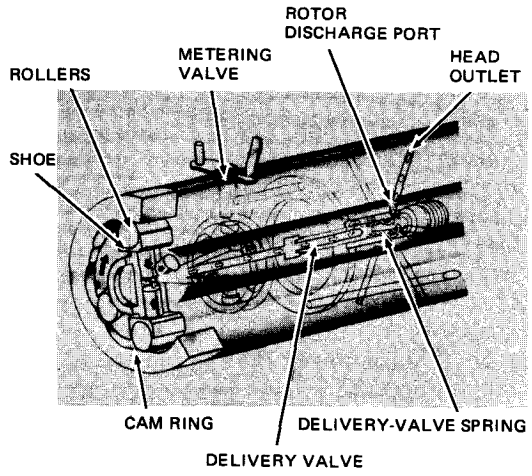


Fig. 34-10 Discharge (injection fuel flow). *(International Harvester Company.)*

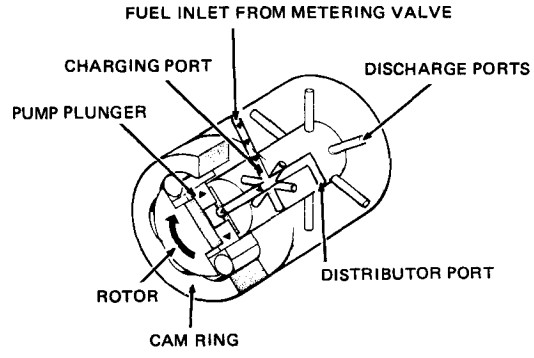


Fig. 34-11 DPA metering (or charging fuel flow).

the cam advance pin and semirotates the cam ring back and forth in the housing to advance or retard the injection cycle. (Some pumps use a combination load and speed advance.)

On DB and DC injection pumps, fuel under transfer pressure passes by the metering valve and is directed into a second passage in the head, and then to the locating screw. It then passes through a check valve and flows to the pressure side of the advance piston (Figs. 34-13 and 34-17). The fuel pressure forces the piston against the spring force and the

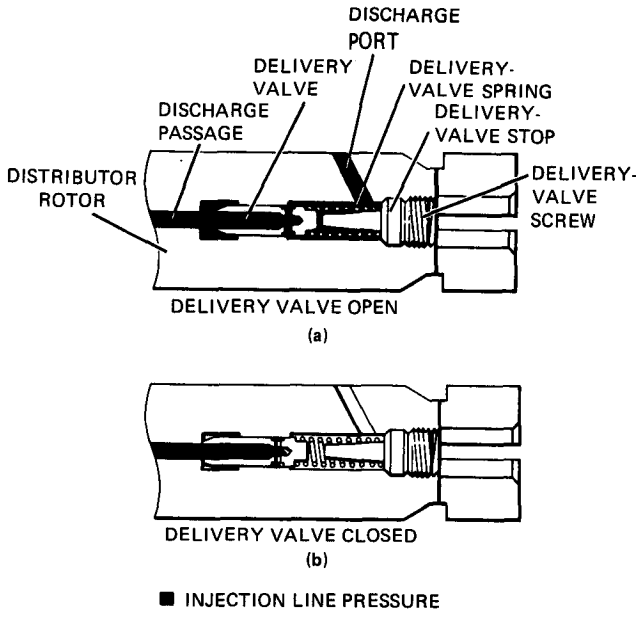


Fig. 34-12 Delivery valve position (*a*) when open and (*b*) when closed. *(Stanadyne Diesel Systems.)*

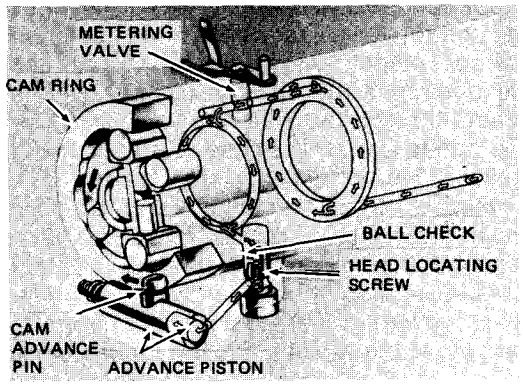


Fig. 34-13 Speed-advance operation. (The arrows show the fuel flow.) *(International Harvester Company.)*

dynamic injection loading on the cam ring, caused by the action of the rollers striking the cam ring. The cam ring then moves in the opposite direction of the rotor rotation. The check valve holds the fuel pressure in the chamber, preventing the cam ring from retarding. When the fuel pressure is reduced because of a reduction in engine speed, fuel drains from the piston area through the orifice below the ball check valve, to allow the cam ring to retard. At engine idle speed the transfer pressure is low, and the cam ring is held in the retard position by the spring and the roller force. The maximum movement of the cam ring is limited by the length of the piston or by the size of the piston hole plugs. *(NOTE: On DM and DB2 fuel-injection pumps, the transfer-pump pressure is placed directly on the advance piston.)*

Stanadyne diesel systems' and DPA injection pumps use a trimmer screw or shims to change the preload on the advance spring and thereby change the beginning of the cam ring movement.

DPA Mechanical Governor Action When the throttle lever moves to the full-fuel position, the gov-

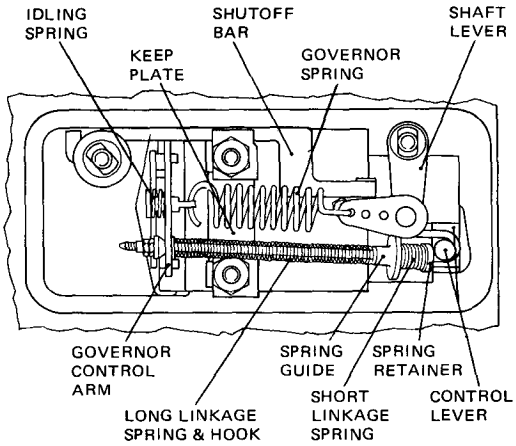


Fig. 34-14 Top view of a DPA mechanical governor. *(CAV Limited.)*

ernor spring fully compresses the idling spring, and the spring guide bottoms against the governor control arm (Figs. 34-5 and 34-14). The spring force pivots the control arm on the control bracket and forces the thrust sleeve to move, causing the governor weights to close. At the same time the governor control arm moves the spring-loaded linkage hook to the right, rotating the control lever as well as the metering valve. Governor weight (engine speed) force and spring force determine the position of the governor control arm and thereby the metering valve position. If the engine speed drops (because of added load), the flyweights move inward and the control arm moves the linkage hook, the control lever, and the metering valve. This increases fuel flow and maintains the selected engine speed. If the engine speed increases (because of decreased load), the governor weights move outward and the governor control arm pivots in the opposite direction, moving the metering valve and reducing the fuel flow. The desired engine speed is thus maintained by the reduction in fuel flow.

When the throttle shaft is in the idle position, the tension from the governor spring is removed and the light idle spring assures sensitive idle-speed control because of the low weight force. The energy of the idling spring is set through the low-idle-speed adjusting screw. The energy of the governor spring is set by the high-idle adjusting screw.

To stop the engine, you must move the shutoff lever to the no-fuel position. The rotation of the shutoff lever moves the shutoff bar and the control lever. The control lever rotates the metering valve and closes off the fuel flow. The governor actions on Stanadyne diesel systems' fuel-injection pumps would be identical except for the lever and links from the governor arm to the metering valves. (See Figs. 34-1 and 34-8.)

DPA Hydraulic Governor Action The components of a DPA hydraulic governor are shown in Figs. 34-15 and 34-16. The metering valve is lap-fitted to the hydraulic head and is center- and cross-drilled. The cross-drilled hole leads to an annulus which is in line with the metering port, and the transfer-pump pressure is always exerted onto the lower area of the metering valve. The up-and-down movement of the valve varies the area of the metering port opening and, therefore, the fuel flow to the pumping chamber. The rack or control sleeve fits loosely over the extended stem of the metering valve and within the governor housing.

When the governor is assembled as shown in Fig. 34-16, the shutoff nut and washer pressurize the idle and governor springs, and thereby position the rack or the sleeve on the metering valve stem. As the throttle moves to the full-fuel position, the throttle lever moves the rack or the sleeve to the right (Fig. 34-15), and the governor spring moves the metering

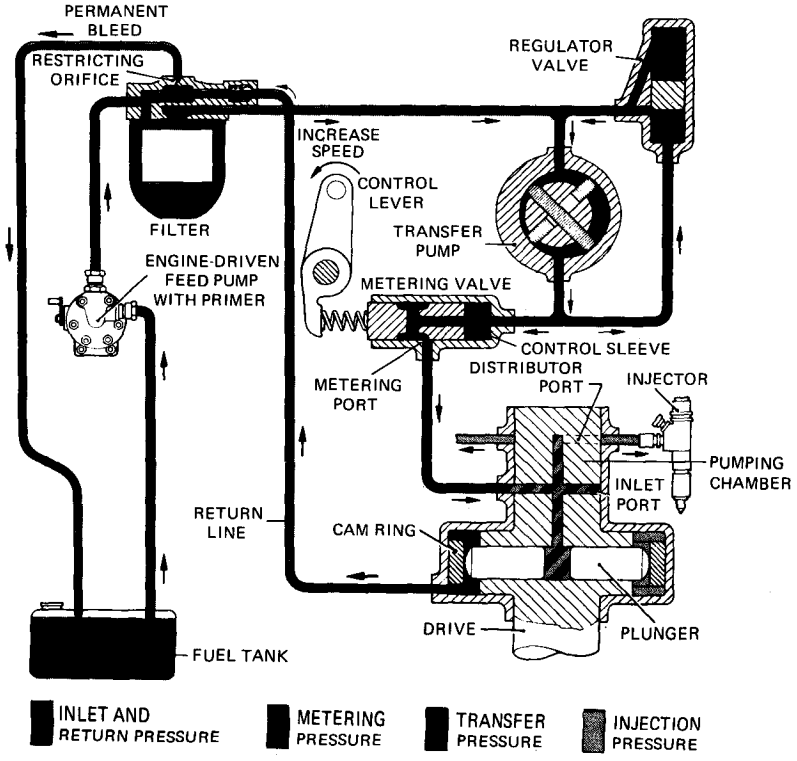


Fig. 34-15 Schematic illustration of DPA fuel-injection system having a hydraulic governor. *(CAV Limited.)*

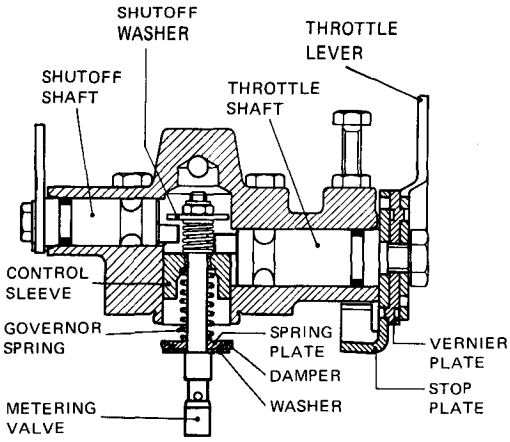


Fig. 34-16 Sectional view of a DPA hydraulic governor. *(CAV Limited.)*

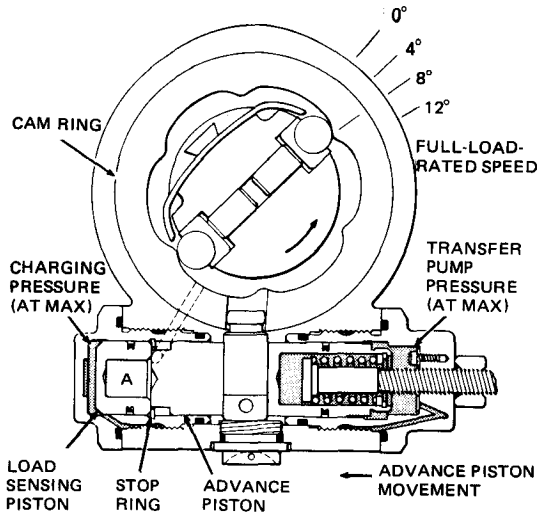


Fig. 34-17 Schematic view of speed and light-load advance. *(Stanadyne Diesel Systems.)*

valve, thus increasing the effective metering port area. As the engine speed increases, the fuel pressure increases and the metering valve is forced to the left until the force on the metering valve and the governor spring are equal. Valve movement then stops and the fuel flow through the metering port remains constant. If there is a reduction in fuel pressure (because of lower engine speed), the metering port opening increases because the spring force is stronger than the fuel pressure.

When the throttle lever is moved to the idle-speed position, it compresses the idle spring and moves the metering valve to the left. A balance is reached when both forces are equal and the fuel flow to the metering port is constant.

A change in the idling speed accordingly increases or decreases the fuel pressure. The spring force increases the metering port opening until the fuel pressure and the spring force are again equal.

Adjustment to the high- or low-idle positions is made by turning the adjusting screws clockwise or counterclockwise, respectively. This increases or decreases the spring force.

Speed and Light-load Advance To achieve a proportionate injection beginning in regard to load and speed (to ensure peak diesel engine performance), some CAV and Stanadyne diesel systems' fuel-injection-pump models are equipped with a speed- and light-load-advance mechanism. One such type of mechanism is described below. The load-sensing and advance pistons are positioned opposite the speed-advance piston (Fig. 34-17). Pressure from the charging passage is connected to the load-sensing piston (point A).

OPERATION When the engine is started, low fuel pressure is exerted onto the speed-advance piston (right-hand side), the load piston, and advance piston (left-hand side); therefore the injection pump is at its static timing, say, 0°. However, the low charging pressure has moved the load piston to the left and the advance piston to the right against the advance pin. As the engine accelerates (no load), the transfer-pump pressure increases, and the speed-advance piston, the advance pin, and the advance and load pistons move to the left, thereby moving the cam ring clockwise. At high idle, no load, the cam ring has moved, say to the 12° mark. *(NOTE: This is the point where the plunger starts to move inward and not the beginning of injection.)* With no load on the engine, the metering valve is only slightly open; therefore the charging pressure is low and the force on the load piston is less than the force on the speed-advance piston. As the engine is placed under load, the fuel flow and pressure in the charging annulus increases, and as the pressure acting on the load piston overcomes the force of the speed-advance piston, the load-sensing and advance pistons move to the right (with the load-sensing piston coming to rest against the stop ring). The advance pin and speed-advance pistons are then forced to the right, thus causing the cam ring to move counterclockwise, retarding injection to, say, 4°. You will notice (Fig. 34-17) that the cam ring is in a balanced position between the charging and transfer-pump pressure, placing the beginning of injection in position to achieve desired engine performance.

Removing Distributor-type Injection Pump from Engine Thoroughly clean the injection pump, the injectors, the fittings, and the surrounding area to prevent dirt from entering the system when the fuel and injection lines are being removed.

CAUTION Do not steam-clean the injection pump while the engine is running. The heat of the steam could damage (seize) the pump.

Crank the engine over to bring the No. 1 piston onto compression stroke and to allow the engine timing marks to coincide. Turn off the fuel supply. Remove the timing window. If the pump is correctly timed, the timing line on the cam ring will be in line with the timing line (degrees) marks on the weight retainer hub. Remove the injection lines. Take care not to bend or twist them. (See sections on removal of fuel injectors, Unit 27). Disconnect the throttle, the shutoff lever, the aneroid connection (if applicable), the fuel inlet line, and the fuel return line. Cap all the openings promptly to keep out any dirt. Remove the mount-

ing nuts and washers and carefully slide the injection pump from the drive shaft. *(NOTE: Some pump models are removed from the engine without the drive shaft, i.e., the drive shaft stays with the engine, and must be removed separately. On most new models, the drive shaft is removed and stays with the pump. Refer to engine manufacturers' instructions for particular models.)*

Servicing DPA and Stanadyne Diesel Systems' Distributor-type Injection Pumps Appropriate service details for each individual model are given in company service manuals and they should be followed closely when servicing.

Wash the injection pump with clean fuel, dry it with compressed air, and then mount it in a holding fixture. Remember that dirt is the fuel-injection pump's greatest enemy. Keep the disassembled components or parts in clean fuel until they are to be reassembled. Inspect each component or part carefully during disassembly; set aside those parts which are not reusable. (This step will speed up the reordering process.) Always discard used seals, gaskets, washers, and O rings.

Disassembling Distributor-type Injection Pump

STANADYNE DIESEL SYSTEMS' DM To disassemble a Stanadyne diesel systems' DM injection pump, first remove the cover and gasket. Then, with the special tool provided, or with a screwdriver, remove the horseshoelike shutoff cam and throttle shaft retainer. Slide out the throttle shaft assembly and throttle shaft lever from the shutoff lever (Fig. 34-18). Take note of the position of the throttle shaft key in relation to the groove on the throttle shaft assembly.

While removing the guide stud from the housing, remove the governor spring together with the idling spring, retainer, and guide (Fig. 34-19). Press down on the metering valve and raise the governor linkage hook at the metering valve end. Then disengage it from the governor arm and hang the linkage over the housing. Lift out the metering valve and spring.

To remove the governor control arm, remove one cap nut from the pivot shaft, then withdraw the shaft, and lift out the control arm.

To disassemble the transfer pump, first remove the end-cap locking screw and install a removal plug to the end cap. With a socket wrench, unscrew the end cap then remove, in sequence, the following: transfer-pump pressure plate, filter screen and retainer, transfer-pump regulator assembly, transfer-pump blades with springs, and transfer-pump liner. Note the liner and roll pin location. Disassemble the regulator by removing the plug assembly, spring piston, screen seal, and piston seal (Figs. 34-7 and 34-20).

To remove the advance mechanism and the hydraulic head, you must first remove the advance plug and end plugs. Next, lift out the advance pin. Slide out the advance components as shown in Fig. 34-21. Remove the head locating screw. When removing the hydraulic head from the housing, tilt the rear of the pump slightly downward, then remove the two head locking screws. Next, pull while swiveling the hydraulic head with both hands to release it from the

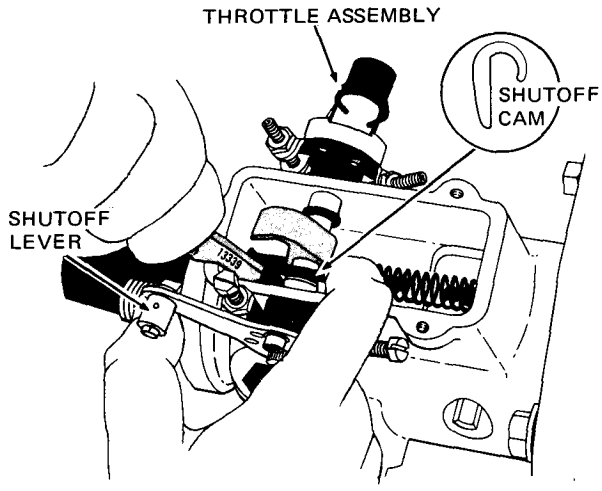


Fig. 34-18 Removing a Stanadyne diesel systems' throttle shaft lever and throttle shaft assembly. *(International Harvester Company.)*

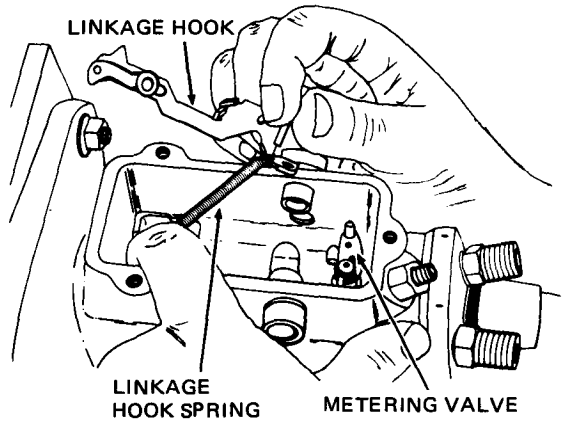


Fig. 34-19 Removing metering valve assembly. *(Stanadyne Diesel Systems.)*

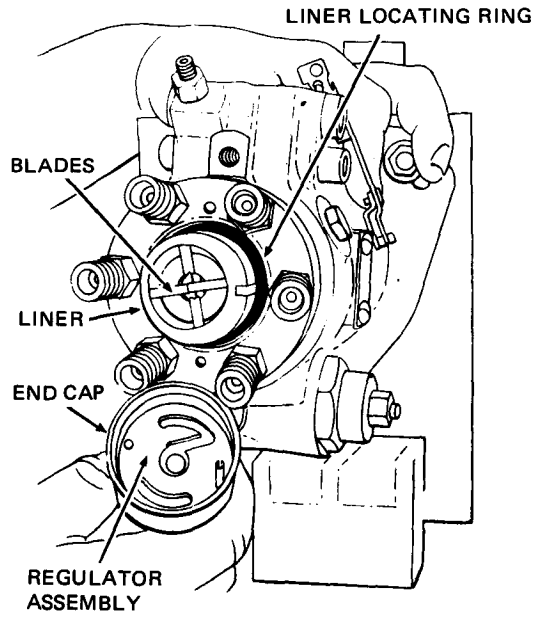


Fig. 34-20 View of components end cap is removed. *(Stanadyne Diesel Systems.)*

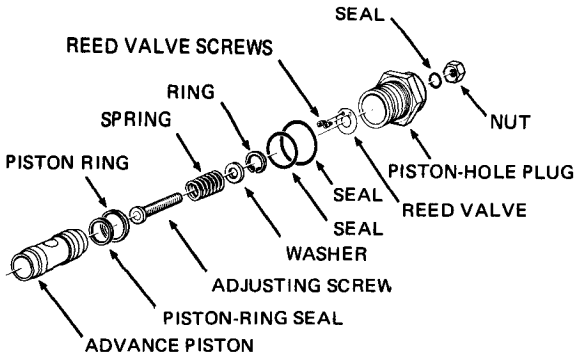


Fig. 34-21 Speed-advance components. *(Stanadyne Diesel Systems.)*

housing. Take care not to drop the weights, thrust sleeve, or washer when removing the hydraulic head from the housing.

To remove the distributor rotor from the hydraulic head, place the weight retainer on the specially designed holding fixture, remove the retaining ring, then the two retainers, and lift and hydraulic head from the rotor (Fig. 34-22*a*). Next, lift off the cam ring (Fig. 34-22*b*). Note the direction of the arrow located on the cam ring.

To remove the pumping plungers, remove the leaf spring screw(s), the leaf spring(s), the cam rollers, and the shoes. Use corks to hold the plungers in place until they are examined and cleaned. Before removing the delivery valve, you must first remove the screw plug with a hex wrench; then allow the stop and spring to fall into your hand. Remove the delivery valve with the appropriate valve-extracting tool (Fig. 34-23).

The weight retainer cage is removed from the rotor of a DM model *after* removing the retaining rings, retainer plates, and cushions (Fig. 34-1).

To remove the drive shaft from a DM model pump, use a puller arrangement and pull the drive hub (if present) from the drive shaft. Remove the retaining ring and the spring washer. Slide the drive shaft (with bearing) from the housing. If necessary remove the bearing from the drive shaft by removing the roll pin and snap ring. Press the bearing from the shafts while supporting the inner race. Next, remove the seal retainer ring and press out the two seals.

DPA To disassemble a DPA injection pump, first remove the throttle arm and shutoff lever nuts and lift the levers from the shafts. With light finger force, press the throttle shaft downward while lifting the cover from the housing. With the cover removed, press out the shutoff shaft. Disconnect the governor spring from the link and idle spring guide. Remove the governor spring, throttle shaft with link, idle spring, and guide. Remove the cover studs. Lift out (as an assembly) the control bracket, governor arm, metering valve, and linkage hook assembly.

To disassemble the speed advance, remove the piston plug, seal and piston, piston spring cap, seal, shim washers, and spring. Then remove the head locating screw, seal, and washer. Next, pry the advance housing (with piston) from the pump housing and, with a special wrench, unscrew the advance screw. Remove the four end-plate screws. Lift the end plate and thrust plate from the hydraulic head. Remove the regulator components from the end plate in the order shown from top to bottom in Fig. 34-24. Before you remove the liner and pump blades, take note of the position of the slot on the liner. To remove the transfer-pump head, note the direction in which the rotor is rotating. Loosen it in the direction of pump rotation. Use only the special wrench; otherwise the transfer-pump head may be broken.

After removing the transfer-pump head, remove the head locating screw and the vent screw assembly, and then withdraw the hydraulic head.

To remove the rollers, cam shoes, and plungers, first lift the cam ring from the rotor. Remove the drive plate bolts, drive plate, top adjusting plate, rollers, cam shoes, and the lower adjusting plate. Use cork plugs to hold the plungers in their bores.

To withdraw the weight retainer from a DPA drive shaft, first remove the drive shaft screw by holding the weight retainer in a special holding fixture. Then slide the drive shaft with its weight retainer from the pump housing. Lift the cushion-drive back plate, cushion-drive rubber insert, drive splined hub, and the weight retainer from the drive shaft (Fig. 34-25).

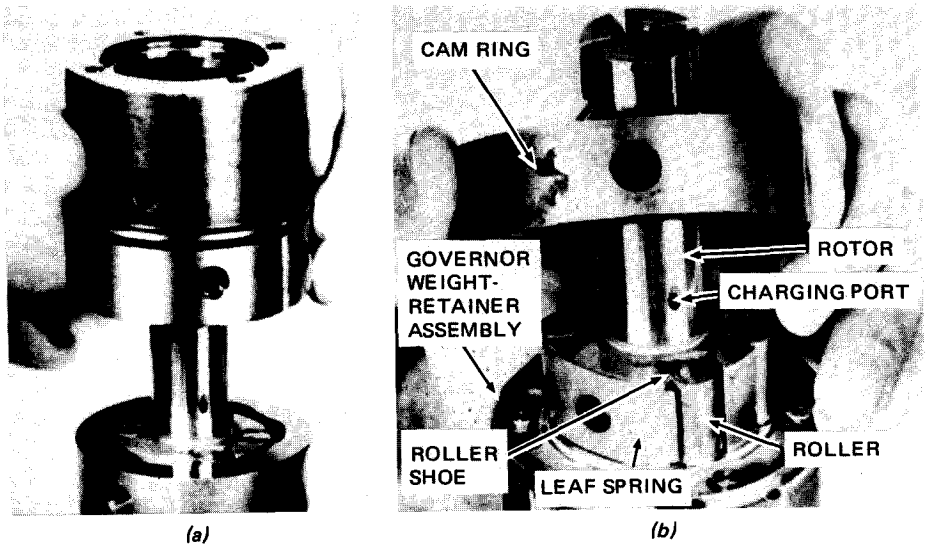


Fig. 34-22 Removing (*a*) hydraulic head and (*b*) cam ring.

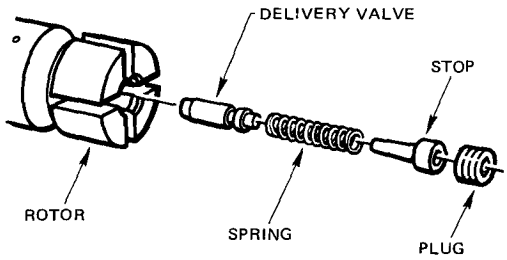


Fig. 34-23 Stanadyne diesel systems' delivery-valve components. *(Stanadyne Diesel Systems.)*

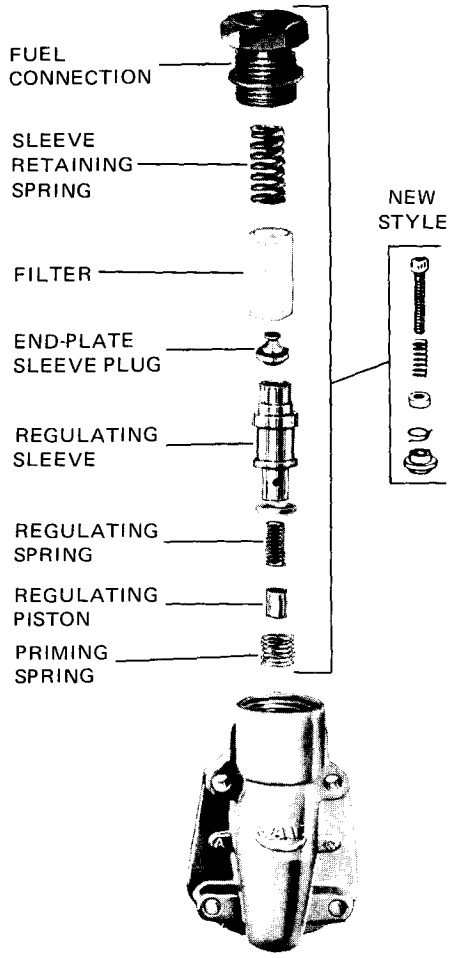


Fig. 34-24 DPA regulator components. *(CAV Limited.)*

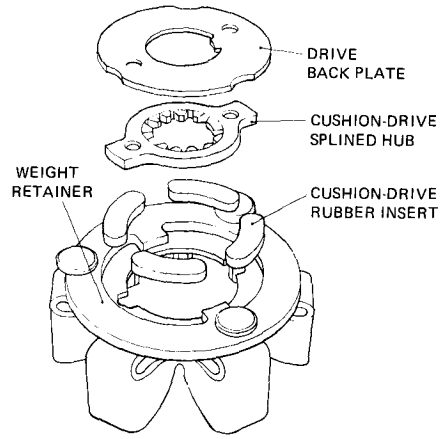


Fig. 34-25 DPA weight retainer components. *(CAV Limited.)*

Supplementary Inspection

DRIVE SHAFT Measure the wear of the drive shaft tang. The wear of the tang should not exceed the specification given in the service manual. Check the drive shaft seal area for nicks or scratches and the drive shaft splines for wear.

HYDRAULIC HEAD Check the discharge fitting threads for damage and wear. Check the internal bore and the charging and discharging ports for nicks, scratches, scores, or rust. If any of these conditions have occurred, the head and rotor must be replaced. Make certain that the vent wire in the hydraulic head air passage is loose and that the passage is clean.

DISTRIBUTOR ROTOR Measure the tang slot or check the drive splines for wear. Check the contact area of the leaf spring(s), where they contact the rotor radii, for wear. The charge and discharge ports must have no chipped edges or scratches. The rotor should be free of excessive scratches. (Excessive rotor-to-hydraulic head wear can only be determined when cranking fuel delivery is checked.)

Check the delivery-valve retraction (cuff) for corrosion and chipped edges. Discard the delivery-valve stop—it cannot be reused and must be replaced.

Do not handle the rotor shank when the plungers are removed for inspection. Make certain that each plunger is correctly replaced in the end of the bore from which it was removed, but do not use force when inserting the plungers into their bores. If the plungers are sticking in their bores but show no evidence of damage, clean them and their bores with acetone or a lacquer thinner. Hold the plungers (with cork plugs) in their bores and slide the rotor into the hydraulic head. Immerse the unit in clean fuel until it is to be assembled.

Make certain that each cam roller is in its shoe and that each rotates smoothly. There should be no chipping or excessive wear on the top edge of the shoes where they are contacted by the leaf springs or adjusting plates.

Check the leaf spring edges at the points where they contact the roller shoe and the radii of the rotor, or check the half-moon grooves of the adjusting plates (DPA).

Carefully check each cam lobe of the cam ring. If there is evidence of wear, spalling, flat spots, or flaking, the cam ring must be replaced.

Check the governor weight heels for flat spots and the toes for rough edges. Check the transfer-pump components for wear. Pay particular attention to the liner and blades.

If either the metering valve arm or the pin is loose or if the valve is pitted or shows wear, the metering valve assembly must be replaced. If the valve spring is distorted, replace it.

TIMING LINE LOCATION—STANADYNE DIESEL SYSTEMS When either the rotor (DM) or the governor weight retainer hub or complete assembly (DB, DC) is replaced, a new timing line must be marked on the weight retainer hub. To do this, place the cleaned and dry rotor or weight retainer on the appropriate locator dial (see Fig. 34-26). Be certain that the

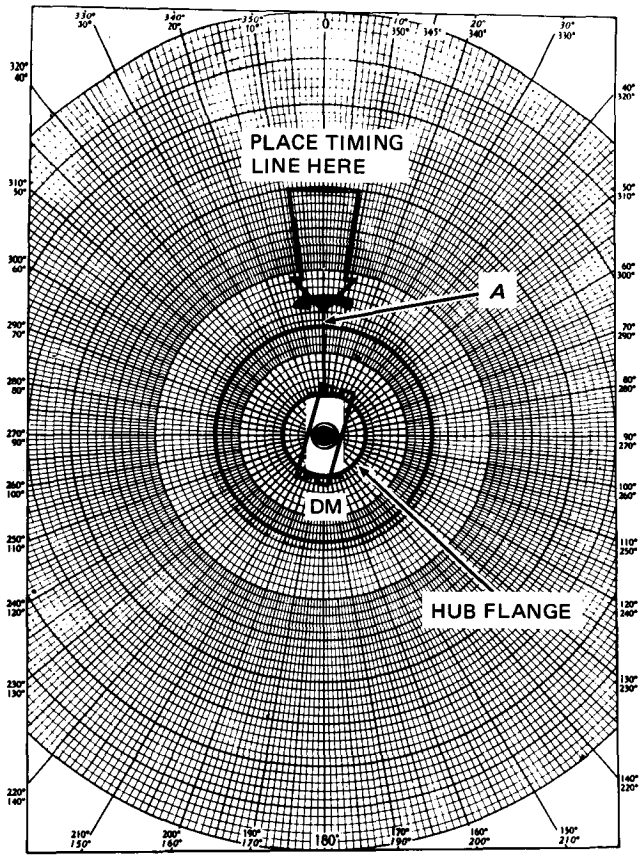


Fig. 34-26 Timing weight retainer hub. *(Allis-Chalmers Corp. Engine Division.)*

stamped line on the weight retainer (DB, DC) or the rotor dot (DM) is aligned with the "O" line on the tool. Rotate the weight retainer and dial in the direction indicated on the tool until it is aligned with the timing degree number listed on the individual pump specification. Check the existing timing line, or place a new one on the hub by first marking with a pencil, followed by overscoring with an electric pencil.

Reassembling Distributor Head Remove the hydraulic head assembly from the fuel container, slide each roller into the end of its shoe, and install the shoes and rollers into the rotor slots. Then position the leaf springs or assemble the drive hub in the order outlined in the DPA service manual (see Fig. 34-27).

Roller-to-roller Measurement and Adjustment This adjustment must be made precisely to specification because the roller-to-roller dimension governs the maximum fuel injected per pumping cycle. To make this measurement, place the rotor in the special tool supplied by the manufacturer or place it in the hydraulic head. Connect an air supply hose with a pressure regulator to one of the discharge fittings. Now, pressurize the head inlet 40 to 100 psi [275.8 to 689.5 kPa] with clean filtered air. Rotate the rotor until the air pressure forces the shoes out against the leaf spring(s) or adjusting plate. Measure the distance across the rollers with a micrometer and compare your reading with that given on the specification. Make certain that the micrometer does not force the rollers inward (Fig. 34-28).

To increase or decrease the distance across the rollers, you must adjust the leaf spring screw. On injection pumps having four plungers, you must adjust the leaf spring screws for each adjacent set of plungers since only one end of each leaf spring changes the shoe travel for each set of plungers.

On a four-plunger pump, to ensure that each roller contacts the cam lobes simultaneously, the rollers must be checked for centrality with a dial indicator. The total variation in roller extension must not exceed 0.003 in [0.08 mm] but must maintain the roller-to-roller dimension. You may have to change the leaf springs, rollers, or shoes to come within specification.

Once the roller-to-roller dimension is adjusted, clean all components thoroughly, lubricate them with fuel, and place the cam ring over the rollers so that the directional arrow points in the direction of pump rotation and the advance pin hole is located at the bottom of the pump housing. Now place the hydraulic head onto the rotor. Assemble the transfer pump and regulator, and screw the end cap onto the hydraulic

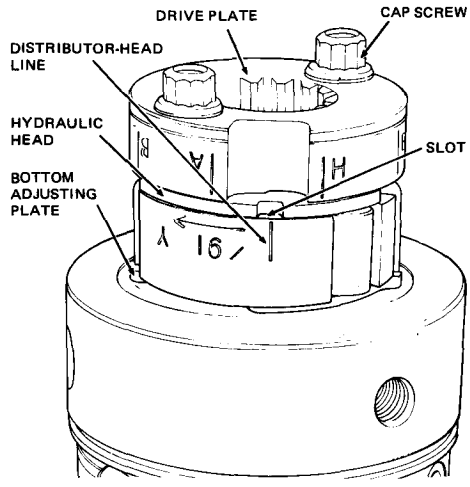


Fig. 34-27 Reassembled DPA drive hub. *(CAV Limited.)*

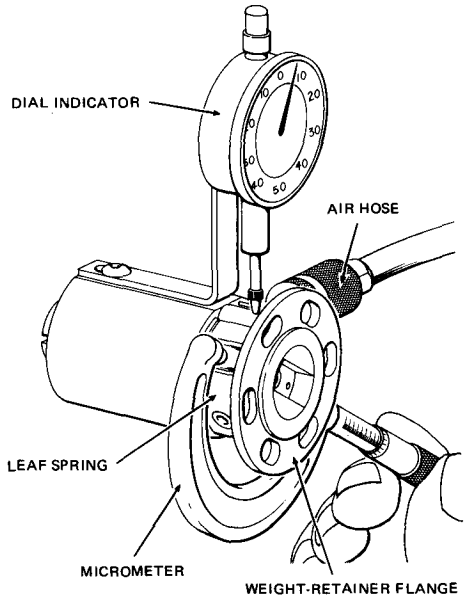


Fig. 34-28 Checking roller-to-roller dimension and roller centrality. *(Allis-Chalmers Corp. Engine Division.)*

head. *(NOTE: During reassembly make certain the rotor retainer slots and transfer-pump liner slot align with the roll pin.)* Turn the head assembly over and place the governor weights in the weight retainer. Insert the thrust washer (bevel edge up) and thrust sleeve (with its two grooves upward) into the weight slots (Fig. 34-29). Tilt the weights and work both components into the correct position. Spin the weight retainer to ensure that there is no excessive restriction. Tilt the holding fixture, line up the holes for the head locating screws, and, with both hands, slide the assembly into the housing. (Use rotary motion but maintain alignment.) Realign the holes. Install the bottom head locating screw and the remaining head locating screws, then torque them evenly to specification.

Install the advance mechanism, making certain that the piston hole plugs are screwed into the correct side to ensure correct advance movement.

Place the governor arm into position with the linkage-hook fork facing the rear. Insert the pivot shaft. Its sharp, milled edge must face toward the governor arm. Place the spring, the shim, and the metering valve on the arm assembly and insert the valve into the bore. (Make certain it rotates freely.)

Depress the metering valve assembly. Install the guide stud and washer to the housing, and then tighten the guide stud. Pull back the governor linkage hook. Stretch the spring just enough to assemble the hook correctly to the fork on the governor arm. Position the opposite end of the hook over the pin on the metering valve arm. Make sure the governor parts move freely (Fig. 34-30).

Apply a light film of grease to the throttle and shutoff shaft seals. Partially assemble the throttle shaft assembly in its bore in the housing. Slide the throttle shaft lever over the throttle shaft so that the projection in the throttle-shaft-lever bore engages with the rear keyway on the shaft. Position the fork end of the throttle lever so that it straddles the guide stud.

When you assemble the shutoff lever assembly, use a slight rotary motion to prevent damage to the seals (Fig. 34-31). If the throttle shaft lever is correctly installed, rotate the throttle shaft assembly toward the rear. It should compress the governor spring.

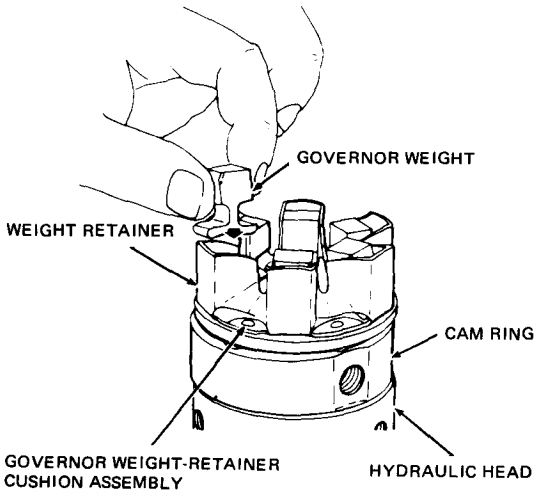


Fig. 34-29 Installing governor weights. *(Allis-Chalmers Corp. Engine Division.)*

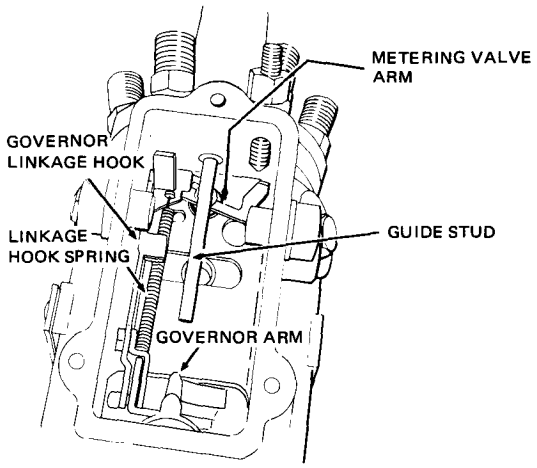


Fig. 34-30 View of semiassembled governor. *(Allis-Chalmers Corp. Engine Division.)*

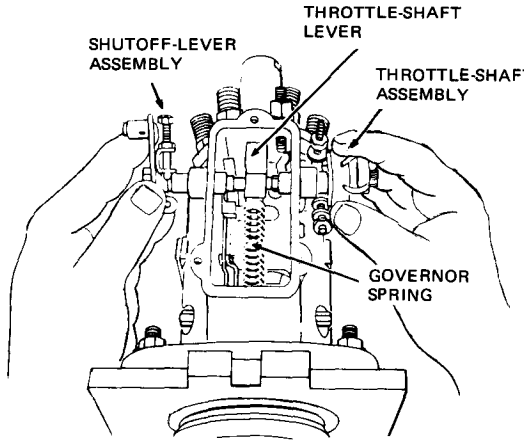


Fig. 34-31 Installing shutoff and throttle shaft assembly. *(Allis-Chalmers Corp. Engine Division.)*

Throttle-linkage Adjustment—DPA Injection Pump To check the governor linkage of a DPA injection pump, measure the distance between the large diameter of the governor-control-cover stud and the metering-valve-lever pin (Fig. 34-32). Make sure that you hold the vernier caliper parallel to the housing and that the metering valve is in the wide-open position. If an adjustment is necessary, loosen or tighten the linkage nut to increase or decrease the distance.

When you install the governor spring, first check the code number and then use the table in Fig. 34-33 to determine in which hole the idle spring guide must be positioned and in which hole of the throttle shaft linkage the governor spring must be hooked.

Throttle-linkage Adjustment—DM Injection Pump To adjust the throttle linkage, back out the torque screw and hold the throttle lever in the wide-open position (Fig. 34-34). Place the linkage gauge between the rear of the shutoff shaft and the vertical tab on the linkage hook, and then check the clearance.

If an adjustment is necessary, loosen the adjusting screw and slide the linkage to its maximum opening. Insert the gauge, slide the linkage hooks together

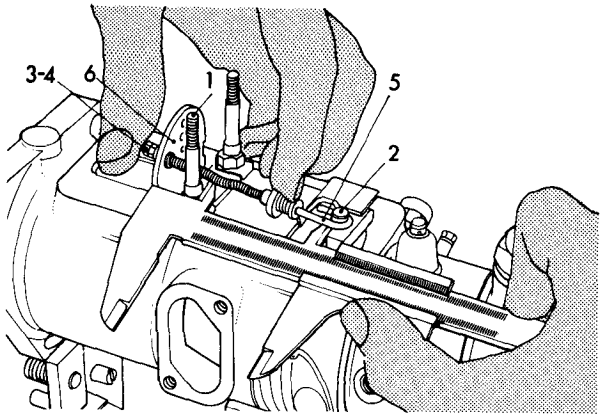


Fig. 34-32 Setting DPA governor linkage. (1) cover stud, (2) metering valve lever pin, (3) and (4) locknut and linkage nut, (5) hook linkage, (6) governor control arm. *(CAV Limited.)*

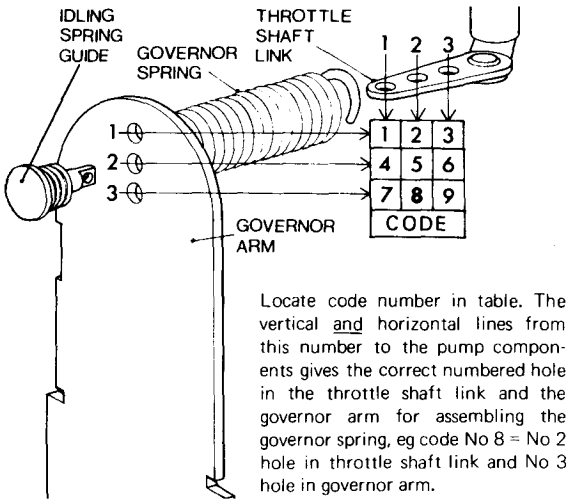


Fig. 34-33 Application of the setting code. *(CAV Limited.)*

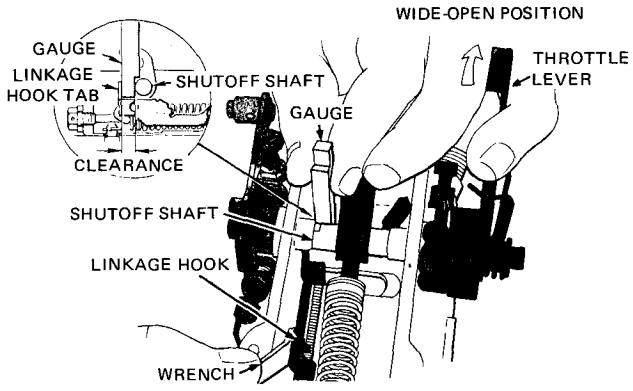


Fig. 34-34 Adjusting DM throttle linkage. *(Stanadyne Diesel Systems.)*

until the face of the tab is flush against the gauge, and then tighten the adjusting screw.

Install a new shutoff cam with the straight inner edge engaging the slot. Install a new throttle shaft retainer with the straight inner edge engaging the slot. Install the cover using a new cover gasket. *(NOTE: It is essential that all bolts, nuts, or screws are tightened to the specified torque given in the service manual.)*

ELECTRICAL SHUTOFF Most distributor-type fuel-injection pumps use an electrical shutoff device. The shutoff solenoid is fastened to the inside of the governor housing cover and electrically connected to the key switch. It can be fastened with the shutoff arm facing either toward the front or toward the rear of the injection pump. In these positions a shutoff (metering valve rotation to the no-fuel position) and a run position can be accomplished by energizing the solenoid.

When the solenoid shutoff arm is facing forward and the solenoid coil is energized, the lower tab on the arm pulls the linkage hood rearward, causing the metering valve to rotate to the no-fuel position.

When the solenoid shutoff arm is facing rearward (Fig. 34-35) and the coil is energized, the lower tab on the arm moves away from the linkage hook, and the metering valve is free to move. When the solenoid coil is de-energized, the shutoff-arm spring pivots the top of the arm to the left (its movement is limited through the armature arm), and the bottom of the arm to the right, thus forcing the linkage hook to move rearward and the metering valve to rotate to the no-fuel position.

If the solenoid fails to operate or the arm malfunctions and prevents a shutoff or run condition, disconnect the key switch wire from the terminal and connect one ohmmeter lead to the terminal and the other to ground. Compare the ohmmeter reading with the specification given in the service manual. *(NOTE: Shutoff solenoids are available that operate on 12, 24, and 32 V.)* If the solenoid checks out satisfactorily, remove the cover, remove the solenoid from the cover, and then check, and if necessary adjust, the armature travel and armature operating height.

Mounting Pump to Test Stand Install the necessary bracket to the test stand. Next, measure the parallel alignment. It must be within 0.005 in [0.127 mm]. With a dial indicator measure the face runout. It should not exceed 0.010 in [0.254 mm]. Mount the pump securely to the mounting bracket. *(NOTE: The test-stand drive shaft must not deflect the pump drive shaft and there must be 0.001 to 0.005 in [0.025 to 0.127 mm] clearance between the coupling surfaces.)*

With a hose, connect the test-stand feed pump to

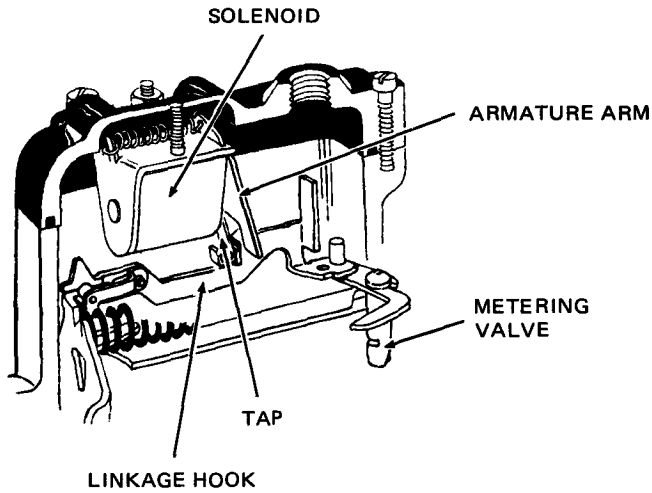


Fig. 34-35 Schematic view of electrical shutoff energized to run.

the transfer-pump inlet. With another hose, connect the return fitting to the test-stand return fitting. Connect the test-stand pressure gauge (with a third hose) to the bottom of the transfer-pump end plate. On DM models, use the special pump connector and shutoff valve, and then install the advance test window. The test-stand oil must be as specified in the service manual. The correct calibrating nozzles must be used and must be adjusted correctly.

Select the specified injection lines and install them. Open the bleedoff valve on the injector holders. When all hoses and lines are connected, turn on the fuel supply and regulate the fuel pressure to 1 to 3 psi [6.894 to 20.675 kPa] unless otherwise specified.

CAUTION The inlet pressure must never exceed 10 psi [68.9 kPa].

When an electrical shutoff, energized to run, is used, energize the solenoid before starting the test-stand motor. Run the pump at the lowest test-stand speed. Back out the high-idle adjusting screw. (Also back out the torque screw, if used.) Move the throttle to the full-fuel positon. Allow air to bleed from the pump and the injection lines before closing the bleedoff valve at the injector holders. When all the air has been bled from the system, operate the pump at 1000 rpm to warm up the pump and the test fuel. During the warm-up period check for fuel leakage and repair any leaks (Fig. 34-36).

Transfer-pump Vacuum Test Make this test to determine if the transfer-pump components are in good condition. Operate the injection pump at 200 pump rpm, close the fuel supply valve, and observe the combination pressure and vacuum gauge. (If the gauge shows less than 18 inHg [45.73 cmHg], check the inlet connection for tightness before you examine the transfer pump.) Insufficient vacuum can be caused by a damaged O ring under the inlet fitting, under the pressure regulating valve sleeve, or between the pump liner and the end plate. It may also be due to excess clearance between the pump blades and end plate, to misalignment of the end plate with the pump liner, to damaged or worn blades, or to a worn pump liner.

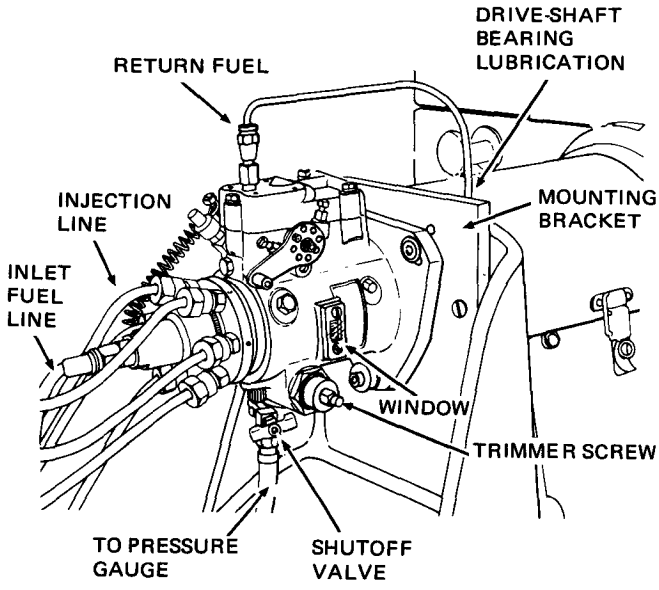


Fig. 34-36 Injection pump mounted to test stand. *(Allis-Chalmers Corp. Engine Division.)*

Fuel Return Flow Test To make this test, measure the amount of fuel flowing from the return fitting while the pump is operating at the recommended speed. Measure the fuel return flow by directing the fuel (from the return fitting) into a graduated vial for 1 minute. Compare the quantity of fuel in the vial with the quantity given in the pump specification.

NOTE: Each of the following test specifications are merely for illustration purposes. However, they coincidentally apply to a specific engine.

Transfer-pump Pressure Test Operate the pump at 1050 pump rpm with the throttle wide open. Observe the transfer-pump pressure. It should be between 85 to 90 psi [586.07 to 620.55 kPa]. If the pressure is not within specification, stop the test-stand motor and adjust the pressure regulating spring plug to increase or decrease the spring force and then recheck the adjustment.

Cranking-speed Fuel-delivery Test Operate the pump at 75 pump rpm. Set the counter to 1000 strokes, and then check delivery. It should be 44 mm^3. If the fuel delivery is less than this (even though the transfer-pump pressure is as specified), check the delivery stop for leakage. If the fuel delivery remains lower than specified, there may be excessive leakage between the rotor and the hydraulic head, and the head and rotor assembly may need to be replaced.

Peak-torque Fuel-delivery Test Operate the pump at 600 pump rpm. Check the pump delivery per 1000 strokes. It should be between 71 to 74 mm^3 and the maximum variation between cylinders should not exceed 5 mm^3. If the fuel delivery is lower or higher than this range, both leaf springs should be adjusted to either raise or lower the fuel delivery. Failure to equalize both springs can result in an uneven load on the pump roller. If the variation between cylinders is higher, the nozzles should be checked.

CAUTION Run several tests before making a final decision.

Rated-speed Fuel-delivery Test (Torque Screw Set Point) Operate the pump at 1050 rpm. Check the transfer-pump pressure and measure the delivery per 1000 strokes. The transfer-pump pressure must be within specification. The average fuel delivery should be between 60 and 62 mm^3. If the fuel delivery is not within specification, the opening of the metering valve must be increased or decreased. (Make certain the high-idle screw is backed out). You can do this by turning the torque adjusting screw inward to decrease the opening.

High-idle-speed Fuel-delivery Test Operate the pump at (high idle) 1150 rpm. Measure the delivery per 1000 strokes. It should be between 22 to 28

mm^3. If the delivery is higher or lower than this range, turn the high-idle adjusting screw outward or inward to change the governor spring tension. After you have made the high-idle adjustment, always recheck the rated-speed delivery.

Speed-advance Test To check the speed advance of a Stanadyne diesel systems' injection pump, first install the advance indicator gauge. Zero the gauge and run the pump in the full throttle position. Operate the pump at slow speed, then gradually increase the pump speed to high idle. During this time observe the movement of the pointer on the indicator. Assume the test specifications are: 200 to 400 pump rpm 1°, 650 to 700 pump rpm 10°, 875 pump rpm 11°. If the cam ring fails to advance at its specified low rpm or fails to complete its full advance at the recommended rpm, adjust the trimmer screw or remove a shim. If the advance starts at a lower pump rpm, add shims, readjust the trimmer screw, or replace the springs.

To check the speed advance of a DPA injection pump, install the advance checking tool as shown in Fig. 34-37. Zero the gauge by moving the scale relative to the pointer. When checking the advance mechanism, fuel pressure moves the advance piston and the cam. This piston movement will be measured by the pointer on the advance checking tool.

Low-idle Fuel-delivery Test Operate the pump at 360 rpm. Move the throttle to the low-idle position. Use the idle adjusting screw to bring the fuel level up to the amount called for on the specification. Check the fuel delivery. At 1000 strokes it should be 25 to 30 mm^3.

To increase or decrease fuel delivery, turn the adjusting screw clockwise or counterclockwise to increase or decrease the idle spring tension. When an electrical shutoff is used, check it at the speeds given in the service manual.

Governor Shutoff Check To check the effectiveness of the governor shutoff, place the throttle in the full-fuel position, set the stroke counter to 1000 strokes, and gradually increase the pump revolutions to 1225 rpm. Trip the stroke counter. The fuel vial should show a maximum output of 5 mm^3. If the fuel output is higher, check the governor linkages and throttle-linkage gap.

Aneroid Test If the injection pump you are testing is equipped with an aneroid, connect the aneroid operating rod to the shutoff lever (Fig. 34-38). Connect a mercury manometer and an air pressure supply hose having a regulator to the aneroid's inlet port. Operate the pump at 1000 rpm and gradually supply pressure to the aneroid. The shutoff lever rear adjusting screw should just lift off from the body when the pressure is between 4 and 6 inHg [10.16 to 15.25 cmHg]. If the shutoff lever starts to move only with a higher pressure, lengthen the operating rod, and if it moves at a lower pressure, shorten it. Increase the pressure 30 to 35 inHg [76.2 to 88.9 cmHg]. The shutoff lever should have traveled its full stroke. If it has not, check the operating rod adjustment again or adjust the front shutoff lever adjusting screw. If the aneroid was properly adjusted but the shutoff lever

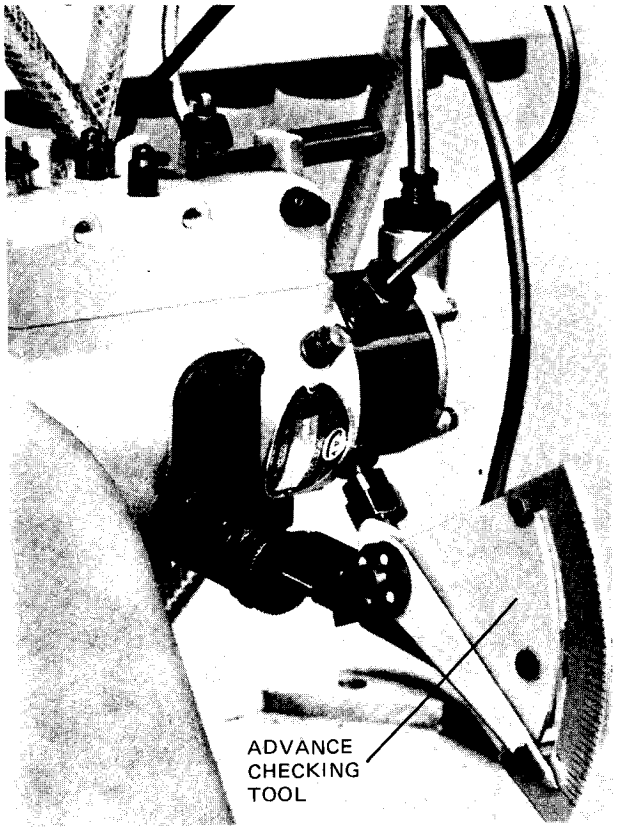


Fig. 34-37 Advance checking tool installed to a DPA injection pump. *(CAV Limited.)*

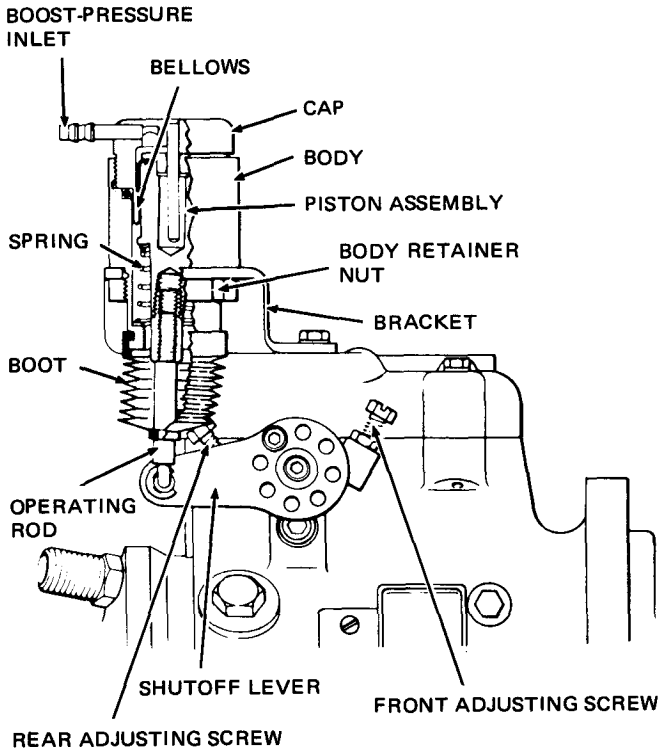


Fig. 34-38 Sectional view of aneroid mounted to injection pump. *(Stanadyne Diesel Systems.)*

did not travel its full stroke, the trouble is within the aneroid and it must, therefore, be removed and serviced.

Air- or Hydraulic-timing of Distributor-type Pump After the injection pump has been flow-tested and adjusted, it must be timed (if this was not done on the timing-dial location indicator) by using compressed air or hydraulic pressure. Air or hydraulic timing establishes the exact point at which the cam rollers contact the face of the cam lobes. This is the static timing point and is the start of injection (at peak-torque delivery).

To air-time or hydraulic-time the injection pump, remove the timing window and replace it with a half-window.

NOTE: An old timing window, cut into two pieces (one long and one short) provides a good nonconductive straightedge. File the ends square, and cut the window to a length appropriate to the cam static position.

Connect the air hose (with a pressure regulator) to the No. 1 discharge fitting, or connect the No. 1 discharge fitting to an injector tester. For Stanadyne diesel systems' injection pump, pressurize the line to about 100 psi [689.5 kPa] with air only. For a DPA injection pump, pressurize it to about 426.0 psi [2937.2 kPa] with fuel. The applied pressure forces the plunger outward. When the drive shaft is rotated (in the direction indicated on the nameplate), it positions the cam rollers so that they stroke the faces of the cam lobes. As soon as you feel this resistance, hold the drive shaft firmly and, with an electric pencil, inscribe a line (on the weight retainer) to coincide with the cam line.

Upon completion of testing, adjusting, and timing the injection pump, use sealing wires to make the adjustments tamperproof. Then wire the throttle in the full-fuel postion.

Pressure-testing Rebuilt Pump It is highly recommended to pressure-test a rebuilt pump for external leakage following calibration on the test stand. To make this test, connect an air hose with a pressure regulator to the inlet line fitting, plug the return fitting, and immerse the pump in clean fuel. Pressurize the pump to about 10 to 15 psi [68.9 to 103.4 kPa] and check for air bubbles. If none appear (except for the fuel line connectors), the pump is ready for installation to the engine.

Installing a DB2 Injection Pump to an Allis-Chalmers 433 Series Engine Before you install the injection pump to the engine, replace the drive shaft cup seals, if used. Before you place the new seals on the installing tool, coat them with grease so that they will slide onto the shaft more easily.

Position the No. 1 piston on its compression stroke so that the engine timing pointer indicates the specified static time position. Remove the timing window from the injection pump and turn the drive shaft to align the timing lines, then slide the pump over the drive shaft onto its mountings. (You may have to rotate the pump to match up the spline or tang connection.) Use the seal compression tool guide and protect the seals when sliding the pump over the seals.

Realign the pump timing lines by rotating the pump before you tighten the mounting stud nuts. Recheck the pump timing by rotating the crankshaft about 45° counterclockwise and then rotating it clockwise until the engine timing marks line up again. The pump timing marks should also line up. Connect the fuel inlet and return lines. Install the injection lines but make certain you do not bend or twist the injection fittings. Always use new washers on each side of the banjo fitting if applicable.

Connect the throttle and shutoff lever. Replace fuel filters if not previously done. Bleed the injection system. Turn the ignition key to start the engine. If the engine does not start, loosen the injection line (at the injectors) and crank the engine until fuel leaves the loose connection. Retighten the connection and again turn the ignition key to start the engine.

When the engine is at its operating temperature, check the high- and low-idle rpm and make any corrections necessary.

CAUTION Never change the timing while the engine is running because this could cause misalignment and result in serious damage to the pump, and possibly personal injury.

Questions

1. List the major differences between the three distributor-type injection pumps.
2. Trace the fuel (metering) of (*a*) a DPA fuel-injection pump, and (*b*) a DM fuel-injection pump, from the inlet fitting to the point where fuel pressure forces the opposed plungers apart.
3. Describe the action of the delivery valve.
4. Describe the action of the Stanadyne diesel systems' governor when the throttle is in the full-fuel position and the engine speed is reduced because of increased load.
5. Describe the action within a DPA hydraulic governor when the engine speed is increased as the load is reduced.
6. Why should the fuel pump timing be checked before removing the pump for service?
7. Describe how to measure and adjust the roller-to-roller dimension of a four-plunger DM injection pump.
8. What is the purpose of measuring and adjusting the throttle linkage?
9. What would result if either the cam ring or the transfer-pump liner were installed backwards?
10. Describe how to test the operation of the transfer pump while it is installed to the test stand.
11. Explain how you would increase the transfer-pump pressure of a pump having a regulator as shown in Fig. 34-1.
12. Outline the procedure to air-time a Stanadyne diesel systems' injection pump.
13. List the required steps to install a distributor-type injection pump to an engine having a static timing of 8°.
14. List the necessary checks or adjustments to be made after the pump is installed to the engine.

UNIT 35 • AMERICAN BOSCH DISTRIBUTOR-TYPE FUEL-INJECTION PUMPS

Four major companies manufacture distributor-type fuel-injection pumps. Each has the same objective—to build a fuel-injection pump which will complement small-bore engines and yet remain simple in construction and economical to service.

The American Bosch Company is one of the manufacturing pioneers of the distributor-type injection pump. Its PSB model has been modified over the years from the PSB, PSJ, PSM, and finally model 100 (see Fig. 35-1). The construction of these four models differs slightly; however, their pumping, metering, and distributing principles are the same and all have the same characteristics: (1) They have constant-beginning and variable-ending delivery, (2) they are driven at engine speed, (3) they use a single plunger and barrel and a single delivery valve, (4) they use a sleeve-metering principle, (5) they use a mechanical governor and a gear-type transfer pump, (6) the plunger rotates through a gear train at half camshaft speed to distribute the metered fuel, (7) the pumping action is by reciprocating motion, (8) the distributor section is fuel-lubricated, and (9) the camshaft, tappet, bushing, thrust washers, and governor shaft are oil-pressure-lubricated through internal passages and the remaining components are splash-lubricated.

All PS Series fuel-injection pumps, with the exception of the PSU, have (1) a drive section, (2) a pumping, metering, and distributing section, and (3) a control section. The PSU injection pump is used on small, high-speed engines. It is actually only the hydraulic head of the model 100 or PSM pump placed in a special housing. The camshaft, the drive which rotates the plunger, and the governor are part of the engine rather than part of the pump.

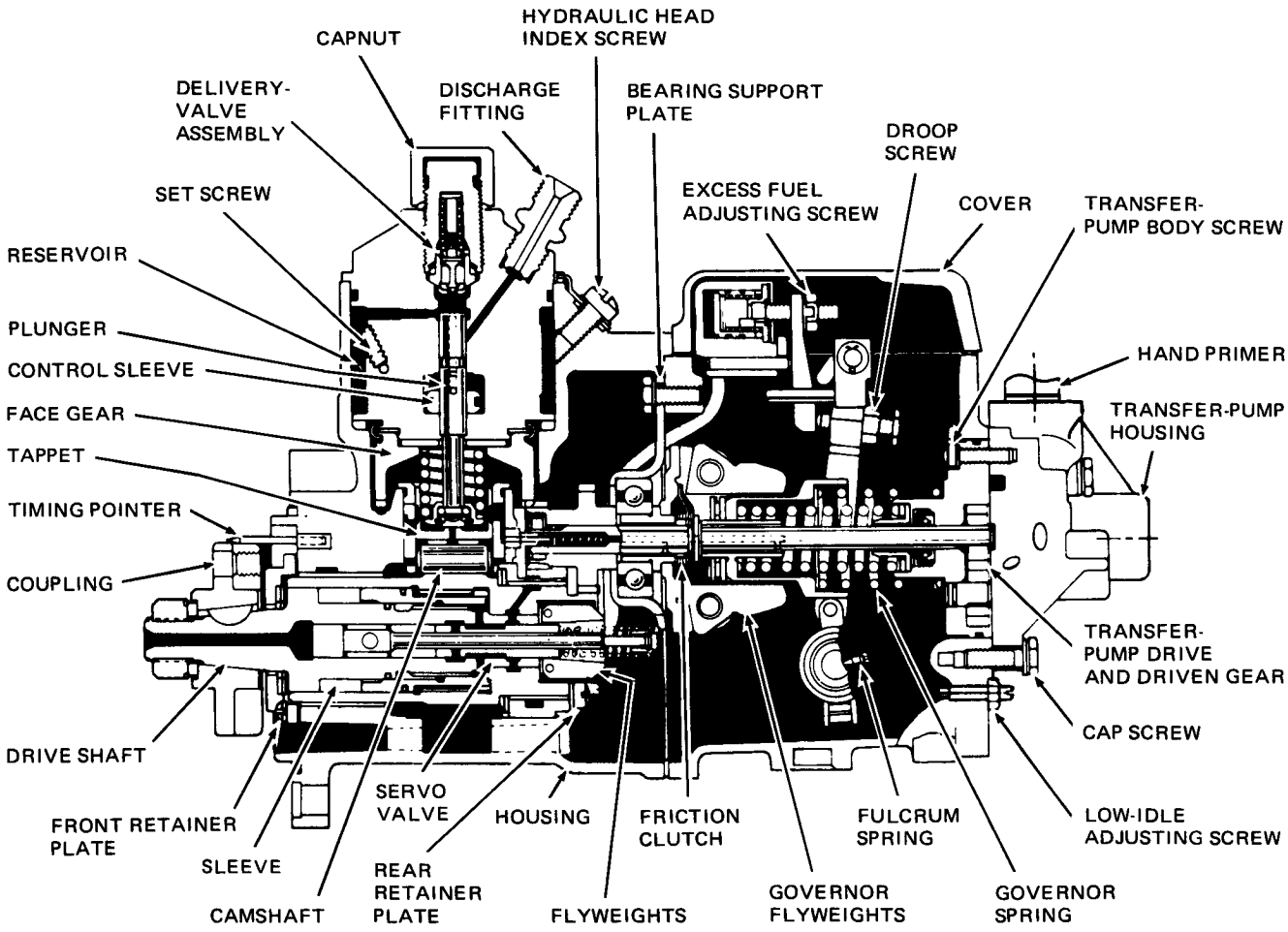


Fig. 35-1 Schematic view of a PS 100 injection pump. *(International Harvester Company.)*

Drive Section The purpose of the drive section is to drive the governor, rotate the plunger, and move the plunger up and down. Its components consist of the drive coupling, camshaft with drive gear, tappet guide and roller, face gear, governor drive gear, governor shaft, friction clutch, and transfer-pump drive gear. When an automatic external mechanical timing device is used, the device is placed between the drive coupling and the camshaft. When a hydraulic automatic advance (intravance) is used, the intravance replaces the camshaft (Fig. 35-2).

Regardless of the fuel-injection-pump drive combination, when the engine is started or is running, the timing gears transmit rotary motion to the drive coupling and onto the three- or four-lobe camshaft. When using an intravance unit, the rotation from the timing gear is transmitted to the drive coupling, drive shaft, sliding sleeve, and the three- or four-lobe camshaft. The gear on the camshaft drives the meshing gear on the governor drive shaft, and the end of the drive shaft drives the transfer-pump gear.

The governor weight assembly is driven over a friction clutch to reduce pulsation. The second gear on the governor drive gear drives the face gear and therefore the plunger.

Intravance Timing Device The intravance unit used with the model 100 is different to some extent from the unit used with the PSM injection pump. (Fig. 35-3). However, each unit alters hydraulically the relation between the drive shaft and the camshaft, the advance curve, and the degree to which the camshaft advance is governed by the longitudinal helical spline on the sliding sleeve, driveshaft, and camshaft. The sliding sleeve has inner and outer longitudinal helical splines. The inner splines are engaged with the drive shaft's helical splines, and the outer helical splines are engaged with the camshaft's helical splines. The governor fingers rest in the grooves of the servo valve, and the valve rests on the shoulder of the followup rod and is held against it through the intravance spring. The other spring end rests against the spring seat, which is threaded onto the right-hand side of the followup rod. The followup rod extends through the servo valve and weight assembly and is pinned (by the cross pin) to the sliding sleeve.

INTRAVANCE OPERATION (MODEL 100) When the engine is at idle rpm or below 1000 rpm, the intravance spring force is greater than the weight force and therefore moves the followup rod, servo valve, and sleeve to the left. This positions the camshaft into the maximum retard position and the servo valve blocks the oil inlet.

As the engine speed increases, the flyweight force moves the servo valve to the right and opens the oil inlet annulus. The oil supplied from the engine lubrication system enters the rear bearing plate and flows past the servo valve into the chamber formed between the driveshaft and camshaft. The oil pressure forces the sleeve to the left and, because of the helical splines, the camshaft advances. The sleeve movement forces the followup rod to the left, thus increasing the intravance spring force onto the servo valve. When the spring and flyweight force are equal the servo valve closes the oil inlet annulus and the sleeve movement stops. If the engine speed is increased, say to 2500 rpm, the flyweight again moves the servo valve and the sleeve is moved even further to the left until it butts against the driveshaft end. At this position the sleeve has advanced the camshaft to its maximum advance position (14°).

When the engine speed decreases, the flyweight force also decreases. The intravance spring then forces the servo valve to the right and opens the right-hand (drain) annulus. Oil can then drain from the chamber through the driveshaft until the weight force and spring force balance, whereupon the drain annulus closes.

To maintain the camshaft in its advanced position during the pumping action, the oil-supply hole in the rear bearing plate comes out of alignment with the

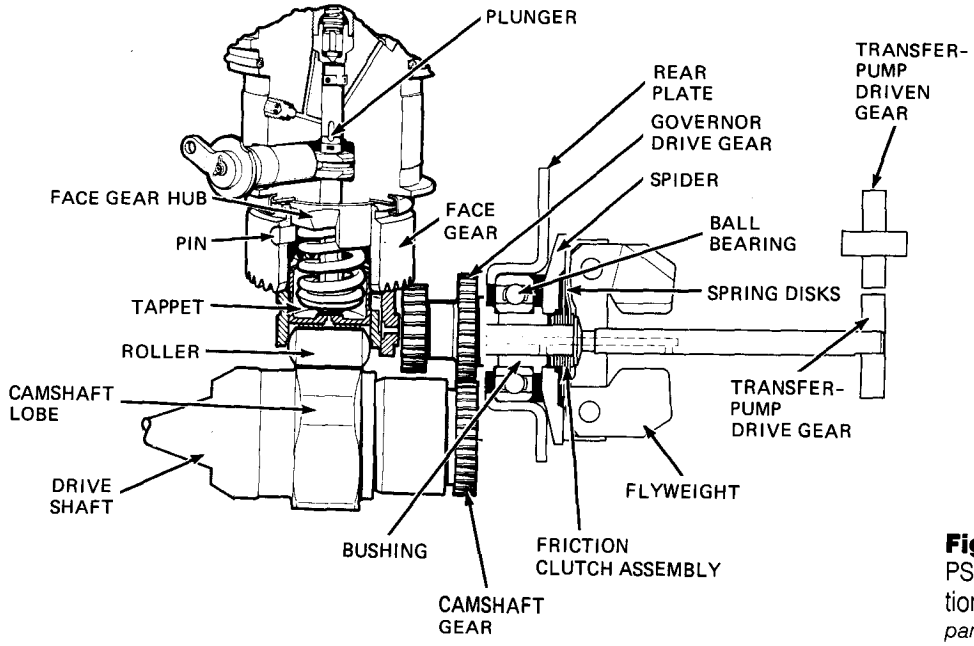


Fig. 35-2 Schematic view of the PS 100 injection-pump drive section. *(International Harvester Company.)*

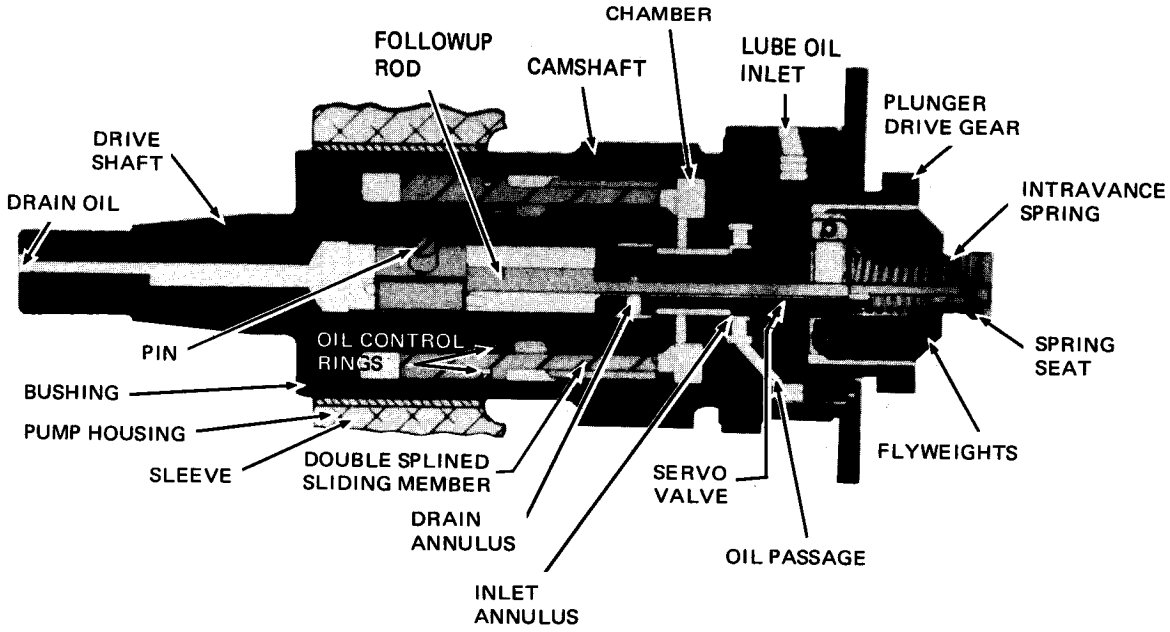


Fig. 35-3 Schematic view of model 100 intravance when advancing the camshaft. *(International Harvester Company.)*

hole in the camshaft. The oil is trapped within the advance unit, preventing the camshaft from moving into the retard position.

TMF Timing Device The TMF is an external mechanical timing device which is bolted to the injection-pump housing. It uses a separate housing to locate and position the advance unit.

The components of the TMF are shown in Fig. 35-4. The drive coupling is keyed to the tapered shaft of the weight spider, and the hub is bolted to the injection-pump camshaft. The spider and the hub have external helical splines, one curved left and the other curved right. The sliding gear has internal helix-angled splines which mesh with the weight spider and hub splines. Four springs are placed between the hub and the sliding gear to force the sliding gear against the flyweight fingers. A bushing and an adapter flange reduce the friction between the sliding gear and flyweight fingers.

OPERATION OF TMF TIMING DEVICE When the engine is running, the drive coupling rotates the weight spider, sliding gear, hub, and camshaft. As the engine speed increases, the governor weights are forced outward against the force of the four coil springs. The weight force causes the sliding gear to move toward the hub. The movement of the sliding gear causes the camshaft to advance in relation to the weight spider because of the helical angle of the splines. The movement of the sliding gear stops as soon as the spring force equals the weight force. The spring rate and preload, the flyweight assembly, and helix-angled splines are tailored specifically for this engine to compensate for its advance curve.

Pumping, Metering, and Distributing Section The major components responsible for pumping, metering, and distributing the fuel are the camshaft and gear, the face gear and hub, the drive guide, the plunger, the hydraulic head, the sleeve, and the control unit (Fig. 35-5). The hydraulic head has a central precision bore to which the plunger is lap-fitted. The top portion is counterbored and threaded to retain the delivery valve and assembly. Four internal passages in the hydraulic head lead from the reservoir, formed by the hydraulic head and housing, to the fill ports, and from the lower section of the reservoir spill sump to the charging ports located below the pressure-compensating annulus and discharge slot. A single (discharge) passage from the delivery valve intersects with the pressure-compensating annulus. Four, six, or eight discharge passages extend symmetrically from the plunger bore to the discharge fitting. The number of passages are the same as the number of engine cylinders.

The plunger has one center drilling and two cross drillings (spill and charging ports). Spill ports are always located in the spill sump whereas the charging ports are only in the spill sump when the plunger is on the cam-lobe base circle. The plunger is connected to the face gear hub through the plunger (drive) guide and the face gear rests over the face gear hub (Fig. 35-6). The assembly is held to the

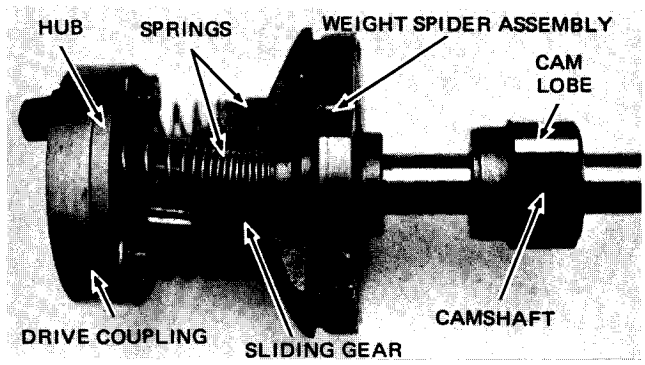


Fig. 35-4 View of TMF timing device.

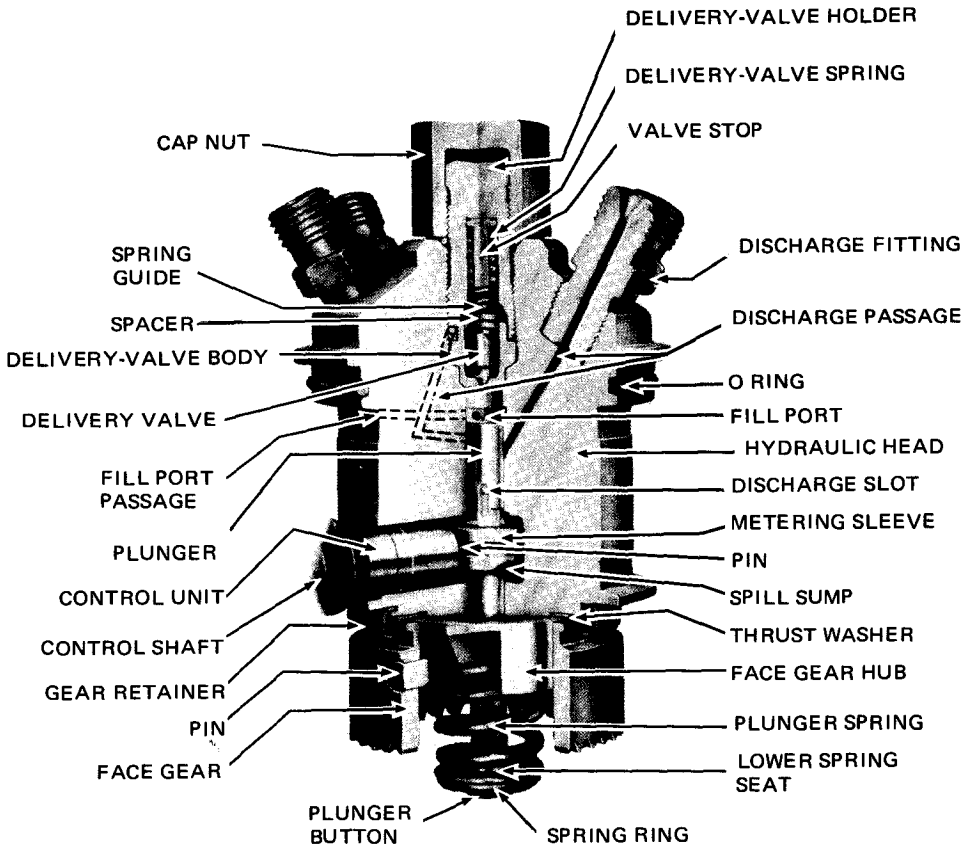


Fig. 35-5 Sectional view of the metering, pumping, and distributing section. *(International Harvester Company.)*

hydraulic head by the gear retainer. When the face gear is rotated, the pin drives the face gear hub and the plunger. One end of the plunger rests against the plunger guide located in the face gear hub. The top end of the plunger spring rests against the washer and its lower end is connected (through the spring seat and split retainer) to the plunger.

Pumping, Metering, and Distributing Principles When the tappet roller rests on the camshaft-lobe base circle, the plunger spill ports and the charging ports are in the spill sump (lower reservoir section). At this time no discharge passage (port) is aligned with the distributor slot. Fuel from the reservoir areas passes through the fill and charging ports and enters the chamber above the plunger and center passage (Fig. 35-7*a*). At the same time fuel from the transfer pump passes through the fill port. As the cam lobe lifts the tappet, the plunger is forced upward. Fuel displaced by the plunger flows through the fill and charging ports until the lower edge of the charging ports closes, and immediately thereafter the plunger closes the fill ports (Fig. 35-7*b*). Fuel is now trapped above and within the plunger. At this time the plunger distributor slot has come into alignment with one discharge passage port and when the fuel pressure overcomes the delivery-valve spring force, the delivery valve is forced upward. As the retraction piston leaves its bore, fuel can pass around the valve, downward through the discharge passage, around the plunger groove, and up to the distributor slot (Fig. 35-7*c*). The distributor slot is then fully aligned with one of the discharge ports. Fuel from the distributor slot flows through the discharge port, and the discharge passage, to the discharge fitting, and into the injection line.

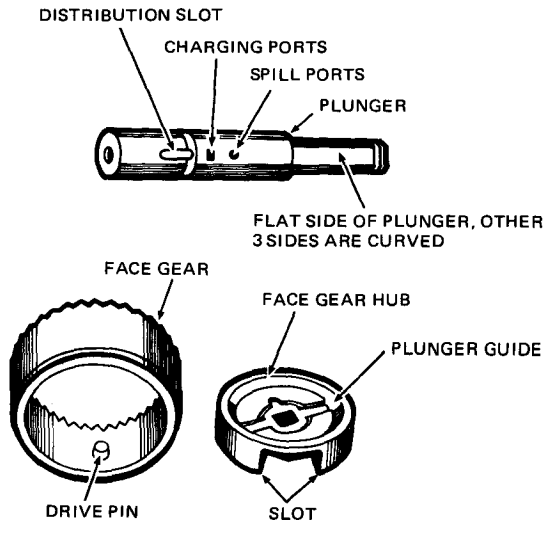


Fig. 35-6 Exploded view of plunger drive assembly. *(International Harvester Company.)*

ENDING OF DELIVERY When the upper edge of the cross-drilled bore (spill ports) passes the upper edge of the control sleeve, fuel at high pressure spills back through the center- and cross-drilled passages (spill ports) into the reservoir. As the spill ports open, the delivery valve snaps onto its seat, reducing the injection line pressure. A fraction of a second later the distributor slot comes out of registration with the discharge port. The plunger closes this port and holds the pressure in the discharge passage (Fig. 35-7*d*).

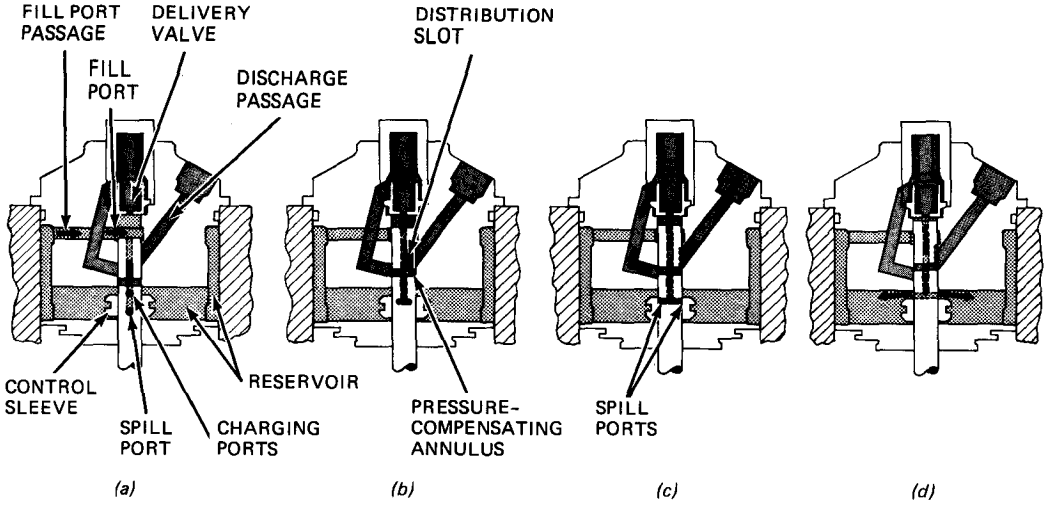


Fig. 35-7 Schematic view of pumping principle: (*a*) intake, (*b*) port closure, (*c*) injection, (*d*) spill back (end of injection).

As the plunger moves downward, fuel enters the spill ports and fills the area vacated by the plunger until the spill ports are covered by the sleeve. For a short interval no fuel can enter the area above the plunger until the fill and charging ports are again opened by the plunger. The plunger is pressure-balanced through the pressure-compensating annulus. In addition the plunger (drive) guide reduces any tendency to side-load the plunger.

Control Section The control section consists of the variable-speed governor, the control unit, control sleeve, control rod (which links the governor with the control unit shaft), and the excess fuel device (Fig. 35-8). The fuel-injection pumps on some turbocharged engines use a combination excess fuel device with aneroid (Fig. 35-9). The purpose of the excess fuel device is to gain control rod travel (excess fuel during engine startup) and the aneroid's purpose is to respond to boost pressure and automatically tailor the control rod travel to more or less fuel.

OPERATION OF THE CONTROL SECTION When the engine is shut down, the oil pressure in the chamber behind the inner piston of the excess fuel device drops. As the pressure decreases, the inner piston spring moves the inner piston, stop-plate adjusting screw, and stop plate to the left (Fig. 35-9). Consequently the control rod also moves to the left, and the control unit shaft semirotates clockwise, raising the control sleeve upward and thereby increasing the effective stroke.

Again, when the engine is stopped and the throttle is moved from high-idle to low-idle position, the operating shaft and torsion spring hub turn counterclockwise. This motion is transmitted from the torsion

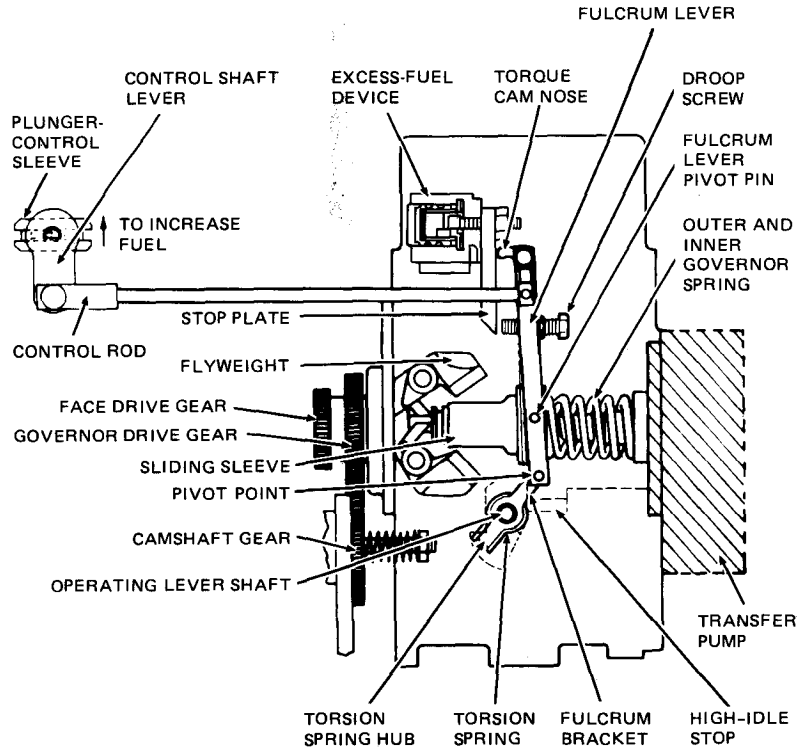


Fig. 35-8 Schematic view of the control section. *(International Harvester Company.)*

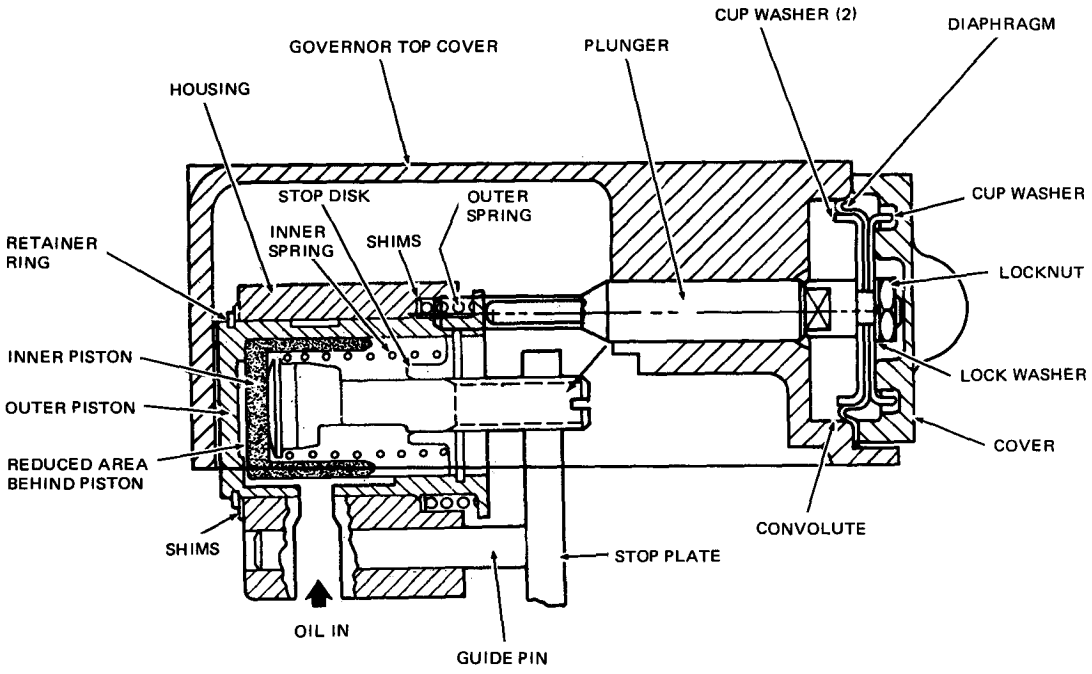


Fig. 35-9 Schematic view of combination excess fuel and aneroid device. *(International Harvester Company.)*

hub onto the torsion spring, and from the spring ends to the fulcrum lever bracket (spring plate). This action and the governor springs move the sliding sleeve, fulcrum lever, and control rod to the left, the flyweights toward each other, and the droop screw against the stop plate. The control shaft then semirotates clockwise and the off-center pin in the shaft moves the control sleeve upward. This places the control sleeve almost to the starting fuel position (maximum upward). When the throttle is moved in a clockwise rotation to full fuel, the fulcrum lever bracket comes to rest against the high-idle stop screw. This causes the fulcrum lever, sliding sleeve, and control rod to move to the right. The governor springs' compression increases, the torque cam nose comes to rest against the stop plate, the control unit semirotates clockwise, and the control sleeve moves slightly upward to the maximum starting fuel position (Fig. 35-10*c*).

When attempting to start the engine, the oil pressure in the chamber behind the inner piston and in the area in front of the inner piston increases, but the piston remains in the retracted position because of the inner spring force and the oil pressure acting on the small (reduced by the adjusting screw) inner piston area.

As the engine rpm is brought to low-idle speed, the oil pressure increases and forces the inner piston, adjusting screw, and stop plate to the right and they come to rest against the retainer in the outer (aneroid) piston (Fig. 35-9).

When the engine is brought to high idle, say 2500 rpm (full-throttle position), the boost pressure is low and the outer piston of the excess fuel device remains in position. However, the flyweight force is now so strong that it forces the sliding sleeve further to the right and as a result the cam nose is moved away from the stop plate. This occurs because the fulcrum lever is held fixed at the fulcrum-bracket pivot point but has moved at the fulcrum-lever pivot point. This lowers the control sleeve and brings the effective stroke to high-idle fuel (Fig. 35-10*b*).

If a load is placed on the engine and the rpm now is, say 2250 rpm, but boost pressure remains low, the excess fuel device's outer piston remains in position. The flyweight force reduces slightly and the governor spring moves the sliding sleeve to the left.

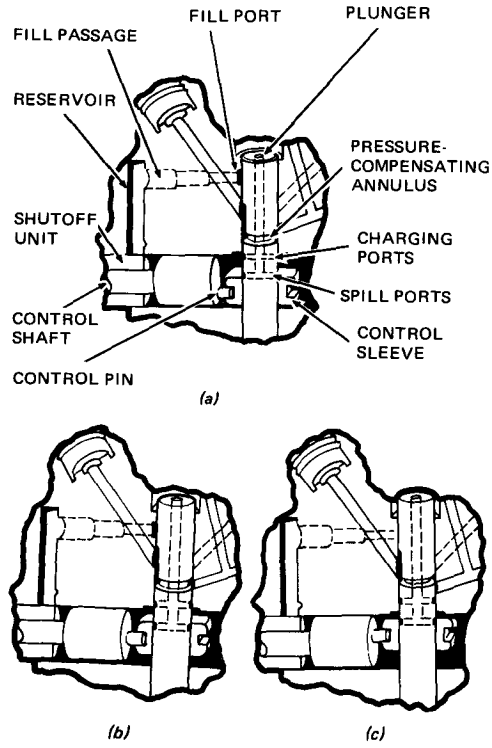


Fig. 35-10 Schematic view of metering principle: (*a*) no delivery, (*b*) normal delivery, (*c*) maximum delivery.

The fulcrum lever at this time is still fixed at the fulcrum-bracket pivot point but the sliding sleeve at the fulcrum-lever pivot point has moved to the left. The torque cam nose then butts agains the lower part of the stop plate, the control rod moves to the left, and the control sleeve moves to the right, thus slightly increasing the effective stroke. If the load on the engine increases, the rpm decreases, say to 1800 rpm (torque speed), and then two actions occur simultaneously: (1) The flyweight force decreases, and (2) the boost pressure increases.

As the flyweight force is reduced, the governor springs force the sliding sleeve, the fulcrum-lever pivot point, and the fulcrum-bracket pivot point to the left and semirotate the fulcrum bracket. The torque cam nose moves upward on the stop plate. *(NOTE: The pivot point can move to the left because the higher governor springs' force acting on the pivot point forces the fulcrum lever bracket to the left and is absorbed by the torsion spring.)*

The upward movement of the cam nose moves the control rod to the left and moves the control sleeve upward, thus increasing the effective stroke. During the time the engine speed is decreasing from 2250 to 1800 rpm, the boost pressure is gradually increasing and at 1800 rpm it is at its maximum. The boost pressure acting on the diaphragm moves the aneroid plunger, the outer piston, and (through the retainer ring) the retainer to the left. The increased inner spring force moves the adjusting screw with stop plate and inner piston to the left. At maximum boost pressure the outer piston shoulder comes to rest against the housing, thus limiting, indirectly, the stop-plate movement to the left (Fig. 35-9). When the engine load further increases and the engine rpm is around 1250, the sliding sleeve, fulcrum-lever pivot point, and control rod have moved to the left. Meanwhile the tension spring has deflected even more. When the droop screw is about 1 mm from contacting the stop plate, the pivot points are so aligned that the top of the fulcrum lever starts to move slightly to the right, reducing the effective stroke. When the droop screw contacts the stop plate, the droop screw rather than the cam nose becomes the pivot point of the fulcrum lever. Consequently the control rod moves to the right, thus lowering the control sleeve and reducing the effective stroke.

Any speed increase above 1800 rpm (reduced engine load) (1) increases flyweight force, and (2) reduces boost pressure. The increased flyweight force moves the fulcrum lever to the right, causing the cam nose to slide downward on the stop plate and the control rod to move to the right, which lowers the control sleeve and reduces the effective stroke. The reduced boost pressure allows the outer piston of the excess fuel device to be moved to the right through the force of the outer spring and the oil pressure on the inner piston. As a result the stop plate, cam nose, and control rod move to the right, lowering the control sleeve and tailoring the metered fuel to the boost pressure.

To stop the engine, either the electrical shutoff solenoid is energized or the Bowden cable of the mechanical shutoff device is pulled out. This semirotates (over a lever) the control shaft in a counterclockwise rotation and moves the control sleeve to its lowest position, which therefore cannot cover the spill port (Figs. 35-10*a* and 35-11).

Servicing Model 100 Injection Pump After you have removed all excess grease and dirt from the outside of the pump, wash it with clean fuel or with a noncaustic solvent, and dry it with compressed air. Drain the fuel and lubrication oil from the pump and mount the pump in a holding fixture. Remove the drive hub nut and the drive hub, using the appropriate holding tool and puller. Do not use a jaw puller because it will damage the mounting flange.

Next, remove the overflow valve, the control unit cover, the control unit plate, and the spacer. Carefully disengage the control rod while sliding out the control unit. Loosen, but do not remove, the delivery-valve holder.

To remove the hydraulic head, first loosen the four Allen-head screws. If the head does not rise, turn the camshaft to force it up. Turn the head so that you can remove the screws without damaging the discharge fittings. Lift out the hydraulic head, and using a pair of needle-nose pliers lift out the tappet guide and roller. Before you remove the transfer pump, loosen the pressure regulator valve plug, then remove the mounting bolts. Using two bars, pry the transfer-pump housing from the governor housing. Lift from the governor drive shaft the governor springs, spring seat, and spacer. Remove the excess fuel device *very carefully* because it is connected to the oil-supply tube.

After the governor mounting screws are removed, tap the governor housing with a soft-face hammer to

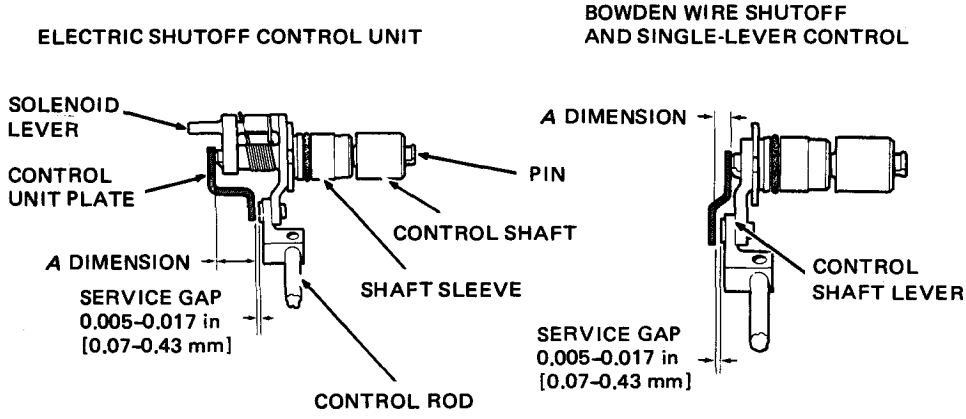


Fig. 35-11 Schematic view of control units. *(International Harvester Company.)*

break it from the injection-pump housing and dowels. Tip the housing slightly to prevent the control rod and oil-supply tube from bending while lifting the governor from the pump housing.

If the camshaft requires servicing, remove the front-thrust-washer retaining plate and the rear bearing plate, and push the camshaft to the rear to remove it from the housing.

Servicing Excess Fuel and Aneroid Devices When the excess fuel device shows any damage such as a bent guide pin or adjusting bolt, or corrosion, the assembly must be replaced. Otherwise remove the lock tap from the nut and the locknut from the adjusting bolt. With a screwdriver turn the adjusting bolt to remove the stop plate. Remove the outer and inner retainer rings from the outer piston. This allows you to remove the adjusting bolt, stop disk, spring, and inner piston from the outer piston, and the outer piston from the housing. *(NOTE: Retain both sets of shims as a unit.)*

Thoroughly clean the components, and if the piston surfaces or the outer piston bore are damaged or show erosion, or if the stop disk bore is worn, the stop plate guide bent, or the springs damaged, bent, or corroded, the assembly must be replaced.

To reassemble the excess fuel device, lubricate all components well with oil. Place the outer spring and shims onto the outer piston and then insert the piston into the housing cover bore. Place the second set of shims onto the right-hand side of the outer piston and then install the retainer ring. Place the inner piston into the outer piston bore, and the spring and then the stop disk onto the adjusting bolt. Thread the stop plate onto the adjusting bolt and place the assembly into the outer piston and hold it in place with the retainer. Install the lock plate and nut onto the adjusting bolt and then bolt the excess fuel device to the fuel-injection-pump housing.

To service the aneroid, first remove the four cover screws and remove the cover and plunger assembly. If the plunger or bore show score marks which cannot be cleaned up, or if the diaphragm shows any weakness which could cause an air leak at a later date, the assembly should be replaced. When reassembling the aneroid make certain the diaphragm is positioned as shown in Fig. 35-9. After the aneroid is assembled, connect an airline to the inlet fitting and apply 20 psi [137.9 kPa] onto the diaphragm. No air should leak from the assembly.

Servicing Drive Section Wash the drive section components in clean diesel fuel and dry them with compressed air. Check the injection-pump housing for cracks and damaged surfaces. Check the threaded holes for damaged threads. Use compressed air to clean the lubrication oil passage.

Check and measure the front housing bushing for wear. If the front bushing is worn beyond specification, the pump housing must be replaced. If the rear bearing plate is damaged or the bushing is loose within the plate, or if the bushing is worn beyond specification, the plate must be replaced. As a general rule the thrust washer is automatically replaced at this time.

Check the tappet sleeve for wear. If the clearance between the sleeve and a new tappet is more than 0.001 in [0.025 mm], the pump housing must be replaced (see Fig. 35-17).

Check the drive shaft for damage and/or scored taper. Check the keyway for damage and wear. If the camshaft lobes are worn, pitted, or scored, or if the bearing journals are damaged, grooved, or worn, the intravance must be replaced.

If no external damage is noticeable, disassemble the intravance by moving the followup rod toward the spring end and then remove the spring seat from the followup rod by turning the seat in the opposite direction to drive rotation. Remove the washer, spring, control valve, with the flyweight assembly. The flyweight assembly will normally fall from the control valve. Next, slide the camshaft from the splined sleeve and then withdraw the cross pin from the splined sleeve, drive shaft, and followup rod. Remove the piston ring from the driveshaft and splined sleeve (Fig. 35-12). Wash all components in clean fuel, taking care not to damage the control valve. Examine the surfaces of the control valve and camshaft bore

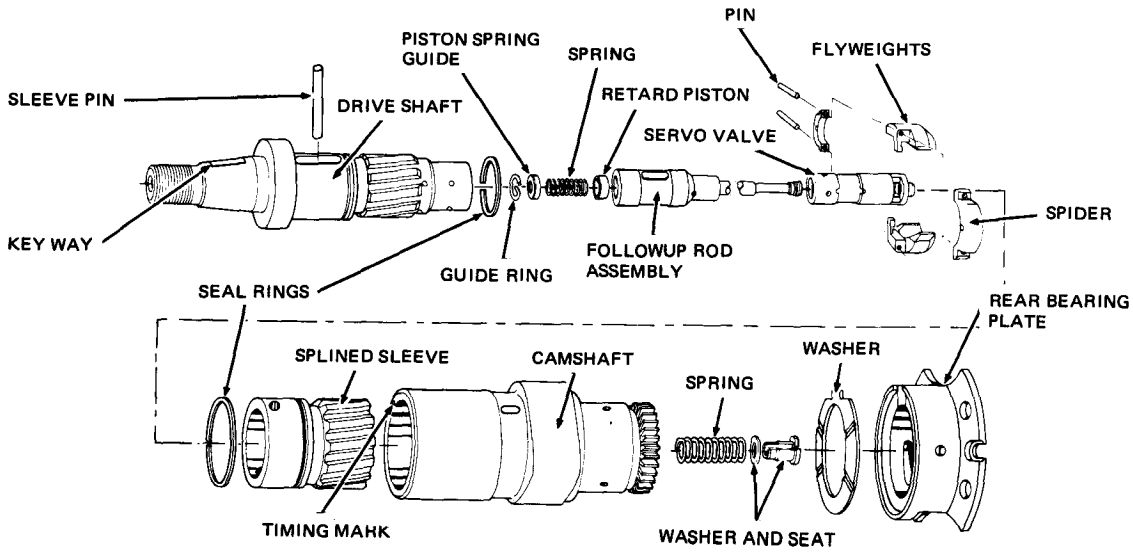


Fig. 35-12 Exploded view of intravance. *(International Harvester Company.)*

for damage. If either shows a greyish coloration, it indicates excessive wear and the intravance must be replaced. If the flyweight fingers, the pins, the spiders, or the groove in the control valve is worn or damaged, *all* components should be replaced. Automatically replace the intravance spring. Next, examine the splines on the sliding sleeve, camshaft, and driveshaft, and if they are grooved or show excessive wear or rough spots, the intravance should be replaced.

To reassemble the intravance, first clean all components and lubricate them well with oil. Reassemble it in precisely the reverse order of disassembly; however, there are three important reassembly steps you must follow: (1) The square shoulder on the weight spiders must face toward the camshaft, (2) the drill point on the camshaft must align with the keyway, and (3) the specified washer thickness must be placed between the spring and spring seat.

Disassembling Hydraulic Head To disassemble the hydraulic head, first remove the retainer ring and the plunger button, then place the hydraulic head in a press as shown in Fig. 35-13. Compress the plunger spring and remove the two split retainer rings. (You may have to lift the plunger with a screwdriver in order to remove the retainer ring.) Slowly release the force and then lift the low spring seat, spring, and washer from the plunger.

Lift, in sequence, the face gear, face gear hub, plunger drive guide, thrust washer, and the plunger from the head (Fig. 35-6). Slide out the control sleeve and immediately place it on the plunger. Unscrew the delivery-valve holder. Lift out the components in the order shown from right to left in Fig. 35-14. [You may need to use a wire to lift out the spacer (not shown).]

Servicing Hydraulic Head Wash the components of the hydraulic head separately in clean diesel fuel to prevent foreign particles from contaminating the head passages and grooves.

Inspect the head for damage and cracks and for

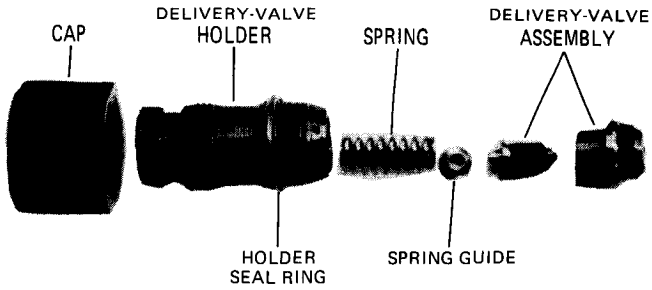


Fig. 35-14 Exploded view of delivery-valve assembly.

damaged or leaking discharge fittings. Check for scored or damaged fill port and discharge ports. If the thrust washer contact surface on the hydraulic head is scored, the head assembly must be replaced.

Check the set screw located on the side of the hydraulic head for damage and leakage. If the plunger or the sleeve bore show scratches or scuff marks, or if the spill ports, charging ports, and/or the pressure-compensating annulus or the distributor slot show wear, the head assembly must be replaced.

Check the control unit for damaged, loose, or bent levers. Make certain the shaft rotates freely within the control unit, that the plunger sleeve pin is not worn, and that the clearances are within specification.

Inspecting and Installing Camshaft After the components are washed and dried with compressed air, lubricate the bearing journals and bushings. Next, slide the camshaft into the housing.

Install the O ring on the oil tube and position it in the rear bearing plate. Place the thrust washer onto the bearing plate so that the bronze side faces toward the camshaft and the tang is locked into the bearing plate.

Install the rear bearing plate with the large cutout facing up (12 o'clock). Make certain that the oil tube and its O ring are correctly placed in the oil duct and that the rear bearing thrust plate is correctly seated in the plate, as shown in Fig. 35-15. Next, install and tighten the screws to the recommended torque.

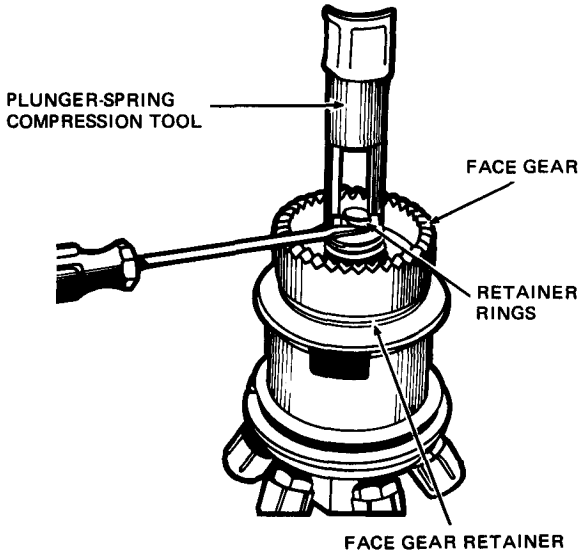


Fig. 35-13 Schematic view, removing split retainer rings. *(International Harvester Company.)*

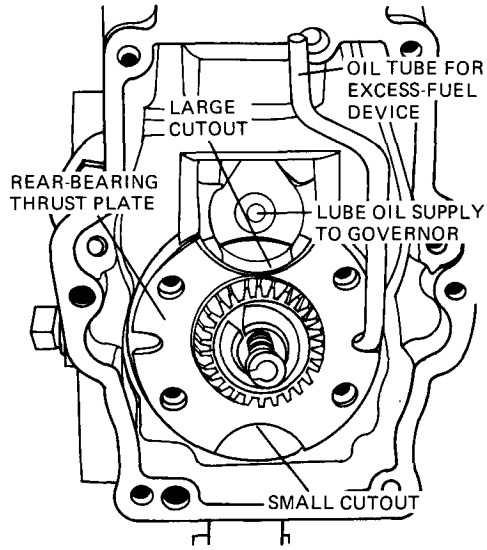


Fig. 35-15 Schematic view of rear bearing plate in the correct position.

Place the shims on the front housing and the thrust washer on the retainer plate (Fig. 35-16). (The bronze side must face toward the camshaft and the tang must be in the plate slot.) With the retainer plate in the correct position, gradually tighten the screws (alternately) to the specified torque.

NOTE: Turn the camshaft while tightening the screws. This will prevent retainer flange distortion due to tangs misaligned with slots or using insufficient shims.

After the screws are torqued to specification, measure the end play. If the end play is not within specification, add or remove shims of suitable thickness to obtain the correct end play.

Clean the tappet guide, especially its oil passages, and then check the guide and the roller. If they show ridges, score marks, and/or excessive wear on the bottom pad, replace both the guide and the roller. To determine if the bronze bearing and/or tappet bottom pad are worn beyond specification, place a ¼-in drill rod onto the bearing and measure the distance shown as *C* on Fig. 35-17. Subtract 0.250 in (shown as *B*) from the measurement. The distance (shown as *A*) should be not less than 0.158 in; otherwise the assembly must be replaced.

To check the clearance between the tappet-guide bronze bearing and the roller, turn the camshaft so that the keyway faces up (12 o'clock). Lubricate the roller and place it onto the cam parallel with the camshaft. Place a strip of Plastigage on the tappet-guide bronze bearing and insert the guide (into its bore) onto the tappet roller. With a soft punch, lightly tap the guide to flatten the Plastigage. Remove the tappet guide and measure the clearance. If the clearance is larger than specified, replace the tappet guide and/or the roller.

If the delivery valve or seats are not in perfect condition, the complete assembly should be replaced. However, it is sometimes permissible to lap the valve seat to its body seat.

CAUTION Never put lapping compound onto the relief piston or onto the fluted stem.

Carefully check the plunger drive guide and the button for cracks, grooving, or uneven wear.

Check the face gear for worn or damaged teeth, the drive hub thrust surface for wear, and the plunger guide for damage. If the plunger spring shows wear or has flat spots, the spring is bent, or the spring seat is damaged, replace the damaged component, and always replace the thrust washer.

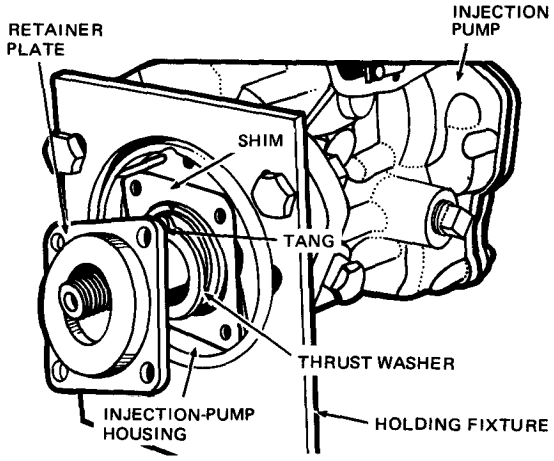


Fig. 35-16 Exploded view of front intravance support components.

Testing Delivery Valve The delivery valve of the American Bosch distributor-type injection pump must be tested for leaks as well as for its opening pressure. To make these tests, install the valve assembly (without the spacer) into the test fixture. Connect the assembly to an injector tester. Slowly increase the pressure until the valve relieves the applied pressure and then raises it again to about 50 psi [344.7 kPa] below the opening pressure. If there is a pressure drop although the connections are not leaking (and assuming the tester is in good condition), the delivery valve must be lapped or replaced. The opening pressure should be 1150 to 1450 psi [7429.2 to 9997.7 kPa]. If the opening pressure is not within this specified range even though a new delivery-valve spring is used, change the spring guide to raise or lower the opening pressure. (Spring guides are available in various thicknesses.)

Reassembling Hydraulic Head First install the delivery-valve spacer, then install the remaining components in the order shown from left to right in Fig. 35-14. Make sure before installing the valve holder

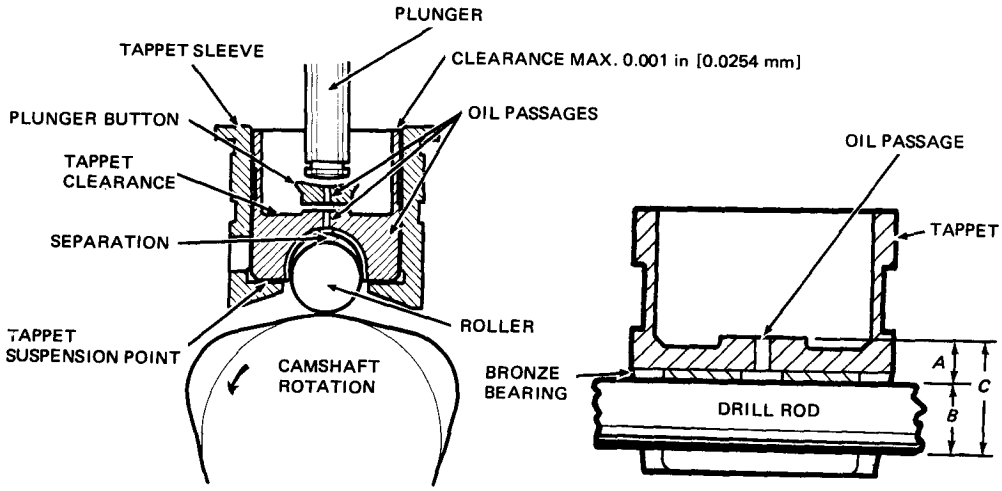


Fig. 35-17 Schematic view of tappet assembly showing check and measuring points. *(International Harvester Company.)*

that it has no nicks or burrs. Tighten it fingertight, then place the hydraulic head into the holding fixture. Place the lubricated thrust washer on the bottom of the head.

Slide the control sleeve into position with the drill marks facing upward, as shown in Fig. 35-18, and carefully, by rotating the plunger, slide it into the sleeve. Next, place the plunger guide and face gear onto the hydraulic head. Position the gear hub onto the guide so that the face gear drive pin rests in the gear hub slot. Place the face gear retainer in the groove of the face gear and head.

Check to make sure that the sleeve and plunger do not stick. If they stick, totally immerse the assembly in clean fuel. Rotate and push the plunger back and forth, and move the sleeve up and down until the plunger and sleeve move freely. Position the washer, plunger spring, and lower spring seat over the plunger. Place the hydraulic head on a press. Place the spring compression tool onto the lower spring seat and carefully compress the spring until the two retainer rings can be installed. You may have to raise the plunger in order to install the retainers. Remove the hydraulic head from the press, and install the plunger button and then its retainer. Place the assembly in clean fuel until it is to be installed into the fuel pump housing.

Servicing Transfer Pump The transfer pump must be disassembled and checked to ensure that the pump can supply the proper quantity of fuel and can pump against a pressure of 40 psi [275.8 kPa]. When the pump is disassembled (Fig. 35-19), check the internal bores for wear and grooving. Check the idler shaft and the governor drive shaft for wear, paying particular attention to the contact surface of the transfer-pump seal area. If the pump cover is damaged or grooved, or the primary check valves show wear, the cover must be replaced. Small nicks and burrs should be removed by lapping the cover and body surface. If the gear teeth indicate wear, the gears should be replaced. Always replace the governor shaft seal and the relief-valve spring. When pressing the new double-lip seal into place, use a sealing compound on the outer surface and push it flush with or slightly below the edge of the seal bore.

If the pump body and the gears are reusable, measure the gear clearance; it should not exceed the specification.

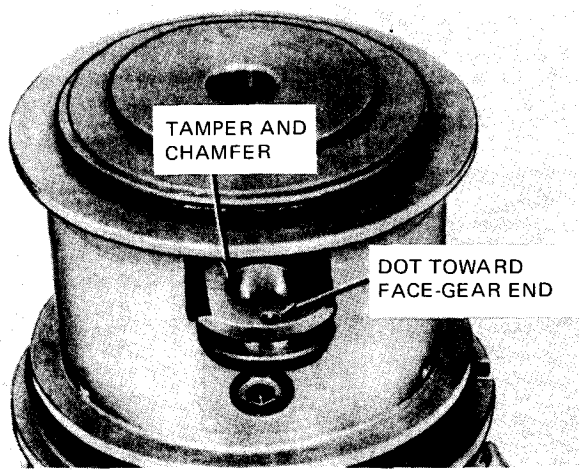


Fig. 35-18 View of control sleeve for correct position.

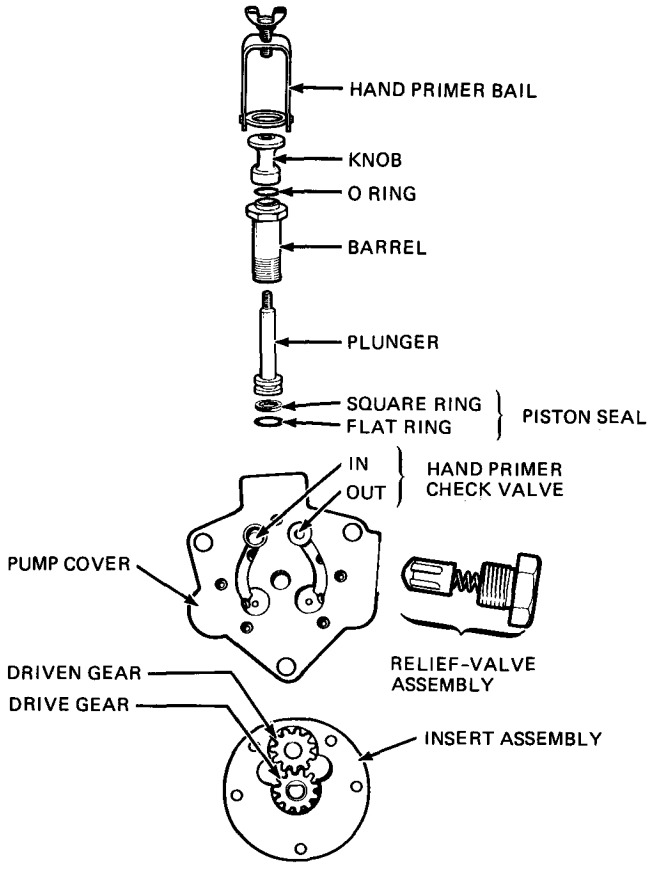


Fig. 35-19 Exploded view of transfer-pump components. *(International Harvester Company.)*

Do not forget to service the hand primer. Check the hand primer barrel for out-of-roundness, damage, and corrosion. The plunger must be free of score marks and must slide freely (without the O rings) in the barrel. Check the threads of the barrel and the plunger for damage.

Reassembling Transfer Pump Dip all components in clean diesel fuel. Place the idler gear and the drive gear so that the chamfer faces toward the body counterbore. Install the hand-primer check valve, if removed. Apply a thin coat of sealant to the sealing surface of the cover. Place the cover on the body. Misalignment is impossible as the bolt holes in the cover and body will line up in one position only. Do not forget to torque the screws to the specified torque.

Lubricate the relief valve and install the components in the order shown in Fig. 35-19. When the transfer pump is assembled and the hand primer installed, the pump should be tested for leakage as shown in Fig. 35-20.

Servicing Governor The governor components must be thoroughly checked for wear. If the weight assembly (weight spider), the levers, or the pins have a loose fit, or if the weight fingers have flat spots, they must be replaced.

Replace the thrust bearing and thrust washer if they show signs of wear. If the sleeve is scored, the bush-

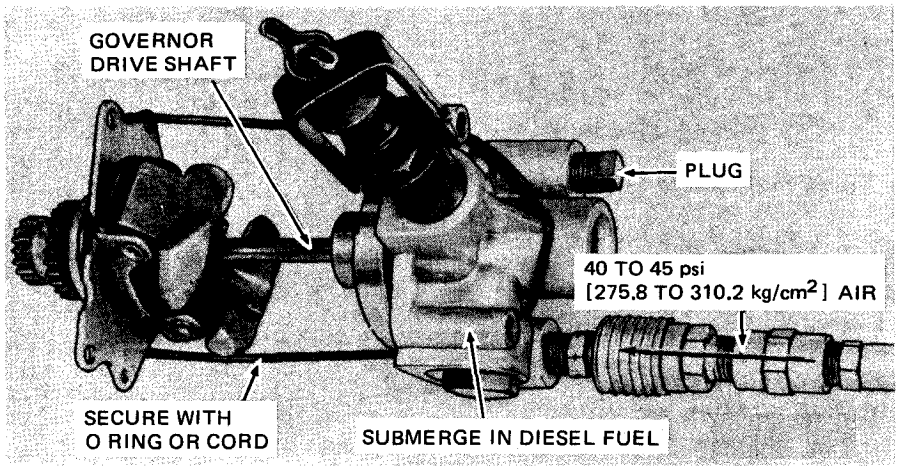


Fig. 35-20 Testing transfer pump for leakage. *(International Harvester Company.)*

ing worn, or the guide slots rough, replace the whole sleeve. It is essential that the sleeve should slide freely on the weight shaft and on the fulcrum pivot pins.

If the throttle-linkage holes are out-of-round or too loose, replace the operating lever. The recommended procedure is to replace the low- and high-idle spring and the spring seats or spacers if they are worn or damaged. If the spring disk or the friction drive spiders are bent, broken, or cracked, they must also be replaced. Always replace the ball bearings and bearing bushing. Check the governor drive gear for damage and chipped teeth. If the governor drive shaft is bent, scored, or worn (especially at the transfer-pump seal area), it should be replaced. Replace the lube pickup when the tip surface is worn (Fig. 35-21).

Reassembling Governor To assure a smooth pulsationfree governor drive, the assembled friction drive must be measured and the pack must be within specification (see Fig. 35-22). When you have this assurance, install the components to the drive shaft.

NOTE: When pressing the bearing into position, press on the outer race only, and take care not to distort the support plate.

When the unit is assembled, clamp the weight assembly (spider) in a soft-jaw vise. Place a $^{15}/_{16}$-in box-end wrench over the drive gear and, with the special wrench, torque the drive gear nut to specification (Fig. 35-23). To measure the friction-clutch slipping torque, lubricate the contact area of the friction drive spider with engine oil. Place a socket with a pound-inch torque wrench over the face-gear drive gear. Rotate the drive gear at 30 to 50 rpm through several complete revolutions using the torque wrench, and continuously observe the torque scale. The slipping torque should be between 30 to 40 lb·in [3.4 to 4.8 N·m]. If the friction-clutch slipping torque is higher, a spacer must be added and when it is lower, a spacer must be removed from the friction drive. If the slipping torque is within specification, lock the nut to the lock cup.

Reassemble the remaining governor components with the exception of the transfer pump (Fig. 35-24). When you install the governor housing to the injection pump, apply the recommended gasket sealer to both sides of the new governor gasket. Position the keyway and the beveled tooth on the governor drive gear to exactly 12 o'clock. Place the gasket on the governor housing, then install the governor to the injection-pump housing. Be careful not to bend or damage the control rod or the lubrication-oil-supply tube. Torque the new long lock screws to specification.

Installing Hydraulic Head Rotate the camshaft so that the keyway faces up (12 o'clock). Place a well-lubricated square O ring into the bore of the hydraulic head. Align the location slot in the flange of the hydraulic head with the tongue of the locating plate. Then rotate the face gear until the timing line on the gear is aligned with the raised timing mark in the timing window. Now, carefully slide the head into the pump housing. Be especially careful not to damage the O ring. Rotate the head slightly out of position to install the four head retainer screws. Tighten these screws fingertight.

Realign the slot with the locating plate. Realign the line mark on the face gear with the raised mark in the timing window. While tightening the head retaining screw, rock the camshaft back and forth. This assures a smooth meshing of the face gear teeth with those of the governor gear. Remember that the keyway must be at the 12 o'clock position and the line mark must align with the mark in the timing window when the head screws are torqued to specification.

When installing the control unit make sure that the O ring is well lubricated. The plunger sleeve and the plunger sleeve pin must be in the lowest position but the pin dot must face up.

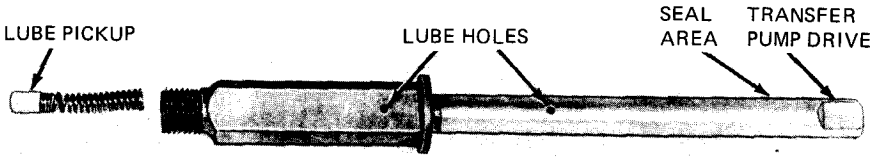


Fig. 35-21 View of governor drive shaft.

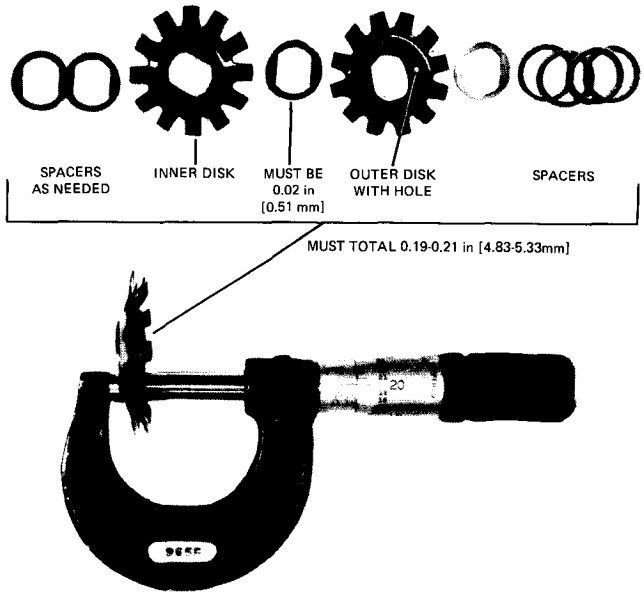


Fig. 35-22 View of friction-clutch components and measuring clutch pack thickness.

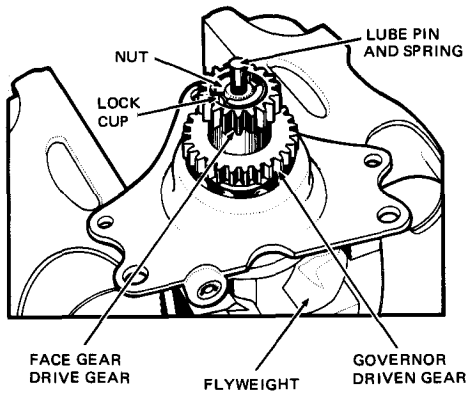


Fig. 35-23 View of governor drive assembly. *(International Harvester Company.)*

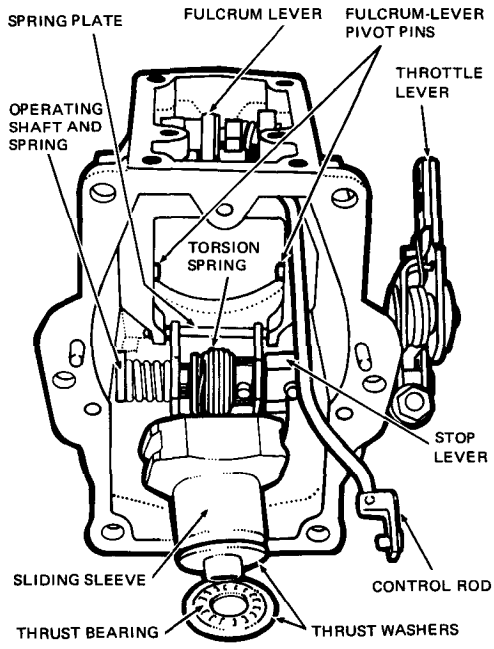


Fig. 35-24 Schematic view of semiassembled governor position to install sliding sleeve. *(International Harvester Company.)*

To check that the plunger sleeve pin is positioned properly, rotate the control unit shaft. When it can be rotated 360°, the pin is correctly positioned.

Slide the control rod pin into the bore of the control arm and install the control unit plate. Now, measure the clearance between the control rod and plate (Fig. 35-11) using a feeler gauge. If the clearance is larger than specified, use a larger offset plate to bring it to specification. Do not forget to lock-wire the two control unit plate screws.

Installing and Adjusting Governor Springs Turn the injection pump so that the transfer-pump end faces you. Move the control lever to the low-idle fuel position. Next, check that the governor weights are closed and that the thrust washer and bearings are seated flat on the governor sleeve. When this is done, place the inner spring (high speed) into the sleeve bore, place the adjusting spacer and spring seat on the spring, and position the governor-spring adjusting tool (Fig. 35-25).

When the spring gauge is positioned properly and the inner spring gauge rests lightly against the spring guide, read the distance from zero to the last visible millimeter graduation. This is the measurement of the inner spring gap. If necessary, remove or add spacers to meet the gap specification. Check with your service manual or injection-pump test specification for the correct measurements.

When you have adjusted the inner spring gap, place the outer spring spacer and the outer spring (low speed) onto the sleeve shoulder and then place the spring seat on the spring.

Reinstall the governor-spring adjusting tool. Be sure there is no space between the inner face of the tool and the spring seat. Record the millimeter reading on the inner spring gauge. Press the outer spring gauge against the governor housing and reread the gauge. The compression of the outer spring is the difference between these two readings. If adjustment is necessary, remove or add spacers in order to increase or decrease the outer compression rate of the spring.

Installing Transfer Pump Place the outer spring seat in the bore of the transfer pump and a new O

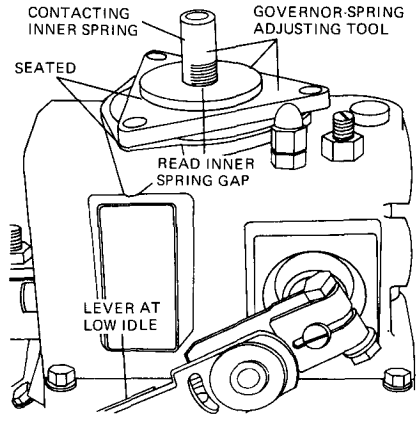


Fig. 35-25 Schematic view of measuring high-speed (inner) spring gap. *(International Harvester Company.)*

ring in the groove of the pump body. Lubricate the O ring, the end of the drive shaft, and the double-lip seal before you place the pump on the governor housing. Turn the drive shaft slowly to engage the flat side of the governor drive shaft with the flat side of the transfer-pump drive gear. Do not use force or tilt the pump housing during the alignment because this will damage the seal. The screws must always be torqued to specification. When this has been done, turn the drive shaft to check that the transfer-pump gears turn freely.

Spill-timing for Port Closure and Measuring Plunger Lift-to-port Closure When the injection pump is assembled, the plunger lift-to-port closure must be measured and, if necessary, adjusted. The injection pump must then be spill-timed and, if necessary, the timing line remarked on the drive hub. To measure the plunger lift, first remove the delivery-valve assembly and install the plunger-lift measuring tool in place of the delivery valve (see Fig. 35-26). Install a swan neck pipe to the No. 1 discharge fitting and a fuel filter to the inlet fitting. Also loosely install the port-closure locking plug if used.

Align the timing mark of the face gear with the raised mark in the timing window. This should bring the keyway on the camshaft to the 12 o'clock position and the tappet on the base circle. Now zero the dial. Next, place the throttle in the idle position. Turn on the fuel to remove air from the reservoir and passage within the hydraulic head. When only fuel leaves the swan neck pipe, move the throttle to the full-fuel position. Rotate the camshaft slowly in the direction specified until you have found the point of port closure, that is, when one drop falls within 5 to 10 seconds from the swan neck pipe. In this position read the dial indicator. The dial-indicator reading is the plunger lift-to-port closure. It should be 0.123 to 0.209 in [0.60 to 0.75 mm].

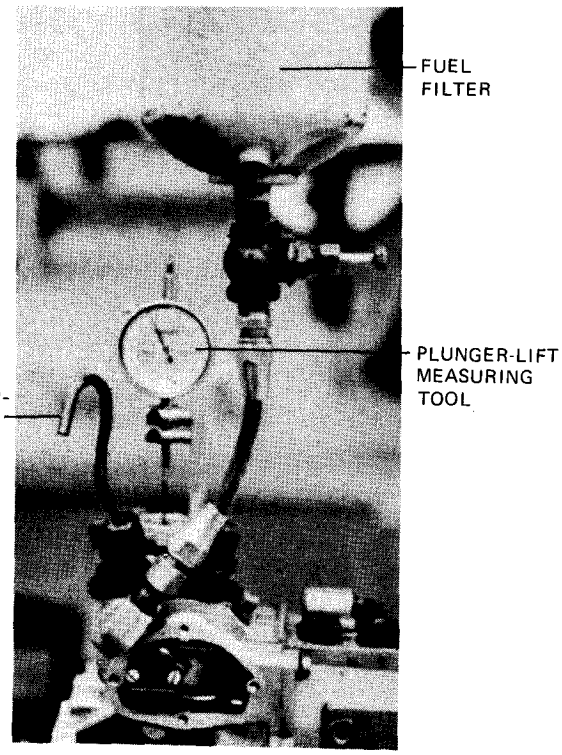


Fig. 35-26 Tools installed for measuring port closure.

NOTE: When you check the port closure, make certain that the intravance is fully retarded, that is, that the followup rod is fully extended.

If the plunger lift-to-port closure is not within specification, say it is 0.80 mm, you must remove the hydraulic head and replace the plunger button with one having a dimension at least 0.05 mm more than the original. Repeat the spill-timing and remeasure the plunger lift.

When plunger lift-to-port closure is within specification, spill-time the injection pump again and inscribe a line on the drive hub to coincide with the pointer. Make sure that the old mark is removed, then remove the plunger-lift measuring tool and reinstall the delivery-valve assembly.

Pressure-testing Injection Pump The injection pump must always be tested for fuel leaks. Leaks can occur at the top of the housing and head flange, at the control unit, or at the index plate screw. To make the test, connect an injector tester to the inlet fitting and plug the return fitting with a ¼-in NPT plug. Pressurize the hydraulic head to 400 psi [2758 kPa] and check for any external leakage. If the pressure drop is rapid but no external leaks are noticeable, there may be a leak at the lower O ring, the plunger and barrel may be excessively worn, or the housing may be cracked. *(NOTE: Wetness at the control unit is permissible but no droplets should form.)*

Mounting Pump to Test Stand Secure the injection pump to the test stand, making certain that the pump is properly aligned and that there is a slight clearance between the test-stand and the injection-pump drive couplings. Connect the lubrication-oil-supply pump to the injection pump. Switch on the lubrication-oil-supply pump and adjust the pressure to 40 psi [275.8 kPa]. There must be no oil leakage. (Lubrication oil when mixed with the test fuel will change the fuel viscosity.)

Connect a hose from the lift fitting on the test stand to the inlet side of the transfer pump. With another hose, connect the outlet side of the transfer pump to the 2.5-μm (micrometer) final-stage filter. Two more hoses will be required in order to connect the filter to the hydraulic head inlet fitting and the overflow valve to the return fitting on the test stand.

Be certain that you have the correct test injector and that the opening pressure is adjusted properly. Connect the injection lines to the injector holder and to the discharge fitting on the hydraulic head (Fig. 35-27). The first injector holder corresponds to the first cylinder in the firing order and so on, respectively. Make sure that you use injection lines of the specified length and the correct inside diameter.

Checking and Adjusting Injection Pump Assuming the test stand is in good working order and the test fuel meets specification, measure and adjust the torque cam nose. To do this, remove the governor cover and turn out the droop screw and the high-idle adjusting screw. Rest two feeler gauge blades

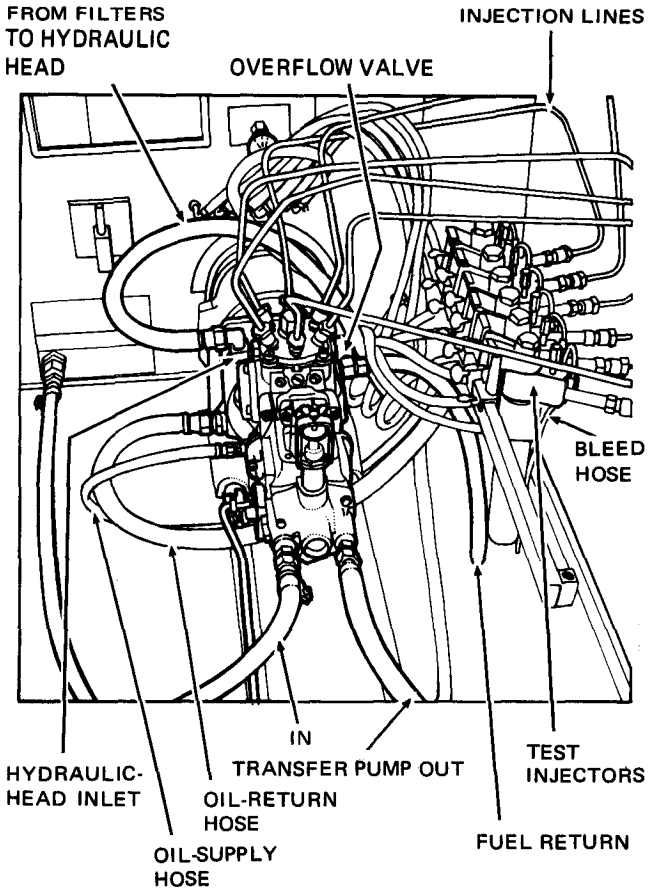


Fig. 35-27 Schematic view of injection pump installed to test stand. *(International Harvester Company.)*

against the cam nose as shown in Fig. 35-28, then withdraw the gauge and measure its angle with a protractor. (All test specifications given in Tables 35-1 and 35-2 are hypothetic.)

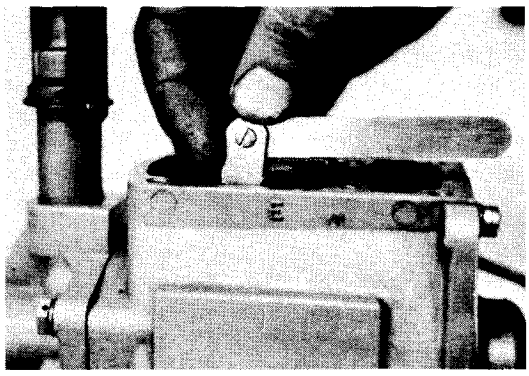


Fig. 35-28 Measuring torque-cam angle.

TABLE 35-2

ANEROID CUTBACK DELIVERY

Speed	Fuel-delivery aneroid open to atmosphere, cm^3 per 1000 strokes
2800 Ref.	80
2800 Ref.	70

If an adjustment is required, use the support block to support the fulcrum lever while loosening the cam-nose retaining nut. After making the adjustments, install the special governor cover so that you can observe the governor and the action of the excess fuel device.

Start the lubrication-oil-supply pump. Readjust the pressure, if necessary. At the same time, check the action of the excess fuel device. Within 15 seconds the stop plate must move to its full outward position. Stop the lubrication pump and note the retraction of the excess fuel device. Repeat this several times to ensure that the excess fuel device operates smoothly. Next, bleed the air from the injection pump by using the hand primer through the open bleed screw at the injector holders. Energize the shutoff solenoid or move the mechanical shutoff into the run position. Switch on the drive motor and set the throttle to the low-idle position. With the injection pump camshaft turning at low speed (500 rpm), set the throttle to the full-fuel position. When all the air has been removed from the injection lines, close the bleed screw on the injector holder and warm up the injection pump and test fuel.

Functional Test of the Shutoff Devices To check the operation of the electrical or mechanical shutoff device, operate the test stand at rated rpm and bring the throttle to full-fuel position. Now de-energize the electric circuit, or pull out the Bowden cable. The fuel delivery should stop immediately.

Flow-testing Torque Check-speed When the test fuel temperature is about 110°F [43.3°C], set the counter to 2000 strokes (since two camshaft revolutions are required to provide a single injection from each head outlet). Set the throttle to the full-fuel position and increase the test-stand rpm to torque check speed (2100 rpm). At this pump speed, the cam nose should be in contact with the stop plate and the transfer-pump pressure as specified. Now, trip the counter and observe the fuel rate. The average fuel delivery of all six injectors should be within specification (102 ± 3.5 cm^3) (Table 35-1). If the fuel delivery is lower

TABLE 35-1

TEST BENCH DATA

	Rated speed	Torque check speed	Droop check speed	Low-idle speed	High-idle speed	Cranking speed
Pump speed, rpm	2800	2100	1400	625	3080	150
Fuel delivery, cm^3 per 1000 strokes	100±2	102±3.5	102	19	24	120

or higher than this, you must adjust the stop plate. To reduce the travel, move it away from the head. When making this adjustment, take care not to bend or twist the stop-plate screw or the guide. Use the stop-plate support bar (Fig. 35-29). Recheck the fuel delivery at the torque check speed.

Flow-testing Rated Speed To check the fuel delivery at rated speed, increase the test-stand speed to the rated speed (2800 rpm). Trip the counter and measure the fuel delivery. The average fuel delivery should be 100 ± 2 cm^3 (Table 35-1). If the average delivery is higher than specified, the governor spring gap must be rechecked. When the gap is correct, change the torque cam angle slightly.

To adjust the high-idle adjusting screw, increase the pump speed by 80 rpm (to 2880 rpm) and then turn the high-idle adjusting screw until the cam nose just moves off the stop plate.

To check the governor cutoff speed, increase the test-stand speed 17 percent above high idle, that is, 3604 rpm, and trip the counter. The average fuel delivery must not exceed 4 cm^3.

Droop-speed Adjustment To measure fuel delivery at droop speed, reduce the test-stand speed to droop check speed (1400 rpm) then trip the counter. The average fuel delivery should not exceed 102 cm^3. If the fuel delivery is incorrect, loosen the droop-screw adjusting locknut and turn the screw in or out to reduce or increase droop-speed fuel delivery (Fig. 35-28).

Low-idle Speed Adjustment To adjust the low-idle speed, decrease the test-stand rpm to low idle (625 rpm). Trip the counter. The average fuel delivery should be 19 cm^3. If the fuel delivery is too high, turn the low-idle adjusting screw counterclockwise; if it is too low, turn the adjusting screw clockwise. When the adjustment is made, lock the adjustment with the locknut.

Check Starting Fuel Delivery and Aneroid To check the starting fuel delivery, remove the governor cover, clamp the excess fuel device in the start position, and place the throttle in full-fuel position. Operate the test stand at 150 rpm and trip the counter. The average fuel delivery should be 120 cm^3. If this value cannot be achieved, it indicates a worn plunger and hydraulic head bore and the hydraulic head must be replaced.

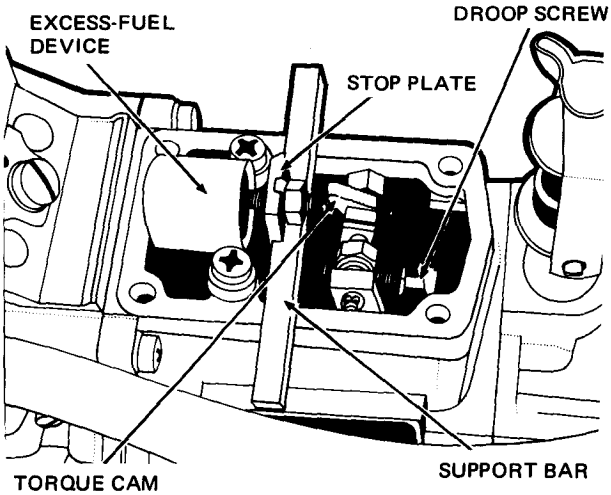


Fig. 35-29 Schematic view of stop-plate support bar installed. *(International Harvester Company.)*

To check the operation of the aneroid, remove the clamp from the excess fuel device and install the governor cover. Operate the test stand at the rated speed (2800 rpm) with the throttle in full-fuel position. Apply 20 psi [137.9 kPa] to the diaphragm. Trip the counter and the fuel delivery should equal rated fuel delivery, that is, 100 ± 2 cm^3. Next, reduce the applied pressure to 10 psi [68.95 kPa] and again trip the counter. The fuel delivery should remain the same. Next, remove all the pressure from the aneroid and trip the counter. The fuel delivery should be 80 cm^3. Reduce the test-stand rpm to 2000 rpm and again trip the counter. The fuel delivery should be 70 cm^3. If you cannot achieve the results mentioned above, the combination excess fuel and aneroid device must be replaced.

Checking Intravance To check the operation of the intravance, run the test stand at idle speed, switch on the pressure phase switch, and set the degree wheel on No. 1 injector to zero. Gradually increase pump speed to high idle. Observe when the advance starts and at what speed the camshaft has fully advanced (14°). If the advance starts too early, you must add a washer between the spring seat and spring. If it starts too late, you must install a thinner washer.

Your final adjustment is to position the throttle shaft lever on the throttle shaft according to the engine application. This ensures that the throttle can be placed in high and low position without interference. (See specific service manual for this adjustment.)

Installing Injection Pump to Engine Position the engine timing mark (with the No. 1 piston on the compression stroke) and align the pump hub line with the pointer. Then mount the injection pump to the engine. Place the drive gear on the drive hub while meshing the gear teeth and timing gear teeth. *(NOTE: The gears do not need to be timed.)*

Holding the camshaft, install and tighten the drive gear bolts. To recheck the timing, remove the port-closure timing plug and install the regular plug. Rotate the engine crankshaft about 45° counterclockwise, and then slowly rotate it in a clockwise direction until the engine timing marks are aligned. Next, check the drive hub timing.

Install the fuel supply and fuel return lines, lubrication lines, and injection lines. Also install the throttle and the components, covers, etc., which were previously removed.

Bleed the system. Leave the injection lines loose at the injector holder. Crank the engine until fuel leaves the injection line, and then tighten the connection. Start the engine and bring it to its operating temperature. Check the high- and low-idle speed, making any necessary adjustments.

Questions

1. List differences between the Stanadyne diesel systems' fuel injection pump and the American-Bosch distributor-type injection pump.
2. Explain how the intravance changes the beginning of injection.
3. What is the difference (in regard to the most significant operation) between the intravance and the TMF timing device?
4. Describe the mechanical action within the injection pump during camshaft rotation.
5. Explain the pumping, metering, and distributing action from the point where the camshaft forces the plunger upward to the point where the tappet roller again rests on the base circle of the camshaft.
6. How would you increase the end play of the camshaft?
7. Why is there a specified clearance between the tappet guide and roller?
8. Why is it so essential for the opening pressure of the delivery valve to be within specification?
9. What checks must be made and what precautions must be taken when you reassemble the hydraulic head?
10. Outline the procedure to check for leaks in the transfer-pump check valves.
11. What would occur if the slippage torque of the friction drive was less than specified torque? What would happen if it was more than specified torque?
12. Outline the procedure to install the hydraulic head.
13. Describe how to spill-time and measure plunger lift-to-port closure.
14. If (when flow-testing for rated speed) the average delivery tested out lower than specification, what checks and adjustments would then be required?
15. How is droop speed adjusted to increase fuel delivery?
16. Explain how to check the operation of (*a*) the excess fuel device and (*b*) the aneroid.

UNIT 36 • CATERPILLAR SLEEVE-METERING FUEL-INJECTION SYSTEM

The sleeve-metering fuel-injection pumps made by Caterpillar Tractor Co. are used on the 3208 and 3300 Series engines. They are comparable in metering and injection *principles* to the American Bosch distributor-type fuel-injection pump discussed in Unit 35, but otherwise are distinctly Caterpillar-designed.

The sleeve-metering fuel-injection pumps are manufactured in three models: in-line 4, in-line 6, and V 8. The first two are used on the 3300 Series engines and the V 8 model on the 3208 Series engines.

Sleeve-metering Fuel-injection System Components The fuel system comprises the components shown in Fig. 36-1. The variation which exists between the in-line and V pumps lies in the location of the components. On in-line fuel pumps the filter base, which is part of the syphon break housing and hand priming pump, is fastened to the outside of the housing cover. On the V-type fuel-injection pump, the filter and the hand priming pump are mounted separately, and the syphon break housing and the shutoff solenoid are mounted to the cover. The constant bleedoff valve, which is screwed into the syphon break housing, is an internal part of the return fuel elbow. The channel is bolted to the inside of the housing cover.

FUEL FLOW HAND PRIMING To prime the fuel-injection system, open the bleed valve and pull the hand priming knob upward. This creates a low pressure in line B and the filter housing. Fuel flows from the fuel tank into line B, then, along with trapped air, passes through the filter, past the hand primer and the inlet check valve, into the void of the priming pump piston. This action brings the disk in the syphon break housing to its lower seat. As the pressure equalizes in chamber A and line B, the priming pump inlet check valve closes. As the piston is forced downward, the outlet check valve is forced open, then air and fuel flow past the fuel pump check valve, into passage A and into the inlet side of the transfer pump. The fuel fills the entire pump housing and the air escapes through the open bleed valve. When airfree fuel leaves the valve, it is then closed, whereupon the fuel pump check-valve spring seats the valve.

FUEL FLOW—ENGINE OPERATING When the engine is operating, the gear-type transfer pump creates low pressure, and fuel flows from the tank, through the filter, through both hand priming pump check valves, into passage A, and into the transfer pump. As the gear pump teeth mesh, they force fuel into the fuel pump housing. Pressure within the housing is, therefore, increased because the constant bleed valve restricts the return flow. The constant bleed valve floats to maintain a pressure of 25 to 32 psi [172.3 to 220.6 kPa] within the fuel pump housing. Should the fuel pressure exceed 32 psi [220.6 kPa], the pressure-relief valve opens and directs fuel through passage A back to the inlet side of the transfer pump. A fuel flow of about 0.15 gal/min [0.56 L/min] passes by the constant bleed valve to provide fuel pump cooling, and to remove any air which may be in the system. When the engine is stopped and air is in the system,

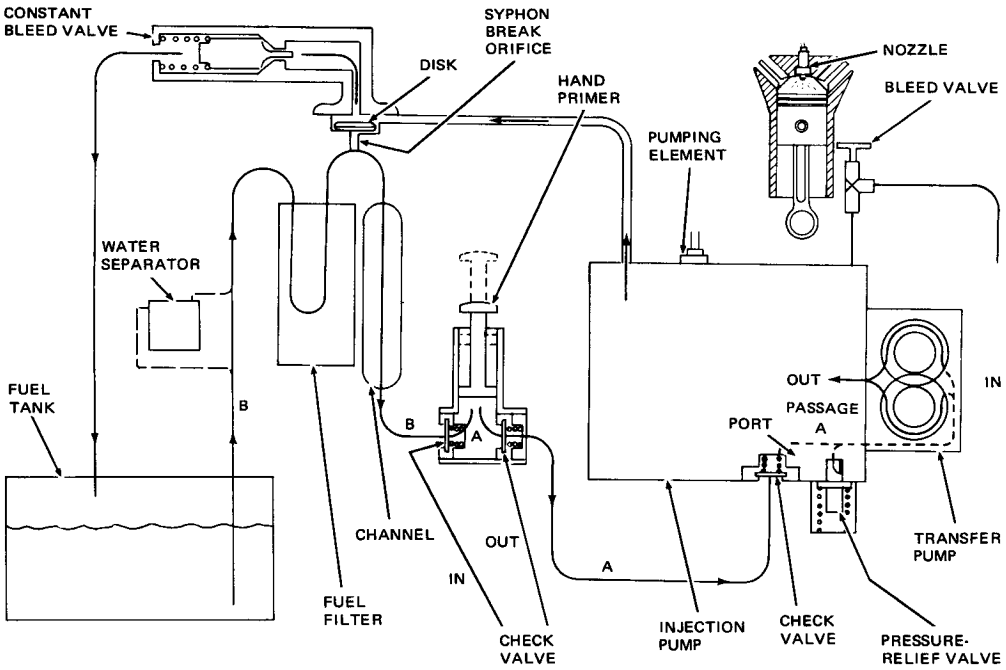


Fig. 36-1 Schematic view of a sleeve-metering fuel-injection system. *(Caterpillar Tractor Company.)*

it can escape through a passage within the syphon break housing (not shown), past the disk, and back to the fuel tank. However, fuel cannot syphon from the fuel pump housing, or filter, back to the fuel tank.

Fuel-pump and Injection-pump Design Refer to Figs. 36-1 through 36-5. The camshaft is supported by bushings in the fuel pump housing. The gear-type transfer-pump housing is fastened to the right-hand side of the fuel pump housing, and its drive gear is keyed to the fuel pump camshaft. An internal passage in the fuel pump housing connects the fuel inlet with the transfer-pump inlet. The camshaft is driven through a drive gear or the mechanical variable-timing gear. The drive gear is fastened, through a cap screw, to the tapered sleeve which is splined to the right-hand end of the camshaft, or the variable-timing flange is fastened to the camshaft. *(NOTE: The mechanical variable-timing unit is comparable in design to the unit used on the 3406 engine except that the flange has a tapered bore.)* The camshaft end is sealed by two back-to-back seals located in the transfer-pump housing. The flyweight assembly is bolted to the left-hand side of the camshaft. The mechanical governor is standard; the Woodward PSG governor is optional. The two-piece roller-type lifters are supported in their housing bores and held in alignment through a pin which rests in the lifter groove (Fig. 36-4).

Each injection-pump element consists of a retainer, bushing, bonnet, check valve, spring, barrel, plunger, sleeve, and plunger-return-spring lower spring seat

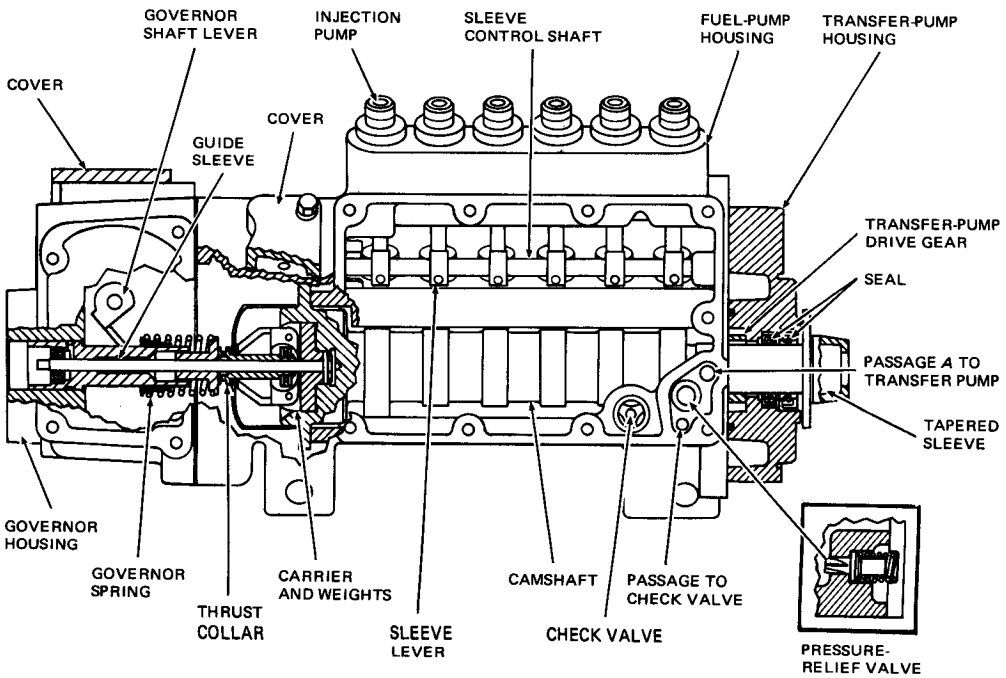


Fig. 36-2 Schematic view of a six-cylinder fuel-injection pump. *(Caterpillar Tractor Company.)*

(Fig. 36-3). These components are similar in design to the American Bosch distributor-type pump. The plunger is also center-drilled and has two cross-drilled holes (the fill and spill ports.) The precision-lapped sleeve is again similar to the American Bosch type except that the sleeve operates on the lower end of the plunger and the barrel has no passages or ports.

When the injection pump is assembled and positioned in the fuel pump housing, the barrel rests against the housing shoulder, the lower spring seat is hooked into the plunger groove on which one end of the spring rests, and the other spring end fits over the barrel. The bonnet is held to the barrel by the ring. The control sleeve, located on the plunger, is positioned by the fork between the spring seat and lifter. The fork is clamped to the control shaft and rests in the sleeve groove. The lower end of the plunger rests on the top of the wear button and the lifter roller rests on the camshaft. The assembly is held to the fuel pump housing through the bonnet and retainer bushing (Fig. 36-4).

PUMPING PRINCIPLE When the throttle is in the no-fuel position, the sleeve is moved (by the control shaft and fork) below the spill port (Fig. 36-5*b*). The plunger area remains pressurized since equal pressure exists at the spill port and within the fuel pump. As the plunger is forced upward through the action of the cam lobe and lifter, the plunger fill port closes. The spill port remains uncovered. Fuel in the barrel is displaced by the plunger and released out of the spill port until the plunger is at TDC. As the plunger is forced down by the plunger spring, fuel flows through the spill port and fills the area vacated by the plunger.

When the throttle is being moved to the idle, the half-fuel, or the full-fuel positions, the control shaft and fork move the sleeve to cover the spill port (Fig. 36-5*c*). At idle position the sleeve's upper edge barely covers the upper edge of the spill port (Fig. 36-5*d*). With an advance in throttle setting, the sleeve is moved further upward, thereby increasing the distance from the upper edge of the sleeve to the upper edge of the spill port, thus increasing the effective stroke.

In the fuel-on position, regardless of the position of the sleeve, only the fill port is open (Fig. 36-5*a*). As the plunger moves upward and the fill port closes, the fuel pressure in the passage within the plunger and the area above quickly increases and lifts the check valve off its seat (Fig. 36-5*c* and *d*). This, in turn, increases the pressure in the injection line until the force on the nozzle valve overcomes the spring force. As soon as the upper edge of the spill port passes the upper edge of the sleeve, the fuel spills back through the spill port (Fig. 36-5*e*). This reduces the fuel pressure, causes the check valve to seat, and ends injection. The plunger continues ascending until it reaches TDC, during which time the displaced fuel leaves through the spill port. As the plunger moves downward, fuel can enter through the spill port until it is closed by the sleeve. There is a short distance of plunger travel when no fuel can enter the plunger

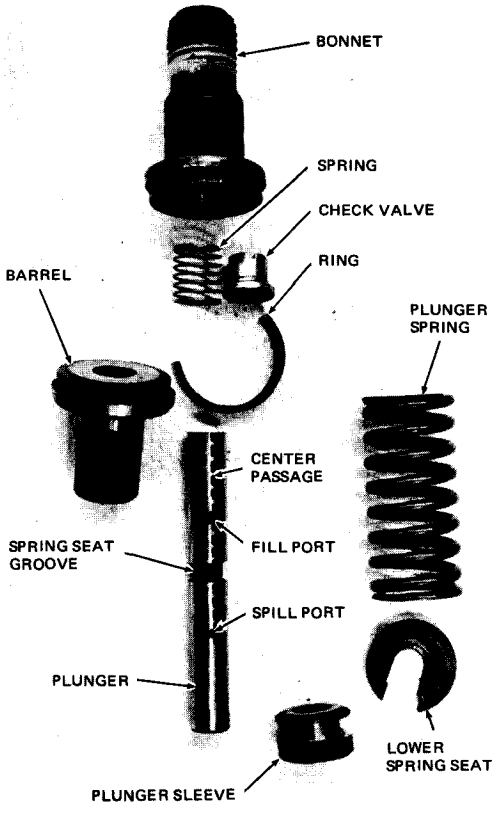


Fig. 36-3 Exploded view of one fuel-injection-pump element.

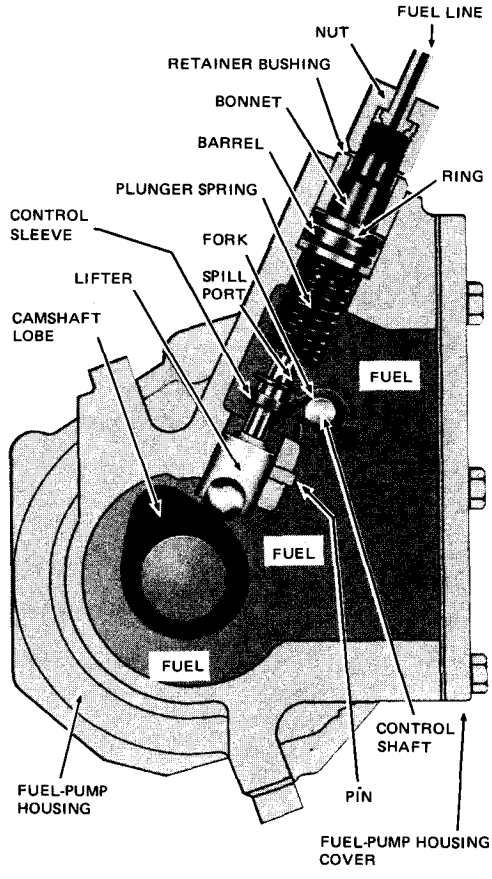


Fig. 36-4 Schematic view of injection pump installed. *(Caterpillar Tractor Company.)*

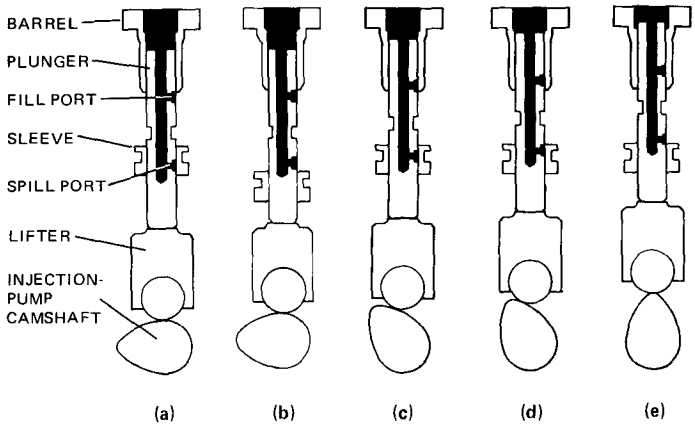


Fig. 36-5 Schematic view of control sleeve in various positions. *(Caterpillar Tractor Company.)*

area. This is the period between the closing of the spill port and the opening of the fill port.

Governor Operation Although the mechanical governor used with the sleeve-metering injection pump differs somewhat from the other mechanical governors (see Figs. 36-2 and 36-6), the governor spring and weight assembly measure the engine speed and through the raiser change the position of the various levers in order to increase or decrease the fuel quantity injected per cycle.

When the engine is operating and the throttle is moved to the full-fuel position, the force on the governor spring increases, the flyweights collapse, and the raiser is forced to the right. This action causes the governor shaft and lever, and the load stop lever, to semirotate. The load stop lever moves the load stop pin upward, and the governor lever semirotates the control shaft lever, control shaft, and fork. The fork and sleeve move upward to increase the effective stroke. The maximum allowable travel of the raiser and, therefore, the control shaft, is reached when the load stop pin compresses the torque spring (Fig. 36-7*a*) or butts against the adjusting screw (Fig. 36-7*b*).

Any changes in the spring force due to throttle shaft movement, or in the weight force due to increased or decreased load on the engine, are directly transmitted to the load stop lever and governor lever and cause the control shaft, fork, and sleeve to move up or down on the plunger.

One significant feature of the sleeve-metering mechanical governor is that its weight assembly is bolted to the camshaft, which is therefore driven at camshaft speed.

The fuel-ratio control is indirectly linked to the governor shaft, thereby limiting the movement of the governor lever.

The governor used on the V 8 fuel pump is generally similar to the in-line fuel pump governor, but the semirotation of the right-hand control shaft (on the V 8) is transmitted over two link levers fastened to each control shaft (Fig. 36-8).

ADJUSTABLE AND NONADJUSTABLE DASHPOT GOVERNORS All recently manufactured fuel pumps are

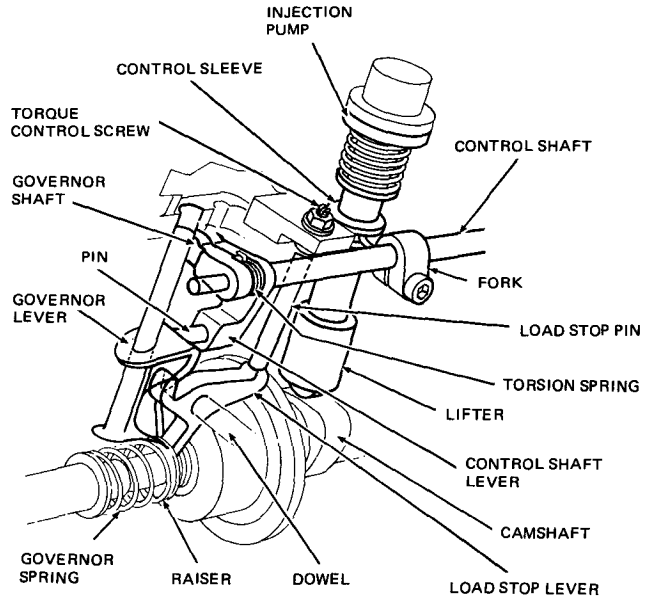


Fig. 36-6 Schematic view of governor. *(Caterpillar Tractor Company.)*

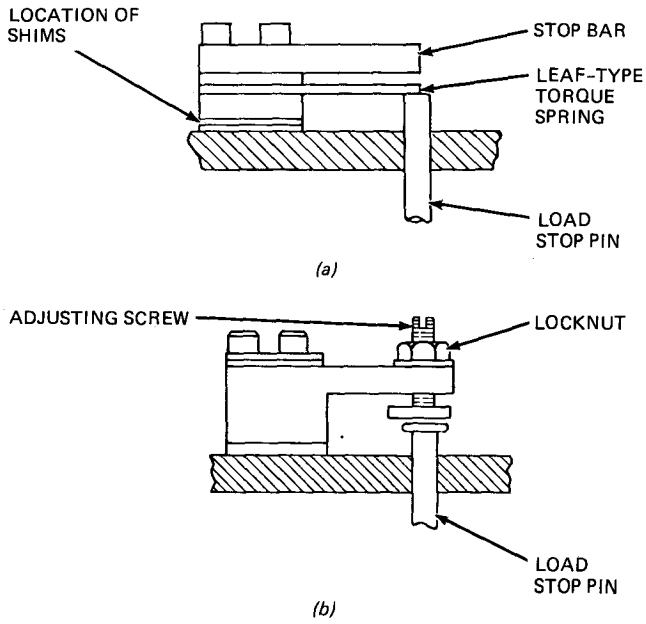


Fig. 36-7 Fuel-injection system setting (adjustment): (*a*) leaf-type torque spring, (*b*) adjusting screw. *(Caterpillar Tractor Company.)*

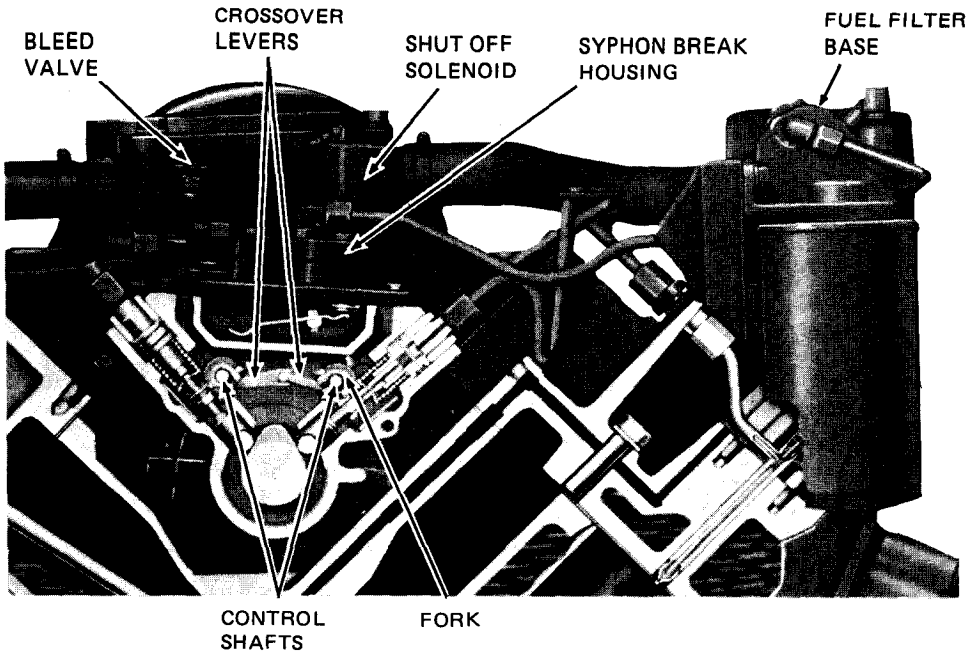


Fig. 36-8 Schematic view of control shaft linkage. *(Caterpillar Tractor Company.)*

equipped with adjustable or nonadjustable dashpot governors. Fuel pumps used on electric sets use the adjustable dashpot governor.

The purpose and design of the dashpot governor assembly is the same as the dashpot governor assembly used on the 3400 Series engine except that fuel is used as the power source on the sleeve-metering fuel pump instead of lubrication oil.

The dashpot assembly consists of the components shown in Fig. 36-9. The cylinder has replaced the guide sleeve to accommodate the dashpot assembly. The dashpot seat rests against the raiser and the governor spring rests against the seat.

When the engine is operating at a constant rpm, the fuel pressure within the fuel pump and dashpot piston chamber are equal. When the dashpot seat is moved through the action of the throttle and governor spring, or is moved through the action of the flyweight and raiser, the dashpot piston (through its spring) is forced to the left or right. However, because of the fuel restriction caused by the orifice, the fuel pressure in the dashpot chamber then increases, and therefore restricts the movement of the dashpot piston. Subsequently, the dashpot spring force onto the seat and the raiser increases, thereby stabilizing the raiser movement and thus reducing rpm oscillation during engine load or speed changes.

The adjustable dashpot governor uses a needle valve instead of the fixed orifice.

Servicing Sleeve-metering Fuel-injection Pump The tests and checks outlined for fuel-injection service in Unit 30 apply to the sleeve-metering pump. The fuel pump should never be removed for service unless the failure is specifically diagnosed as being in the injection pump.

After you conclude that the problem is in the fuel pump, position the No. 1 piston at TDC on compression stroke, and then remove the fuel pump from the engine. Thoroughly clean the fuel pump and mount it in a holding fixture. Remove the side cover, the check valve, and the bypass valve (Fig. 36-10).

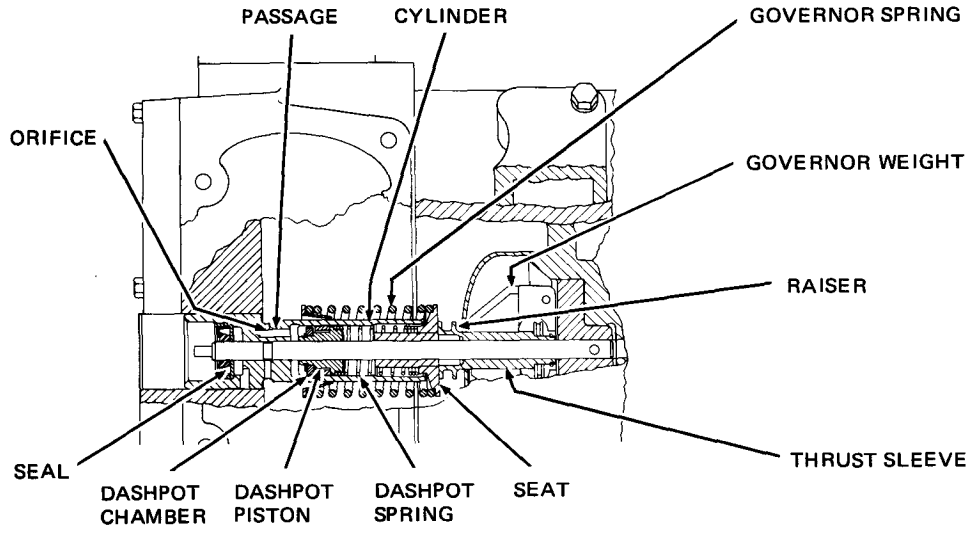


Fig. 36-9 Schematic view of a dashpot governor. *(Caterpillar Tractor Company.)*

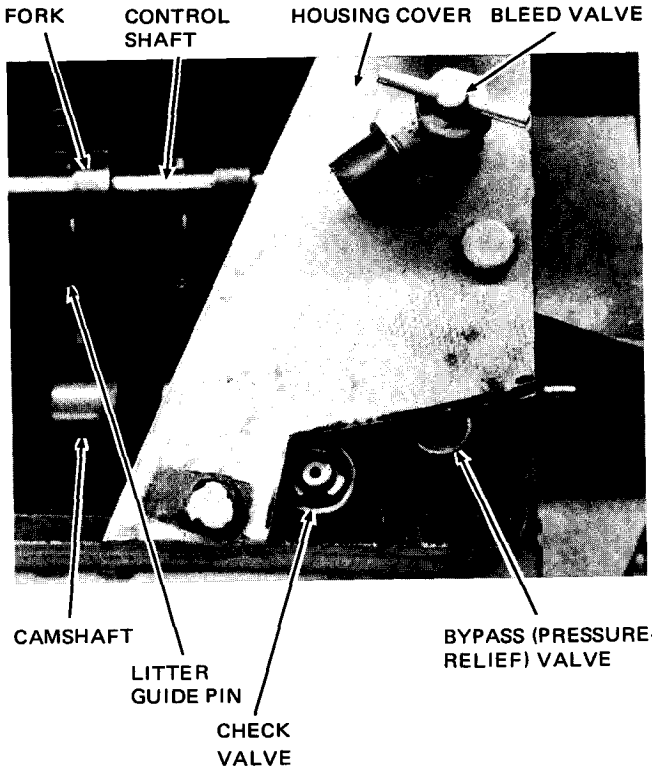


Fig. 36-10 Side view of fuel pump.

NOTE: If not thoroughly experienced with Caterpillar pumps, refer directly to your service manual before proceeding with further service. Highlights, only, are outlined here.

Remove the pumping elements by removing the retainer bushing and lift out the pumping element. The fork will slide out of the sleeve as you lift the pump element out. At this time do not disassemble it; place it in clean fuel.

To disassemble the element, carefully pull on the spring to remove it and the plunger from the barrel.

CAUTION Take care not to nick the plunger during removal.

Remove the ring to separate the barrel from the bonnet. Lift out the check valve and spring. If the plunger shows any sign of surface damage on the areas where it contacts the sleeve, the lifter, the barrel, or the edges of the fill/spill port holes, the assembly must be replaced.

If the components appear to be reusable, measure and test the plunger spring, and lap the mating surfaces of the bonnet, barrel, and check-valve seat. Clean the plunger and the barrel following the procedures outlined for port and helix injection pumps.

Wash all components in clean fuel. Assemble them in the order indicated in Fig. 36-4.

NOTE: The groove on the sleeve must face toward the fill port; no other alignment or timing is necessary.

Keep the elements in clean fuel until you are ready to install them.

SERVICING TRANSFER PUMP To remove the transfer pump, install the timing pin to hold the camshaft, and then thread the bolt into the drive sleeve. Tighten the bolt and pull the sleeve from the splined end of the camshaft (Fig. 36-11).

Remove the mounting bolts and lift the transfer-pump assembly from its housing. If the wear marks from the gears (on the inlet side of the pump) are past 2 o'clock, the body must be replaced because this indicates the shaft or the bores are worn beyond their limit. If the transfer-pump housing surface is worn slightly, refinish the surface with an oil stone. However, if the damage is significant, the pump housing must be replaced.

Always replace the seals. The lip of the inner-lip seal must face toward the gear. The lip of the outer-lip seal must face outward.

SERVICING GOVERNOR When the governor requires service, remove the governor housing cap screws which attach it to the fuel pump housing and then lift off the governor housing (Fig. 36-12). Remove the torque spring cover, torque spring assembly, and

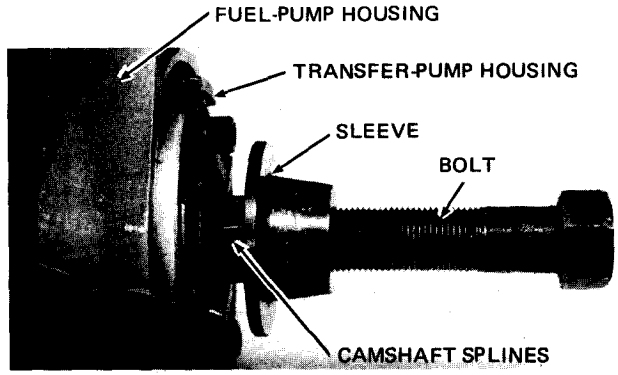


Fig. 36-11 Removing drive sleeve from camshaft.

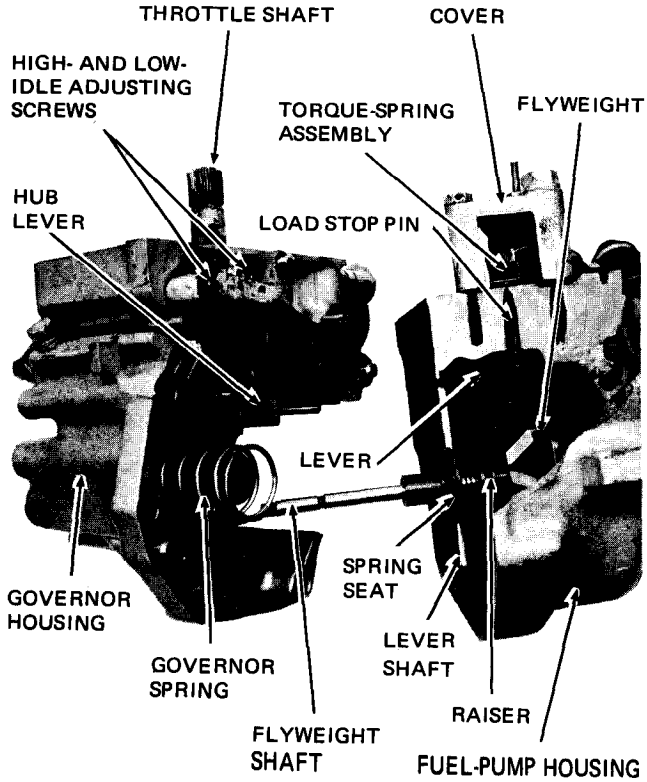


Fig. 36-12 View of partly removed governor housing.

load stop pin. Pull the governor shaft with lever (1) upward, to remove it from the fuel pump housing. Remove the dowel from the fuel pump housing while sliding the load stop lever from it (Fig. 36-6). Remove the governor weight cover. Place the timing pin into the camshaft slot to hold it firmly while removing the cap screws which hold the governor weight assembly to the camshaft.

If the throttle shaft requires service, remove the shaft cover and coil spring.

CAUTION Be prepared for the force on the cover created by the coil spring.

Remove the high- and low-idle-speed adjusting screw cover, and both adjusting screws, then lift out the spring and spring guide. Lift the front plate, pin, and spacers, from the throttle shaft, then lift out the throttle shaft. The hub, lever, spring washer, and rear plate will slide out (Figs. 36-13 and 36-18).

When inspecting the governor components for serviceability, check the speed-sensing components, that is, the thrust collar, thrust bearing, washers, and weight assembly (Fig. 36-14). Do not overlook the levers which transmit the motion from the thrust collar raiser to the control shaft, and always replace the housing and cover seals.

Fuel Pump Housing and Camshaft Inspection

The checks and measurements that must be performed on a sleeve-metering fuel-injection pump housing and camshaft are the same as those for a compact-housing or flange-type fuel pump.

Reassembly

REASSEMBLING FUEL PUMP Wash the injection-pump housing, camshaft, governor components, and transfer pump and dry them with compressed air. Generously lubricate the bushings and the camshaft journals. Place the camshaft in the housing, turning it to ensure that it rotates freely. Install the key and transfer-pump drive gear on the shaft. Place a new O ring in the groove of the transfer-pump housing. Install the idler gear. Lubricate the interior of the transfer-pump housing and the seals before you place the transfer-pump housing on the fuel pump housing.

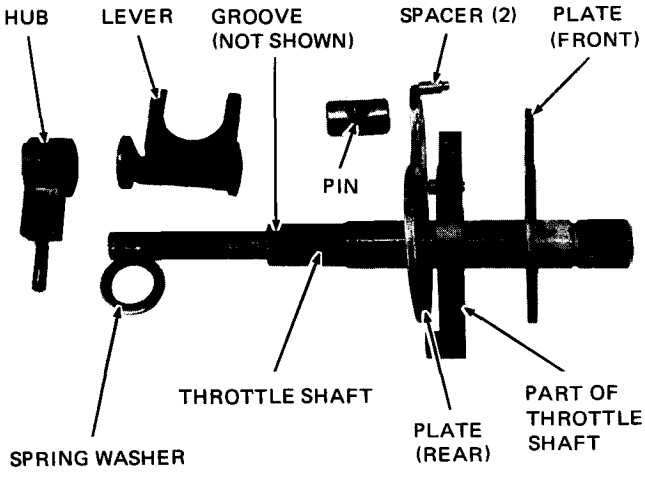


Fig. 36-13 Exploded view of throttle shaft assembly.

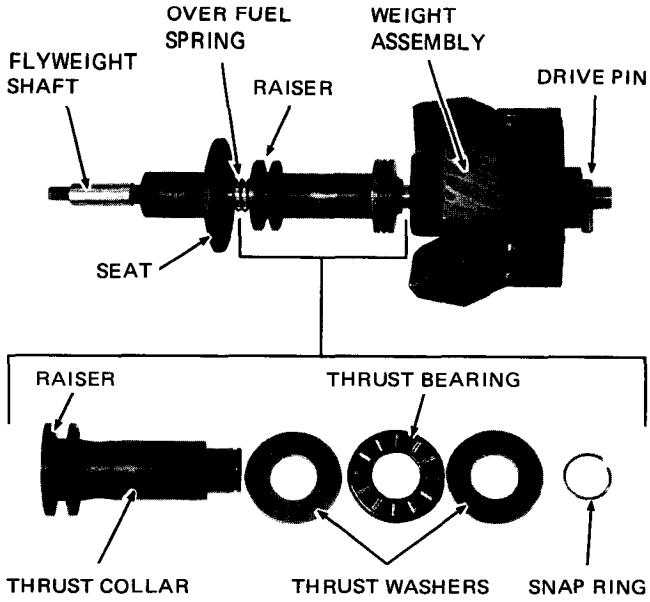


Fig. 36-14 Exploded view of flyweight and thrust collar assembly.

Place the timing pin in the camshaft. Install and tighten the sleeve to the specified torque. Recheck to make sure that the camshaft rotates freely. If it does not, recheck the transfer pump. Measure the end play. It must be within specification. Do not install the side cover on the fuel pump or the high- and low-idle speed adjusting screw cover at this time.

REASSEMBLING THE GOVERNOR Make certain that you lubricate the bushings, shafts, seals, pins, and thrust bearing before you reassemble the governor. Slide the flyweight shaft pin into the camshaft, install the three cap screws, and torque them to specification. Reassemble the remaining governor components and bolt the governor housing to the fuel pump housing. Make certain that the load stop lever and governor shaft lever rest in the raiser. At this time do not install the side cover onto the fuel pump, or the cover of the high- and low-speed adjustment screw.

Fuel Pump Calibration It is not necessary to time the fuel pump camshaft because the beginning of injection is governed through the precision-machined plunger ports, barrels, lifters, and cam lobes. However, it is essential to measure the fork height. Before you install new or serviced pumping elements, the individual forks on the control shaft must be adjusted to the height specified in the service manual. This ensures correct positioning of the sleeve in order to meter the specified amount of fuel.

To measure the height of the fork, thoroughly clean the calibration pump and install it into the bore with the plunger's flat side toward the fork (Fig. 36-15). Turn the calibration pump 180° to engage the plunger groove with the fork. When it is engaged, tighten the special retainer bushing to the recommended torque. Install the calibration pin in the calibration hole and hold it with the special adapter, in place. Set the dial indicator onto the microgauge. After the pointer has moved 1½ revolutions, zero the dial and lock it in position. If 1½ revolutions cannot be achieved,

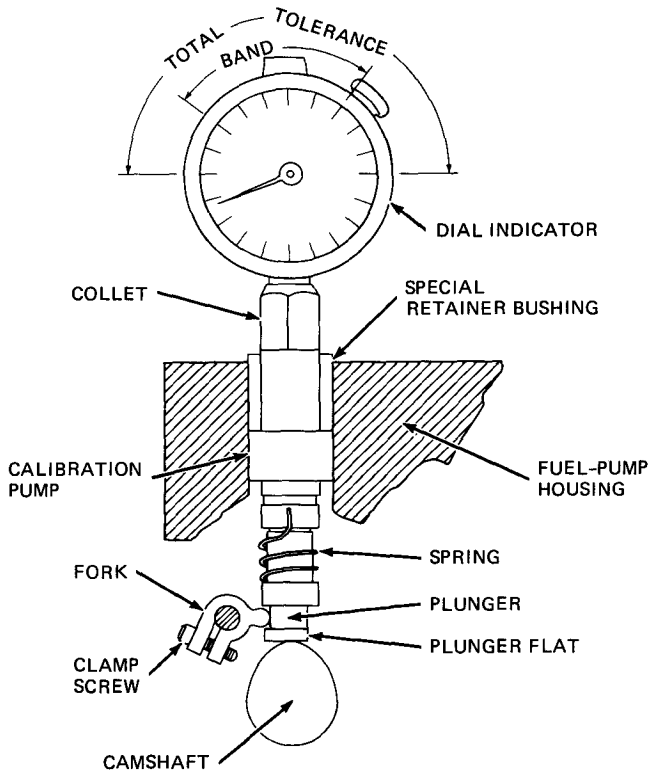


Fig. 36-15 Schematic view of calibration pump and dial indicator (position—ready for injection-pump adjustment). *(Caterpillar Tractor Company.)*

loosen the collet (base of the dial), move it up or down, then repeat the dial-indicator adjustment procedure. When the adjustment is made, hold the dial indicator firmly onto the top of the calibration pump.

NOTE: The dial indicator used is calibrated in 0.002-mm increments. Suppose, for example, the specification states that the dial indicator should read "zero" ± 0.005 mm and an adjustment of the fork is necessary. Loosen the fork screw with an Allen wrench and swivel the fork on the control shaft (up or down) to attain a zero dial-indicator reading (Fig. 36-16).

NOTE: When tightening the fork, the plunger moves downward by about 0.001 mm and, therefore, compensates the plunger position. To check the adjustment, move the control shaft toward the governor and (through the fork) move the calibration plunger up and down. The dial indicator should indicate zero. Next, measure and adjust the remaining forks.

Installing Pumping Elements Turn the camshaft until the lifter roller of the injection pump being installed is on the camshaft-lobe base circle. Place the throttle in the full-fuel position. This brings the fork into the highest position to aid installation. Remove the pump element from the fuel container. Slide the assembled pumping element into its bore. Engage the sleeve with the fork.

Place a new sealing ring on the bonnet. Tighten the bushing (using the special wrench) to the recommended torque. Cap the bonnet opening.

Install the remaining elements and then place the bypass valve, spring, and cover into position. When installing the cover on the pump housing, make certain that the bypass valve spring is in its groove.

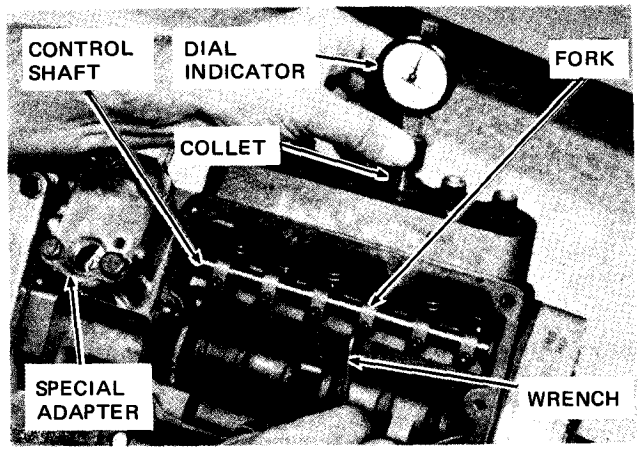


Fig. 36-16 Adjusting fuel-injection pump. *(Caterpillar Tractor Company.)*

Fuel-injection System Setting This involves checking or adjusting the sleeves for the maximum fuel position, that is, when the load stop pin contacts the torque spring or the load stop pin contacts the adjusting screw. (Refer to Fig. 36-7 for locations of the torque spring and load stop pin.)

First remove the shutoff solenoid, fuel-ratio control, and torque spring assembly cover. Install the calibration pin and position the spring onto the pin. Place the special adapter over the pin and bolt it to the fuel pump housing. Place the throttle in full-fuel position, install the dial indicator as shown in Fig. 36-17, and

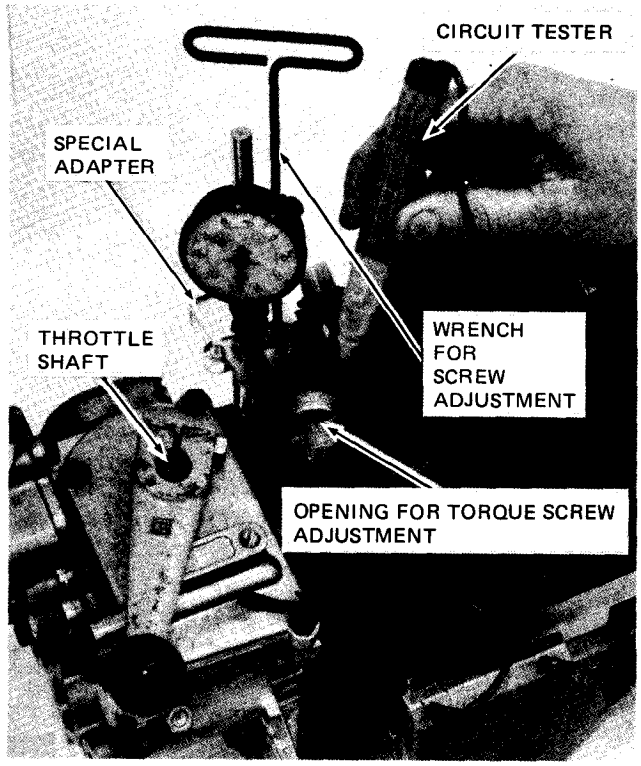


Fig. 36-17 Testing and measuring tools installed for fuel-injection system setting.

zero both dials. Connect one lead of the circuit tester to a good ground and the other to the load stop contact.

Slowly loosen the screw. This allows the governor spring to move the raiser, pivot the load stop lever, and lift the load stop pin until the circuit tester light just glows. Read the dial indicator. When both the dial indicator and the rack-setting specifications are the same, the fuel system is adjusted correctly. When the fuel system is not adjusted properly, the dial-indicator reading will differ from the rack-setting specification.

To bring the dial-indicator reading in line with the rack-setting specification, you must add or subtract shims to lower or raise the torque spring (Fig. 36-7*a*). The number of shims to be added or removed will be determined by the difference between the dial-indicator reading and the rack-setting information.

When a torque control screw is used (Fig. 36-7*b*), loosen the locknut and turn the adjusting screw until the circuit test light just glows and the dial-indicator reading corresponds with the dimension given in the rack-setting specification.

Fuel-ratio-control Setting To set the fuel-ratio control, place the throttle in the shutoff position, install the fuel-ratio control, and then place the throttle in the full-fuel position. Withdraw the screw about six turns. Now the fuel-ratio-control spring pulls the raiser and the control shaft into reduced fuel position and the calibration pin moves downward. If the ratio control is adjusted correctly, the dial-indicator reading and the fuel-ratio-control specification should coincide. If not, remove the fuel-ratio-cover cap screws and, with the cover, turn the valve until the dial-indicator reading coincides with the specification.

Remove all test tools, replace all covers, bolts, and cap screws, and then install the shutoff solenoid.

Engine Timing After the fuel pump is installed to the engine, bleed the fuel system and time the fuel pump to the engine. Engine timing can be performed by the three methods outlined in Unit 30, that is, by using the timing bolt method, timing by the fuel flow method (spill-timing), or by the timing light method.

To check the high-idle speed, move the throttle to the full-fuel position. Measure the engine rpm with a strobe light or a tachometer. When the engine speed is above or below specification, make the necessary adjustment by turning the high-idle adjusting bolt (Fig. 36-18). When checking the low-idle speed, move the throttle to the low-idle position and then, if necessary, change the rpm by turning the low-idle adjusting screw.

NOTE: To assure proper engine speed adjustment, change the engine speed after each adjustment by moving the throttle.

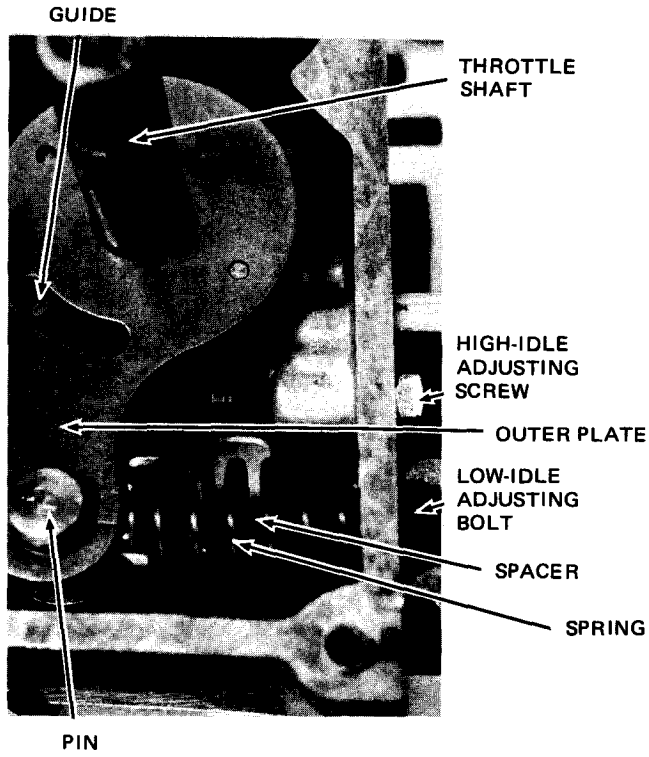


Fig. 36-18 View onto high- and low-idle adjusting screw and bolt.

Questions

1. List six differences between the American Bosch distributor pump and the Caterpillar sleeve-metering injection pump.

2. Describe the mechanical action which takes place in the fuel-injection pump when the throttle is moved from the no-fuel position to the full-fuel position.

3. Name the fuel-injection component which changes the effective stroke.

4. If the sleeve were placed on the plunger with the narrow flange downward, how would metering and beginning of injection be affected?

5. What precaution must be taken when removing the pumping element from the fuel pump housing?

6. Which part of the governor requires particularly close scrutiny when checking the governor for serviceability?

7. Why does the Caterpillar sleeve-metering pump *not* require a phase-angle adjustment?

8. Explain how to calibrate a Caterpillar sleeve-metering injection pump. List the components which must be adjusted or measured to accomplish calibration.

9. Explain how to adjust the fuel-injection system setting on a fuel pump having a torque screw adjustment, when the dial indicator reads 0.127 mm less than specification.

10. Why must the fuel-ratio control be attached and readjusted *after* the fuel-injection system is adjusted?

SECTION 5
ELECTRICAL SYSTEM
UNIT 37 • ELECTRICITY AND MAGNETISM

ELECTRICITY

Electron Theory An understanding of the electron theory and of magnetism is mandatory in order for you to service electrical components efficiently. The following is a review of some pertinent facts about these topics.

All matter is composed of small parts called *molecules*. These molecules are made up of two or more atoms. Atoms are made up of even smaller particles called *electrons, neutrons,* and *protons.*

All matter has an atomic weight. It is expressed by an atomic number which also represents a total number of electrons (or protons). For example, copper has an atomic number of 29. It has 29 electrons that orbit in four rings around a nucleus of 29 protons and 29 neutrons.

Electrons revolve only in a certain orbit or energy level around the nucleus. The nucleus has the same number of protons and neutrons as it has electrons (Fig. 37-1).

The greater the atomic number, the more numerous are the electrons circulating around the nucleus. The nucleus, which has the greatest mass and weight, keeps the electrons in orbit around itself by gravitational pull. The electrons which are closest to the nucleus are more strongly attracted (pulled) to it than the electrons which are farthest away. The electrons in the outer orbit are partially free from the pull, and therefore can sometimes be forced off their orbit. They are called *free electrons*. Those in the inner orbit are called *bonded electrons.*

Normally the atom is electrically balanced. If a state of imbalance should develop through the loss of electrons (which is a negative change), the atom becomes positive in charge. It then tends to attract other electrons in order to regain its balance. This electrical imbalance (potential difference) is the basic principle underlying electric current because imbalance causes electrons to flow from atom to atom.

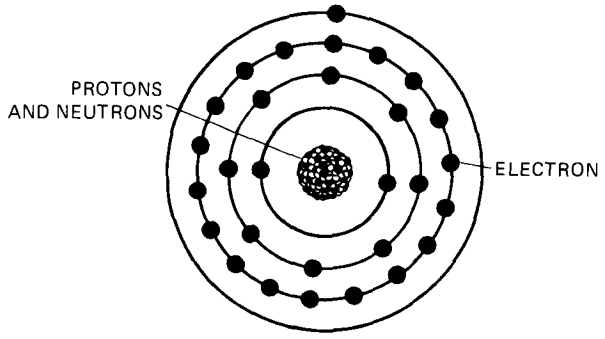


Fig. 37-1 Copper atom.

Conductors A *conductor* may be defined as matter made up of atoms whose free electrons are dislodged easily and whose orbits overlap, allowing easy electron flow from atom to atom.

The atomic structure governs the conductivity of an element, or the extent to which it resists the movement of electrons. Elements such as silver, copper, or aluminum are good electron carriers because their free electrons are not very closely tied to the atom. Copper is presently the most common carrier of current (electrons) because it is commercially economical, bends easily, and offers little resistance variation with changes in temperature.

Two other factors in addition to temperature which can change the resistance of a conductor are the cross-sectional area and the length. As the cross-sectional area is increased, the electron-carrying capacity increases because there are more atoms available to carry the electrons (current) and so the resistance is reduced. When a conductor is lengthened without increasing its square area, more electrons have to be dislodged. This causes heat, which increases resistance.

Insulators (Nonconductors) An *insulator* is composed of one or more atoms with an atomic structure of more than four electrons bonded in a compact outer orbit. The structure will not allow the movement of electrons because there are no free electrons present. The most common insulators used for electrical wiring are natural or synthetic rubber, varnish, mica, Bakelite, and various fibers.

Insulators are essential to the conductors of any electrical device because they prevent electron losses, prevent a short or grounded circuit, and can separate two conductors. They also protect the conductor from external damage, oil, dirt, water, and heat.

Semiconductors Semiconductor materials (elements) are neither good conductors nor good insu-

lators because they are elements which have an atomic structure of three or five electrons in their outer orbit. However, these elements can be altered to fulfill a useful purpose, that is, to act as an electrical device which can perform as a conductor under certain conditions and as a nonconductor under other conditions. (See the section on semiconductors in Unit 45 for more details.)

Resistance *Resistance* is any force tending to hinder motion. Each atom resists removal of its free electrons due to the gravitational pull of the nucleus. Resistance in a conductor, semiconductor, or insulator is the opposing force which the atoms give to the movement of electrons.

NOTE: The resistance of insulators or special resistors usually decreases with increase in temperature.

Electron Flow Electrons will flow from atom to atom when there is a difference in magnitude and when there is a path which connects the concentration of electrons on the negative terminal with a positive terminal which lacks electrons. When the terminals are connected (by a conductor), an electric circuit is made and the free electrons flow from atom to atom (from terminal to terminal) at a speed of 186,000 nmi/s (nautical miles per second) [344,472 km/s (kilometers per second)]. However, it has been proven scientifically that they travel only a few inches per minute in the conductor.

Current Flow Current flow involves two theories, the conventional theory and the electron theory. The conventional theory is based on the principle that current will flow (when there is a potential difference) from the positive terminal of the power source to the negative terminal. The electron theory is based on the principle that electrons flow from the negative to the positive terminal of the power source (see Fig. 37-2). This electron flow, or *current,* is the rate of electron flow per second past a given point. Current is measured with an ammeter, which indicates electron flow in amperes.

NOTE: Whenever there is a current flow, all electrons that leave the negative terminal will reenter the positive terminal. Consequently, whether you measure the current flow at the negative or at the positive side of a circuit, the ampere reading will always be the same.

DIRECT CURRENT AND ALTERNATING CURRENT *Direct current* refers to the flow of electrons in one direction only. This means the voltage source does not change its polarity. When the flow of electrons changes direction (cycles), it is called *alternating current.*

Voltage or Electromotive Force Voltage is the difference in the concentration of electrons between the negative and the positive terminals. When the two points of different potential are connected, the potential difference at these two points causes the electrons to move because of their forces of attraction and repulsion. The potential difference is called *voltage* or *electromotive force* (emf), and the unit of measurement is the *volt* (V). The greater the concentration at one terminal, the greater will be the voltage or potential energy to do work. Work is the combined effort of voltage and current expressed in *watts (W).*

Ohm's Law Ohm's law is a law to the effect that the intensity of the electric current in a circuit is proportional to the voltage (emf) and inversely proportional to the resistance. In other words, the current flow can be changed by changing the voltage or by changing the resistance in the circuit. Note, however, that current has no effect on resistance or voltage, but each has an effect on current.

If you know two of the three factors [*I* (amperes), *V* (volts), or *R* (resistance)], then you can apply Ohm's law to find the third factor.

Voltage Source There are many ways to produce voltage including friction, heat, light, pressure, chemical energy, and magnetism. This textbook will be concerned only with voltage produced by heat, chemical energy, and magnetism.

Voltage through Heat You may associate the principle which creates voltage through heat with such devices as thermocouples, heat indicators, or temperature gauges. In each instance heat is used to produce voltage. When two wires or plates made of different metals twisted or welded together are heated, the junction transmits the heat to their opposite ends, causing a potential difference (see Fig. 37-3). The greater the difference in temperature between the opposite ends of the wires or plates, the greater the voltage, and therefore the greater the cur-

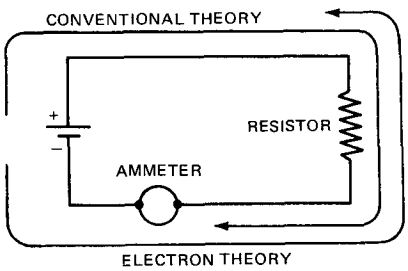


Fig. 37-2 Demonstrating the electron theory and the conventional theory.

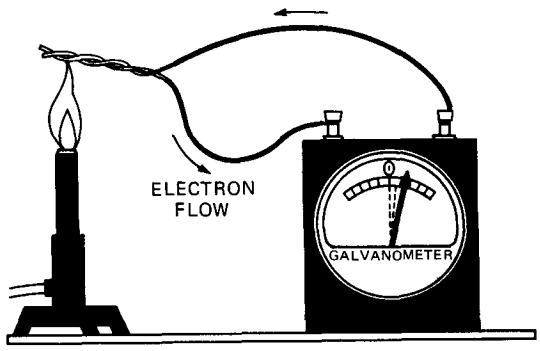


Fig. 37-3 Creating voltage through heat by means of a thermocouple. *(Delco Remy, Division of General Motors.)*

rent flow. The voltage produced through heat is very small, but the current flow is sufficient to energize the coil of a small gauge.

MAGNETISM

Theory of Magnetism Each molecule in iron or in iron alloy has a north and south pole. When not magnetized, the molecules are oriented randomly within the material. An iron bar can be magnetized through magnetic induction by striking a magnet over the bar to magnetize it, by placing the iron bar in a strong magnetic field, or by electromagnetic induction. These actions cause the molecules within the bar to align themselves with all north poles pointing in the same direction (Fig. 37-4). It is now known that these magnetic lines of force are essentially electrical in nature. They arise from the interaction between the spinning and orbiting electrons. When these electrons align so that their forces are combined, the iron bar is magnetized.

Basic Facts about Magnetism

1. A magnet has a north and south pole and the magnetic lines of force leave the north pole and enter the south pole. This can be proven by placing a compass near a magnetic bar. The compass needle will align itself so that the south pole of the compass needle points to the north pole of the bar.
2. The concentration of magnetic lines of force is heaviest at the pole ends and decreases in density midway between the poles since magnetic lines have "like" polarity and therefore repel each other.
3. Like poles (charges) repel each other, and unlike poles (charges) attract each other.
4. If you cut a portion from the north pole end of a magnet, regardless how small the portion, the result will be a second magnet with a north and a south pole.
5. To date there is no known insulation against magnetic lines of force. However, magnetic lines can be reduced by placing an iron core near one pole piece. This results in magnetic lines of force splitting into two separate paths, reducing the lines of force of the left magnet (Fig. 37-5).

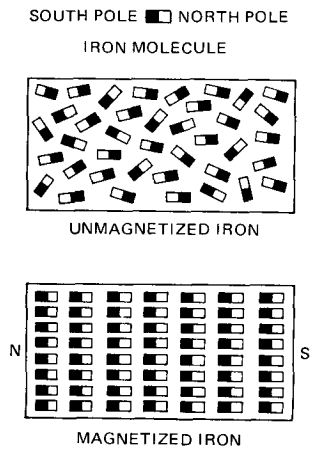


Fig. 37-4 Unmagnetized iron and magnetized iron. *(Delco Remy, Division of General Motors.)*

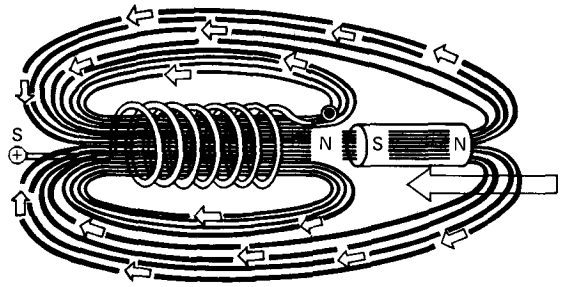


Fig. 37-5 Reducing magnetic lines of force. *(Delco Remy, Division of General Motors.)*

6. Magnetic lines of force can penetrate certain materials more easily than others.
7. Permanent magnets can be either natural or an alloy such as nickel-iron, or aluminum-nickel-cobalt (magnetized) because these alloys have an atomic structure similar to iron. An alloy with a loose molecular structure allows magnetic lines of force to pass through itself more easily and is used as a temporary magnet.

Basic Facts about Electromagnetism

1. A straight wire which carries current creates a magnetic field around itself. The lines of force form concentric circles around the wire. The right-hand rule is used to determine the direction of current flow, whereas the left-hand rule is used to determine the electron flow (Fig. 37-6). The magnetic field of a current-carrying conductor behaves in the same manner as the magnetic field of a permanent magnet, as long as there is a current flow.
2. When the direction of current flow is changed, the direction of the lines of force also changes. The symbol used to indicate current flow is shown in Fig. 37-1.
3. When two conductors are placed side by side with an equal current, but flow in opposite directions, the

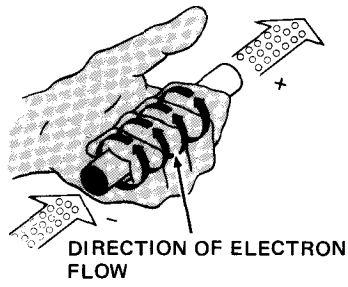


Fig. 37-6 Left-hand rule (electron theory) for determining the direction of electron flow. *(Delco Remy, Division of General Motors.)*

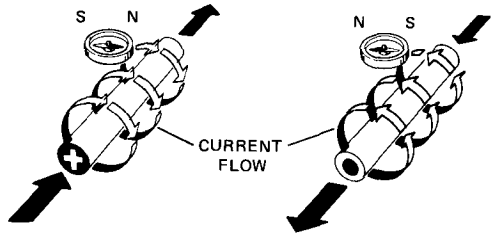


Fig. 37-7 Symbol indicating current flow and direction of magnetic lines of force. *(Delco Remy, Division of General Motors.)*

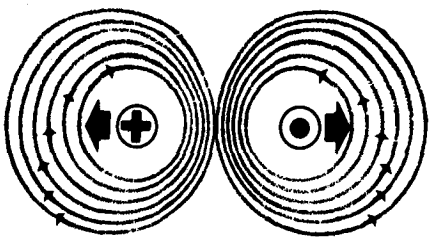


Fig. 37-8 Strong magnetic field between conductors. *(Delco Remy, Division of General Motors.)*

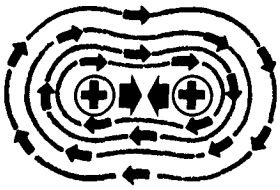


Fig. 37-9 Magnetic field between conductors canceled. *(Delco Remy, Division of General Motors.)*

lines of force are also opposite in direction and are more concentrated between the conductors than on the outside (see Fig. 37-8). Consequently the current-carrying conductors move apart to relieve the imbalance in the magnetic fields.

4. If there is an equal current flow in the same direction through two or more parallel conductors, each conductor alone creates a circular field of force in the clockwise direction (Fig. 37-9). The lines of force between the conductors move in the opposite direction. Because the strength of each field is the same, the total magnetic effect between the conductors is canceled. The conductors will tend to move toward each other, causing the magnetic effect to increase as the lines of force from each conductor join and surround the conductors.
5. An electromagnet is produced when a straight current-carrying conductor is formed into a single loop. All lines of force enter the inside of the loop on one side and leave on the outside.
6. When the number of loops (coils) is increased, the magnetic field of force increases. When using the right-hand rule to determine the polarity of the coil for the conventional current theory, the lines of force travel from the south to the north pole.
7. Air is a very poor conductor of magnetic lines of force. The smaller the air gap, the greater the number of lines of force for a given magnet.
8. When a soft iron core is inserted into a coil, it forms a true electromagnet (Fig. 37-10). The magnetic

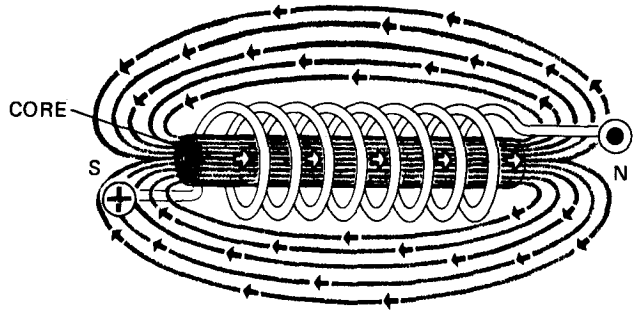


Fig. 37-10 An iron core placed inside the coil increases the number of lines of force (field strength). *(Delco Remy, Division of General Motors.)*

flux (lines of force) will increase as much as several hundred times, because the permeability of rough iron may be 2500 times that of air.
9. When the current flow is increased, say from 10 to 50 A, the magnetic lines of force also increase in the ratio of 1:5.
10. The same magnetic force will be produced by an electromagnet having 1000 turns of wire carrying 10 A as that of an electromagnetic force having 200 turns of wire carrying 50 A. The number of turns, times the amperes, equals 10,000 ampere-turns in either case.

Questions

1. Define matter, conductor, and insulator.
2. List four reasons why it is necessary to insulate conductors.
3. List the four most common causes of insulation failure.
4. What is the term used for one-way flow of electrons?
5. If you break a neutral magnet in half, would you have two neutral magnets? Why or why not?
6. Refer to Fig. 37-5. Explain why the magnetic lines of force have changed their path.
7. How can you transform unmagnetized material into magnetized material?
8. Explain why a magnetic field has a north and south pole after the conductor has been formed into a coil.
9. Give three methods by which the magnetic strength of a coil conductor is increased.
10. List three methods used to increase the electromagnetic force.

UNIT 38 • ELECTRIC CIRCUITS AND TEST INSTRUMENTS

Electric Circuits An *electric circuit* is an individual electrical path in an electrical system. It can perform work, and consists of a voltage source, a resistance unit (field coil, light bulb, etc.), and conductors (wires), which form the path for the current flow.

Electrical Failures No matter how well an electrical system is built or how well an electrical component (resistor unit) is designed, it cannot last or operate indefinitely. There are four types of electrical component or conductor failures: a short circuit, an open circuit, a grounded circuit, and a circuit having high resistance.

The term *short circuit* indicates that part of the circuit resistance is removed (Fig. 38-1*a*). A short circuit can be caused by a coil winding touching an adjacent winding.

The term *open circuit* indicates that the circuit is broken either by the conductor or by the resistor unit (Fig. 38-1*b*). This term also is used when the conductor is removed from the terminal or is loose and without conductivity.

The term *grounded circuit* indicates that the circuit is partly isolated because the conductor has found another ground (either accidentally or intentionally) (Fig. 38-1*a*).

High resistance refers to the resultant added resistance caused by a conductor with a poor, loose, or corroded connection.

Test Instruments In order to make an electrical diagnosis quickly and precisely, accurate electrical measuring instruments such as an ammeter, voltmeter, or ohmmeter are required. Equally important is the mechanic's ability to connect and read the instruments correctly (see later sections in this unit on the various types of circuits).

The three test instruments mentioned above have common basic working parts which include a permanent horseshoe magnet and a movable coil. Current flowing through the movable coil reacts with the permanent magnetic field causing the coil to rotate. The relative movement of the coil is in proportion to the amount of current flow through the coil windings. A pointer attached to the coil moves across a calibrated scale indicating the number of volts, amperes, or ohms. The ohmmeter, additionally, has its own voltage source and one or more resistors which are directly related to the scales.

VOLTMETER A voltmeter is used to measure voltage and/or voltage differential (voltage drop), that is, the voltage between two points of a circuit. It must always be connected in parallel (across the circuit) because of the high meter resistance (Fig. 38-2). A voltmeter for use with diesel engines should have more than one scale. The lowest scale should be calibrated in tenths of a volt.

AMMETER The ammeter shown in Fig. 38-3, has a shunt of low resistance connected parallel with the measuring coil winding. This shunt carries most of the current. Only a small current passes through the coil winding. An ammeter measures electron flow within a circuit, within part of the electrical system, or within the entire system. It must, therefore, be connected in series to the circuit. However, it can be placed on the positive or the negative side of the circuit.

For an alternator-regulator tester, an ammeter should have scales calibrated from 1 A to no less than to 100 A and as high as 1000 A for a battery-starter tester.

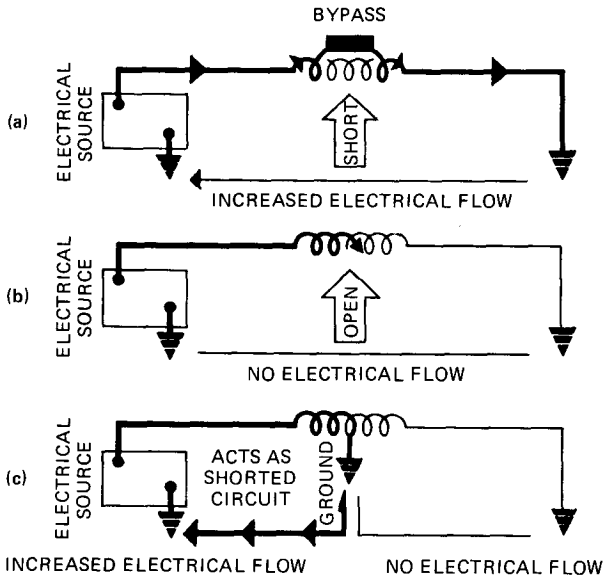


Fig. 38-1 Circuit failure: (*a*) short circuit, (*b*) open circuit, (*c*) grounded circuit. *(Delco Remy, Division of General Motors.)*

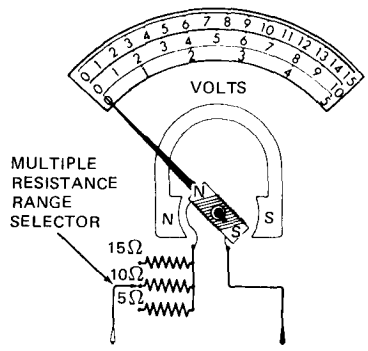


Fig. 38-2 Basic construction of a voltmeter. *(Delco Remy, Division of General Motors.)*

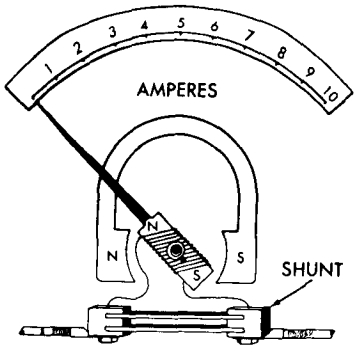


Fig. 38-3 Basic construction of an ammeter. *(Delco Remy, Division of General Motors.)*

OHMMETER An ohmmeter, when connected, supplies its own test voltage by forcing current through the coil winding (tester) to the electrical components or to the circuit and back to its own voltage source (Fig. 38-4). The ohmmeter scale is directly related and calibrated to the resistor within the ohmmeter to indicate the circuit or component resistance value in ohms (Ω).

An ohmmeter should have a selection of scales with the lowest scale calibrated to 10 Ω and the highest not less than 1000 Ω.

CAUTION Do not connect a voltmeter in series, an ammeter in parallel, or an ohmmeter to a live (hot) circuit. Any of these connections could damage the test instruments.

CARBON PILE A carbon pile is used to vary the resistance in a circuit. This type of resistor instrument can absorb and dissipate reasonably high current flow without being damaged by heat. A carbon pile consists of a stack or pile of carbon disks which can be forced together or separated by a screw-type thread, thereby increasing or decreasing circuit resistance (Fig. 38-5). When the carbon pile is connected into the circuit and the screw has separated the disks, no current can flow through the carbon pile and the circuit remains open. As the control knob is turned, the screw forces the disks together and gradually reduces the resistance. When the disks are forced tightly together, all resistance is removed and a conductorlike effect is produced.

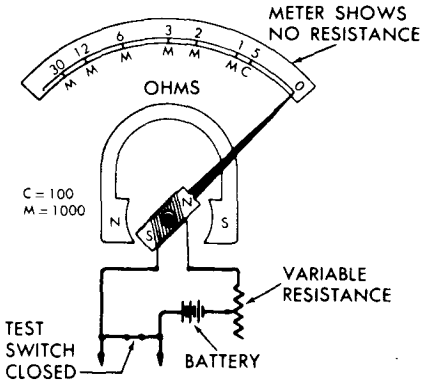


Fig. 38-4 Basic construction of an ohmmeter. *(Delco Remy, Division of General Motors.)*

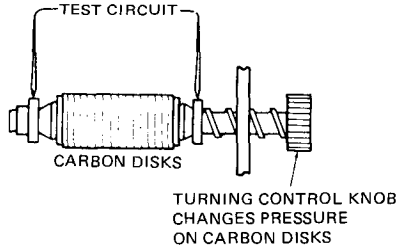


Fig. 38-5 Basic construction of a carbon pile. *(Delco Remy, Division of General Motors.)*

RHEOSTAT A rheostat (although not useable for high current) is also used to vary the resistance of a circuit by lengthening or shortening the resistor wire. It consists of a resistance wire wound around an insulator, over which a movable contact can slide (Fig. 38-6). The contact slip ring is connected to the right test lead, and the left side of the resistor is connected to the other test lead.

When the rheostat is connected in series to a circuit and the movable contact is in the position shown in Fig. 38-6, no resistance is inserted into the circuit.

However, when the contact is moved in a clockwise direction over the resistance wire, the resistance increases. The resistance inserted into the circuit depends on the position of the movable contact and the resistance of the coil wire.

Series Circuit Electric circuits are classified according to the manner in which the electrical components (resistors) are connected into the circuit. In a series circuit the current has only one path through which it can flow. In this case the total circuit resistance is equal to the sum of all individual resistors.

Figure 38-7 illustrates a 12-V series circuit with four resistors. The total resistance for this circuit is 2 Ω + 5 Ω + 4 Ω + 1 Ω, or 12 Ω. The current, calculated in accordance with Ohm's law, is $I = V/R = 12/12 = 1$ A.

When an ammeter is connected to this circuit, it should read 1 A. However, if the current flow is higher than 1 A, it is apparent that the circuit has less resistance. An ohmmeter can be used to identify the components with the lower resistance, but before you can make this identification you need to know the value of the resistor and you must remove the battery connection.

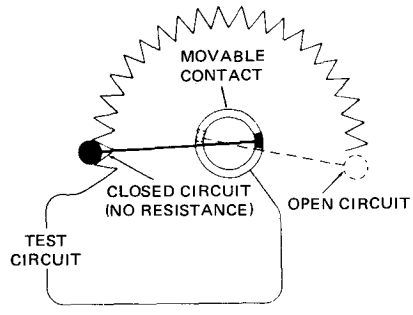


Fig. 38-6 Basic construction of a rheostat. *(Delco Remy, Division of General Motors.)*

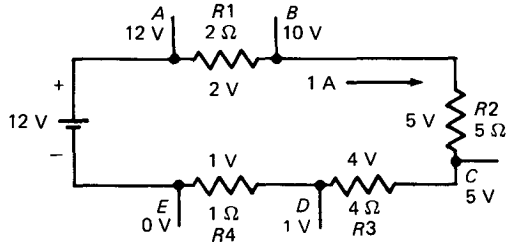


Fig. 38-7 Series circuit. *(Delco Remy, Division of General Motors.)*

A more expedient way of identifying a component with a lower or higher resistance is to use a voltmeter because the voltage drops once the current has passed through the resistor.

When using the voltmeter method, you must know the voltage, the value of each resistor, and the current flow. As noted above, in Fig. 38-8 the voltage is 12 V, the values of the resistors are 2, 5, 4, and 1 Ω, and the current flow is 1 A.

To calculate the voltage drop across the resistor *R*1, multiply the amperes by the resistor value: $I \times R = 1 \times 2 = 2$-V drop. Subtracting 2 V from 12 V equal 10 V. Therefore, when the voltmeter is connected to point *B* and to ground, it should read 10 V. When it is connected at points *A* and *B*, the voltmeter should read 2 V.

When the voltmeter is connected at point *C* and to ground it should read 5 V because the resistor *R*2 has a 5-Ω resistance. ($I \times R = 1 \times 5 = 5$ V.) When there are 10 V at point *B* and the voltage drop is equal to 5 V, to arrive at the voltage at point *C*, you must subtract: 10 V − 5 V = 5 V. When the voltmeter is connected at points *C* and *D*, it should read 4 V because the resistor *R*3 has a 4-Ω resistance. ($I \times R = 1 \times 4 = 4$ V.) To arrive at the voltage at point *D*, you subtract: 5 V − 4 V = 1 V. When the voltmeter is connected at point *E*, and to ground, the voltmeter should read 0 V. When connected at points *D* and *E*, it should read 1 V; but after connecting the voltmeter from *A* to *E*, it should read 12 V.

Parallel Circuit In a parallel circuit the current has as many paths as there are resistors in parallel. These paths are sometimes called *branch circuits* (Fig. 38-8). The sum of the branch circuits' current is equal to the total current flow in the circuit. Current flow through each branch will differ as the resistance differs. The total current flow should be 12 A.

$$I = \frac{V}{R} = \frac{12}{6} = 2 \text{ A} \quad \text{in branch one}$$

$$I = \frac{V}{R} = \frac{12}{3} = 4 \text{ A} \quad \text{in branch two}$$

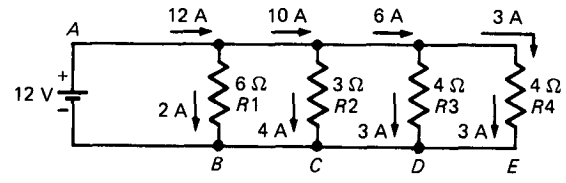


Fig. 38-8 Parallel circuit. *(Delco Remy, Division of General Motors.)*

$$I = \frac{V}{R} = \frac{12}{4} = 3 \text{ A} \quad \text{in branch three}$$

$$I = \frac{V}{R} = \frac{12}{4} = 3 \text{ A} \quad \text{in branch four}$$

Therefore, the total current is

$$2 + 4 + 3 + 3 = 12 \text{ A}$$

Another formula to calculate the total resistance R_T of a parallel circuit in order to arrive at the current flow is:

$$R_T = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \frac{1}{R4} = \frac{1}{6} + \frac{1}{3} + \frac{1}{4} + \frac{1}{4}$$
$$= 0.17 + 0.33 + 0.25 + 0.25 = 1\ \Omega \times 12 = 12 \text{ A}$$

When an ammeter is connected to the circuit and the current flow shows a reading lower than 12 A, it may be due to additional resistance in the circuit (in the form of a loose or poor connection) either on the live or ground side, or it may be that the one or more resistors yield a higher resistance due to a damaged coil. When the current is higher than 12 A, one or more resistors may have short circuited or grounded.

To locate the cause of high or low current flow in the parallel circuit shown in Fig. 38-8, you would, in sequence, connect a voltmeter at points *A–B*, *A–C*, *A–D*, and *A–E*. If a battery voltage of 12 V occurred each time, then the voltage drop across each resistor would be the same. However, if the voltage at any of these points is lower, it would be the result of additional resistance after points, *B*, *D*, and *E* (including battery connection).

To locate the resistance, connect the voltmeter at *B* to battery ground terminal, and then connect it at *C*, *D*, and *E*. If voltage readings occur at any of these points, there are probably loose or poor connections or partly damaged conductors.

Series-parallel Circuit A *series-parallel circuit* is one major path and two or more branches through which current flows (see Fig. 38-9). The total current flow in these circuits is also based on Ohm's law: $I = V/R = 12/12 = 1$ A.

You should notice that the 18- and 9-Ω resistors and the 12- and 4-Ω resistors are in parallel and the

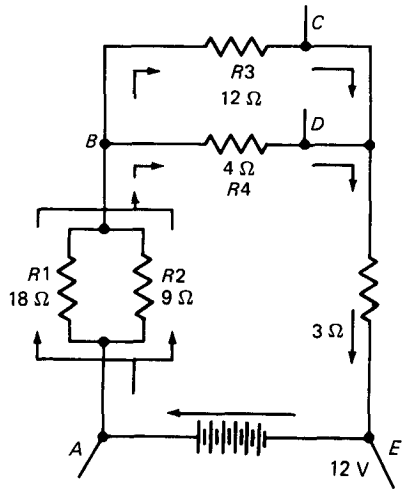


Fig. 38-9 Series-parallel circuit. *(Delco Remy, Division of General Motors.)*

3-Ω resistor is in series with them. To arrive at the total circuit resistance, the two parallel resistors must be reduced to series resistance, using the formulas

$$R_{eq1} = \frac{R1 \times R2}{R1 \times R2} = \frac{18 \times 9}{18 + 9} = \frac{162}{27} = 6\ \Omega$$

$$R_{eq2} = \frac{R3 \times R4}{R3 + R4} = \frac{12 \times 4}{12 + 4} = \frac{48}{18} = 3\ \Omega$$

$$R_T = R_{eq1} + R_{eq2} + R5 = 6 + 3 + 3 = 12\ \Omega$$

$$I_T = \frac{V}{R_T} = \frac{12}{12} = 1\ \text{A}$$

where R_{eq1} = equivalent resistance of $R1$ and $R2$, Ω
R_{eq2} = equivalent resistance of $R3$ and $R4$, Ω
R_T = total resistance, Ω
I_T = total current, A
V = voltage, V

When the ammeter indicates that the current flow in this circuit is more or less than 1 A, use a voltmeter to measure the voltage drop and thereby locate the point of higher or lower resistance.

Questions

1. Briefly define Ohm's law.
2. Why must a voltmeter be connected in parallel?
3. Why must an ammeter be connected in series?
4. What is the most significant difference between a carbon pile and a rheostat?
5. Basic test instruments use which of the following principles: (*a*) revolving coil and magnet, (*b*) revolving coil and rotor, (*c*) permanent-magnet moving-coil meter movement, or (*d*) none of these?
6. A voltmeter is used to measure which of the following: (*a*) watts, (*b*) intensity of current, (*c*) lack of pressure, or (*d*) electromotive force?
7. In which way is a voltmeter connected: (*a*) in parallel to the load, (*b*) in series with the load, (*c*) not used in connection with a load, or (*d*) none of these?
8. In which way is an ammeter connected (*a*) in parallel to the load, (*b*) in series with the load, (*c*) across the load, or (*d*) none of these?
9. An ohmmeter is used to measure which of the following: (*a*) current, (*b*) voltage, (*c*) resistance, or (*d*) none of these?
10. Give the abbreviations for the following: pressure (volts), volume (amperes), and resistance (ohms).
11. When electrical devices are connected so that the same current flows through all of them, you then have a (*a*) parallel circuit, (*b*) series circuit, (*c*) parallel-series circuit, or (*d*) series-parallel circuit.
12. When electrical devices are connected so that the same voltage is applied to each, you then have a (*a*) parallel circuit, (*b*) series circuit, (*c*) parallel-series circuit, or (*d*) series-parallel circuit.
13. When three resistors of 2, 2, and 4 Ω are connected in parallel the resistance of the combination is (*a*) 0.014 Ω, (*b*) 0.8 Ω, (*c*) 8 Ω, (*d*) 16 Ω, or (*e*) 0.008 Ω.
14. Voltage drop is also called (*a*) *VR*/1 drop, (*b*) *VR* drop, (*c*) *VI* drop, (*d*) *IR* drop, (*e*) $V \times IR$ drop, or (*f*) none of these?
15. If a circuit has a voltage of 12 V and a resistance of 6 Ω, what is the amperage: (*a*) 2 A, (*b*) 4 A, (*c*) 1.75 A, (*d*) none of these?
16. Current flow in a circuit depends on (*a*) voltage only, (*b*) resistance only, (*c*) a combination of voltage and resistance, or (*d*) none of these.

UNIT 39 - WIRES AND TERMINALS

Wiring Diagrams The schematic wiring diagram illustrated in Fig. 39-1 is similar to those illustrated in service manuals. The purpose of wiring diagrams is to help the mechanic trace and therefore effectively service the wiring system. The manuals also include separate wiring diagrams for each individual circuit to allow more detailed layout of the conductor connections. The conductors are color-coded, and the electrical components are indicated by a symbol or are illustrated schematically.

Some manufacturers prefer a two-wire system; others use the frame as the second wire (the ground wire). SAE recommends the following color code for a tractor-trailer combination: black for a hot wire (live wire), white for ground, brown for license and taillight circuit, yellow for stop and left-turn light circuit, green for stop and right-turn light circuit, and blue for the auxiliary circuit.

Conductor Size Selection The conductor size (wire number) used to connect the various electrical components is governed by the maximum allowable circuit resistance (voltage drop).

The maximum allowable circuit resistance (including connections and switches) must not exceed the values in Table 39-1.

Deduct the following from the total circuit resis-

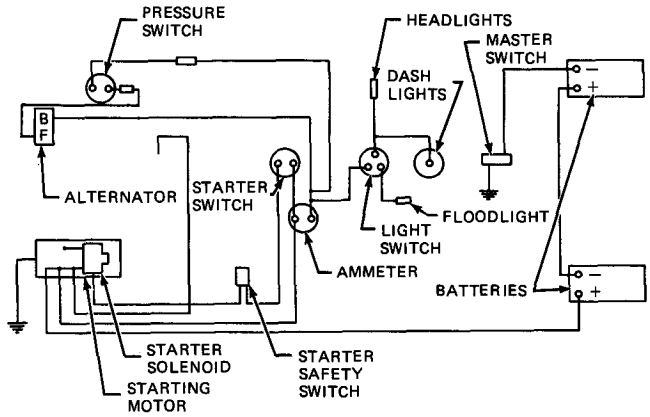


Fig. 39-1 Typical wiring diagram. *(Allis-Chalmers Corp. Engine Division.)*

TABLE 39-1

MAXIMUM ALLOWABLE VOLTAGE DROP AND CIRCUIT RESISTANCE FOR A 12-, 24-, AND 32-V CRANKING-MOTOR CIRCUIT

Circuit voltage, V	Maximum voltage drop, V/100 A	Maximum resistance, Ω
12	0.12	0.0012
12 (High-output starting motor)	0.075	0.00075
24–32	0.2	0.002

tance recommended before determining wire sizes for a given length:

- Each connection = 0.00001 Ω
- Each contactor = 0.0002 Ω

NOTE: Make certain when you make the cables up that the resistance of each soldering connection is not higher than 0.00001 Ω and that each contact resistance in the circuit is not higher than 0.002 Ω.

Cranking-motor Circuit The cranking-motor circuit supplies the high current to the motor. The selection chart shown in Fig. 39-2 gives the resistance in ohms of various size battery cables, according to their length.

Cranking-motor Control Circuit The cranking-motor control circuit is the one that permits switching. To stay within the maximum allowable voltage drop, the resistance of the cranking-motor control circuit, that is, the resistance between the battery, the solenoid switch, and ground, should not exceed 0.007 Ω in a 12-V starting circuit or 0.030 Ω in a 24-V starting circuit. The selection chart shown in Fig. 39-3 is indicative of the wire size required to maintain resistance within these values.

Battery to Alternator When the total wire length from the battery to the alternator does not exceed 16 ft [4.88 m], the recommended wire sizes are as shown by Table 39-2. If it exceeds 16 ft [4.88 m] in length, use the next larger size.

Accessory Circuit Resistance The wire size for all accessory feed circuits should be No. 12 or No. 14 if the total length does not exceed 15 ft [4.62 m]. All other control circuits should use No. 14 wire (except the glow-plug circuit). When an insulated ground circuit is used, No. 10 wire is recommended. If the length exceeds these specifications use the next larger size wire.

TERMINALS

The electrical system is by far the most troublesome area in automotive or diesel equipment and the greatest cause of downtime. Often the problem is the result of loose, corroded, or incorrectly selected terminals. Sometimes it is simply that the terminals are not properly fastened to the wires (conductors). In any event, preventive maintenance is the solution.

Terminal Ends Some terminal ends (wire ends) are shown in Fig. 39-4. Before selecting a terminal end, you must decide where crimping or soldering is to be used. Crimped terminal fastenings are acceptable for some applications while others require the security of solder.

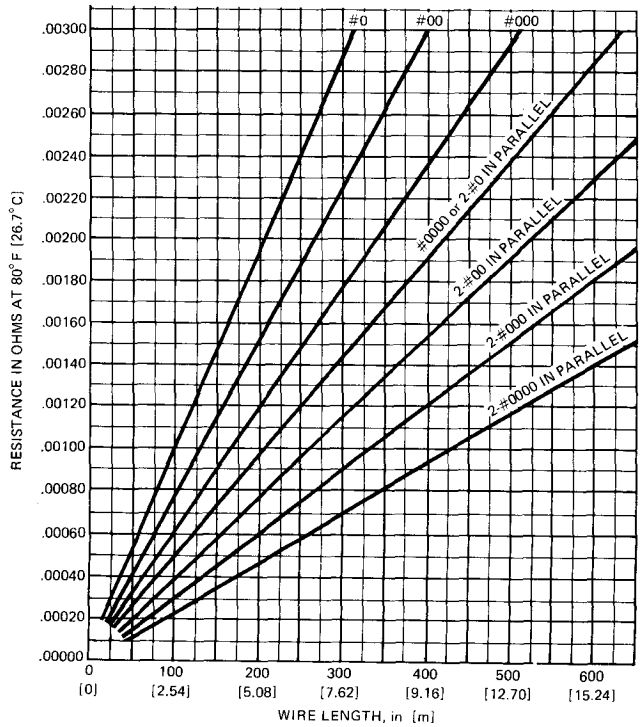


Fig. 39-2 Battery-cable selection chart. *(Delco Remy, Division of General Motors.)*

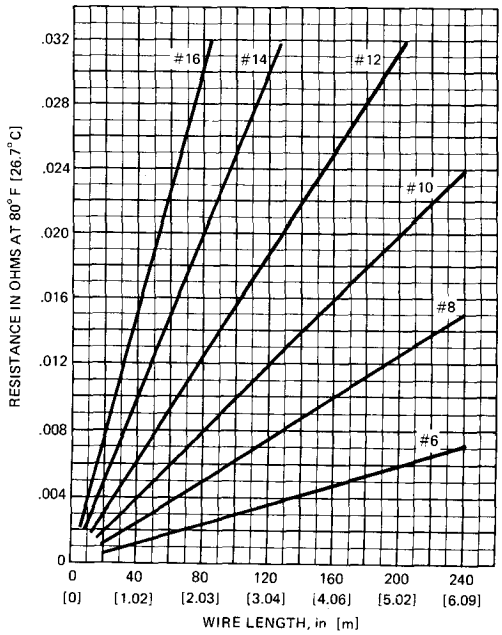


Fig. 39-3 Standard-wire selection chart. *(Delco Remy, Division of General Motors.)*

TABLE 39-2			
BATTERY-TO-ALTERNATOR WIRE SIZES			
12-V system		**24- to 32-V system**	
Amperes (max.)	**AWG* size**	**Amperes (max.)**	**AWG size**
53	8	25	14
85	6	40	12
125	4	60	10
205	2	100	8

* American Wire Gauge.

NOTE: A soldered terminal is more effective than a crimped fastening because the crimped fastening may connect only three-quarters of the strands with the terminal. This will reduce the current flow and may cause overheating.

Fastening Terminal Ends To crimp or solder the terminal end to the wire, you must first remove part of the insulation. Use a wire stripper to cut and remove insulation equal to the length of the terminal barrel. To prevent cutting conductor strands, use the correct stripper opening.

FASTENING THROUGH CRIMPING To fasten a terminal end through crimping, first insert the wire into the terminal barrel until it bottoms or is flush with the barrel end. In this position, secure the wire by placing the crimping tool over the barrel (make certain to use the correct crimping opening), and squeeze the barrel by forcing the handles together.

NOTE: Do not use a pair of pliers, a side cutter, or a vise to crimp the terminal barrel because they do not produce an adequate connection.

FASTENING THROUGH SOLDERING When you use solder, insert the stripped wire into the terminal barrel. Apply a small amount of soldering paste to the open end of the barrel. Hold the soldering iron in contact with the barrel and simultaneously hold the rosin-core solder on the inner edge of the barrel. Allow sufficient melted solder to flow into the barrel, then remove the soldering iron from the terminal to allow the solder to bond with the barrel and wire. Clean the soldering connection and push the insulation over the barrel.

When you solder a lip-type terminal to a wire, position the wire so that the insulation is flush with the holding tang, then roll the tang around the insulation. Use a crimping tool to fasten the wire to the terminal. Bend the lips over onto the wire. Hold the soldering iron on the bent lips and hold the rosin-core solder in contact with the wire, between the bent lips and tang. When the soldering iron reaches a high enough temperature, the solder will melt and draw toward the lips, bonding the wire and terminal.

Replacing Battery Terminals Figure 39-5 illustrates five conventional battery terminals. No matter which terminal is selected as the replacement for the worn one, it must be soldered to the battery cable.

When you replace a battery terminal, cut the cable as close as possible to the worn terminal. Use a 32-tooth hacksaw blade to ensure that the cable maintains its roundness. Strip away enough insulation to expose the cable by the exact length of the terminal barrel.

Hold the terminal (with the barrel up) in a vise. With an acetylene or propane torch, apply low heat to the cable end and terminal. Tin the cable end by holding the rosin-core solder against the copper wire until all strands are saturated with the solder.

Apply soldering paste to the inside of the barrel and let the solder flow into the barrel.

Place the cable end over the terminal opening.

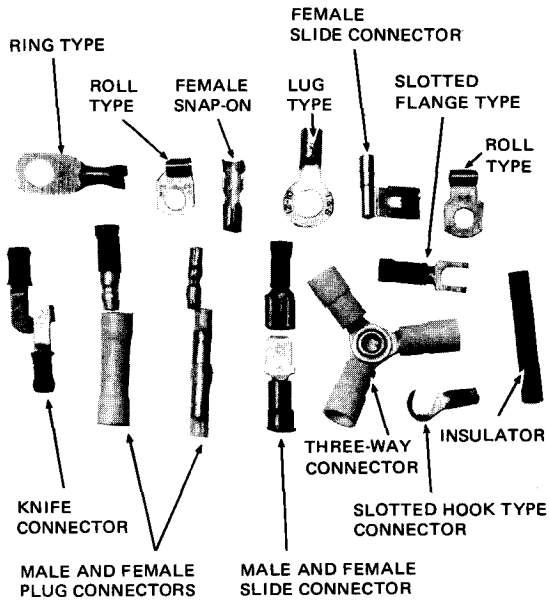


Fig. 39-4 Terminal ends.

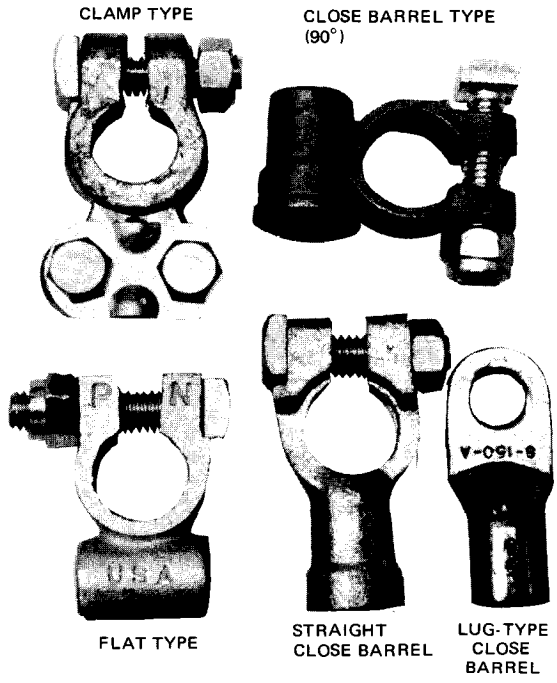


Fig. 39-5 Conventional battery terminals.

Maintain low heat to the terminal and the cable end until the cable slides in the opening. Solder may run out of the opening at this point; however, continue to apply low heat to ensure a good bond.

When the solder on the edge of the opening is drawn into the barrel, the joint between the barrel and cable end will be well soldered. When there is no solder on the edges of the barrel, more should be applied to the terminals to ensure joint effectiveness.

After removing the torch, hold the cable steady until the solder is set.

Clean the terminal and tape part of the barrel and insulation to prevent corrosion.

Pointers for Connecting Wires

1. When you connect a terminal to a component, make certain that the contact surfaces are clean and not pitted.
2. If possible, use an internal-external lock washer. If this is not available, place a plain washer below the plain lock washer.
3. Do not allow the terminal to touch the component.
4. Do not allow the terminal stud bolt (post) to turn as you tighten the nut.
5. When you have a slide or bullet connector, tape the unit to prevent its separation.
6. Be certain the terminal screw is not too long because this may ground out the terminal.
7. Return the wire as it was originally routed and clamped.
8. When you install an additional circuit, use the existing wire or cable route, clamps, and grommet.
9. If you are forced to reroute the cable in a new direction, use rubber grommets or short pieces of rubber hose to prevent the wire from being cut by the sheet metal or by the sharp corners of the frame.
10. Secure the wire in enough places so that it does not hang loose.

Questions

1. Which factor governs the selection of battery cables: (*a*) battery to cranking motor or (*b*) battery to alternator?
2. If you had a starting circuit of 24 V and the wire length from the key switch to the solenoid was 24 ft [7.3 m], what would the wire conductor size be?
3. Under the circumstances outlined above, what would the result be if you had selected a smaller size conductor?
4. List three factors that determine the selection of wire ends.
5. Outline the procedure to attach a ring-type terminal end to a No. 10 wire: (*a*) through crimping and (*b*) through soldering.
6. Why should battery terminals be restricted to the soldering type?
7. Why should the existing cable routes be followed and the existing clamps be used when repairing or installing an additional circuit?
8. Why should a ring (closed) type wire end be used on diesel engines?
9. When should a flag ring-type wire end be used?
10. Outline the procedure to join two wires by soldering.
11. After replacing a battery terminal, what steps or precautions should be taken before connecting the cable to the battery?
12. When attaching a terminal end to a terminal, why is it essential to use only the correct (length) terminal screw?

UNIT 40 - RELAYS, SWITCHES, AND SOLENOIDS

Applications of the various relays, switches, and solenoids are almost limitless. Some are designed to lift or push hundreds of pounds [kilograms], others are refined to push or lift only a fraction of an ounce [gram]. Some control a high current flow, while others are used to control low current.

Relays Relays are mechanical switches that operate electromagnetically. Generally speaking they have many different applications, but on diesel engines they are only used to close the field circuit to the alternator when the engine is operating, or to shut off the fuel flow.

All relays operate on the principle that a small current controls a large current flow (see Fig. 40-1). The small current is controlled by a toggle, pushbutton, or key switch which closes the electric circuit of the coil winding. The electromagnet pulls the armature toward its core, closes a set of contact points, and thereby closes the electric circuits with the higher current flow.

Magnetic Switches A magnetic switch is a mechanical switch that is operated electromagnetically. It is used on a starting circuit having a 24-V cranking motor and 12-V charging system.

The main difference between a relay and a magnetic switch is that the iron core of a relay is stationary whereas the core of a magnetic switch moves within a tube over which the pull-in coil winding is wound (Fig. 40-2). The contacts of a relay close indirectly; those of a magnetic switch close directly. Furthermore, a magnetic switch is designed to carry a higher current over its contacts.

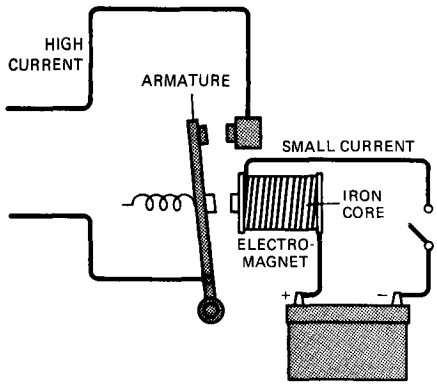


Fig. 40-1 Relay and circuit connections. *(Delco Remy, Division of General Motors.)*

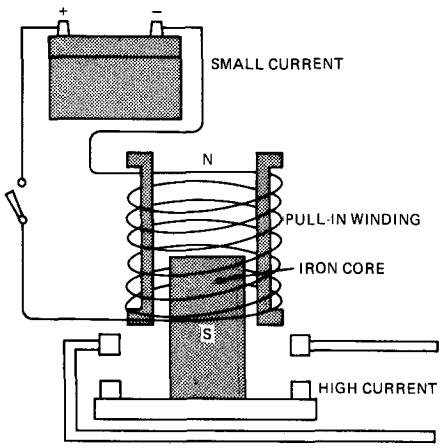


Fig. 40-2 Magnetic switch and circuit connections. *(Delco Remy, Division of General Motors.)*

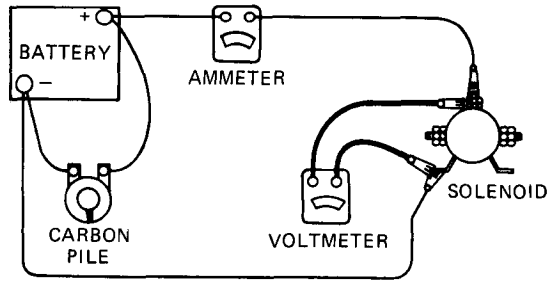


Fig. 40-3 Testing a magnetic switch or solenoid. *(Delco Remy, Division of General Motors.)*

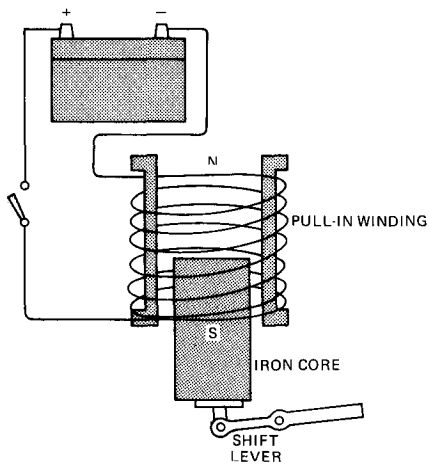


Fig. 40-4 Solenoid and circuit connections. *(Delco Remy, Division of General Motors.)*

Testing Magnetic Switch When a magnetic switch fails to pull in or fails to close the electric circuit, the actuating circuit may be defective. Other causes of failure may be an open, short, or grounded pull-in winding, or the contacts may have a high resistance. Several checks should be made to locate the problem area: Check the activating circuit with a voltmeter for voltage loss at the connections and the actuating switch. Check the resistance of the pull-in winding with an ohmmeter or make the test instrument connections shown in Fig. 40-3 and the testing procedure outlined under Testing Solenoid below.

To check the contacts and disk for high resistance, disconnect one wire from the switch. Close the circuit of the pull-in winding and connect an ohmmeter to the two large (high-current) terminals. The ohmmeter should show no resistance.

Solenoids A solenoid is an electromagnet having one or two coil windings wound around an iron tube which also serves as the bushing of the movable iron core (Fig. 40-4). When current passes through the coil windings, the iron core is pulled in or pushed out. This movement shifts a transmission or a cranking-motor drive-in mesh, or shuts off the fuel supply, or moves the fuel rack to the shutoff position.

Testing Solenoid When the action of a solenoid is too slow or fails to operate, the problem may be an open, short, or grounded pull-in winding, a poor connection, or high electrical or mechanical resistance of the movable iron core. To check the solenoid electrically, use an ohmmeter and connect the test probe to the two terminals. The resistance (in ohms) of the coil winding must coincide with the manufacturer's specification. A check can also be made by connecting a voltmeter, ammeter, and carbon pile as shown in Fig. 40-8. Close the coil circuit and adjust the carbon pile to the specified voltage. Read the amperage and compare the reading with the specification. A high ampere reading indicates a short-circuited or grounded winding and a low reading indicates excessive resistance.

Solenoid Switches A solenoid switch combines features of the solenoid and the magnetic switch. It does "work" and it also closes the electric circuit.

A solenoid switch is used on cranking motors which employ an overrunning clutch-type cranking-motor drive. It has two coil windings wound over a hollow cylinder and paired off at the S (starter) terminal (Fig. 40-5). The coil winding with the smaller gauge wire has its own ground and is called the *hold-in winding*. The *pull-in winding* (of heavier gauge copper wire) is connected to the cranking-motor terminal and is in series with the field coil, armature, and the ground brushes. The iron core plunger is connected at one end to the shift lever and at the other end to a spring-loaded copper disk.

Two insulated heavy-contact terminals are fastened

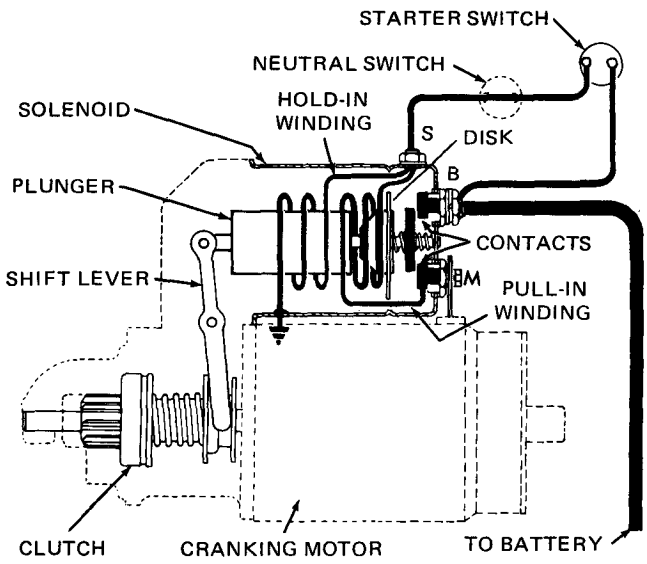


Fig. 40-5 Solenoid switch and circuit connections. *(Delco Remy, Division of General Motors.)*

in the end of the solenoid-switch housing. The terminal marked "battery" is connected to the battery and the terminal marked "cranking motor" is connected to the cranking motor.

Operation of Solenoid Switch The starting circuit, which energizes the solenoid switch, consists of a starter or key switch, a neutral switch, and the necessary conductor wires (Figs. 40-1 and 40-5). When the neutral switch is in neutral position and the starter switch is closed, current flows from the battery terminal of the solenoid switch, through the starter and neutral switches, to the S terminal of the solenoid switch. From this point on the current flows through the hold-in winding to ground and through the pull-in winding, through the cranking-motor field windings, live brushes, armature windings, and ground brushes to ground. Both windings create a south pole at the right-hand side, pulling the plunger to the right (in Fig. 40-5). The plunger pivots the shift lever and causes the cranking-motor pinion to mesh with the ring gear. Just before the meshing is completed, the spring-loaded disks contact both B and M terminals, thereby making a direct connection from the battery to the cranking motor, and cranking takes place. At the same time the high current flows to the cranking motor, the pull-in winding is out of the circuit because the contact disk has connected both ends of the coil winding to the positive side of the battery. Only the magnetism of the hold-in winding holds the plunger, which in turn holds the pinion in mesh and the disk in contact.

When the starting circuit is open, the hold-in winding is de-energized. However, for a split second, current from the battery flows from terminal B, through the disk, to the M terminal, then in a reverse direction through the pull-in winding to the S terminal, and finally in the normal direction through the hold-in winding. This causes the pole polarity to change in the pull-in winding and to oppose the pull-in coil polarity. The magnetism is instantly canceled out. The plunger-return spring forces the plunger to the left, opens the cranking-motor circuit, and moves the cranking-motor drive pinion out of mesh.

Solenoid-switch Failures Under normal circumstances a solenoid switch seldom causes cranking trouble. However, when the solenoid switch will not pull in or will not stay in mesh, the trouble could be due to a faulty or discharged battery or to a poor battery connection. The problem may also be a defective starter or neutral switch, or the cranking-motor drive may be damaged. Complications can also arise from an open, short, or grounded hold-in or pull-in winding, or from contacts and disks which are burned, pitted, or misaligned.

Testing Starter Switch When tracing the cause of cranking trouble, start with inspection and testing of the power source, that is, the battery and its connections. Next, check and test the starter switch to determine if there is a poor or loose connection or a loose terminal. Use an ohmmeter to measure resistance when checking for damaged or burned contact points. Alternatively, connect a voltmeter as shown in Fig. 40-6 and measure the voltage drop.

Testing Neutral Switch A neutral switch that is ineffective may be misadjusted or the electrical wiring may be damaged. To check misadjustment and/or the electrical condition of the switch, connect an ohmmeter as shown in Fig. 40-7. Then move the shift lever slowly into the neutral position. When the shift lever is in the neutral position, the ohmmeter should show no resistance. If there is resistance, remove the switch and actuate it by hand. If the ohmmeter shows no resistance you may assume the switch is not defective but it does need to be adjusted.

Testing Solenoid Switch A solenoid switch can be tested while the cranking motor is installed or after the motor has been removed. In either case, however,

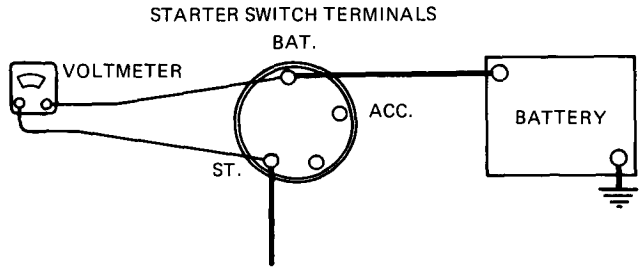


Fig. 40-6 Testing and starter switch. *(Delco Remy, Division of General Motors.)*

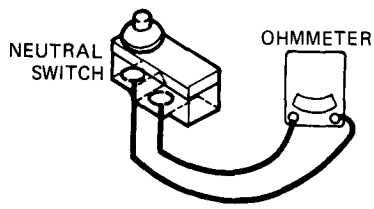


Fig. 40-7 Testing the neutral switch. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

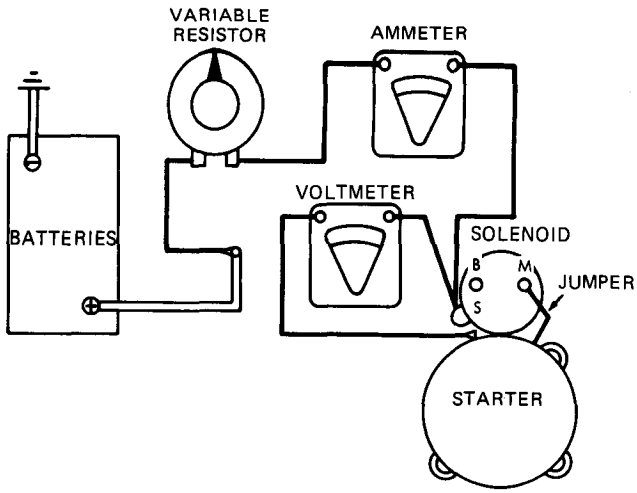


Fig. 40-8 Instrument connections for testing the solenoid switch. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

the test specification for the solenoid switch must be known before this test can be made:

TEST SPECIFICATION
Current draw at 10 V, 80°F [26.7°C]
Both windings, 70.5–77.8 A
Hold-in winding, 18–20 A

To test the solenoid switch while it is on the cranking motor, first remove the connector between the switch motor terminal and the motor terminal. Next, remove the battery cable and starter-switch wire. Connect the test instruments as shown in Fig. 40-8 and, with the variable resistor, slowly close the circuit until the voltmeter reads 10 V. The ammeter should read 70.5 to 77.8 A.

To check the hold-in winding, disconnect the jumper lead which grounds the pull-in winding. Adjust the variable resistor to obtain the specified 10 V. The current draw for the hold-in winding should be 18 to 20 A. If the solenoid switch does not meet specification, the switch should be repaired or replaced.

To check the resistance between the contact disk and the contact terminals, connect an ohmmeter to terminals B and M. Push the plunger so that the disk closes the circuit. The ohmmeter gauge should show no resistance.

Servicing Solenoid Switch When either of the solenoid switch windings are short-circuited, open, or grounded, the solenoid coils must be replaced. Broken connections, a burned disk, burned terminal contacts, or burned insulation, however, are problems you will more likely encounter. Consequently, when you disassemble the switch, be careful not to break the connections or damage the insulation. Use a smooth file to clean up the disks and contacts or replace them if necessary. Never use damaged insulators, washers, or grommets. When you reassemble the switch, use the service manual as a guide to position the terminals and insulators in their correct places. Make sure the switch assembly is completely sealed so that dirt or water cannot enter it. Always repeat the testing procedures previously outlined to verify operation of the solenoid switch.

Questions

1. Explain how a simple relay works.
2. What is the main difference between a relay and a magnetic switch?
3. Trace the flow of current through the solenoid switch shown in Fig. 40-5 after the key has been turned to the start position.
4. Refer to Fig. 40-5. Why is there no current flow in the pull-in winding when the disk bridges the B and M contacts?
5. Why is the contact disk spring-loaded and flexible?
6. What is the purpose of the hold-in winding?
7. If the pull-in winding is short-circuited, what effect could it have on the operation of the solenoid switch?
8. If the starter or neutral switch contacts are pitted, how would the operation of the solenoid switch be affected?
9. Briefly outline the procedure to test the operation of a relay.
10. If the air gap between the armature and the iron core is greater than specified how would it affect the operation of the relay?
11. List several conditions which would adversely affect relay operation.
12. List several reasons why a solenoid switch could chatter if the key switch were turned (and held) in the start position.

UNIT 41 • BATTERIES

BATTERY CONSTRUCTION

Function of Battery A battery is an electrochemical device that stores electrical energy in chemical form and releases it as electrical energy. The battery, regardless of size, capacity, construction, or type, is the heart of any electrical system. Just as the whole body suffers if the heart flutters in any way, so the electrical system will not function properly if the battery is faulty.

Battery Types There are two types of batteries: primary batteries, which are used in test instruments, and secondary batteries, which are used to (*a*) store electrical energy in chemical form, (*b*) stabilize voltage, and (*c*) supply electrical energy to the system.

Primary batteries (sometimes called *dry batteries*) irreversibly convert chemical energy into electrical energy. In other words, they cannot be recharged. The nickel-iron and nickel-cadmium batteries, however, can be recharged because they are primary *and* secondary batteries. In most primary batteries the electrolyte used is a pastelike substance that affects certain materials.

The most common primary batteries are the carbon-zinc, the mercury-oxide, and the silver-oxide. The secondary batteries with which you are most concerned are those that convert chemical energy into electrical energy by a process that can be reversed. There are three types of secondary batteries: lead-acid, nickel-iron alkaline, and nickel-cadmium. The lead-acid battery, developed by Gastone Planté in 1859, is the most economical. It produces the highest voltage per cell (2.2 V) and the lowest cost per watt-hour for its capacity. The cells withstand fairly high charge and discharge ranges.

Lead-acid Battery Generally speaking, apart from very minor changes, the internal and external construction of lead-acid batteries is similar regardless of trade name. The major difference lies in the number and the area (size) of plates used. Two types of plates (negative and positive), and a separator, form the basic elements. In the Planté-type battery, the active material is electrically transformed to pure lead by repeated reversal of the charging current. In the Faure type, the active material of the positive and negative plates is formed by applying a paste (largely of lead oxide) to the individual plate grids. The plate grids are made from lead-antimony to give them adequate strength and stiffness. Then, during the manufacturing process (precharge), the active material of the negative plates is converted to a gray sponge lead (Pb) and the positive plates are converted to lead peroxide (PbO_2), which is chocolate brown (see Fig. 41-1.) The positive and negative plates are welded (lead-burned) to the terminal post or plate strap casting to form a plate group (Fig. 41-2). As you can see from the illustration, the negative plate group has one additional plate to cover the positive plate. This improves the chemical action during charging and discharging.

Separators are placed between the negative and positive plates to prevent contact between them. The material used may be microporous plastic, rubber with or without plastic ribs, fiberglass, mats, resin-impregnated fiber with or without fiberglass mats, and cellulose fiber impregnated with resin.

The two groups of plates shown in Fig. 41-2 together comprise an *element.* One element makes up a battery cell. The number and the area of the plates governs the amount of energy [ampere-hours (Ah)] that can be stored.

The voltage (emf) of a fully charged cell is about 2.2 V with specific gravity (electrolyte) of 1.275. With a higher specific gravity, say, 1.285, the voltage rises to about 2.3 V. With a specific gravity of 1.265, the voltage is 2.15 V.

The one-piece battery case is made of a hard rubber or plastic compound to withstand the temperature changes, stress, shock loads, and the sulfuric acid.

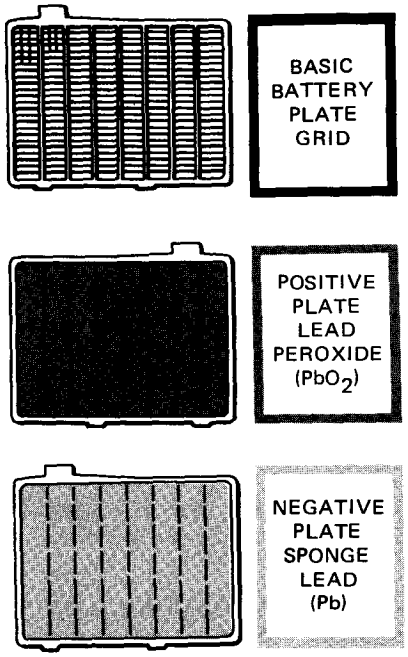


Fig. 41-1 Battery plate construction (lead-acid battery). *(Delco Remy, Division of General Motors.)*

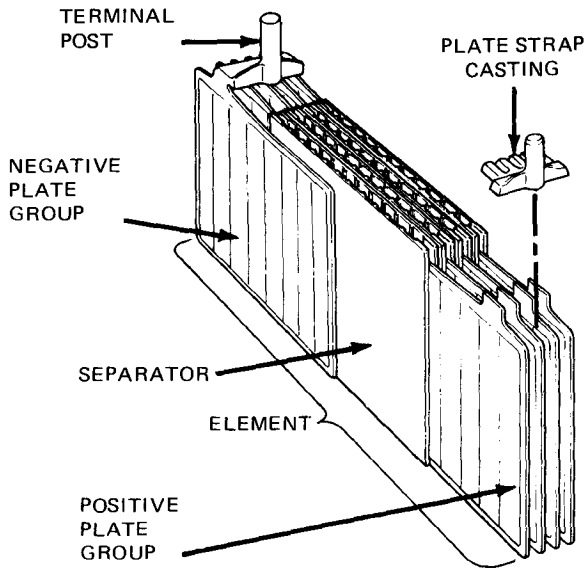


Fig. 41-2 One battery element (lead-acid battery). *(Delco Remy, Division of General Motors.)*

It is partitioned to separate the cells. Sediment chambers on the bottom allow the active material, which wears off during charging and discharging, to settle without interfering with the plates. Such interference would cause a short circuit.

The cells are placed in the battery case and secured to supports. When a one-piece battery cover is used, cell connectors are welded to the intermediate terminal posts to connect the cells in series (Fig. 41-3). When individual cell covers are used, one cover is placed over each of the six cells (Fig. 41-3*b*). A positive intermediate terminal and a negative battery post, supported by lead bushings, protrude through one end cover. A negative intermediate terminal and a positive battery post protrude through

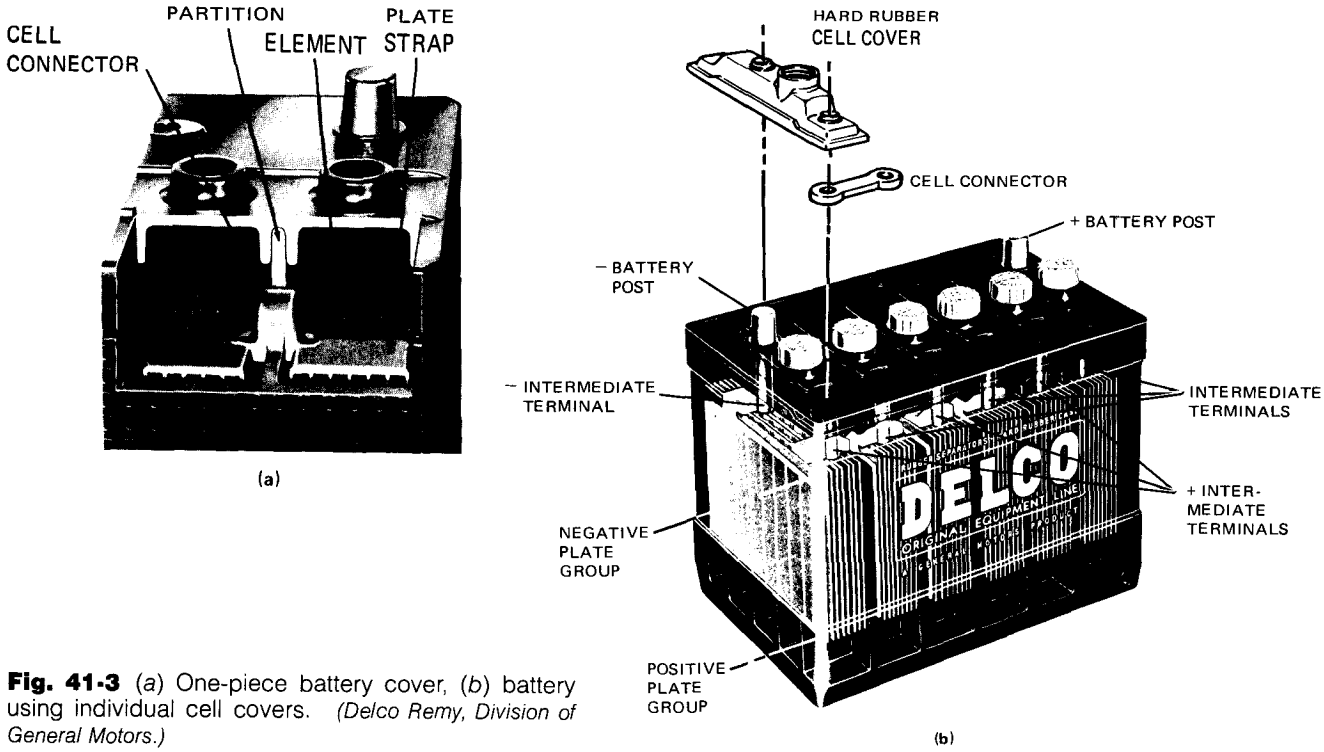


Fig. 41-3 (*a*) One-piece battery cover, (*b*) battery using individual cell covers. *(Delco Remy, Division of General Motors.)*

the other end cover. An intermediate terminal connected to the positive plates and an intermediate terminal connected to the negative plates protrude through the center cover.

The cell connectors are welded externally so that the negative internal post of one cell is joined with the positive post of the adjacent cell.

Two advantages of a one-piece battery cover over a battery having individual covers are that it provides an acidtight seal and has shorter connections between the cells which reduce voltage loss. To prevent battery cables from being installed in reverse polarity, the positive and the negative battery terminals are standard, varying in diameter (but not in taper and length). The positive post has a top diameter of 0.6875 in [17.46 mm] and the negative post has a top diameter of 0.625 in [15.87 mm].

When the individual covers are installed and the cells are connected, the covers are sealed with a special bituminous substance that withstands temperature changes. This substance can be removed. The immovable one-piece cover is sealed with a permanent resin sealer.

The cell cover(s) have vents of different construction. Their cover openings are closed off by the vent cap. The vent cap serves a dual purpose: (1) It allows the gases which are formed during charging and discharging to escape and (2) it closes the openings through which electrolyte is checked and water is added.

Sealed-type Battery In an effort to extend the battery serviceability, to minimize the need for maintenance, and to increase its dependability, a new type of battery has been developed (see Fig. 41-4). The external appearance of this new Delco heavy-duty Freedom battery is somewhat similar to that of the conventional battery except that it has no filler caps nor the conventional battery posts and it includes a state-of-charge indicator. (The state-of-charge indicator gives you instant read-out of the charge condition of the battery.)

Internally, the Freedom battery is immensely different from the conventional battery. It is constructed as a completely sealed unit and has the inherent advantage of a lifetime supply of electrolyte (1.265); there is, consequently, no need to check the electrolyte level. The cells cannot be under- or overfilled and there is no danger of using unsuitable water. The battery terminals are made of stainless steel and the battery-cable connection is made mostly through the lead base of the terminal and only partly through the terminal bolt. *(NOTE: Some of the light-duty Freedom batteries have conventional battery posts.)*

Because the battery terminals are constructed of stainless steel, it has been possible to modify the cable ends (see Fig. 41-5). Short No. 2 battery cables are used to connect the individual batteries and connect the batteries with the main battery cable. The No. 2 cable is spliced to the main cable which connects the batteries with the cranking motor. The main cable may be made up of three No. 000 or four No. 000 battery cables. The No. 2 terminal ends are covered with plastic and the protruding surfaces of the connectors ensure a good electrical contact. Additionally, stainless steel crown nuts, which are corrosion-resistant, are used to provide further protection against a poor terminal connection.

INTERNAL CONSTRUCTION The sealed battery was made possible by replacing the lead-antimony grid with a lead-calcium grid. These batteries have greater counterelectromotive force (cemf) than the conventional battery, thus preventing overcharging which greatly reduces gassing. The gases which are formed during the charging and discharging cycle

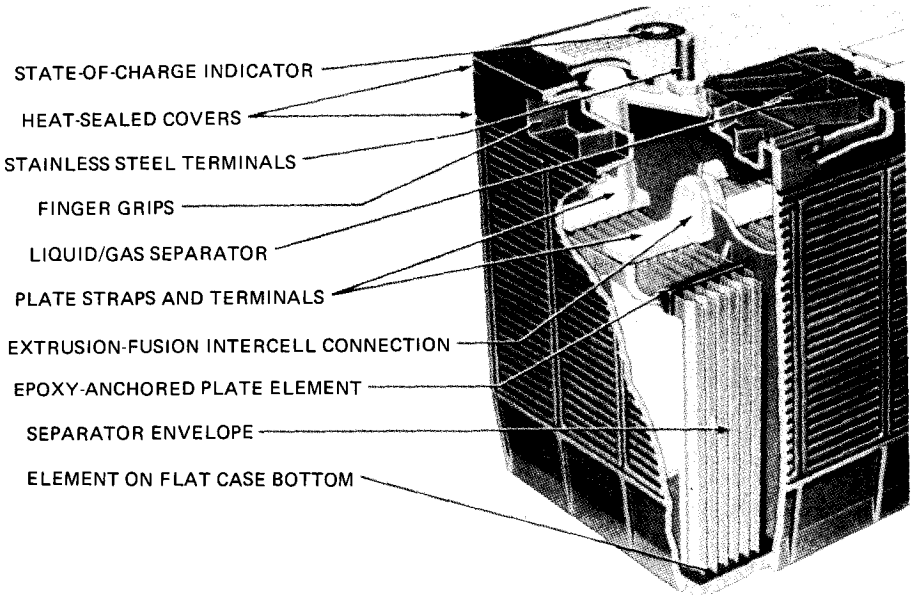


Fig. 41-4 Cutaway view of a Delco Freedom (1200) battery. *(Delco Remy, Division of General Motors.)*

rise upward and are trapped in the liquid/gas separators. As the gases cool, they transform to liquid and reenter the electrolyte through special passages. The cooling is accelerated through the sealed cover which is located above the gas separator. Any internal pressure that may arise is released through two small vent holes in the side cover which have specially designed flame arrestors to prevent an internal gas explosion from an external spark or flame.

The plates used in Freedom batteries are produced by the same method and are of the same material as a conventional lead-acid battery. They are placed in porous envelopes which allow electrolyte to penetrate and electric current to flow from one group of plates to the other group of opposite polarity. The intercell connection is made through extrusion-fuse welding of the plate straps to the center of the plates. This design has increased terminal voltage because of this shorter electrical path and has strengthened the plate group support within the battery. The end-plate straps are connected to sealed terminal ends which prevent oxidation and/or corrosion at the cable connection. Each element rests securely in its own cell partition.

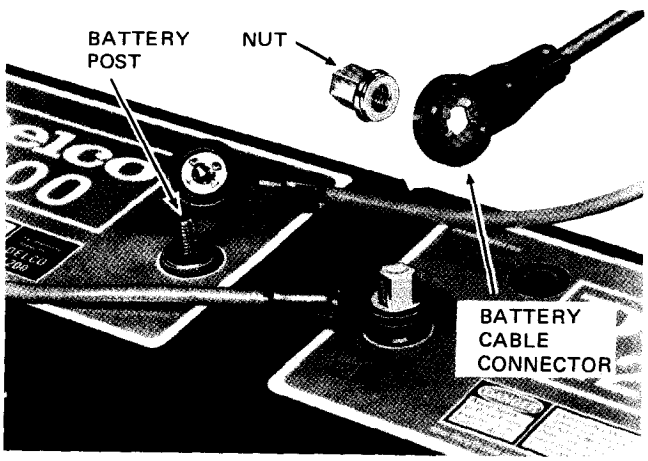


Fig. 41-5 Battery post and battery cable terminal connectors. *(Delco Remy, Division of General Motors.)*

STATE-OF-CHARGE INDICATOR

The hydrometer is built into the cover. Its glass tube extends into the electrolyte. On the end of the glass tube is a cage in which a green ball rests. When the electrolyte has a specific gravity of 1220 or less (low state of charge), the ball sinks within the cage, away from the center of the glass tube. The indicator eye is then dark. As the battery becomes charged and the specific gravity exceeds 1220, the green ball rises and appears visible at the hydrometer eye. *(NOTE: If the indicator eye is clear, this indicates a low electrolyte level.)*

CAUTION Batteries must not be charged more than 50 to 70 Ah (ampere-hours). If the state-of-charge indicator is light, do not attempt to charge or test the battery. It must be replaced.

Battery Classification and Ratings The amount of current (capacity) that a battery can deliver depends on the number, size, and weight of its plates, and the volume of acid present. The emf, that is, the open-circuit voltage of a fully charged cell with a specific gravity of 1.265 is 2.1 to 2.15 V regardless of the number, size, or weight of the plates. But the voltage on discharge is influenced by the size of the cells—the larger the plate area, the longer the cranking voltage remains the same (under any given condition) when comparing it with a battery having a smaller plate area.

To crank an engine, you need electrical power. The power demanded from a battery varies with the engine displacement and compression ratio. Engine manufacturers test their engines to establish starting power, that is, the energy (in watts) required to crank an engine at 0° F [−17.8°C]. From this test factor the recommended minimum cold-cranking amperes (CCA) for a given engine is established. For example, suppose that 18,000 W are required to start the engine, and that the cranking-motor voltage is 12 V. To arrive at the cold-cranking amperes, divide 18,000

TABLE 41-1

CCA RECOMMENDATIONS

Manufacturer	Model	Displacement	CCA	Watts
Caterpillar	1674	638	1500	18,000
Mack Maxidyne	,675	672	1460	17,520

by 12. The answer is 1500 CCA. If the cranking-motor voltage were 24 V, only 750 CCA would be required. Two engine manufacturers' recommendations are listed in Table 41-1.

To standardize the CCA requirements for the great number of diesel and other internal-combustion engines, battery manufacturers in cooperation with SAE have classified batteries with a number and letter system. This system distinguishes battery voltage, battery dimension, reverse capacity, cold-cranking amperes at 0 and −20°F [−17.8 and −28.9°C], overcharge, and charge acceptance in amperes.

The classification and rating for battery groups recommended for use on diesel engines are listed in Table 41-2.

BATTERY SERVICE

Electrolyte To utilize a battery of the conventional design, you must first bring it to life by filling it with electrolyte. The electrolyte supplies the sulfation and acts as a current (electron) carrier between the positive and the negative plates. The plate grids and the cell connectors carry the current running to and from the active material to the negative and positive battery posts.

The electrolyte is a solution of 65 percent water and 35 percent sulfuric acid by weight or about 76 percent water and 24 percent sulfuric acid by volume. This solution has a specific gravity of 1.265 at 80°F [26.7°C] since water has a specific gravity of 1.000 and sulfuric acid has a specific gravity of 1.835.

To increase the life of the battery, most manufacturers produce electrolyte with a specific gravity of 1.265 when it is to be used in a moderate climate. However, if the battery is to be used in a tropical climate, the specific gravity may be reduced to 1.250. If the battery is to be used in arctic climate the specific gravity may be increased to 1.285 (see Table 41-3). As indicated in the table, when the strength of the electrolyte changes, the open-circuit voltage changes also.

Filling Cells with Electrolyte Electrolyte usually is shipped in a plastic container. Use a plastic funnel when filling the individual cells to the recommended level. Make sure that the battery and electrolyte are both at room temperature.

CAUTION Handle the container with care. Use rubber gloves and eye protection. Do not spill the electrolyte during filling operations. It is an acid and will cause blisters if it contacts the skin directly. It will also damage clothes and deteriorate iron and paint, etc.

If electrolyte is accidentally spilled, immediately wash away the acid with water, sprinkle baking soda on the contacted area, or wash the area with a solution of water and baking soda.

After filling, recheck the electrolyte level, since the plates react like sponges and quickly reduce the level of the first fill. Always clean away any spillage before you charge the battery.

If it ever becomes necessary to mix your own electrolyte from a concentrated sulfuric acid, do so with extreme care; wear rubber gloves, goggles, and an apron. Mix the solution in a plastic or rubber container.

CAUTION Mix by pouring pure acid very slowly *into the water.* (Pouring water into the concentrated acid will cause an explosion.) Use a glass, plastic, or wooden stick for mixing. Do not let the temperature exceed 150°F [65°C] while mixing.

To arrive at a specific gravity of 1.265, start with 1 qt [0.95 L] water and a little less than ¼ qt [0.237 L] acid. Take care when adding the final acid not to exceed the desired 1.265 specific gravity. After adding the last sulfuric acid, allow the temperature of the solution to cool to about 90°F [32.2°C] before you take a hydrometer reading.

Battery Inspection Batteries are sometimes so neglected they will no longer start the engine. To prolong battery service life, they should be regularly inspected and serviced. When you inspect the batteries, look for cracks caused by overly loose or overly tight hold-down clamps. Inspect the battery compartments for foreign matter.

Check for signs of wetness or leakage on the top of the batteries which might be the result of a missing filler cap, overfilling, or overcharging.

Check the battery terminals for corrosion. Excessive corrosion indicates high resistance (poor connections) at the terminals or within the battery itself.

TABLE 41-2

BATTERIES RECOMMENDED FOR DIESEL ENGINE SERVICE

Ref No.	SAE	Voltage, V	Reserve capacity, min	Cold-cranking amperes		High discharge, 15 seconds, A
				At 0°F [−17.8°C]	At −20°F [−28.9°C]	
6T3A	7D 900	6	430	900	650	450
20T4A	4D 640	12	285	640	450	450
20T6A	6D 800	12	350	800	555	450
20T8A	8D 900	12	430	900	650	450
Delco 1200	4D 640	12	130	475	375	230
Delco 1110	4D 640	12	160	625	. . .	160
Delco 1150	4D 640	12	180	580	. . .	290

TABLE 41-3

ELECTROLYTE-STRENGTH VARIATIONS

Specific gravity	Opening voltage, V	Freezing temperature, °F [°C]
1.285	2.30–2.40	−100[−73.3]
1.275	2.20–2.30	− 88[−66.7]
1.265	2.10–2.20	− 79[−61.7]
1.250	1.90–2.00	− 62[−52.2]

To service the batteries efficiently, remove them to the service area. This will minimize battery damage during servicing and permit unobstructed access to the battery compartment.

Battery Maintenance To simplify reinstallation, make a mental note of the position of the terminal posts before you remove the batteries. Disconnect the ground cable first so that it cannot accidentally touch the ground and cause a short circuit which could damage the batteries or other components. It also may prevent your hands from being burnt, especially if you are wearing a ring.

Remove battery hold-down clamps (covers). When they are damaged or corroded, replace them. If they are in good condition, clean them thoroughly and paint them with acid-resistant paint. Use two wrenches when loosening the terminal bolt nut to prevent loosening or breaking the terminal post from the cell connector. Pull the terminals from the battery post with a battery puller. Do not use a pair of pliers or a screwdriver because either of these may damage the post connection or cell cover. Use a carrying strap to lift and carry the battery to the service area. Do not use a pair of pliers or a vise grip to lift the batteries from the compartment. Do not carry the batteries in your hands.

Before you clean the battery, tape or block the vent holes. Use a wire brush to remove excessive dirt or oil from the battery. Wash away corrosion and electrolyte from the battery and terminals with a baking soda solution, then rinse with clean water. If necessary, use steel wool or a terminal-cleaning brush to clean the battery posts. Use compressed air to dry the batteries but make sure the sealer has not broken away from the battery case as this could allow acid to be drawn from the battery.

Battery Leakage Test The first test you should make is the electrical leakage test, since electrical leakage will drain the battery continuously. Use a low-reading voltmeter or adjust the voltmeter to its lowest scale. Clamp the negative voltmeter probe to the negative battery post. Rest the positive voltmeter probe lightly on the sealing compound or cell cover near the negative post. Slowly slide the probe from the negative side toward the positive battery post and watch the voltmeter's reaction. When the probe rests on the last cell cover near the positive post, the voltmeter should read not more than 0.1 V. If the reading is higher, check for cracks, a loose intermediate post, a loose battery post, or seal-to-battery separation.

Hydrometer Design Hydrometers are devices to measure specific gravity of a liquid. They operate on Archimedes' principle that buoyancy or lift (buoyant force) equals weight of liquid displaced.

A typical hydrometer consists of a sealed weighted glass vial, a glass barrel, and a bulb syringe to draw up a sample of the electrolyte (Fig. 41-6). The vial stem may have a scale calibrated in terms of specific gravity etched on it, or it may have a paper scale inserted in the stem.

A small thermometer and a correction scale are built into most hydrometers to allow for temperature effects when determining the correct specific gravity reading (Fig. 41-7). When the temperature of a liquid rises, the liquid density decreases; conversely, when the temperature decreases, the liquid shrinks and its density increases. Therefore, temperature changes cause the buoyancy to increase with a decrease in temperature and to decrease with increase in temperature. Figure 41-7 shows that the "zero" point of the correction scale is at 80°F [26.7°C]. To arrive at the correct specific gravity when electrolyte temperatures exceed 80°F [26.7°C], you must add 0.004 for every 10° F [5.6°C] over 80°F [26.7°C]. When the electrolyte temperatures drop below 80°F, you must subtract 0.004 for every 10°F [5.6°C] below 80°F [26.7°C].

Hydrometer Test The state of charge of a battery may be measured with a hydrometer by testing the specific gravity of the battery fluid (electrolyte) or by using cadmium probes. As a cell discharges, sulfuric acid from the electrolyte enters the battery plates (positive and negative) and the active material gradually changes to lead sulfate. The chemical action produces water and consequently lowers the strength of the electrolyte. The specific gravity of the electrolyte varies directly in proportion to the strength of charge of each individual battery cell.

Before you check the specific gravity, make sure that the battery gassing has stopped, the gases have escaped, the sediments have settled, and the surface charge is removed. To remove the surface charge,

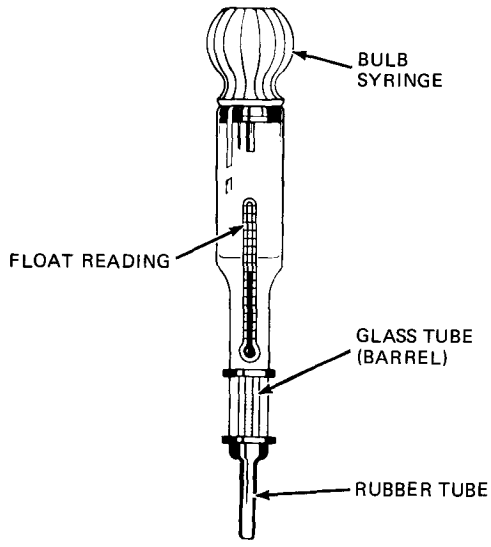


Fig. 41-6 Hydrometer. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

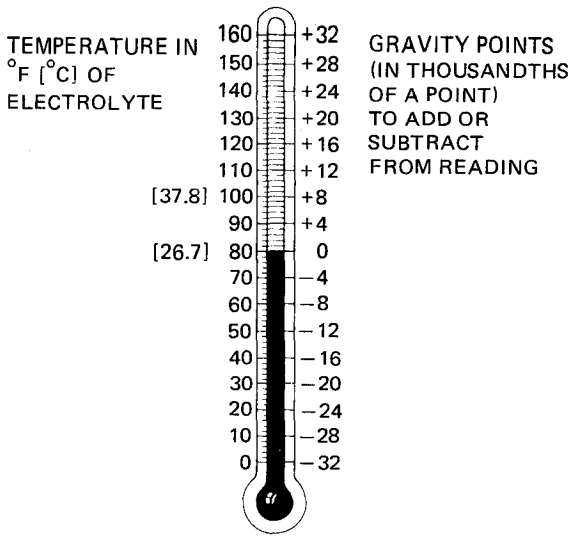


Fig. 41-7 Hydrometer temperature correction scale. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

crank the engine over once or twice or turn the headlights on for a few minutes.

NOTE: Do not take a hydrometer test if water has just been added or if the engine has been cranked too long. In either case, fast-charge the battery for 15 minutes; then take the test.

To ensure an accurate reading, warm up the hydrometer float to that of the electrolyte temperature by drawing electrolyte in and out of the barrel. Draw up enough electrolyte so that the float moves to the middle of the barrel. Hold the hydrometer at eye level without tilting it and allow the float to float. Do not take the fluid level at the float stem or at the barrel since it is high at both of these points because of surface tension of the fluid. At the same time, take the temperature reading.

Assume the hydrometer reading is 1.240 and the electrolyte temperature is 100°F [37.8°C] (see Fig. 41-7). Add 0.008 points specific gravity to account for the temperature rise above 80°F [26.7°C]. So, 1.240 + 0.008 = 1.248, the correct specific gravity. The cell is then about 90 percent charged and should have a voltage of 2.05 V.

Check all the cells of one battery and compare their specific gravity. A difference of more than 50 points (0.050 specific gravity) between the cells is generally an indication that the plates are deteriorating. However, the difference may be caused by an internal short circuit, a loss of electrolyte due to leakage, or an excessive charging rate. A battery with a high variation should be recharged and retested. If the variation persists, the battery should be replaced.

When battery cells have a specific gravity of less than 1.215, the battery's service life is questionable. It should be recharged and retested, or replaced.

Open-circuit Voltage (emf Voltage) Another method of determining if a battery is in a fully charged condition, if it requires recharging, or if it is defective is by the use of a low-reading voltmeter with a 2.3-V scale with 0.10-V divisions.

Place the test prong of the voltmeter across each battery cell. The individual cell voltages should be within 0.05 V of each other. When there is a greater difference (or when any cell voltage is 1.95 V or less), the battery should be recharged and retested. A high-discharge (capacity) test should then be made.

NOTE: Batteries with a one-piece cover cannot be tested with a voltmeter. A cadmium probe tester must be used to test their voltage (see Fig. 41-8).

Light-load Test A light-load test is more reliable than an open-circuit voltage or a hydrometer test because the light-load test requires the battery to convert chemical energy into current flow. For this test the low-reading voltmeter or the cadmium probe tester may be used.

When you use a cadmium probe tester to perform the light-load test, place a carbon pile across the battery and draw about 15 A from the battery. Alternatively, when the batteries are installed, turn on the headlights or other electrical components. This will equal a 15-A draw. Attach the cadmium probes to the leads of the voltmeter, positive to positive, and negative to negative. With current flowing from the battery, hold the positive cadmium probe against the positive battery post, insert the negative probe into the first cell (see Fig. 41-8), and record the voltage. Then place the positive probe into No. 1 cell and the negative probe into No. 2 cell. Record the voltage. Continue until all cells are tested. If each cell voltage is 1.95 V or higher with no voltage variation, the battery is in good condition. When the voltage is lower, but without variation, the battery requires recharging and retesting. When the voltage variation is more than 0.5 V, recharge and retest the battery. Also perform a high-discharge test to determine if the battery is reusable.

High-discharge Test and Cold-cranking Test The battery tests with which you will be most concerned are the high-discharge test, the cold-cranking

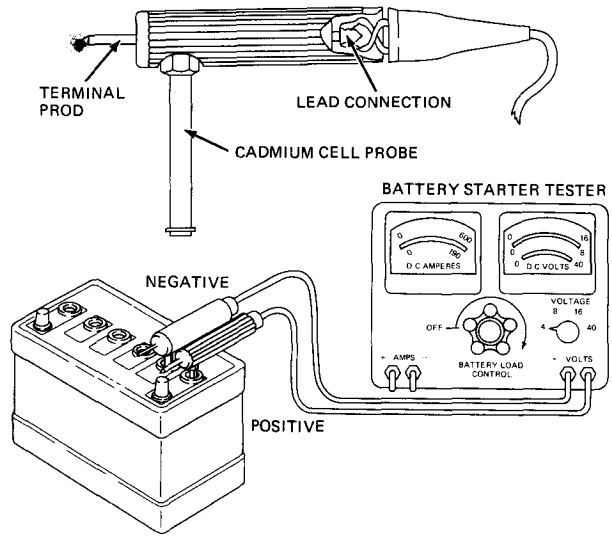


Fig. 41-8 Checking the battery using cadmium cell probes. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

test, and the reserve-capacity test. These tests are the most reliable because, under maximum and minimum strain, they measure the battery capacity to change chemical energy into current flow.

To perform the high-discharge or cold-cranking test, an ammeter, voltmeter, and carbon pile (variable resistor) or a conventional, or an electronic, battery starter tester are required. Connect the tester lead as shown in Figs. 41-9 and 41-10.

NOTE: To perform a cold-cranking test, the temperature of the battery should be brought to 0°F [−17.8°C]. If this is not possible, a high-discharge test is used to simulate the cold-cranking test. When the instruments are connected, measure the open-circuit voltage. When the open-circuit voltage is 6 V or lower for a 6-V battery (12 V or lower for a 12-V battery), or if the specific gravity is lower than 1.220, recharge the battery before testing; otherwise the battery plates could be damaged during testing.

One more requirement before making the actual high-discharge test is that you remove the surface charge in order to obtain a true battery-capacity reading. This is done with the help of a carbon pile. The amount of current draw from the battery needed to remove the surface charge is fixed for each battery group. For instance, batteries recommended for diesel engines, such as groups 7D, 4D, 6D, 8D, and Delco Remy Freedom batteries, would require a current drain of 300 A for 15 seconds.

To perform a high-discharge test on groups 7D, 4D, 6D, or 8D batteries, draw 450 A from the battery for 15 seconds. When testing Delco Remy Freedom batteries, use the specifications given in Table 41-1. At the conclusion of the test the voltage in all cases should register not less than 9.6 V for a 12-V battery

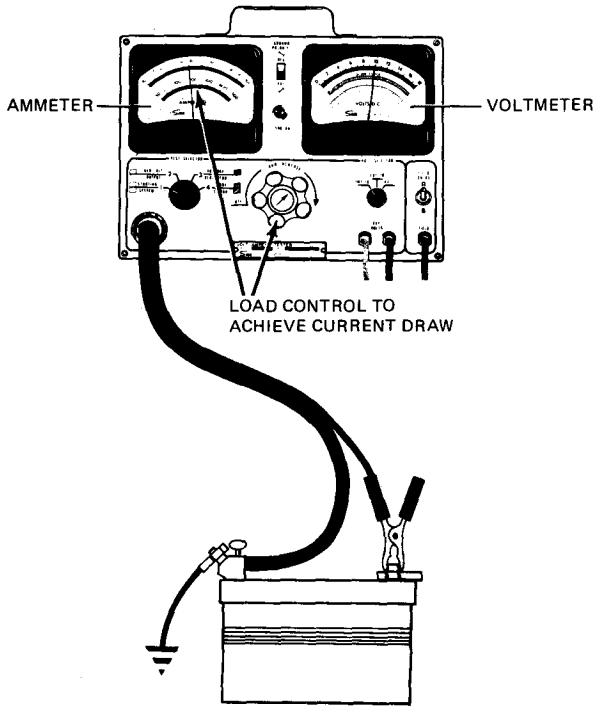


Fig. 41-9 Connections for a battery-capacity test (high-discharge test). *[J.I. Case Agricultural Equipment Division (TENNECO).]*

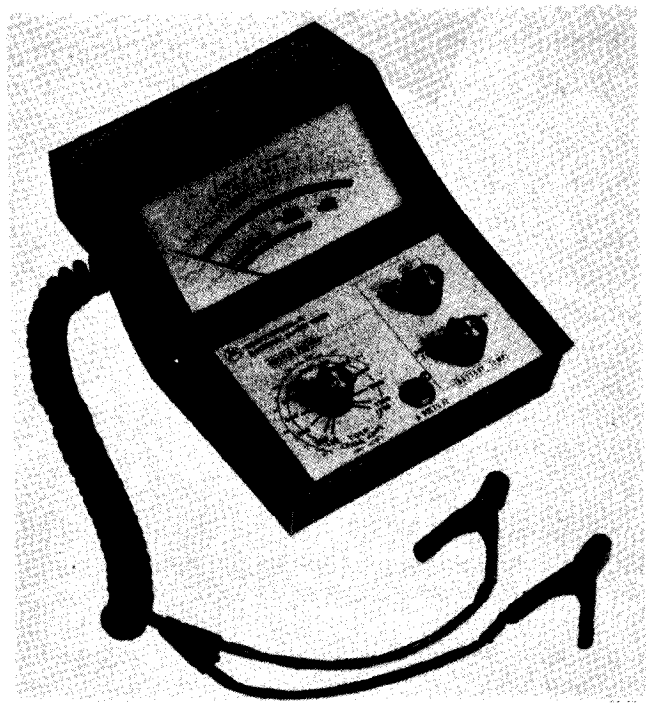


Fig. 41-10 Electronic battery tester. *(Mack Trucks Canada Limited.)*

and not less than 4.8 V for a 6-V battery, assuming that the ambient temperature is 70°F [21.1°C] or more. If the ambient temperature is less than 70°F, the minimum acceptable voltage is less, as indicated in Table 41-4.

When the load from the battery is removed (the variable resistor is open), the voltmeter reading should be within 0.2 V of the open-circuit voltage reading before the test. If the test voltage is lower than the 9.6 or 4.8 V previously referred to, or if it did not recover within 0.2 V of the open voltage at the start of the test, the battery is in poor condition and should be replaced.

To perform a true cold-cranking test, place the fully charged battery in a cold room to lower its temperature to 0°F [−17.8°C]. When the battery reaches this temperature, connect to it the same instruments used to perform the high-discharge test. Now use the carbon pile and discharge the battery for 30 seconds at the same rate as the cold rating of the battery. At the end of 30 seconds the individual cell voltages must be 1.2 V or more, that is, the terminal voltage must be 7.2 V for a 12-V battery, and 3.6 V for a 6-V battery.

Reserve-capacity Test The reserve-capacity test procedure is similar to that of the old 20-Ah test. That is, a 100-Ah battery fully charged must deliver 5 A for 20 hours at a temperature of 80°F [26.7°C], and the cell voltage at the end of the test must be 1.7 V or higher.

The reserve-capacity test also tests a fully charged battery at 80°F [26.7°C], but you draw 25 A from the battery until the individual cell voltage reaches 1.75 V, or the terminal voltage for a 12-V battery reaches 10.5 V (5.25 V for a 6-V battery). The reserve-capacity is defined as the time (in minutes) from the moment of ampere withdrawal to the moment cell voltage reaches 1.75 V.

TABLE 41-4

AMBIENT TEMPERATURE AND MINIMUM VOLTAGE

Temperature, °F [°C]	70 and above [21.1]	60 [15.5]	50 [10]	40 [4.4]	30 [−1.1]	20 [−6.6]	10 [−12.2]	0 [−17.8]
Minimum voltage, V	9.6	9.5	9.4	9.3	9.1	8.9	8.7	8.5

Three-minute Charging Test This test should only be made when the battery has failed its high-discharge test. The result of a 3-minute charging test indicates the condition of the plates as well as the condition of the connections within the battery.

To make this test, connect a fast charger and a voltmeter to the battery as shown in Fig.41-11. Set the voltage selector switch to 8, 16, or 24 V (depending on battery voltage). Set the timer for 3 minutes. Start the charger and adjust the charging rate to 10 percent of the CCA of the battery. Observe the voltmeter while charging. The charging voltage should not exceed 15.5 V for a 12-V battery, or 7.75 V for a 6-V battery throughout or at the conclusion of the 3-minute charging time.

When the voltage is higher than specified, the battery is sulfated, damaged, or has high resistance in its connections. When the voltage is lower than specified, check the individual cell voltage. If the variation is not greater than 0.1 V, the battery should be recharged and the high-discharge test repeated.

Chemical Action in Battery when Discharging While a battery is discharging, the sulfuric acid within the electrolyte is chemically absorbed by the sponge-lead negative plates and by the positive lead peroxide plates, whereupon both plates gradually are changed into lead sulfate and the specific gravity is lowered. The greater the similarity between the positive and the negative plates, the lower the voltage within the cell, as voltage depends on the difference between the two materials.

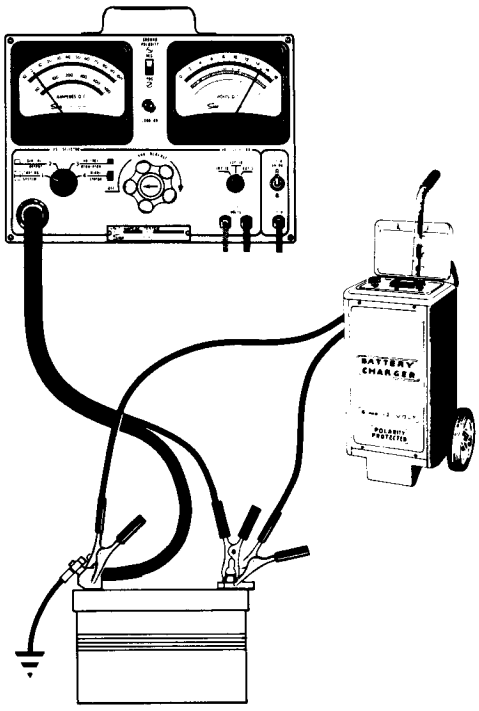


Fig. 41-11 Connections for a 3-minute charging test. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

Chemical Action in Battery during Charging While the battery is being charged by a generator or charger, current passes through the battery in a direction opposite to that of discharge. The sulfuric acid leaves the plates and returns into the electrolyte, increasing the specific gravity. The negative plates change gradually to lead sulfate and the positive plates change to lead peroxide. During the charging action, the negative and positive plates give off a hydrogen and oxygen gas. As the battery nears the fully charged state, the gassing action increases.

CAUTION Do not approach the battery area with an open flame. Do not smoke when checking or testing batteries. The gases are highly explosive; therefore, the possibility of an explosion is always present.

Battery Charging Four major battery chargers are used to recharge batteries: (1) a dc or ac generator, (2) a constant-potential (voltage) charger, (3) a constant-current charger, and (4) a trickle charger (used to maintain test stand and storage batteries in a charging state).

Before you charge any battery, you should clean it thoroughly, test it, and adjust the liquid to the correct level. When you adjust the electrolyte levels, add only water that is within specified purity. Do not use electrolyte.

When possible, use the liquid level indicator to ensure proper liquid height. If this indicator is not available, fill the cells to the lower edge of the cell opening.

NOTE: Add electrolyte only when you accidentally have spilled some of this solution when preparing to charge the battery.

Battery Charging with Fast Charger Fast chargers are commonly of the constant-potential (voltage) type. The batteries to be charged must be of the same voltage, or connected to make up the same voltage, and then connected to the charger in parallel. The number of batteries that can be connected depends on the capacity of the charger. In all cases, follow the manufacturer's instructions.

Batteries which are in good condition will not be damaged (by a fast charger) when the charging temperature does not exceed 125°F [51.6°C] and the voltage selector switch is set to the correct battery voltage. Adjust the charging current to 10 percent of the CCA of the smallest battery.

NOTE: A battery with badly sulfated plates cannot be fully charged with a fast charger.

Connect the batteries first, before switching on the charger. When the charger is switched on, you will notice that you have to adjust the current selector switch very high to achieve the desired charging current. Since electrolyte expands because of heat and gassing bubbles, as the batteries are warming up, reduce the current selector setting and, if necessary, remove some electrolyte to prevent it from spilling over. (Store the removed electrolyte for later replacement when the battery is charged.) You will notice that as the battery voltage (emf) increases, the charging current gradually decreases.

NOTE: When the temperature is close to 125°F [51.6°C], reduce the charging rate.

When all cells are gassing freely, the battery is nearing its fully charged state. After this point take the hydrometer reading frequently. When the specific gravity ceases to increase, stop charging. When the battery has cooled off, check the electrolyte level.

CAUTION Switch the charger off before you disconnect the batteries to prevent an explosion. Avoid overcharging the batteries because this may corrode and bend the positive plates. Furthermore, the excessive gassing bubbles will remove active material from the plates and may increase the acid level, which is harmful to the plates and separator.

Battery Charging with Slow Charger If time is available or if the condition of the battery plates is unknown, a constant-current charger (slow charger) should be used to prevent damage to battery plates. When being charged with a constant-current charger, the batteries must be connected in series. Note that a 6 and a 12-V battery may be placed in the same line.

The most common charging rate is 1 A per positive plate of the smallest cell connected to the charger. For example, if the smallest cell has 11 plates, then it has 5 positive plates. Therefore, the selector switch of the charger should be set to allow a current flow of 5 A into the batteries.

When using a constant-current charger at normal rate, you will notice that the terminal voltage gradually increases from 2.14 to 2.3 V and then increases rapidly to 2.5 to 2.6 V. This latter interval is known as the *gassing period*. When this period is reached, you should reduce the charging rate in order to avoid unnecessary erosion of the plates.

Battery Installation Before you install a battery, make certain the battery compartment is clean and preferably repainted. Make sure all battery cables and terminals (including the battery-terminal bolts and nuts) are in good condition and that the battery hold-down clamps or covers have been repaired or replaced.

NOTE: To prevent future electrical problems, install only fully charged batteries. When your equipment requires more than one battery: Do not install one new battery alongside older batteries; do not install batteries of different capacity; do not install batteries from different battery manufacturers because the counterelectromotive force of the batteries may differ and the capacity or plate area may also vary. This last point is especially important when a series-parallel switch is used. (See Cranking-Motor Circuits in Unit 42).

Before you install the batteries in the battery compartments, arrange them on the shop floor in a sequence corresponding to the location and direction they will take in the compartments. This step not only speeds up installation, but also prevents the necessity of reinstalling because of insufficient cable length, wrong polarity, or insufficient voltage. Two common battery connections are shown in Fig. 41-12.

After you lift the batteries into place with a lift strap, make certain they are level and flat in their compartments. Tighten the battery hold-down bolts uniformly so that the cover rests evenly without cracking or distorting the battery case. Apply a light coat of grease on all battery posts and terminals to reduce corrosion. Push the terminal ends onto the battery posts. Do not drive them on with a hammer as this will damage the battery. When necessary, use a terminal spreader to increase the diameter. Use two wrenches to tighten the battery bolts to prevent damaging the cell cover and connections.

Before you connect the ground terminal to the battery post, check the cranking-motor connection, and the ground connections from the engine to the frame and from the frame to the battery. Use a voltmeter to determine if your equipment has an unwarranted ground (electric current drain) but make certain all accessories are shut off. If there is no leakage to ground, the voltmeter will read zero. You can then connect the ground cable. Start the engine and observe the charging system. Check if the charging voltage is as specified or needs adjustment.

Battery Capacity versus Temperature Do not expect 100 percent effectiveness from a fully charged

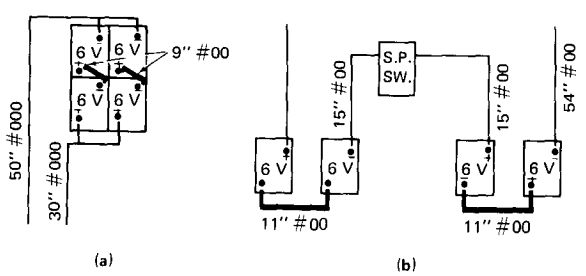


Fig. 41-12 (*a*) Battery connection for a 12-V starting system; (*b*) battery connection for a 24-V starting system using an S.P. S4. *(Cummins Engine Company, Inc.)*

battery when the temperature is near the freezing level because at low temperatures the chemical action of the battery is reduced and in addition more power is required to turn over a cold engine.

To overcome starting difficulties at extemely cold temperatures, remove the batteries, drain the lubricating oil and coolant, and store them at room temperature. When you are ready to start the engine, fill the cooling system with coolant and the crankcase with oil. Install the batteries. This procedure will help warm up the engine, give the batteries more cranking power and, at the same time, will reduce component wear.

Booster batteries are another way to aid starting when the temperature is very low or when batteries are partly discharged. (See "Cold-Weather Starting Aids," Unit 44.)

Booster Batteries to Aid Starting When you use booster batteries to assist starting, connect only boosters having the same voltage as those in the motor-truck, tractor, etc. Follow the steps outlined below to prevent battery explosion.

Connect the red end of the booster cable end securely to the tractor battery live post, and the black end of the booster cable to the booster battery post having the same polarity.

CAUTION Reverse polarity could damage the regulator, generator, radio, and other accessories.

Connect the black end of the second booster cable to the booster battery ground post and the other end of the booster cable to a good ground. Do not connect the cable end to the motor vehicle battery terminal since this could cause a battery explosion because of the high current flow from the booster batteries to the lower charged motor vehicle batteries.

After the engine has started, first remove the booster cable from the ground connection and then remove the cable from the live posts of the booster battery.

Questions

1. State the basic purpose of the lead-acid battery.
2. Name the main components of the lead-acid battery.
3. Briefly outline the procedure to fill a dry-charge battery.
4. Why is a hydrometer correction scale needed?
5. What factors influence battery capacity?
6. What is meant by a 20-hour rating at 80°F [26.6°C]?
7. List obvious defects which would indicate that a battery needs to be repaired.
8. List four battery conditions which a light-load test might determine.
9. Explain how to make a battery-capacity test using a variable resistor (carbon pile), a voltmeter, and an ammeter.
10. What information will a 3-minute test reveal with respect to battery condition?
11. Write a short paragraph on the differences between a fast charger and a slow charger.
12. What precautions must be taken when charging batteries, removing batteries, and installing batteries?
13. List three advantages of a Freedom battery over a conventional battery.
14. List the major differences between an element of a Freedom battery and an element of a conventional battery.
15. What service steps would you take if the state-of-charge indicator was dark?
16. Explain how to boost-start an engine.

UNIT 42 • ELECTRIC STARTING (CRANKING) SYSTEM

The three most common diesel engine starting systems are the electric starting system, the air starting system, and the hydraulic starting system. Though each system has individual advantages or disadvantages, their common purpose is to rotate (crank) the crankshaft so that the engine will start. This unit discusses electric starting systems; Unit 43 discusses air and hydraulic starting systems.

ELECTRIC-STARTING-SYSTEM COMPONENTS

The electric starting system consists of a battery (or batteries), the cranking motor with a solenoid switch, a starter switch, and the complementary wires and cables (Fig. 42-1).

Some electric starting systems have additional components such as the following:

- A *master switch,* as shown in Fig. 38-1, which is a safety switch to disconnect the batteries. It is commonly used on industrial engines.
- A *neutral switch,* which prevents the starting circuits from closing when the transmission is in gear.
- A *series-parallel switch,* which connects the batteries in series for starting (24 V), and connects them in parallel when the engine is running (12 V).

If any of these components are in poor condition electrically or mechanically, the cranking motor will

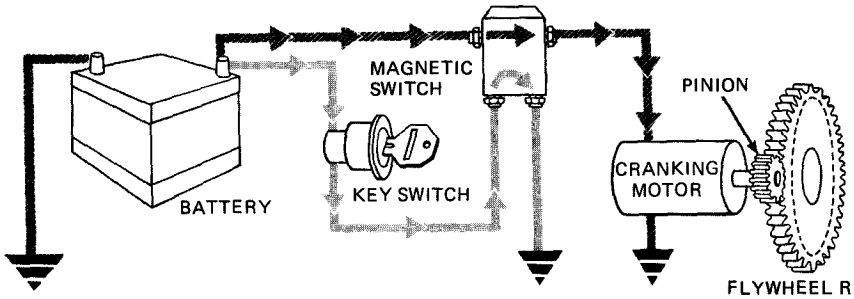


Fig. 42-1 Simplified starting circuit. *(Delco Remy, Division of General Motors.)*

not crank the engine at the rpm required to start the engine.

Cranking-motor Principle The purpose of the cranking motor is to rotate the crankshaft in order to start the engine. The cranking motor receives direct current from the battery and converts it to mechanical energy (rotating motion). The mechanical energy is transmitted from the armature and the pinion (of the cranking motor) onto the flywheel ring gear, causing the crankshaft to rotate.

Its operating principle involves the effect of a current-carrying conductor in a magnetic field. If a single current-carrying conductor is placed between the ends of a horseshoe-shaped magnet, two separate magnetic fields are created. The lines of force of the horseshoe magnet travel from its north pole to its south pole and around the conductor in a clockwise direction (see Fig. 42-2). You will notice that at the left the magnetic lines of the conductor and the horseshoe magnet travel in the same direction and at the right they travel in the opposite direction and are therefore canceled out. This creates a high concentration of magnetic lines on the left-hand side of the conductor and a very low concentration on the right. Consequently the conductor is forced to the right. *(NOTE: The stronger the magnetic field produced by this magnet and the higher the current flow in the conductor, the greater is the force to move the conductor.)*

A basic motor is illustrated in Fig. 42-3. The conductor is formed into a loop (armature) and its ends are connected to semicircular bars (commutators). A heavy wire is wound around a piece of iron (pole shoe) which has a concave inner surface. One coil (field coil) is wound around the pole shoe in a clockwise direction, and the other in a counterclockwise direction. When current flows through the coils, the right-hand wound field coil produces a north pole and the left-hand wound coil produces a south pole. To connect the battery with the armature, spring-loaded brushes are placed onto the commutators. Current then flows first through the right-hand field coil then the left, through the left-hand (live) brush, the armature (loop), and ground brush, and back into the battery. The following magnetic fields then occur: a magnetic field from the field coils from the right to the left (north to south); and a magnetic field of a counterclockwise rotation around the right-hand armature leg and a clockwise rotation around the left-hand armature leg. The end result is that the right-hand leg is forced downward and the left-hand armature leg upward, and the armature rotates clockwise. As the armature legs near their highest or lowest positions, the force on them is reduced because they have then left the strongest magnetic lines of force of the field coil. The inertia, however, pulls them through the static neutral point (commutation). At the same time the commutator bars interchange position with the brushes, causing the current to flow through the armature in the opposite direction. Consequently, the lines of force change direction, the top armature leg is forced downward, the lower one is forced upward, and the armature then continues in clockwise rotation.

Armature Assembly An armature assembly consists of the armature shaft, a laminated iron core, the commutator, and the armature loops. The armature shaft has machined bearing surfaces, drive splines,

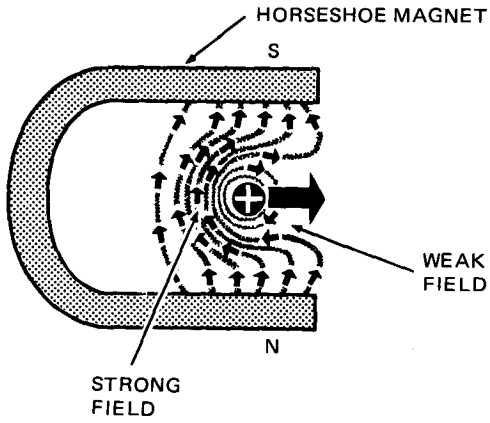


Fig. 42-2 Motor principle. *(Delco Remy, Division of General Motors.)*

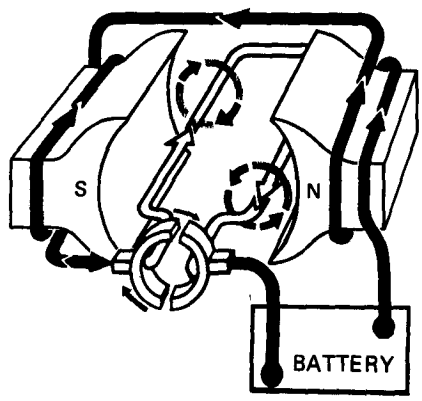


Fig. 42-3 Schematic view of a one-loop cranking motor. *(Delco Remy, Division of General Motors.)*

and devices to hold the laminated sections and the commutator to the armature shaft. Thin steel sections, insulated from each other, reduce eddy current and keep the armature temperature low. Eddy current develops as the induced voltage (emf) causes the free electrons in the laminated sections to swirl about. The insulated armature loops (conductors) are placed in the laminated-iron-core grooves to transmit the force from the conductor to the iron core and onto the armature shaft. The armature loops are made from heavy guage wire or heavy copper ribbon and are soldered either in a wave-winding or lap-winding pattern to the individual commutator segments.

The ends of the wave-wound armature coil for a four-pole motor are connected to the commutator at an angle of approximately 180°, while on the armature of the six-pole motor the angle is approximately 120°. The brushes contacting the commutator bars, and the commutator bars, are of the same polarity. When commutation occurs the loop is short-circuited.

The ends of the lap-wound armature coils are connected to the adjacent commutator segment. Since both ends of a coil contact a brush simultaneously, the coil is short-circuited in the commutation position. The wave-wound armatures have only two paths through which the current can flow, whereas the lap-wound armatures have as many paths as there are poles. The commutator segments are fastened to the armature shaft and are insulated from the shaft and from each other.

The static neutral point of a cranking motor is always in the center between the north and south poles. When the armature loops carry current, they create a magnetic field which distorts the lines of force between the poles. As a result, the load neutral point moves against the armature rotation. The brushes of the cranking motor, therefore, are positioned about ½ to 1½ commutator segments before the static neutral point, as shown in Fig. 42-4, to ensure an arcless (brush) commutation. The higher the current flow and the faster the armature speed, the greater is the line of force distortion and the further the brush is retarded.

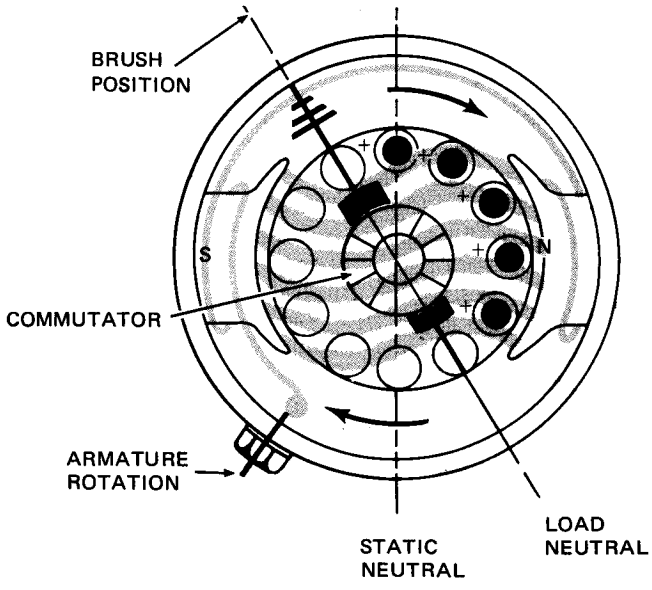


Fig. 42-4 Brush position of a cranking motor.

Field-frame Assembly The field-frame assembly consists of two or more field-coil windings, having the same number of pole shoes, one or more terminal connections, and the iron frame (Fig. 42-5). The field-coil windings are made of heavy copper ribbon to minimize resistance to the high current flow. A four-pole, four-coil cranking-motor circuit is made of two field coils wound in a right-hand rotation to make one pair of the pole shoes north in polarity, and the other two are wound in a left-hand rotation to make the other pole shoes south in polarity. The pole shoes (surrounded by their field coils) are mounted alternately within the field frame. The field frame is the mounting surface for the commutator end frame and the drive housing. The pole shoes and the field frame concentrate the magnetic lines of force and its path.

Cranking-motor Circuits To increase torque or the speed of a cranking motor, the field-coil windings are connected in combinations of series, and/or series-parallel. Cranking-motor torque can also be increased by adding more field coils or by increasing the ampere turns of the field coil.

A straight series circuit is used when high top speed is required (Fig. 42-6*a*). One or two shunt coils may be used to limit the top speed and thus prevent the armature loops from flying out of their grooves (Fig. 42-6*b*).

When a cranking motor runs, it generates voltage (emf) that cannot be shut off and, as the armature speed increases, the generated voltage increases in proportion to the armature speed. The induced voltage, which opposes the battery voltage, is called the *counterelectromotive force (cemf)*. It is because of the cemf that a cranking motor develops its maximum torque and its highest current flow when the armature is not rotating. As the armature starts to rotate and increase speed, torque and current flow decrease as the cemf increases.

When a shunt coil is used to limit high armature speed, it creates the same magnetic strength as the other field coils during cranking and maintains its strength because its current flow is not directed through the armature. It has its own ground; therefore, it is not affected by the armature's cemf. It holds the armature speed to a specific limit.

To increase the current flow (cranking power), and to create stronger magnetic fields, the field-coil current can be directed into two, three, or even four separate paths. Each separate field-coil circuit has its own live ground brush (Fig. 42-6*c*) except where the cranking-motor circuit has the current flow split into four separate paths. In this case, two of the field coils use one live and one ground brush. You may notice when examining the cranking-motor circuits that all live brushes are connected to each other. The jumper leads equalize the voltage at the brushes to prevent arcing (burning) of the brushes and commutators. The ground brushes of cranking motors used in marine applications, or used with series-parallel switches, also have the ground brushes connected through a jumper lead with the insulated ground circuit (Fig. 42-6*c* and *d*).

Drive Housing and Commutator End Frame The drive housing and the commutator end frame,

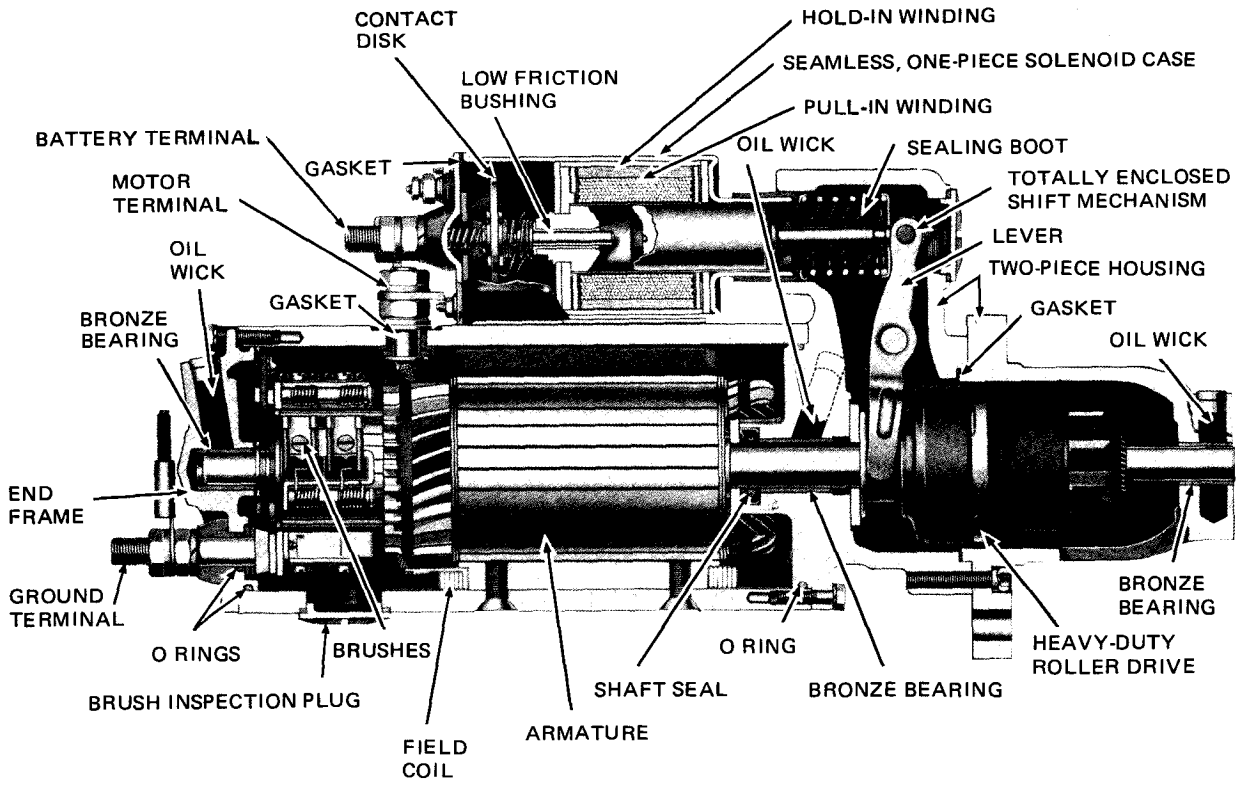


Fig. 42-5 Cross-sectional view of a heavy-duty cranking motor. *(Delco Remy, Division of General Motors.)*

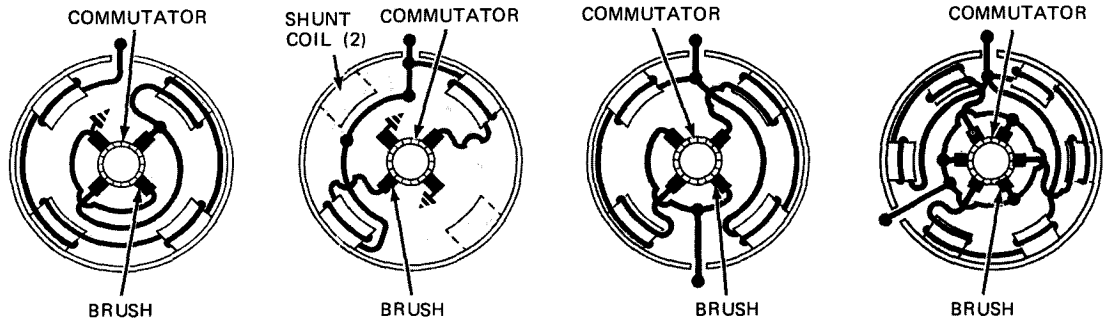


Fig. 42-6 Typical cranking-motor circuits.

which are bolted to the field frame, enclose and support the armature (Fig. 42-5). To prevent the armature shaft from bending, most large cranking motors have an additional bearing support between the field frame and the drive housing. The cranking motor is bolted through the drive housing to the engine. Its drive housing encloses and supports the armature and also shields the cranking-motor drive. In most cases, the commutator end frame is also the mounting surface for the brush holders and the terminal bolt.

Cranking-motor Thermostat A cranking-motor thermostat protects heavy-duty cranking motors against damage due to excessive heat as a result of continuous cranking over a long duration. The thermostat is fastened to the field frame with its temperature-sensing end attached to field coils, but note that the thermostat and its temperature-sensing end are insulated from the cranking motor. The electrical connections are shown in Fig. 42-7.

When the start switch is closed, current from the battery terminals (of the solenoid switch) flows over the start switch, over the neutral switch, through the pull-in winding of the magnetic switch, and over the closed motor-thermostat switch to ground. The magnetic switch is then energized, connecting the S terminal with the battery, and the current flows to both pull-in and hold-in windings to ground. As a result, the solenoid plunger is pulled in, the shift lever semirotates, causing the drive pinion to engage with the ring gear. The solenoid switch contacts then close, the cranking commences.

If the cranking motor is actuated for more than 30 seconds, or if there is high resistance within the cranking-motor circuit, or some other malfunction with the engine that draws a higher cranking current, ex-

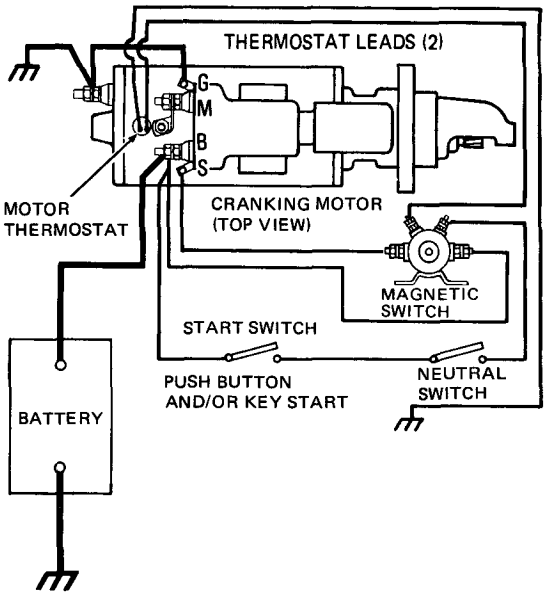


Fig. 42-7 Actuating and cranking circuits using a motor thermostat. *(Delco Remy, Division of General Motors.)*

cessive heat will develop within the motor. As the heat reaches the thermostat's designed cutoff temperature, its switch opens and the cranking stops to protect the cranking motor. *(NOTE: A lapse of 1 to 6 minutes is needed to cool the cranking motor before the thermostat switch will close.)*

CRANKING-MOTOR DRIVES

Although there are many different drives used to engage or disengage the cranking motor from the engine, to reduce motor speed, and to increase cranking torque, there are two major types. They are the inertia drives and the overrunning clutch drives which require a solenoid switch and a shift mechanism. The inertia drive which relies on inertia for pinion engagement is no longer used on modern diesel engines. The friction-type clutch (inertia drive) is used, in conjunction with air and hydraulically operated cranking motors, mainly because the overrunning clutch drive engages the pinion with the ring gear prior to the closure of the cranking-motor circuit.

Friction-clutch Drive The friction-clutch drive is used exclusively with large cranking motors and air-operated (air starter) cranking motors. The clutch assembly is keyed to the armature shaft. The multiplate clutch plates are spring-applied. The screw shaft is fastened to the outside clutch hub and the pinion is located on the shaft (Fig. 42-8).

To prevent pinion engagment during engine operation, an antidrift spring is positioned between the pinion and the stop-nut ring. To reduce pinion and ring gear tooth wear and to assist in engagement, the pinion is chamfered and a meshing spring is positioned between the pinion and the clutch housing.

OPERATION When the starting circuit is closed, the armature starts to rotate. This rotation carries through to the multiclutches and continues to the screw shaft. The loosely fitted pinion, because of its inertia, does not revolve with the screw shaft. Therefore the screw shaft rotates within the pinion, causing the pinion to move longitudinally to engage with the ring gear. The engagement is made easier because of the design of the pinion and ring gear chamfer. When the pinion is in mesh, the shock load, as well as the torque, is transfered to the multiclutch. If the shock load is too great, the clutch slips. When the engine is running and when the ring gear drives the pinion faster than the speed of the armature, the pinion moves longitudinally on the screw shaft out of mesh, since its speed is higher than that of the armature.

Servicing Friction-clutch Drive All inertia drives have the common problems of the pinion not staying in the engaged position, not engaging properly, or disengaging improperly. However, the friction-clutch drives are often subject to the additional problems of ineffectively transmitting torque transfer to the armature or not transmitting at all. In either case, a worn or improperly adjusted clutch pack is usually the cause.

In order to adjust the drive clutch so that its drive is positive but it can nevertheless slip sufficiently to

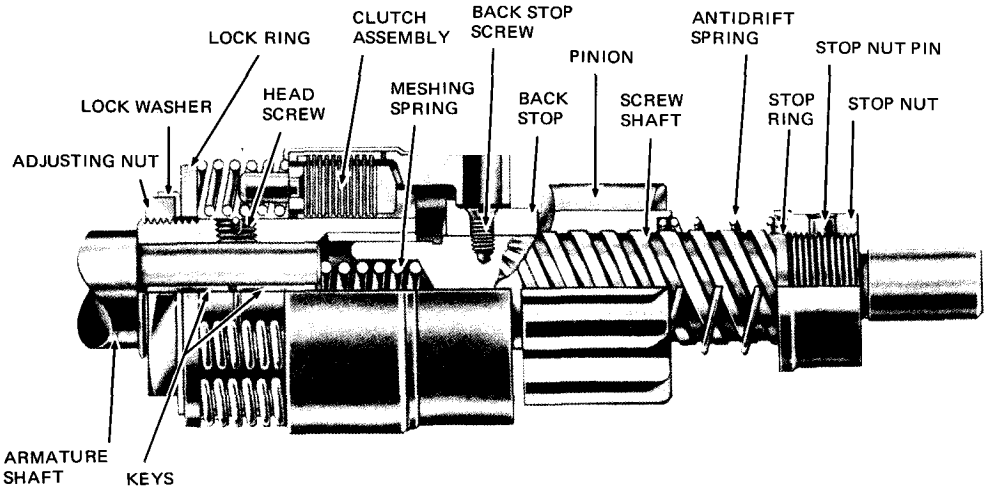


Fig. 42-8 Sectional view of a friction-clutch drive.

absorb the shock load, the cranking motor must be removed from the engine. The drive housing must also be removed in order to bend the locking plate lip back to turn the adjusting nut.

PROCEDURE Turn the adjusting nut clockwise either one-half turn or one turn, depending on the amount of slippage. The increased spring tension increases the force on the clutch plates. Lock the adjusting nut. Reassemble the cranking motor. Install the motor and recheck cranking-motor operation. If the clutch continues to slip, repeat the adjustment procedure previously outlined but adjust the nut only one-half turn at a time. This trial-and-error method must be followed until cranking-motor efficiency is attained.

NOTE: Do not turn the adjusting nut to the point where the clutch springs are fully compressed. If this point is reached, you must then service the drive assembly.

When the drive assembly is rebuilt, adjust the friction clutch, in the following manner. Install a dummy shaft with key in the lock ring, and hold the shaft in a vise. Install a deep socket on the pinion, and use a torque wrench to check the breakaway of the friction clutch. Adjust the nut until the breakaway of the clutch corresponds with the stalled torque test specification.

Overrunning Clutch The ball- or roller-overrunning clutches are manufactured in various sizes to accommodate smaller cranking motors and heavy-duty cranking motors. The sleeve (Fig. 42-9) has internal splines at the left which fit loosely on the straight or spiral armature shaft splines. The collar fits snugly over the sleeve but can move on it to the right. The pinion is permanently secured within the shell-and-sleeve assembly and is supported on the sleeve. Internal bushings support the pinion-and-drive assembly on the armature shaft (at the front). Coil or accordian springs hold the rollers or balls in their taper-cut recessed area located in the inner area of the shell. The balls or rollers, when restricted, lightly contact the pinion surfaces.

OVERRUNING CLUTCH OPERATION When the solenoid switch is engaged, the shift lever moves the collar over the sleeve and compresses the clutch spring. The clutch spring then moves the shell-and-sleeve assembly to the right, causing the pinion to mesh with the ring gear. Should the teeth not mesh at this time, the collar further compresses the clutch spring and, as soon as the armature starts to rotate, the pinion engages. As the armature revolves, the shell-and-sleeve assembly revolves also, thus transmitting torque because the friction between the ball or roller and pinion surfaces forces the balls or rollers to roll out of their grooves and wedge the pinion against the shell. When the engine has started and the ring gear drives the pinion faster (overruning the armature), the friction of the pinion surface forces the balls or rollers back into their grooves and the connection between the pinion and the armature is broken.

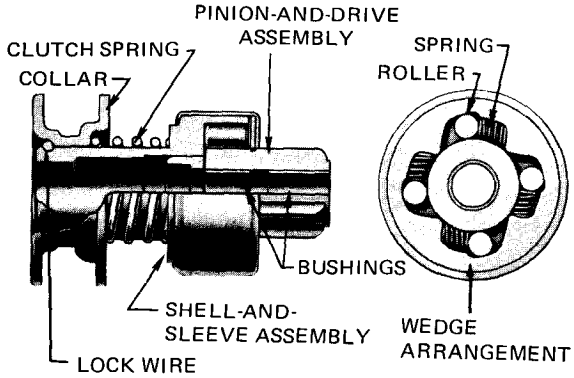


Fig. 42-9 *Sectional view of a small roller-overrunning clutch. (Delco Remy, Division of General Motors.)*

OVERRUNNING CLUTCH FAILURE Overrunning clutch failure is often brought about by worn bushings which cause misalignment between the pinion and the shell and, therefore, prevent the balls or rollers from locking the pinion.

The overrunning clutch cannot be serviced. When it fails to operate properly, it must be replaced.

Sprag Clutch Cranking-motor Drive The sprag-type clutch is not used on newer cranking motors, having been replaced with the heavy-duty Positork or roller-overrunning clutch. It was designed for use on heavy-duty cranking motors. The sprag clutch has banana-shaped locking elements instead of rollers or balls. The collar-and-shell assembly is a one-piece unit (with internal splines) splined to the armature shaft (see Fig. 42-10). The bushing, pressed in the sleeve, supports the armature shaft at the front, and at the rear the shaft is supported in the shell. The sprags are located between the shell surface and the sleeve surface and are held against these surfaces by a garter spring. The sleeve and the sprags are held in the shell by a snap ring. Bronze washers on both sides of the sprags are used to reduce friction. A seal protects the sprag assembly, preventing the entry of water or dirt. The pinion is spirally splined to the sleeve and is held by the meshing spring against the pinion stop.

SPRAG CLUTCH OPERATION When the solenoid switch activates the shift lever, it moves the entire sprag clutch on the spiral armature shaft, causing the assembly to rotate about 10° and ensuring a smooth pinion engagement. Should the pinion butt against the teeth of the ring gear, the sleeve movement will stop. This also causes the shift lever to stop in its travel because the two retainer cups butt against each other. Since the cranking-motor circuit cannot be closed by the solenoid switch, the pinion and ring gear are protected from damage and the armature shaft cannot bend or twist.

The starter circuit must be opened and reclosed to accomplish pinion engagement. When the solenoid switch closes the cranking-motor circuit, the armature rotates, and with it, the collar and the shell. The friction from the shell surface causes the sprags to tilt, locking the sleeve to the shell. When the ring gear drives the pinion faster than the armature, the pinion friction tilts the sprags in the opposite direction, allowing the pinion to overrun.

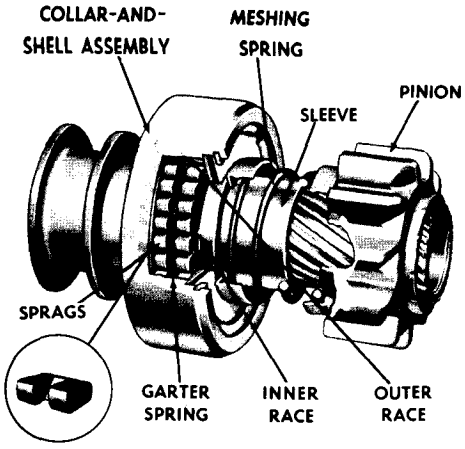


Fig. 42-10 Sectional view of a sprag clutch. *(Delco Remy, Division of General Motors.)*

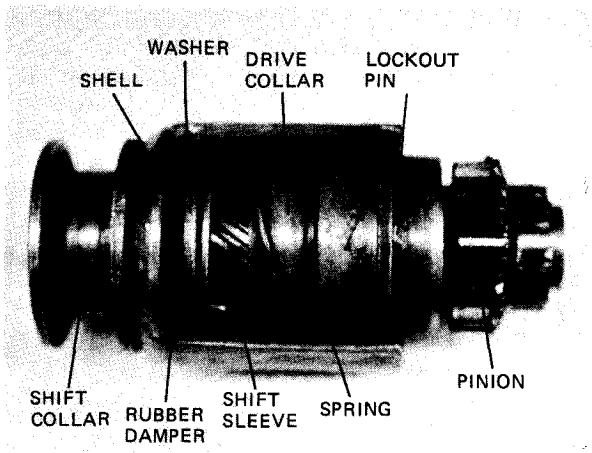


Fig. 42-11 Positork drive.

Servicing Sprag Clutch The sprag clutch should last the normal life of the cranking motor without requiring servicing. However, when the cranking motor is serviced, the drive assembly should also be cleaned and checked. When you disassemble the sprag clutch, take note of the position of the sprags before removing them. Check the collar for grooves which may have been caused by the shift lever. Check the drive splines of the shell and sleeve for damage and wear.

NOTE: When the bushing in the sleeve is worn, you must replace the sleeve, otherwise the sprag may not lock or may not disengage properly.

Make certain the bronze thrust washers are smooth (without grooves). Check the pinion for worn spiral splines. Check the teeth and the chamfer for wear or damage. Replace the retainer cups if excessive wear is noticeable. Check the sprags and the lock surfaces of the pinion and shell for brinelling or rough surfaces. Lubricate the sprag-clutch assembly with light engine oil and the splines with graphite powder to promote longer, troublefree service life.

CAUTION Do not forget to lock the pinion stop; otherwise the whole assembly could come off the armature shaft.

Dyer Drive Although older cranking motors using the Dyer drive may still be in service, space economics does not favor further discussion other than to mention it has been replaced with the heavy-duty roller and Positork drives.

Positork Drive The Positork drive, shown in Fig. 42-11, is used with heavy-duty cranking motors. It provides a positive engagement with the pinion remaining in engagement until the activating circuit is de-energized. If the pinion does not mesh with the ring gear teeth, the cranking motor cannot be energized and therefore the pinion and ring gear teeth cannot be damaged.

The components of a Positork drive are shown in Fig. 42-12. The shift lever is supported (at the front) by its bore on the armature shaft and (at the rear) by short helical splines that mesh with the helical splines of the armature shaft. A snap ring fastens the shift collar to the left-hand side of the shift sleeve. The shell, rubber damper, and washer are placed over the shift sleeve. The drive collar has internal helical splines which mesh with the external splines of the shift sleeve. A flat washer and a cone washer are placed against the inner shoulder of the drive collar, and the three lockouts are loosely pinned to the interior of the drive collar. A snap ring holds the assembly to the shell.

POSITORK DRIVE OPERATION When the solenoid-switch circuit is energized, it causes the shift lever to move, which in turn moves the pinion teeth in mesh with the teeth of the ring gear. A smooth engagement is assured because the shift lever is forced to turn on the armature shaft as the shaft lever moves the shift sleeve. Should the pinion not mesh with the ring gear, the pinion rebounds and is cushioned on the rubber damper. However, the drive collar is forced to turn as it and the pinion move against the damper. Effective engagement results as the spring forces the drive collar and pinion to the right. When the pinion is fully engaged, the cranking-motor circuit is closed (by the solenoid switch) causing the armature and the Positork to rotate as a unit.

When the engine has started, the ring gear rotates the pinion faster than the remaining parts are driven by the armature, and a demeshing of the pinion with

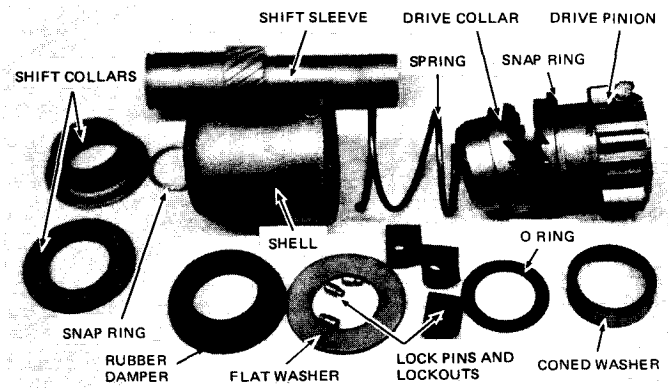


Fig. 42-12 Disassembled components of a Positork drive.

the drive collar occurs. The three lockouts now hold the pinion in a demeshed position from the drive collar until the pinion reaches the speed of the armature or until the cranking motor is de-energized. The lockout prevents pinion and drive collar reengagement whenever the pinion is engaged with the ring gear while the engine is running. When the solenoid switch is de-energized, the solenoid spring disengages the Positork drive from the flywheel ring gear. Simultaneously, the Positork drive spring forces the drive collar in mesh with the pinion, causing the coned washer to force the three lockouts against the shift sleeve. The teeth of the pinion can then mesh with the teeth of the drive collar.

Servicing Positork Drive The Positork drive can be disassembled and serviced by drilling a 3/16-in [4.76-mm] hole in the shell to remove the snap ring. When the snap ring is removed, the components can be lifted from the shift sleeve in the order shown in Fig. 42-12.

When servicing the components, you will sometimes find that the cone washer has grooved the three lockout pieces at their cone ends and/or that the pinion teeth are damaged. Other than this you should find no damage to the other components. Lockout grooves occur when the cranking motor was energized too long (or for short periods, too often) while the engine was running. Grooving can prevent proper lockout, causing pinion and ring gear wear. It can also wear down the drive collar and pinion teeth.

CRANKING-MOTOR SERVICE

Let us assume that you are faced with a cranking motor which turns the crankshaft too slowly or not at all. Before removing the cranking motor, you should test and check the batteries, the motor connection, and the starter, neutral, and solenoid switches. Check that all components are mechanically and electrically in good working order, that the engine is not seized, the cranking-motor drive is not locked with the ring gear, and that the ring gear is not loose and has no broken teeth. If, through this process of elimination, it is obvious that the trouble lies in the cranking motor, it will then have to be removed.

Removing Cranking Motor When you remove a cranking motor, always remove the ground battery cable first. If it is necessary to raise the vehicle to gain access to the cranking motor, make certain the vehicle is safely supported.

Remove the battery cable, starter, and ammeter wires from the cranking motor. When an insulated cranking motor is used, also remove the ground cable. Remove the mounting bolts, and then carefully remove the motor from its mounting.

CAUTION Always wear safety glasses when installing, removing, assembling, or disassembling a cranking motor. Do not overestimate your strength when lifting a large cranking motor from an engine. Follow the prescribed safety rules at all times.

After the motor has been removed from its mounting, check the condition of the ring gear teeth. With a prybar, rotate the flywheel 360° so that all ring gear teeth can be examined.

Disassembling the Cranking Motor Before you make any attempt to disassemble the cranking motor, clean it with a wire brush and solvent. (See Figs. 42-5 and 42-13 regarding disassembly procedure.)

With a center punch, mark the commutator end frame, drive housing, and the field-frame assembly. These alignment marks will ensure proper commutator, end frame, drive housing, and field frame positions when reassembling.

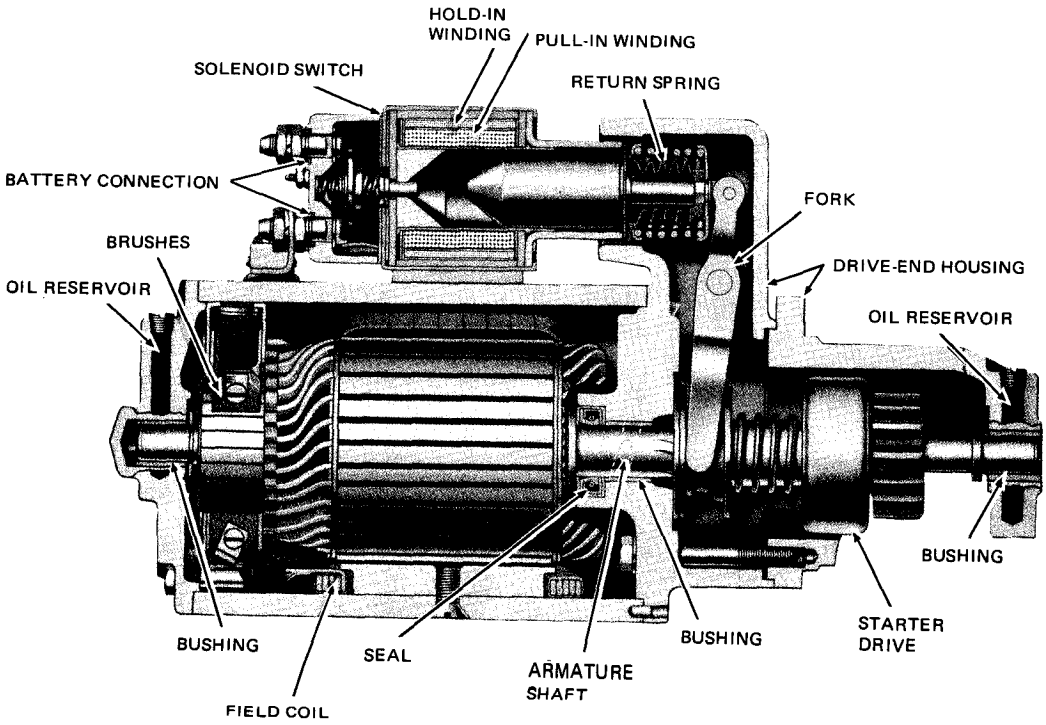


Fig. 42-13 Cross-sectional view of a medium-duty cranking motor.

Remove the field-coil connection from the solenoid terminal and the ground wire from the solenoid ground terminal. At this point you can, on some models, remove the solenoid switch from the field-frame assembly. Remove the dust cover, if applicable, or brush inspection plug(s) and then remove the screws which connect the field coils to the brush holders. Remove the hex bolts or thru-bolts which hold the drive housing and commutator end frame to the field frame, and then remove the commutator end frame and drive housing from the field frame. Remove the armature and solenoid switch as an assembly, and then pull the lever assembly from the solenoid.

Inspecting Armature Visual inspection, prior to cleaning and testing the armature, can often disclose the cause of trouble. If the armature is excessively greasy, it should be cleaned with wood alcohol; otherwise compressed-air cleaning is sufficient.

An armature that is polished on one end is an indication that the shaft may be bent, the bushings worn, or the pole shoes loose. If there are signs of wear on the armature-coil insulation, the coils are probably loose in the grooves of the armature core because of overspeeding of the armature. In this case check the cranking-motor drive and ring gear for damage.

If one or more commutator bars are burned, one or more armature coils have an open circuit. Check the coil-to-commutator connection. If the commutator is excessively worn or out-of-round, it is possible that the armature shaft is bent, the bushings are worn, the brush-spring tension is too high, or the wrong brushes are being used.

If the mica (insulation between the commutator segments) is higher than the bronze commutator bars, the brushes are too soft or the mica should have been undercut.

If you find thrown solder, it is an indication that the cranking motor was overheated. Advise the operator to use the cranking motor for 30 seconds only, then allow it to cool before reusing it again.

Testing Armature Shaft and Commutator for Runout Large armatures should be checked for commutator and armature-shaft runout. When the commutator has to be serviced, test the armature-shaft runout only. Later when the commutator is resurfaced, test the commutator runout.

To test the armature-shaft runout, place the armature between two V blocks and position a dial indicator on the armature-shaft center-bearing surface (Fig. 42-14). Rotate the armature 360° and note the runout. If the runout is higher than 0.003 in [0.076 mm], the shaft must be straightened. If the bearing surface is damaged or worn, the armature must be replaced.

Testing Armature for Grounded Circuit An armature growler is used to test the armature loops for grounded, open, or short circuits. To test the armature for ground, place the armature onto the growler as shown in Fig. 42-15*a*, and switch on the test-probe circuit. Hold one test probe on the armature shaft or iron core and slide the other probe over and around the commutator. The test light will go on

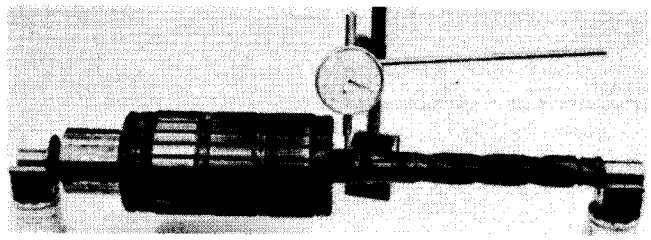


Fig. 42-14 Testing armature-shaft runout.

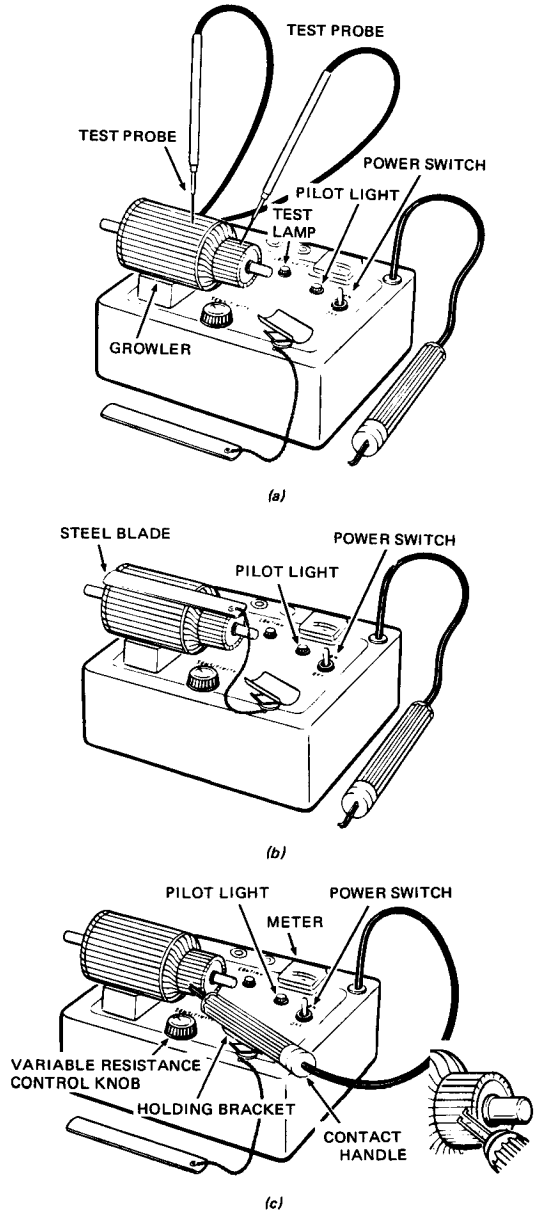


Fig. 42-15 Testing for (*a*) ground, (*b*) short, and (*c*) open circuit.

when one or more loops or the commutator are grounded to the armature shaft, in which case the armature should be replaced.

Testing Armature for Short Circuit Have the armature in the same position as in the previous test (Fig. 42-15*b*), but turn on the switch to energize the growler coil winding. The current flow through the coil windings creates a magnetic field which induces

voltage into the armature loops. Rest the steel blade, supplied with a tester, parallel with the armature loops, and slowly rotate the armature at least 360°. The steel blade will vibrate at 60 hertz [cycles per second] when one or more armature loops touch and short-circuit each other. The armature must be replaced if you cannot locate the short-circuited loops.

Testing Armature for Open-circuit Loops (Armature-loop Balance Test) To test armature-loop balance, first position the armature as in the previous test (Fig. 42-15c). Adjust the test probes so that they are in the center of the commutator with one probe on one commutator segment and the other probe on the adjacent commutator segment. When the ac power is turned on, the current flowing through the growler coil creates a magnetic field and induces ac voltage in the armature loops. This induced voltage is picked up by the test probe resting on the commutator segment. It is directed to the gauge and back to the other test probe.

Adjust the gauge to a full number, say 1, or to the set line of the meter by turning the variable resistor knob. Next, turn the armature one commutator segment, and again hold both probes against a commutator segment. The gauge should once again read "1." Repeat the procedure until all loops are tested. Minute variations may occur because of the probe position; however, if abnormal readings occur during testing, there is a short circuit or a poor connection. When there is no reading at all, one or more armature loops have an open circuit. When the readings are uniform, the armature is electrically in good condition.

Resurfacing Commutator When the commutator is rough, grooved, tapered, or out-of-round, it must be resurfaced. This can be done by machining and then polishing the commutator on an armature lathe or a small machinist's lathe.

To machine the commutator, support the commutator end in a live center or bushing or as shown in Fig. 42-16. Grind the cutting tool for bronze cutting (not undercutting), then adjust it a fraction below the center of the commutator. Remove only enough material to obtain a smooth surface.

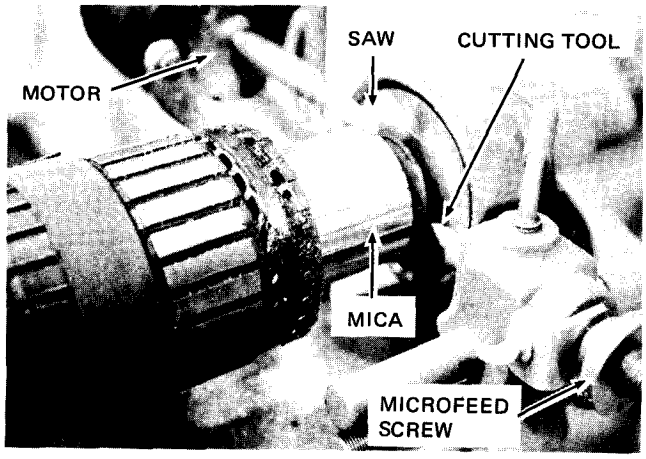


Fig. 42-16 Armature position in armature lathe.

UNDERCUTTING MICA The mica of some commutators require no undercutting because they use special brushes. Let your service manual guide you in this regard.

Mica can be undercut using the special cutting tool supplied with the armature lathe, or with a fine cutting saw fastened to a hand drill, or with a hacksaw blade. When using a hacksaw blade, grind the blade parallel (not tapered) to the width of the mica. To achieve a good cut, pull the hacksaw blade toward you to remove the mica. Do not push it. Undercut the mica to the depth of the distance between the two commutator segments. When the mica is sawn, the cut should resemble *D* in Fig. 42-17.

After the commutator is undercut, reinstall the armature in the lathe, and polish the commutator with a 600-grit body paper until the surface is mirror-finished. Blow the cutting and grinding material from the armature with compressed air. Retest the armature to confirm that you have not damaged it during servicing.

NOTE: Do not forget to polish the bearing surface and to clean the straight or spiral splines. Do not forget to check the keyways, if used, and the snap-ring grooves for wear and damage.

Inspecting Field-frame Assembly Very seldom will the field-frame assembly prevent the cranking motor from operating. However, if this assembly is the cause of cranking-motor trouble, the reason may be a cracked housing, the field-coil insulation burned by a short-circuited or grounded field-coil circuit, or the insulation damaged during assembly or disassembly.

Shiny pole shoes indicate that the armature shaft is bent, the bushings are worn, or the pole shoes are loose. The motor terminal should be partly removed so that the insulation, washers, and grommet can be examined.

After you make this examination, blow the assembly clean with compressed air and, if necessary, wash the field coils with alcohol before testing them.

Testing Field Coils A test light, or a growler, or an ohmmeter can be used to test the field coils for continuity and ground. Field coils cannot be tested for a short circuit with the methods outlined above because of their low coil resistance.

When testing for continuity, hold the test probes to each end of the field-coil winding (Fig. 42-18a). When the test light fails to glow, or the ohmmeter does not

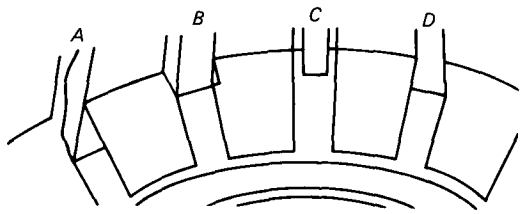


Fig. 42-17 Undercutting the mica. Points *A, B,* and *C* show how an undercut mica *should not* look; point *D* shows how an undercut mica *should* look. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

move to zero, the field-coil circuit is open.

When testing for a grounded coil circuit, hold one probe to ground and the other probe to the field-coil lead (Fig. 42-18*b*). The test light should not glow.

When a motor terminal has been replaced, recheck it for continuity and ground. You may have created a ground when soldering or soldered the joint poorly.

When you replace field coils, use the correct tools, as shown in Fig 42-19, to ensure proper installation. Make certain that the field coils fit properly on the pole shoes and that one coil is wound left and the adjacent coil is wound right, then alternately left and right, so that adjacent poles are in opposite magnetic polarity.

When you solder the coil ends together, take care not to burn the insulation. Also make sure that the joint is thoroughly soldered.

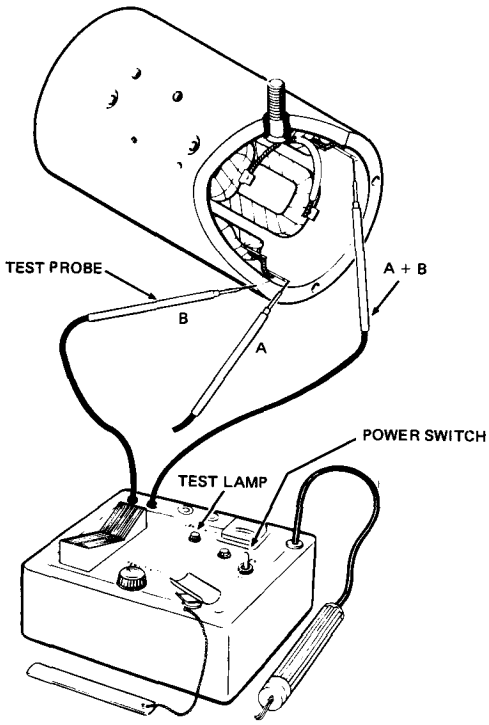


Fig. 42-18 Testing field coil. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

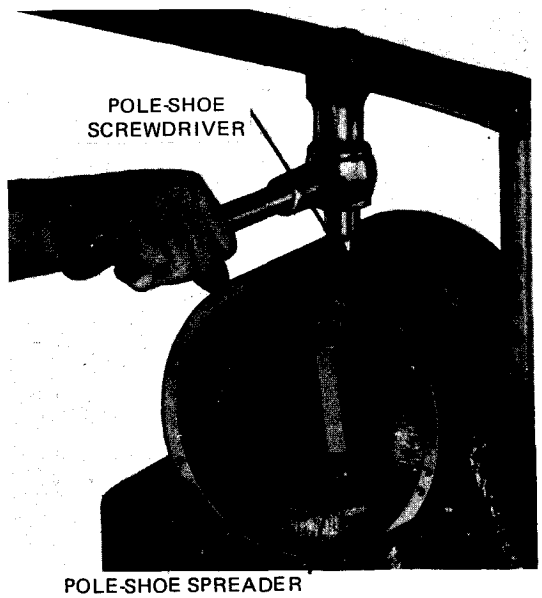


Fig. 42-19 Removing and installing field coils using a pole-shoe spreader and a screwdriver. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

Testing Commutator End Frame Visually inspect the ground and live terminal insulations, and terminal bolt threads. Check the brush springs, and replace any which are corroded or damaged. Gently tug each brush holder to determine if any are loose.

The commutator end frame can be checked electrically with a test light or an ohmmeter. Let us assume that the live and ground brush holders of the cranking motor are insulated. In this case when testing for ground, hold one probe to ground and the other probe to a brush holder. Proceed systematically to each holder until all six brush holders have been tested. Do not forget to test the insulated ground and live terminals.

Servicing Brushes When the cranking-motor brushes are worn to half of their original length, they must be replaced since the spring tension is then greatly reduced. If the brushes are reusable, remove them. Clean their contact surfaces with an 80-grit sandpaper. File off the corners of the brushes to ensure a smoothly gliding brush contact and faster brush seating.

Reinstall the brushes in their holders, but do not tighten the screws at this point. Install the armature to the commutator end frame. Align the brushes to the commutator. Now tighten the screws securely. Keep the brushes in alignment while the screws are being tightened.

Cranking-motor brushes must have a seating area of at least 25 percent, and the seating area must be in the center of the brush. A brush seating on either side (off center) will cause a change in commutation and arcing.

To seat the brushes, cut a strip of 80-grit sandpaper the width of the commutator. Place it between the brushes and commutator with the cutting side toward the brushes. Then slide the sandpaper from underneath the brushes in the direction in which the armature is turning. Make certain you follow the contour of the commutator. Repeat this procedure until the brushes seat properly against the commutator.

TESTING BRUSH SPRING TENSION With the armature in the end plate, check the brush spring tension by placing a small piece of paper under one brush. Hook a spring scale (calibrated in ounces [grams]) onto the brush spring. Pull on the spring scale until you can slide the paper out. At the same time, note the reading on the scale. It should coincide with the recommended specification. Repeat this procedure with all brushes.

BUSHING REPLACEMENT When you replace armature bushings, do not substitute some other type of bushing. Motor bushing material, for example, is made from a special alloy quite different from that of bushings generally.

When driving bushings in or out, use the correct size bushing driver to prevent damage to the bushing or its bore. To remove a bushing having a closed-off bushing bore from the commutator end frame, tap a thread into the bushing. Place a hex bolt in the threaded hole and, with a hammer puller, pull out the bushing.

NOTE: Check all newly installed bushings to ensure that the armature rotates freely in them and soak the oil wicks with SAE20 engine oil.

Assembling Cranking Motor Place the armature in the bushing of the commutator end frame but make certain the brushes do not come out of alignment. Place an O-ring seal into the end frame groove or center housing (if used). *(NOTE: Some cranking motors use a leather washer between the commutator end frame and the commutator, or between the center housing and the armature, to prevent the armature from overspeeding after the pinion is disengaged from the ring gear.)*

Slide the field frame over the armature, align the commutator end frame with the prestamped center punch marks, and install a few bolts to hold it in place. Install and secure the intermediate housing loosely to the field frame. Assemble the shift lever to the solenoid, position it on the field frame, and at the same time place the drive assembly onto the armature shaft so that the shift lever fork rests in the shift collar. Install the solenoid-switch screws. Position and align the drive housing with the field frame. Install all bolts and screws and torque them to specification. To be sure the armature will rotate freely, use a prybar and force the pinion to rotate.

Pinion-clearance Check Cranking motors employing an inertia cranking-motor drive do not require a pinion-clearance check as do cranking-motor drives using a solenoid switch. For the latter, a pinion-clearance check is essential. When inadequately adjusted, the pinion can cause a hammering effect on the end of the drive housing. This may break the housing or cause the armature to bounce back and break the commutator end frame. When properly adjusted, the pinion-clearance check assures effective pinion-to-ring-gear meshing and correct closing sequence of the cranking-motor circuit.

The electrical components and connections required to perform a pinion-clearance test are shown in Fig. 42-20. The connections for all cranking motors using a solenoid switch are the same, but the clearance and the points where the measurements should be made vary between different types of drives. When checking heavy-duty sprag clutch drives, Positork drives, or roller-type clutch drives, the clearance is measured between the drive housing bushing end and the pinion (Fig. 42-21). On light-duty cranking motors, the pinion travel is measured from the drive frame flange to the front of the pinion. To adjust the pinion for clearance on heavy-duty overrunning clutch drives, remove the end plug, loosen the locknut, and then turn the threaded solenoid plunger shaft in or out. To adjust a sprag clutch drive having a serrated shift lever linkage, loosen the bolts and slide the linkage backward or forward to arrive at the correct clearance. To perform this pinion-clearance test, remove the field-coil connector from the starter motor terminal and put insulation on the connector. Connect the battery's positive lead to the S terminal and the other to ground. Connect a jumper cable to the starter terminal. Now, momentarily touch ground with the other end of the jumper cable. Force the armature toward the end plate to remove the end clearance, then measure the pinion clearance.

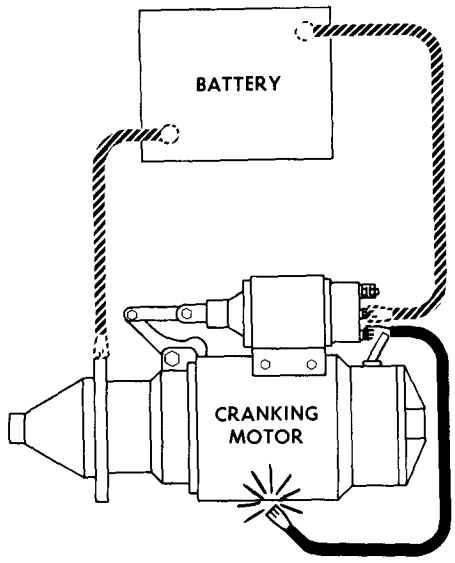


Fig. 42-20 Electric connections for checking pinion clearance. *(Delco Remy, Division of General Motors.)*

Cranking-motor No-load Test To test the cranking-motor efficiency, you should perform a no-load test. To make this test, connect the batteries, test instruments, and carbon pile (variable resistor) as shown in Fig. 42-22, or alternatively, connect a battery starter tester to the cranking motor. The batteries must

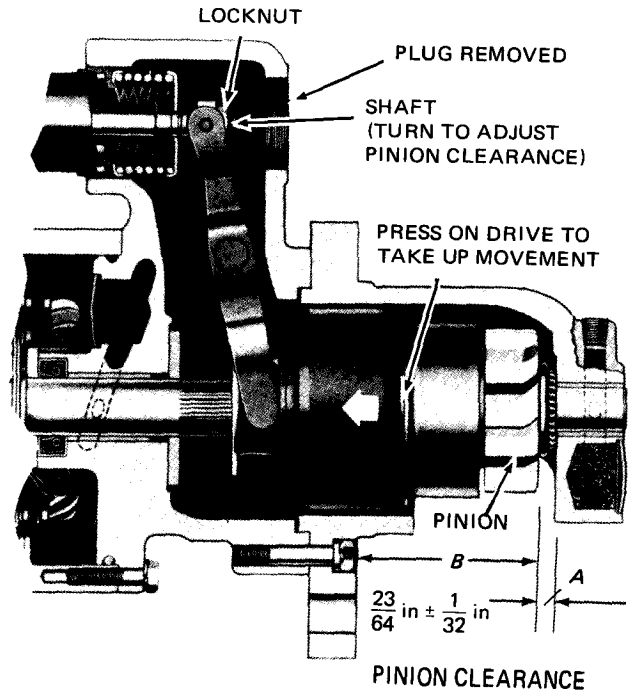


Fig. 42-21 Measuring pinion clearance: *A* heavy duty, *B* light duty. *(Delco Remy, Division of General Motors.)*

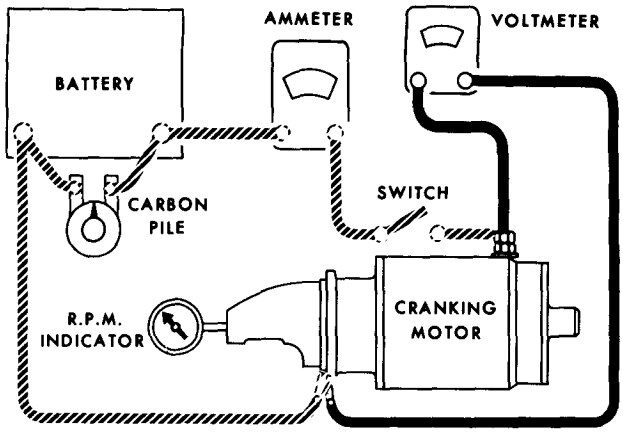


Fig. 42-22 Connection for a no-load test. *(Delco Remy, Division of General Motors.)*

be fully charged and in good chemical and mechanical condition. Use an rpm indicator (tachometer) to measure the armature speed. Begin the test by closing the master switch and, with the carbon pile, adjust the resistance to arrive at the desired specified voltage. Measure the rpm, note the current draw, and observe the brush action.

Inadequate Cranking-motor Performance When a cranking motor has a low free speed and a high current draw, the problem may be a short-circuited armature, grounded armature or field coils, bent armature shaft, one or more loose pole shoes, or worn bearings.

When the cranking motor has low free speed and a low current draw, it could be due to a poor connection, defective leads, dirty commutator, open armature loops, open field coils, short brushes, broken brush spring(s), broken brush link, or high mica. When the cranking motor has a high current draw and either fails to rotate, or rotates very slowly, it could be due to a grounded motor terminal, direct ground of the field coils, seized bearings, or a broken or badly twisted armature shaft.

Cranking-motor Lock-torque Test The cranking-motor lock-torque test is not recommended for newer-model cranking motors because they will produce the required torque if they are performing to specification during the no-load test.

Series-parallel Switch As mentioned previously, this switch is used when 24 V is required for the cranking motor and 12 V for the charging system. Energizing the switch connects two or four batteries in series to make 24 V available for the cranking-motor circuit, and when de-energized the switch connects the batteries in parallel for the 12-V charging system.

A series-parallel switch used with an A circuit charging system is shown in Fig. 42-23 and one used with a B circuit charging system is shown in Fig. 42-24.

OPERATION CHARGING (A CIRCUIT) When the engine is operating 12 V force current to flow from the alternator to terminal No. 1. At this point the current will divide. Half will flow to the battery A positive terminal and half will flow over the closed contact point *A*, out of terminal No. 3 to the insulated terminal of the cranking motor, and from there to battery B positive terminal to charge battery B. The ground circuit for battery B connects from its negative terminal, to terminal 2, over the closed upper contact point *B*, to terminal 5, and over the circuit breaker to ground. The ground circuit for battery A connects from its negative terminal to the Bat. terminal of the cranking motor.

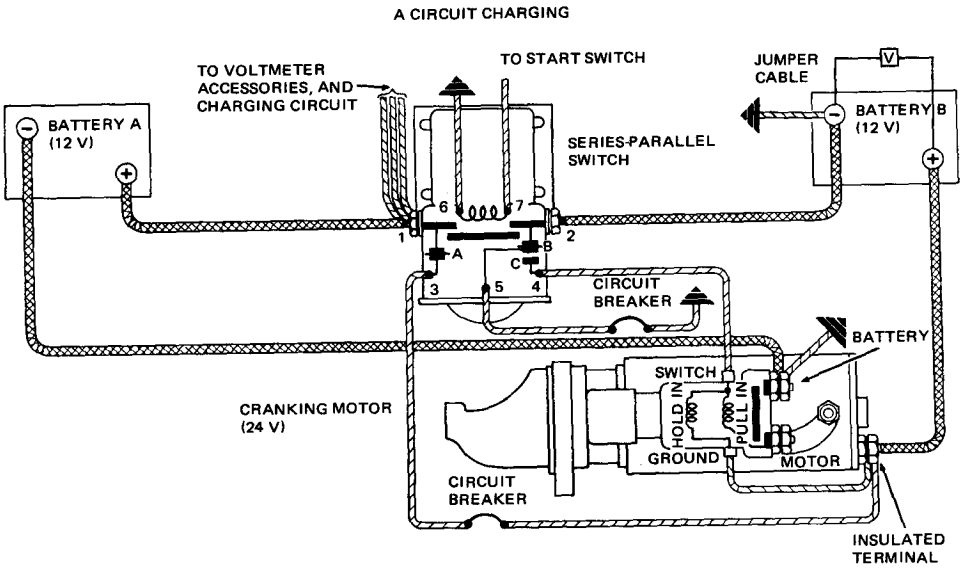
OPERATION CRANKING (A CIRCUIT) When the operator closes the start switch, current enters terminal No. 7, flows through the pull-in winding to terminal No. 6, and then flows to ground. The plunger is pulled upward, the disk bridge terminals Nos. 1 and 2, the left-hand contact points (*A*), and the right-hand upper contact points (*B*) are open, and the right-hand lower contact points (*C*) are closed. The current flows from the positive terminal battery A over the bridge contacts Nos. 1 and 2 to the negative terminal of battery B, and from its positive terminal to the insulated terminal of the cranking motor. From there current flows to the hold-in winding, to terminal B, to the SW terminal, to terminal No. 4, to lower contact points *C*, to terminal No. 5, and over the circuit breaker to ground. Current also flows from junction C through the pull-in winding, field coils, and armature coils, and then to the Bat. terminal to ground. This action energizes the solenoid switch. Current then flows from the insulated motor terminal, through the field coils, and armature coils, to the Mot. terminal, over the contact disk to the Bat. terminal to ground, and back to the negative terminal of battery A.

Troubleshooting Series-parallel Switch Ninety percent of the series-parallel switch trouble can be traced to the undercharged condition of the B batteries. This is understandable when you consider that the current from these batteries must travel through 13 connections as opposed to the A batteries, where current travels over only four connections. The most expedient way to prevent this situation is to:

1. Keep all connections clean and tight.
2. Keep the top of the batteries dry.
3. Replace batteries with those of the same make.
4. Use batteries of the same capacity, age, and chemical and mechanical condition.
5. Interchange A batteries with B batteries periodically to avoid undercharged conditions and to prolong battery life.

To check the charging circuit of the B batteries for high resistance, start the engine and run it at about 1500 rpm. Connect a voltmeter across the B battery or batteries. Let us assume that the voltage reading is 14.2 V. Connect a jumper cable (not a jumper wire) from the negative post of the B batteries to ground. The voltmeter reading should not increase more than 0.3 V. When a higher resistance is present, the series-parallel switch must be serviced.

Testing Series-parallel Switch The service procedure is similar to that for servicing a solenoid switch with the exception that more contacts have to



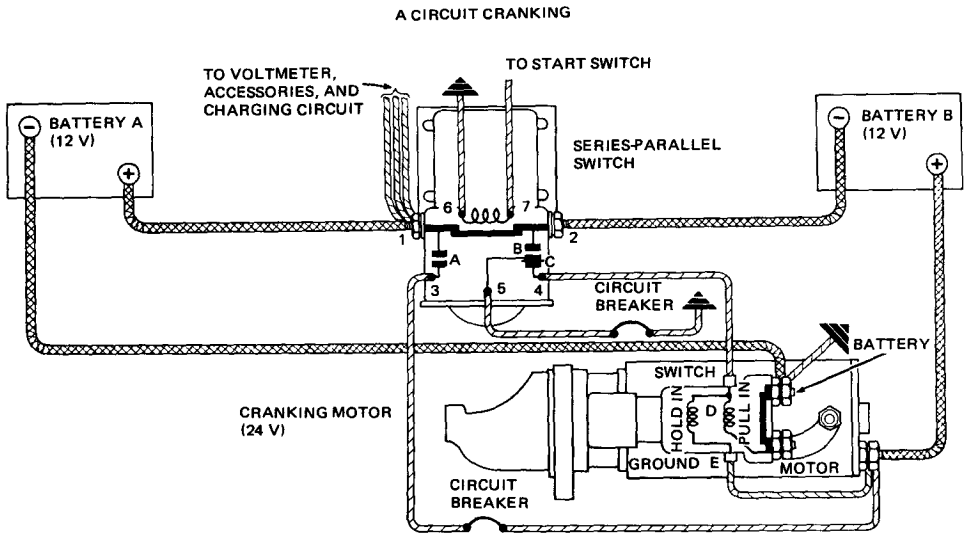


Fig. 42-23 Series-parallel switch used with an A circuit charging system.

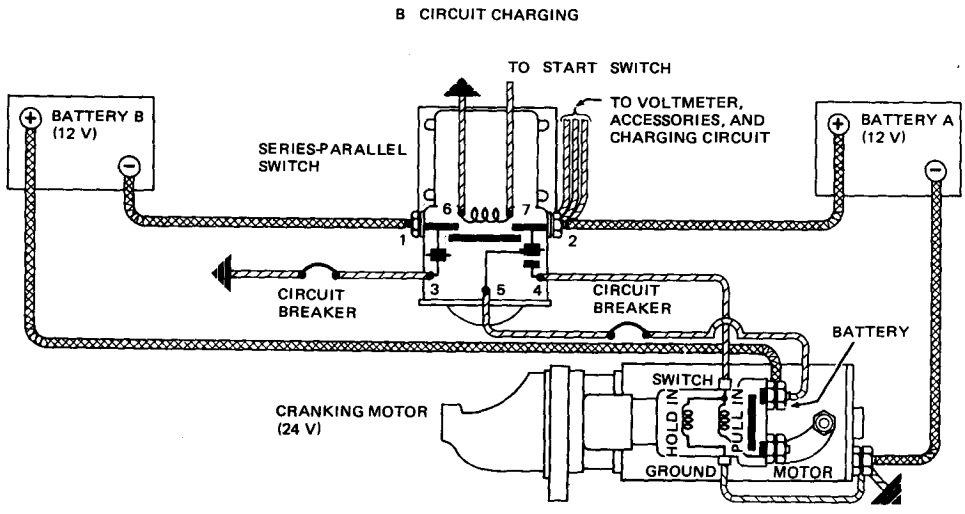


Fig. 42-24 Series-parallel switch used with a B circuit charging system.

be serviced. To check the large contact set for continuity after reassembly, energize the solenoid and connect an ohmmeter to terminals 1 and 2 and to terminals 4 and 5. The ohmmeter should show no resistance. De-energize the solenoid and connect an ohmmeter to terminals 1 and 3 and then to terminals 2 and 5. In each case the ohmmeter reading should show no resistance.

12-V Charging System, 24-V Cranking System without Series-parallel Switch Many of today's diesel engines have very large displacements, and

the conventional series-parallel switches are no longer able to carry the high current demand placed on them. This has brought manufacturers to design fully solid-state switching devices that can do the work of a series-parallel switch and, in addition, prevent over- or undercharging of the batteries and thereby provide a more efficient cranking voltage. One of these devices is shown in Fig. 42-25. This solid-state switching device does not require any additional components such as a special alternator or a transformer or rectifier [with the exception of the dual-voltage control (DUVAC) unit]. Also note that the batteries are connected in series and that both batteries are used for starting. However, battery B is used in conjunction with battery A only for starting whereas battery A is connected to the electrical system of the vehicle, at all times, and all vehicle loads (including voltage regulator) are taken only from battery A.

OPERATION SEQUENCE When the engine is not operating, the controlled rectifier is open, preventing a current flow from the battery to the alternator. When the operator energizes the cranking-motor activating circuit, the solenoid switch connects the cranking motor with the batteries and 24 V become available for cranking.

After the alternator starts to operate and after it exceeds the cemf of both batteries (24 V), current begins to flow into the batteries.

Because the batteries are connected in series and the negative terminal of the A battery is grounded, both batteries are being charged. Current flows from the alternator to terminal A of the DUVAC unit through the diode (out of terminal 2) to the positive post of the B battery, then to the A battery, and finally to ground. The current output of the alternator increases until the A battery voltage rises to the value at which the voltage is adjusted, and is then regulated in the normal manner. Since the voltage regulator senses the voltage of the A battery, the B battery becomes fully charged first. As soon as the B battery becomes fully charged, the voltage detector in the control unit switches the control rectifier on, and the current can now only flow into the A battery. The B battery, therefore, is now out of the charging circuit and is only used again when the engine is to be restarted.

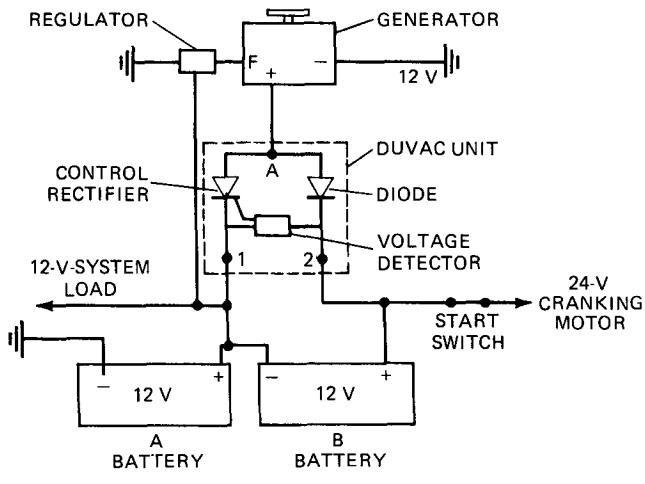


Fig. 42-25 Wiring diagram of the dual voltage control.

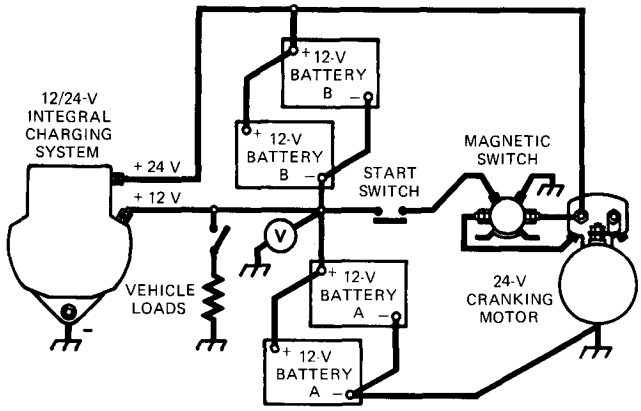


Fig. 42-26 12/24-V integral charging system. *(Delco Remy, Division of General Motors.)*

Transformer Series Alternator Another method of achieving 24 V for cranking is accomplished by modifying an alternator and the electrical connection to the cranking motor (see Fig. 42-26). The alternator has a 12-V and a 24-V battery terminal. *(NOTE: The alternator and its operation are covered in the material on charging systems.)* The 12-V alternator terminal is connected to the positive side of the two (parallel) 12-V B batteries. The entire vehicle load (including the circuit of the magnetic switch that activates the cranking motor) is taken only from the A batteries. The B batteries are used only for cranking. The batteries are permanently connected in series with the cranking motor. *(NOTE: Additionally, a magnetic switch is used to activate the solenoid switch of the cranking motor.)*

CURRENT FLOW WHEN STARTING Current flow for cranking and during charging is explained in the material on 12/24 series alternators in Unit 45.

Questions

1. Refer to Fig. 41-3. What forces the conductor loop to rotate?
2. Why are conductor loops placed in predesigned grooves in the armature?
3. Why is the jumper wire used between a pair of live brushes?
4. Give three reasons why a neutral switch could become ineffective.
5. List the three functions of a cranking-motor drive.
6. Describe the movement of the components during the engagement and disengagement of a heavy-duty roller clutch.
7. List several conditions which will prevent a Positork drive from engaging properly.
8. When is it necessary to undercut the mica?
9. Explain how to test the armature for a grounded circuit, an open circuit, and a short circuit.
10. When using a series-parallel switch, why should the A and the B batteries be consistent in: capacity, size, age, and manufacturing source.

11. Why should the position of the two and four batteries be periodically switched?
12. To find the voltage drop between the battery and starter switch, you would connect (*a*) an ammeter between the grounded post and the starter switch; (*b*) a voltmeter from the ungrounded battery post to the live side of the starter switch; or (*c*) a voltmeter from the starter switch to ground.
13. The field circuit of a dc motor should not be opened, especially if the motor is operating without a load, because the motor armature will become (*a*) heated, (*b*) short-circuited, (*c*) uncontrollable, or (*d*) dirty.
14. The direction of current flow in a dc motor is changed by means of the (*a*) commutator segments, (*b*) field windings, (*c*) brushes, or (*d*) field pole.
15. The rotating armature coil of a dc motor generates an electromotive force which (*a*) increases applied voltage, (*b*) decreases applied voltage, (*c*) opposes applied voltage, or (*d*) supports applied voltage.
16. If a cranking motor has excessive draw, which would be the likely trouble: (*a*) badly worn brushes, (*b*) badly worn bushings, (*c*) battery cables too light, or (*d*) excessive air gap at pole shoes?
17. The most common cause of thrown armature windings is (*a*) overheating of armature, (*b*) grounding of armature, or (*c*) overspeeding of armature.
18. Burned commutator bars usually indicate (*a*) short-circuited armature windings, (*b*) open-circuit armature windings, or (*c*) grounded armature windings.
19. When checking a cranking motor on the tester, low free speed and high current draw with low torque may result from (*a*) open field, open armature, or high internal resistance; (*b*) grounded armature, weak brush springs, or short-circuited fields; or (*c*) internal ground, short-circuited armature, or worn bearings.
20. When checking a cranking motor on the tester, failure to operate with no current draw may result from (*a*) open or grounded fields, short-circuited armature, or worn bearings; (*b*) open field or armature, weak brush springs, or worn brushes; or (*c*) low commutator mica, grounded armature, or worn bearings.
21. When checking a cranking motor on the tester, failure to operate with a high current draw may result from (*a*) open or shorted field, high commutator mica, or weak brush springs; (*b*) jammed engine bearings, stuck piston or rings, or grounded armature; or (*c*) internal ground, frozen motor bearings, or grounded armature.
22. An armature may jam because of a (*a*) loose housing, (*b*) chipped ring gear, (*c*) worn ring gear, or (*d*) none of the above.
23. What are the advantages of a solid-state switching device over a charging system using a series-parallel switch?
24. Why is a 12-V magnetic switch used to energize the solenoid switch of the cranking-motor system shown in Fig. 42-26.

UNIT 43 • AIR AND HYDRAULIC STARTING SYSTEMS

Comparison of Starting Systems The air and hydraulic starting systems have become increasingly popular because of improvements in their design. Torque has increased noticeably, while the need for servicing has been greatly reduced.

Compared with an electric starting system, the air starting system is much less complex. It requires only an air tank, two control valves, a cranking motor, and the complementary hoses. A hydraulic system requires a hydraulic reservoir, a hand pump, an engine-driven pump, an accumulator, a hydraulic cranking motor, and hydraulic pressure lines.

A complete air starting system, including the air tank, weighs as little as 150 lb [68.1 kg] while a hydraulic system weighs approximately 225 lb [102.2 kg]. An electric starting system, including the batteries, weighs approximately 400 lb [181.6 kg]. Cost and maintenance features of the air starting system are also more favorable, amounting to about one-third that of the hydraulic or electric systems. The hydraulic and the air starting systems are also more reliable than the electric starting system.

The air starting sytem has a slight advantage over the hydraulic system in regard to cranking time, but both these systems have a cranking speed of about 100 rpm more than an electric starting system. An air starting system with a standard 6 ft^3 [0.1699 m^3] air tank will crank an average diesel for 9 seconds at 70°F [21.1°C]. At the same temperature a hydraulic system with a standard accumulator will only crank a diesel engine for 3 seconds.

NOTE: Cranking speed is the essential ingredient to start a diesel engine rather than the length of cranking time, or the number of attempted starts. An electric starting system may crank the engine over for a longer period of time, but the cranking speed will gradually decrease. Additionally, with lower ambient temperature, the cranking speed may reduce to one-quarter of that of the air or hydraulic starters, which retain their speed notwithstanding adverse weather conditions.

Since air and electric starters and their components can be serviced in any shop having hand tools, the required service and test equipment is minimal. A

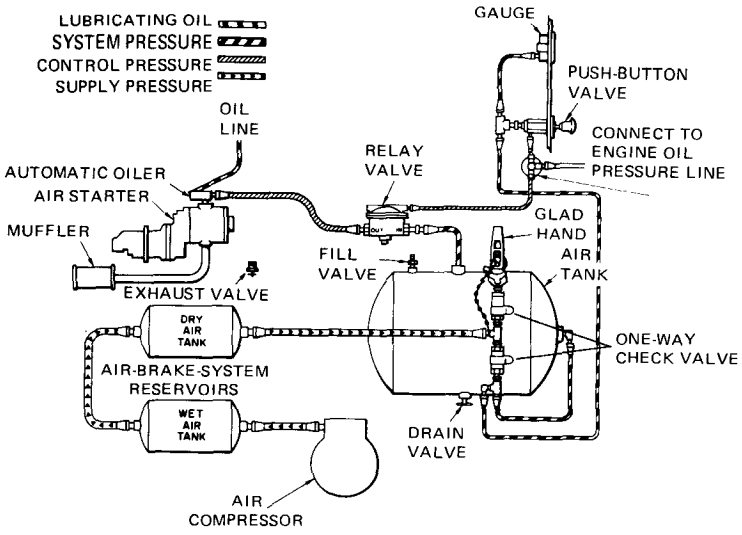


Fig. 43-1 Schematic drawing of remote-control air starting system. *(Stanadyne Diesel Systems.)*

hydraulic starting system, however, requires close-tolerance parts which cannot normally be serviced in the average shop.

AIR STARTING SYSTEM

Components A remote-control air starting system is illustrated in Fig. 43-1. Note that it has its own reservoir (air tank). This is true of all air starting systems. The air tank is connected through a one-way check valve to the reservoirs of the air-brake system and to the relay valve. The relay valve is connected to the air starter by means of No. 16 or larger air hose, or the relay valve is within the air starter. A No. 6 air hose connects the push-button valve to the air tank, to the relay valve, and in some cases to the automatic oiler. The automatic oiler is connected to the air motor by a hydraulic hose.

Push-button Valve A push-button valve, as shown in Fig. 43-2, is used to activate the airflow to the air motor. It is a simple on-off valve. When the operator pushes the knob, the push-button valve closes the exhaust valve and opens the inlet valve. Reservoir air is then directed to the relay valve and, in some cases, to the automatic oiler. The air pressure activates the automatic oiler and the relay valve. When the operator releases the knob, the valve closes the inlet valve, the spring opens the exhaust valve, and the compressed air is exhausted from the relay valve into the atmosphere.

Push-button Valve Trouble When the valve fails to operate or air exhausts during application (when air is applied or when the valve is at release position), the O ring may be damaged or the seat and valve of the inlet or exhaust valves may be damaged.

Relay Valve A relay valve is a remote-control valve. It supplies air direct from the air reservoir to the air motor when the push-button valve directs air onto the diaphragm (Fig. 43-3) or piston (Fig. 43-4). Air pressure forces the diaphragm downward or the piston to the left, closes the exhaust valve, and opens the inlet valve. Air from the tank is directed to the inlet port of the air motor. When the push-button valve exhausts the pilot pressure from the diaphragm or piston, the reservoir pressure and the return spring push the diaphragm upward or push the piston to the right. This closes the inlet valve and the spring force opens the exhaust valve.

Relay-valve Trouble A relay valve will cause very few problems if the air system is kept free of water and oil. Water and oil can cause the valve to stick, reduce airflow, and in time, damage the inlet valve, exhaust valve, and seats. When the relay valve requires servicing, dismantle the assembly and clean the valve internally and externally. Then install the components from the parts replacement kit.

NOTE: Use only the recommended lubricant and all moving components.

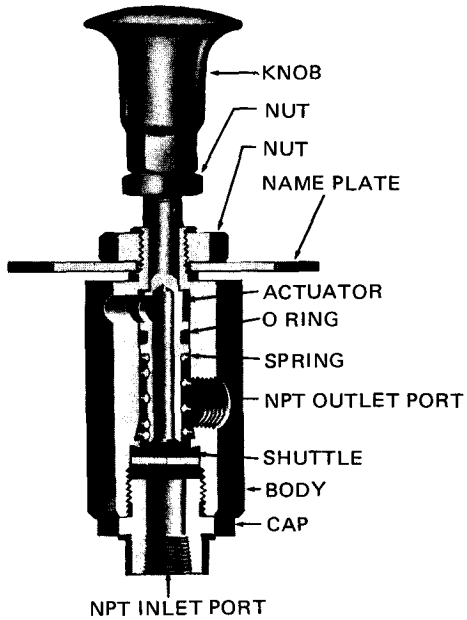


Fig. 43-2 Cutaway view of a push-button valve. *(Stanadyne Diesel Systems.)*

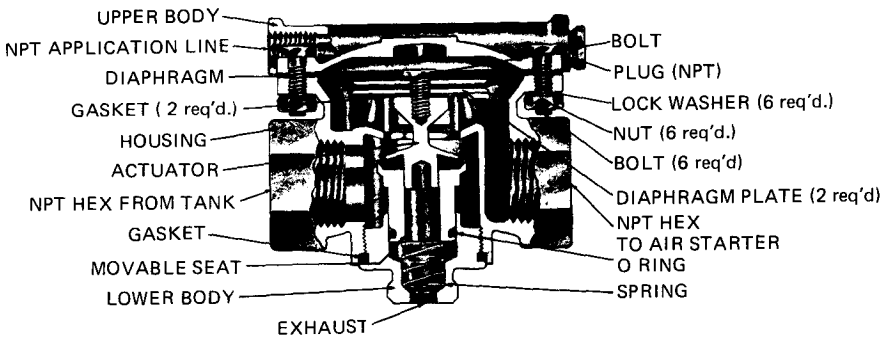


Fig. 43-3 Relay valve. *(Stanadyne Diesel Systems.)*

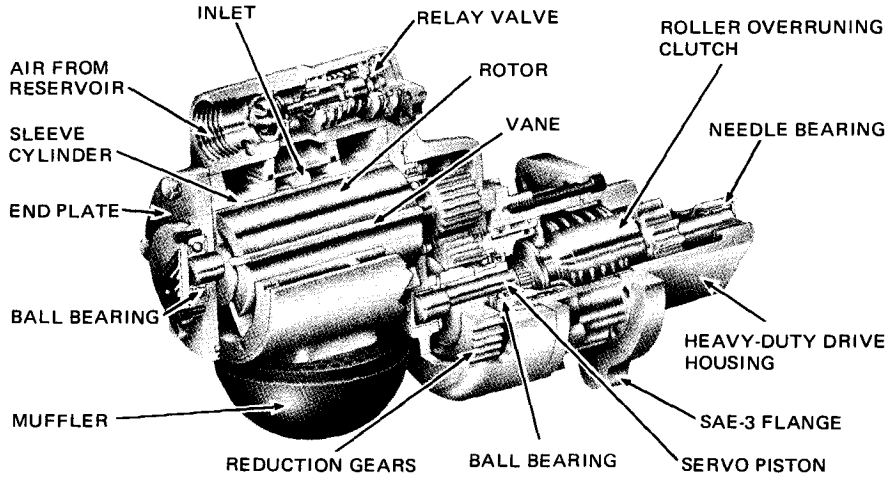


Fig. 43-4 High-torque air starter. *(Stanadyne Diesel Systems.)*

Air Cranking Motor The cranking motor consists of three major parts: an air motor, a reduction gear, and a friction-type inertia drive or a overrunning clutch (Fig. 43-4). The rotating components of the air motor are well supported by ball bearings or roller bearings. A sleeve cylinder is pressed into the housing to decrease the wear and to achieve effective vane sealing. The large inlet and exhaust ports reduce air velocity to maintain air pressure. The reduction gear reduces the high motor speed and increases the torque.

Cranking-motor Operation Compressed air from the relay valve enters the inlet port and is forced into one or two pockets created by the rotor, vanes, end covers, and cylinder. At the same time air is directed through a small passage onto the servo piston. The piston and cranking motor drive are forced to the right, causing the pinion to engage with the ring gear. At this point the air pressure has enough force to rotate the rotor. This opens the adjacent pocket, which then fills with compressed air. At the same time air exhausts from one other pocket as the vane passes by the exhaust slot. This action continues until the airflow from the relay valve ceases. A muffler is screwed or bolted into the exhaust port to reduce the noise created by exhausting air.

Air-motor Trouble Most air-motor troubles can be traced to the automatic oiler. Malfunction in this unit increases wear of the vanes, cylinder, end plates, and bearings. *(NOTE: The motor (Fig. 43-1) has an integral lubricator.)* If detected early, efficiency can be regained by replacing the vanes and, if necessary, honing the cylinder and refinishing the end plates.

Unfortunately, when trouble in the oiler is assessed too late, bearing failure will already have caused the internal components to misalign, resulting in irreparable damage to the end covers, vanes, and rotor. The cylinder, which will also have been damaged, must be replaced.

While the reduction gear is seldom cause for concern if the friction clutch of the cranking-motor drive is correctly adjusted, incorrect adjustment can result in early bearing and gear failure.

Emergency Air Supply Without compressed air, the air cranking motor will not function; therefore, an emergency air supply must always be available.

The most expedient way to replenish the air starter reservoir, if you are in the shop, is to connect the reservoir to the shop's compressed air supply. Without the convenience of the compressed air, you must connect the emergency glad hand of another vehicle to the emergency glad hand of the stalled vehicle. (A *glad hand* is a fast-breakaway coupling used to connect the service line and emergency air line with the trailer.)

Another method of assuring a supply of emergency air is to install an auxiliary air cartridge breech. It can be built into the reservoir or have separate connections. The breech is a steel container connected to the air motor or reservoir into which an air-pack cartridge is secured. When set off in the breech by a standard percussion primer (which may actuate mechanically or electrically), the cartridge releases

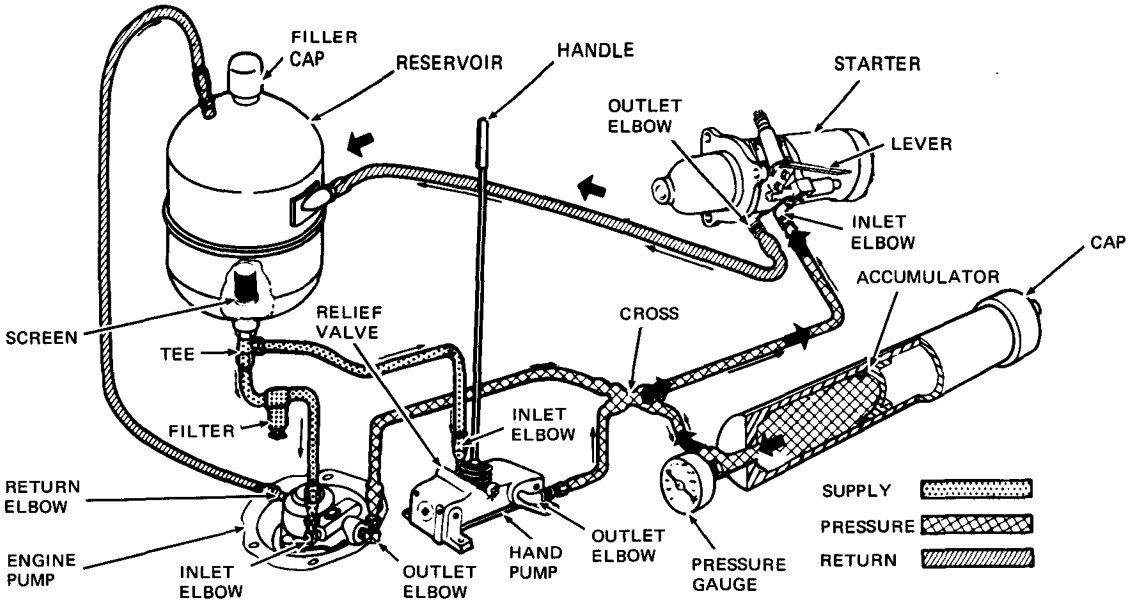


Fig. 43-5 Schematic view of a hydrostarter system showing oil flow. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

high-pressure gases directly to the motor or into the reservoir. A safety valve protects the reservoir or motor from overpressurizing.

HYDRAULIC (HYDRO) STARTING SYSTEM

Components An air starting system relies on compressed air to crank its engine. A hydraulic starting system relies on hydraulic energy.

The components of one of many different hydraulic starting systems and the manner in which they are connected are illustrated in Fig. 43-5. The reservoir of a hydraulic starting system stores and cleans the hydraulic fluid. It is connected to the inlet ports of the hand- and engine-driven pumps. The return lines from the hydraulic motor and the engine-driven pump are also connected to the reservoir.

The accumulator, which stores hydraulic fluid under pressure, consists of a steel shell, or cylinder, closed by two end caps (Fig. 43-6). Inside the shell is a movable piston which divides the cylinder. The end cap on the hydraulic side (fluid cap) is connected to the directional valve, and to the hand- and engine-driven pumps. The nitrogen end cap has an air valve through which the accumulator is charged with nitrogen at a pressure of about 1500 psi [10,342.5 kPa]. Nitrogen is used instead of compressed air because it will not explode if seal leakage permits oil to infiltrate to the nitrogen side of the accumulator.

The engine-driven pump (Fig. 43-5) can be of the gear, vane, or piston type. Each can be driven by belts or directly from the engine. When the engine runs, the hydraulic pump forces fluid against the nitrogen pressure into the accumulator. When the preset pressure is reached, the hydraulic pump unloads. When the pressure is reduced, the pump again pumps fluid into the accumulator.

The hand pump of a hydraulic starting system is a double-action piston pump. It is used to pump fluid into the accumulator for initial cranking when the accumulator has exhausted all fluid.

Hydraulic Motors and Directional Valves Hydraulic motors used for cranking motors are of the fixed displacement vane, swash-plate, or bent-axis piston types (Fig. 43-7). Older hydraulic motors use the inertia-type friction clutch whereas the newer hydrostarters use an overrunning clutch drive. Their displacement per revolution ranges from 0.50 to 3.50 in^3 [0.0081 to 0.0571 m^3], depending on engine displacement. The directional valve, which directs oil to the motor when activated, may be bolted directly to the motor or it may be connected between the accumulator and the cranking motor.

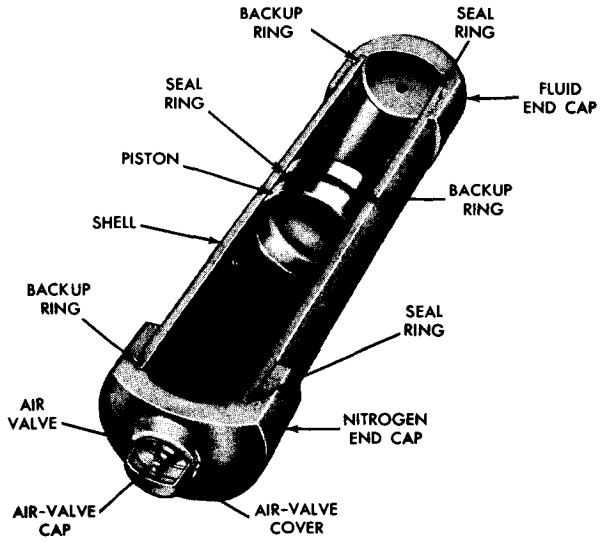


Fig. 43-6 Cross-sectional view of an accumulator. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

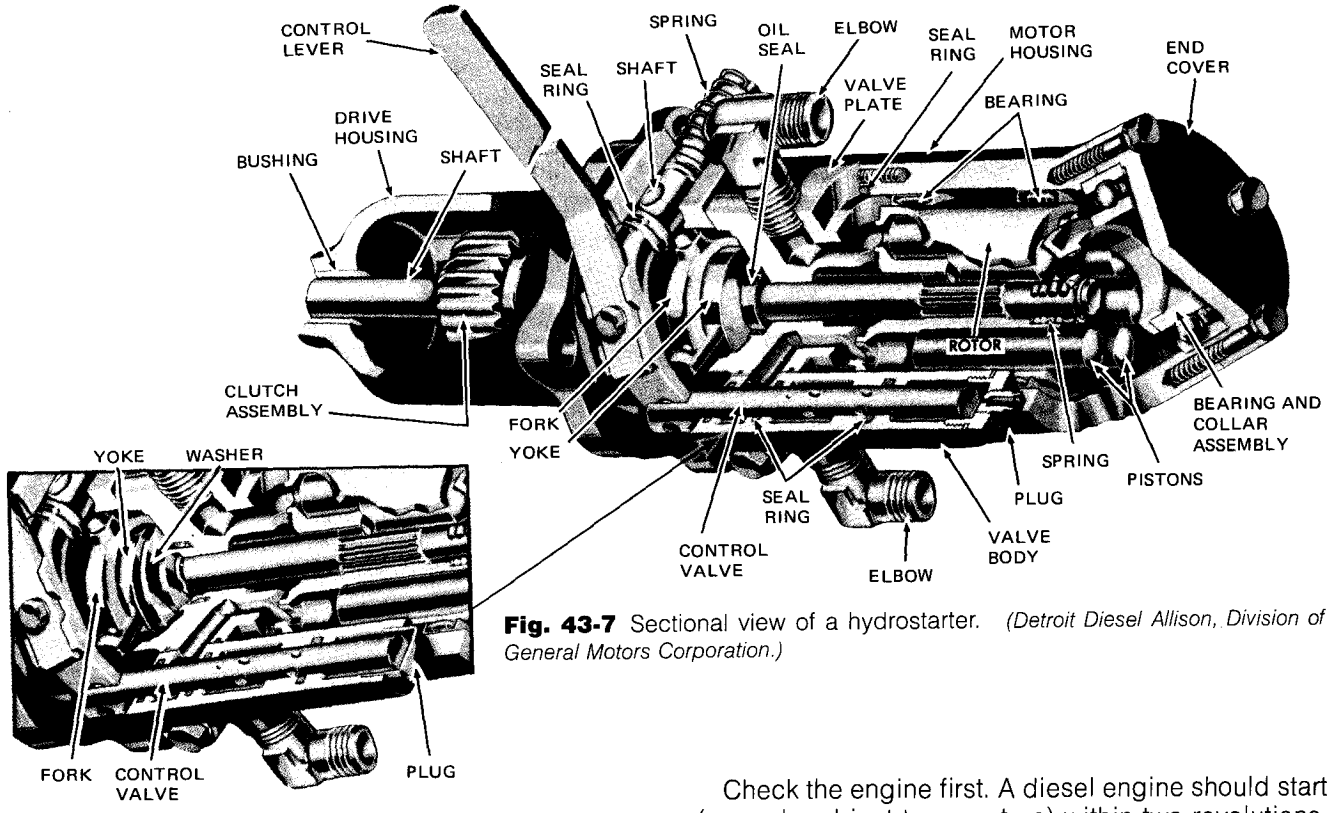


Fig. 43-7 Sectional view of a hydrostarter. *(Detroit Diesel Allison, Division of General Motors Corporation.)*

Action and Fluid Flow when Cranking Assuming the accumulator is under pressure, this pressure is also placed on the directional spool valve. As the operator directly or indirectly moves the valve spool, the drive pinion engages with the ring gear and oil enters the inlet port of the motor. Should a tooth abutment occur, the valve spool directs a small amount of oil into the motor to rotate the pinion. When a seven-piston swash-plate motor is used, three pistons receive oil under pressure, one piston is in neutral, and three pistons are open to the outlet slot and the reservoir. The three receiving pistons are forced against the thrust bearing of the fixed-angle swash plate (bearing collar assembly). They can only move outward by sliding along the swash plate until fully extended. In so doing, they cause the cylinder block (rotor) to rotate and with it the shaft and motor drive (clutch assembly). At the point where one piston begins to retract, the cylinder opening slides over the outlet valve slot located in the valve plate, and oil pressure is released to the reservoir. At the same time one piston is fully retracted and its cylinder opening is over a solid area in the valve plate. However, the adjacent cylinder has just passed the inlet valve slot and oil pressure is forced onto the piston. When the operator positions the spool valve to neutral, the oil flow and cranking cease and the overrunning clutch drive is taken out of engagement.

Troubleshooting Hydraulic Starting System Brief cranking time or low rpm indicate low oil pressure, a malfunction in the directional valve, or that the cranking motor, motor drive, or engine are seized.

Check the engine first. A diesel engine should start (normal ambient temperature) within two revolutions. If it does not, check for the following:

1. Low accumulator pressure
2. A worn pump
3. Low oil level
4. A plugged oil screen or filter
5. Air in the system
6. External leakage
7. A restriced spool-valve movement
8. A damaged or worn motor

Low accumulator pressure caused by a damaged or worn air check valve or low nitrogen pressure can also reduce cranking efficiency.

Questions

1. State the purpose of the relay valve.
2. What is the purpose of the gear train in the cranking motor?
3. Explain the action in the relay valve when air from the push-button valve enters the chamber above the diaphragm.
4. What would prevent an air starter motor from operating? What would cause an air starter motor to operate at too slow a speed?
5. Which components, if faulty, could cause a continuous air supply to the air motor?
6. List several malfunctions which would cause the cranking speed of a hydrostarter to drop to an ineffective level.
7. What problems would you look for if the hydrostarter does not turn over?
8. Trace the oil flow and explain in detail the operation of each component of the hydrostarter system during the cranking period.

UNIT 44 • COLD-WEATHER STARTING AIDS

Since some diesel engines will not start easily at temperatures as low as 25 to 50°F [−3.89 to 10°C] because of their design, or because of the lower compression ratio (turbocharged engines), various devices are available to facilitate ignition. The most effective starting aids under such adverse temperatures are the cylinder-block coolant heater and the engine-oil heater since they keep the engine components warm at all times. Moreover, they minimize engine component wear during starting and during warm-up.

Glow Plugs A *glow plug* is an electrical heating element which heats the intake air inhaled by the cylinders. Although this device is commonly used as a starting aid because of its effectiveness and low price, it, unfortunately, requires the battery power needed for cranking which at this temperature is reduced.

Many different types of glow plugs are available, some for positioning in the intake manifold and others in the precombustion chamber (Fig. 44-1). The heating element of a glow plug heats the surrounding air when the electric circuit is closed. When the engine is cranked, the heated air is drawn into the cylinder, giving the compressed air a higher temperature for ignition.

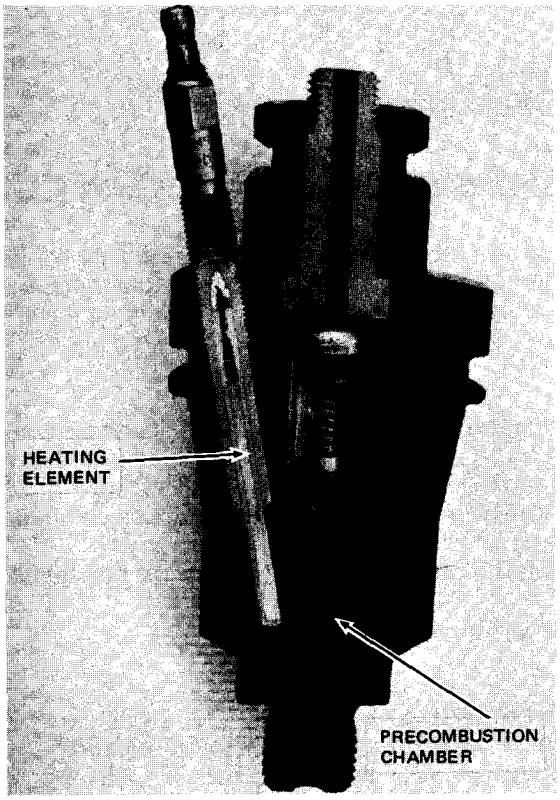


Fig. 44-1 Sectional view of a glow plug installed in a precombustion chamber.

When more than one glow plug is used, they may be connected in series or in parallel. A parallel glow plug circuit is shown in Figs. 44-2 and 45-1. It consists of a three-way starter switch and four glow plugs. The effectiveness of a glow plug can be determined either by removing the glow plug and connecting an ohmmeter, as shown in Fig. 44-3, and then comparing the resistance reading with the specified resistance, or by removing the connecting wire and then measuring the resistance of the glow plug. It can also be determined by connecting an ammeter in series with the glow plug's circuit, then actuating the circuit. The ammeter should then read the specified ampere draw when all glow plugs are working, and a lower draw when one or more glow plugs are not working.

Fluid Starting Aids Just as there are many different types of glow plugs, there are many different fluid starting aids. They all use the same principle,

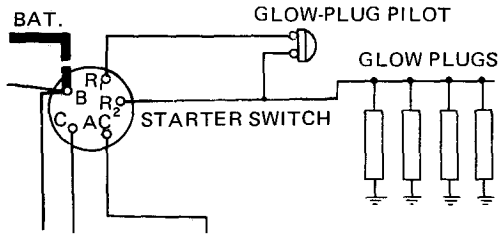


Fig. 44-2 Glow plug parallel circuit.



Fig. 44-3 Testing a glow plug with an ohmmeter.

that is, supplying highly combustible ingredients to the air drawn in by the engine cylinders.

One fluid starting aid is with the use of an ether aerosol can. This method requires two people—one to start the engine and the other to spray the ether. This method leaves much to be desired from a safety standpoint, especially if too much ether is used without being properly atomized. Furthermore, if ether is not properly atomized, or if it is unevenly distributed, it can cause severe damage to the engine.

If you are obliged to resort to the ether method for starting, first crank the engine. At an appreciable distance from the air intake, spray a moderate quantity of ether in its direction. This will allow the air to mix thoroughly with the ether before it is drawn into the engine cylinders. If you fail to do this, the high-power starting fluid will explode too rapidly and excessive damage to the engine may result.

Another fluid starting method that is equally unsafe uses a predetermined volume of ether, in capsule form, placed in a sealed container. The container is connected to a piston-type hand pump and from there to the intake manifold or to the air-intake system. Sometimes a spray nozzle is used to aid in atomization.

If you must use this type of starting aid, remember to crank the engine before breaking the capsule with the piercing pin, then use the hand pump to force starting fluid into the manifold.

QUICK START A safer method, with greater engine protection, is the use of a fluid starting aid called *Quick Start.* It consists of an atomizer and a fluid container to which a metering valve is attached. The metering valve may be connected over a lever to an actuator cable knob which is located within reach of the operator or it may be electrically actuated through a solenoid. In the latter case the push-button switch is located within the operator's reach (Fig. 45-1). The atomizer is located in the intake manifold and can be selected to correspond to a particular engine model so that a safe quantity of starting fluid is metered and the atomization is precisely determined. When using this starting aid, press the starter button or turn the key and at the same time activate the metering valve two or three times. *(NOTE: To ensure a quick starting system at all times, periodically clean the orifice of the atomizer and lubricate any movable valve components.)*

Questions

1. Outline briefly how to prepare and use a fluid starting aid (other than Quick Start).
2. Why is Quick Start safer than ether-fluid starting methods?
3. Why are glow plugs the safest starting aid?
4. How do you test the effectiveness of a glow plug?

UNIT 45 • CHARGING SYSTEM (ALTERNATORS)

Components and Function The charging system consists of a battery (or batteries), a belt-driven or direct-driven alternator, a regulator, and the complementary wiring (Fig. 45-1). The function of the charging system is to supply the electrical system with current and to maintain the batteries in a full state of charge.

NOTE: The wiring diagram in Fig. 45-1 includes the cranking system, glow plug circuit, and Quick Start starting aid circuit. Note that (1) the oil pressure switch is located in the field circuit, (2) an electronic tachometer is used which receives its ac current pulse from the R terminal of the alternator, and (3) when a glow plug is used no Quick Start system can be installed.

Generators A *generator* is a mechanical device that converts mechanical energy supplied by the engine into electrical energy. It furnishes the battery and the electrical system with direct current.

Today's generators (called *alternators*) convert alternating current to direct current through rectification, whereas earlier generators converted alternating current to direct current through brush commutation.

The alternator has fully replaced the generator because:

1. It can produce a high current at lower engine speed.
2. It can rotate in either direction.
3. It can rotate safely, without destruction, at high speed.
4. Its output voltage and current can be controlled easily.
5. It has a long service life.

Electromagnetic Induction The largest source of produced electric energy is through electromagnetic induction. Its history goes back to 1831 when Michael Faraday proved that voltage (emf) is induced in a conductor if the conductor is moved between the poles of a magnet or if the magnet is moved over the

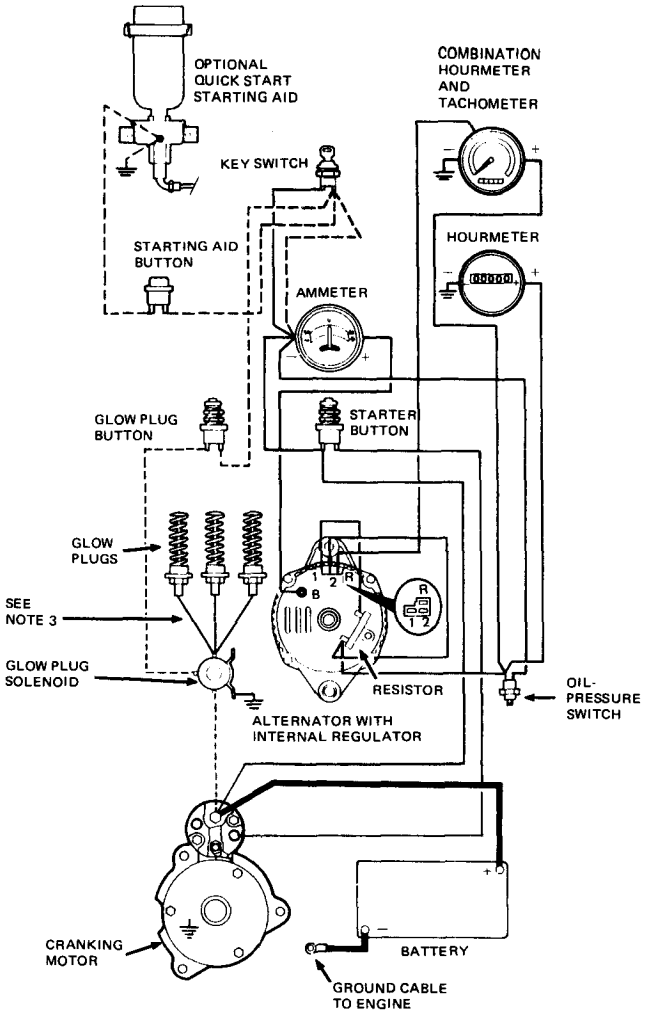


Fig. 45-1 Wiring diagram schematically illustrated. *(Allis-Chalmers Corp. Engine Division.)*

conductor. The emf obtained in this way is said to be an *induced emf* and the process is called *electromagnetic induction*. He also proved that the conductor, when moved through a magnetic field from left to right or from right to left, changes the induced emf polarity (when the magnetic poles maintain the same position) because the magnet's magnetic lines of force move from its north pole to its south pole. Faraday also proved that the polarity of the induced voltage changes when the polarity of the magnetic field changes. When the conductor is moved from right to left, the magnetic lines strike the conductor at the left-hand side, and the magnetic lines of force then move around the conductor in a counterclockwise rotation. When the conductor is moved from left to right the magnetic lines strike the conductor at the right-hand side and the lines of force move around the conductor in a clockwise rotation (Fig. 45-2). To determine the direction of current flow, apply the right-hand rule. When the conductor is moved parallel to the magnetic lines of force, no voltage is induced.

NOTE: When the conductor moves across the magnetic field or the magnetic field moves over the conductor, voltage is induced. However, it must have a complete circuit or there is no current flow.

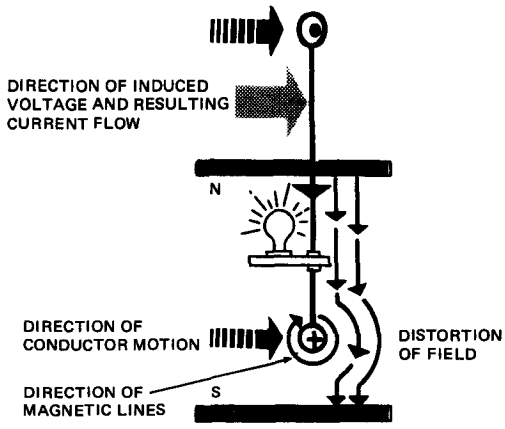


Fig. 45-2 Fundamentals of electromagnetic induction.

Alternating Electromagnetic Induction A simple one-loop (coil) alternator is shown in Fig. 45-3. When the magnet rotates within the coil loop and its south and north poles approach the conductor loop, a voltage is induced. The induced voltage in the conductor near the north pole travels in the same direction (clockwise) that it would if the conductor were moved through a magnetic field from the left to the right (Fig. 45-3*a*). The induced voltage in the conductor near the south pole travels in the same direction (counterclockwise) that it would if the conductor were moved from the right to the left (Fig. 45-3*a*). The induced voltage gradually increases to its maximum, that is, when the south pole is under the conductor and the north pole is above it. As the poles move away from the conductors, the induced voltage decreases, and the current ceases to flow when the poles are in the middle of the conductor loop. As the poles again approach the conductors, the current flow is reversed because the magnetic lines of the magnet have reversed but strike the top and bottom conductors again at the left- and right-hand sides. The induced voltage therefore reverses and gradually rises to its maximum when the north

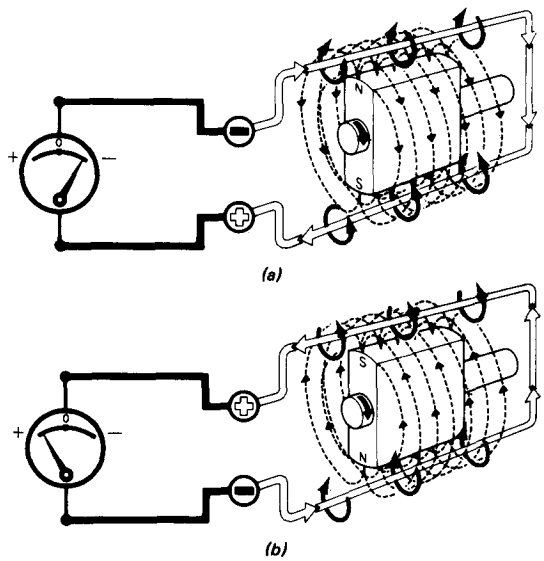


Fig. 45-3 Alternating electromagnetic induction.

pole is under the conductor loop and the south pole is over it (Fig. 45-3*b*). Further rotation decreases the induced voltage to zero, that is, when the poles again return to the middle of the conductor loop. From this point on the cycle is repeated (Fig. 45-4).

The induced voltage (emf) which periodically reverses its polarity (direction) is known as *alternating electromotive force* and the resulting current flow is known as *alternating current.*

Alternator Construction There are many alternator designs to complement the different electrical requirements of today's intricate electrical systems. They must accommodate equipment which operates over long distances, or in short stop-and-go service, or equipment which requires special high current output such as buses or marine applications.

All alternators have certain similarities in construction. Their magnetic fields (rotors) rotate between the stationary conductors (stators). Their rotors are mounted on ball, needle, or roller bearings. One brush carries current from the field terminal to the slip ring. The other brush completes the circuit over the voltage regulator to ground. The stator windings are wound on the laminated stator frame which, in most cases, is the housing or frame of the alternator.

The six diodes (rectifiers) used for rectification (on newer alternators) are mounted in the rectifier bridge; on older models they are mounted in individual heat sinks, or the negative diodes are mounted in the slip ring end frame (see Fig. 45-5). The diodes are connected with the stator windings and the battery terminal of the alternator.

Rotors of brushless alternators are different in design. Here the rotor consists of two permanently magnetized pole pieces (one south, the other north) fastened together with iron that cannot be magnetized (see Fig. 45-6). The field coil of brushless alternators is wound over an iron core which is fastened to the alternator housing and does not rotate. When assembled it fits inside the rotor. *(NOTE: The rotor is the only rotating component in this type of alternator.)*

FACTORS AFFECTING OUTPUT VOLTAGE The output voltage of an alternator is increased when the rotor speed is increased, when the strength of the magnetic field is increased, or when the number of turns of wire in the stator windings is increased.

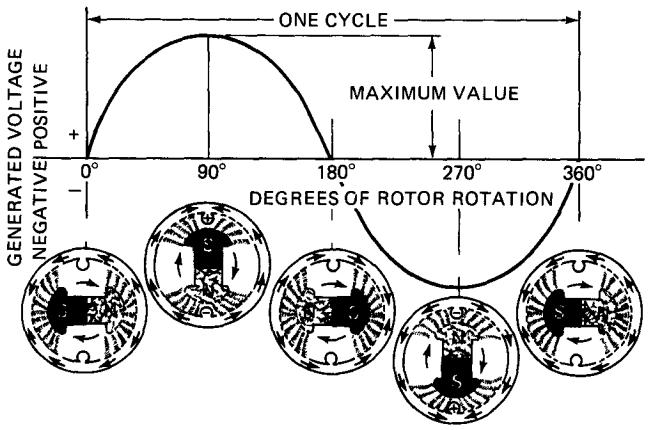


Fig. 45-4 Generated voltage during one cycle (one revolution), one phase. *(Delco Remy, Division of General Motors.)*

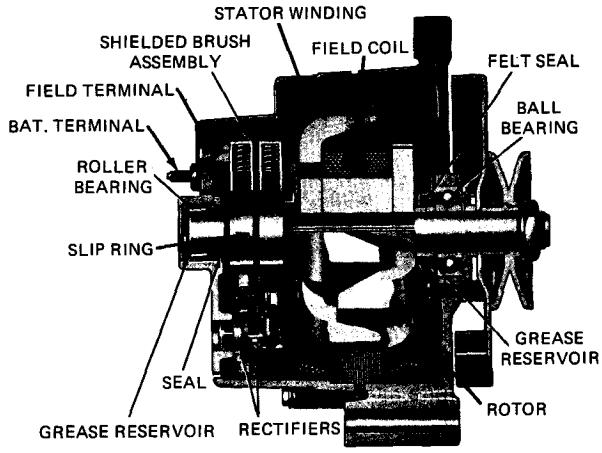


Fig. 45-5 Sectional view of a standard-duty alternator using remote-mounted voltage regulator. *(Delco Remy, Division of General Motors.)*

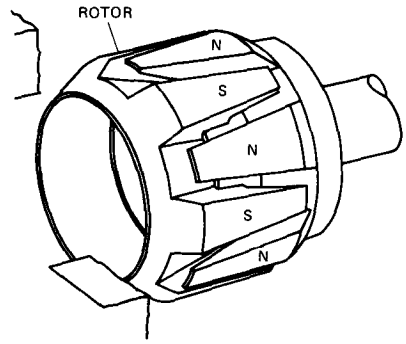


Fig. 45-6 Rotor used in a brushless generator.

Inductive Reactance Alternators are electrically designed so that maximum current output will not exceed their output rating. To cite an example, a 12-V 60-A alternator will produce approximately 66 A with a maximum voltage of about 19 V. The reason for this is that as current flow increases in the stator windings, the magnetic lines of force cut across the adjacent stator windings. The direction in which the lines of force cut the adjacent conductor induces a voltage opposite to that of the applied voltage, limiting the current flow in the stator windings (Fig. 45-7). The inductive opposition to current flow is called *inductive reactance.*

Field Circuit Alternators are built with an electromagnet rather than with a permanent magnet because the former creates a stronger magnetic field. In addition, the electromagnetic field current is used to vary the alternator output voltage. When increasing or decreasing the field current, the magnetic field strength is varied and, therefore, also its output voltage, to safeguard the electrical components against high voltage. The unit which regulates the field current is called a *voltage regulator.*

The field current of an alternator can be connected in two ways, as shown in Fig. 45-8. When connected as a B circuit, the field is grounded in the generator.

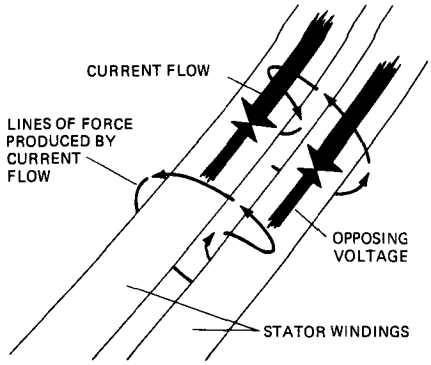


Fig. 45-7 Inductive reactance. *(Delco Remy, Division of General Motors.)*

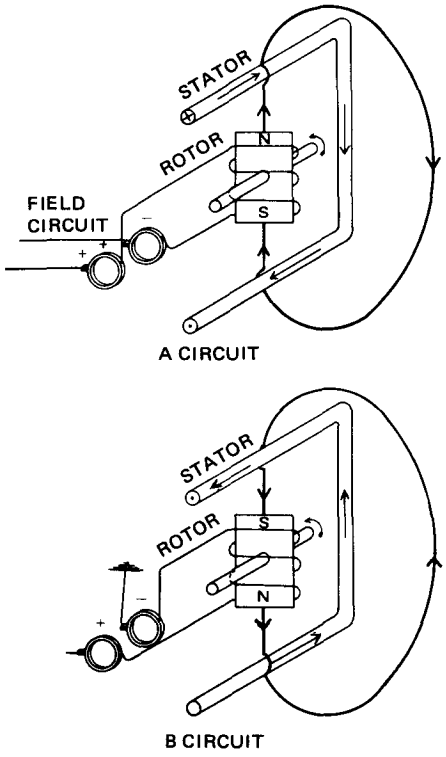


Fig. 45-8 Top, A circuit generator; bottom, B circuit generator.

When connected as an A circuit, the field is grounded in the regulator. In each case, both brushes are insulated. Neither circuit connection (A or B) changes the generator output or voltage. However, all newer alternators have an integrated voltage regulator circuit; therefore, these alternators are all A circuits.

Alternator Stators If an alternator had only a single loop, the induced alternating voltage would be very pulsating and sufficiently low to render it useless. To increase the induced alternating voltage, three independent stator windings (three phases) are used. Each independent phase is formed into as many coils as there are north or south poles. For example, a 12-pole rotor (six north and six south poles) has each stator phase wound into six coils and spaced 60° from each other in the iron core of the stator frame. Therefore 18 coils are used for a three-phase 12-pole rotor (Fig. 45-9). A change in the rotor

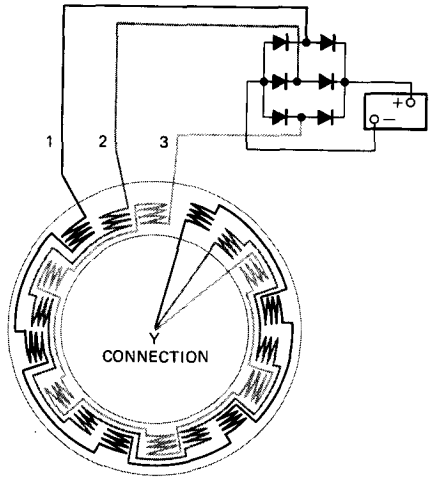


Fig. 45-9 Schematic illustration of a three-phase stator assembly, showing the position of the 18 coils.

poles also changes the number of coils wound into the stator. Each phase coil is placed in the stator frame electrically 120° apart from the other. The three phase windings are connected to each other by a Y or delta connection and each phase winding is connected to one negative and one positive diode (see Figs. 45-9 through 45-11).

Phase As the rotor rotates 360°, an alternating voltage is induced in each phase winding, resulting in an alternating current flow referred to as a *phase.* (See Fig. 45-4.)

Cycle and Frequencies When the rotor has rotated 360° (one revolution), one phase winding has completed one cycle and has produced one positive and one negative sine wave. 120° later the second phase winding has completed its cycle, and 240° later the third phase winding has completed its cycle. One half cycle (one sine wave) is called an *alternation.* The numbers of half-cycles generated per second are called frequencies.

Semiconductors The alternating current produced by a three-phase generator must be rectified

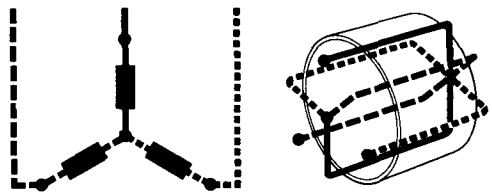


Fig. 45-10 Three-phase Y connection.

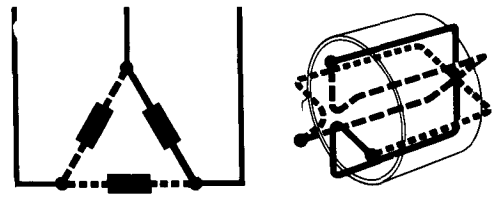


Fig. 45-11 Three-phase delta connection.

to direct current since direct current is required to operate the electric units and to charge the battery. This rectification is achieved through semiconductors known as *diodes*. A diode may also be used as a safety switch or as a resistor.

To understand how a diode can perform these various functions, you should study its design. As outlined in the section on electricity (Unit 37), a conductor must have less than four electrons in its valence ring (outer orbit), and an insulator must have more than four electrons in its valence ring; therefore, an element which has four electrons in its valence ring is neither a good conductor nor a good insulator. Four such elements are known; however, only two of these (silicon and germanium) in a purity of 1 billion to 1, are used to make N- and P-type (for negative and positive) diode material. The element silicon is used because it can withstand high temperatures. When purified and prepared for doping (adding another element to the silicon), the silicon atoms combine in crystalline form. This covalent bonding of the silicon atoms produces eight electrons in the valence (or outer ring) and the diode material then becomes a good insulator (see Fig. 45-12).

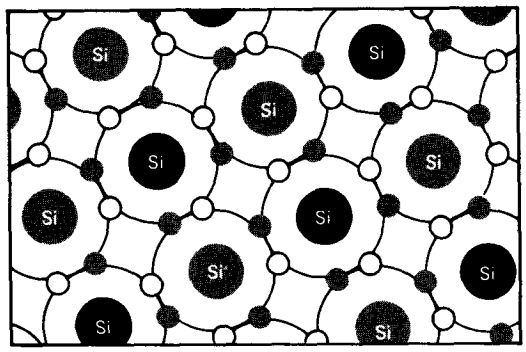


Fig. 45-12 Covalent bonding of silicon atoms. *(Delco Remy, Division of General Motors.)*

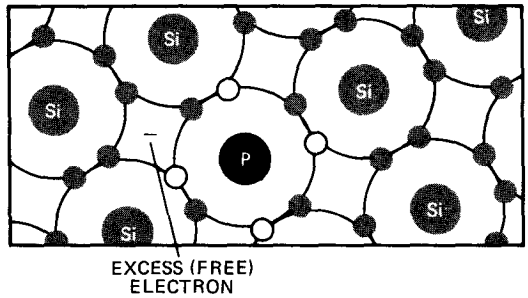


Fig. 45-13 Covalent bonding with excess (free) electron. *(Delco Remy, Division of General Motors.)*

Doping Semiconductor Materials By doping (adding) the silicon material with a controlled portion of such elements as phosphorus or antimony (both of which have five electrons in their valence rings), covalent bonding will occur, as illustrated in Fig. 45-13, with one electron left over. This free electron becomes the electron carrier and can be made to move easily through the material. Material of such construction is called *negative* or *N-type material,* that is, material having an excess of electrons.

When the silicon material is doped with atoms of an element such as boron or indium, which have three electrons in their valence rings, the covalent bond is incomplete and a void is created. This void is referred to as a *hole* (Fig. 45-14). The hole is really a missing electron. Since an electron is a negative charge of electricity, the hole is considered a positive charge of electricity. By robbing an electron from the adjacent atom, the hole can be made to move as easily through the material as the free electron through the N material. Material of this construction is called *positive* or *P-type material* (material having a deficiency of electrons).

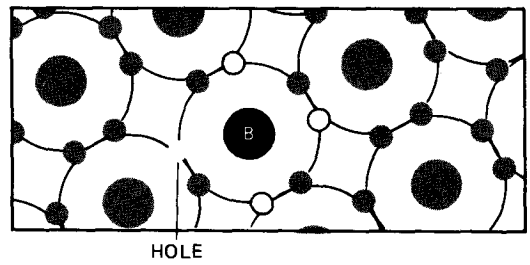


Fig. 45-14 Hole. *(Delco Remy, Division of General Motors.)*

When either material is connected to a circuit with a power source of sufficient voltage, the N- and P-type materials obey the simple law of opposite polarity attracting and like polarity repelling. Electrons will flow through the N-type material (as shown in Fig. 45-15) toward the positive terminal to the power source. Additional electrons flow out of the negative terminal to re-enter the N-type material.

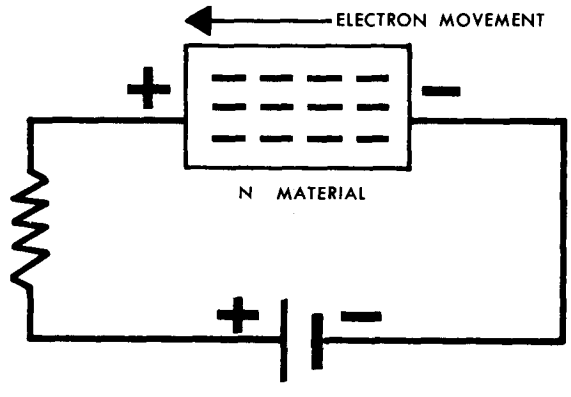


Fig. 45-15 Electron movement through N material. *(Delco Remy, Division of General Motors.)*

Similarly, when the P-type material is connected to the circuit shown in Fig. 45-16, the holes move to the negative terminal. There they will meet with the electrons from the power source and recombine.

Some of the electrons enter the P material, fill the holes, and cause an imbalance within the semiconductor. The electrons are discharged forcibly at the positive terminal, creating new holes which act as current carriers. This movement continues until the circuit is opened.

NOTE: The hole movement is only in the semiconductor material. Electrons flow through the entire circuit.

Diode Construction By a fusion process, manufacturers join two small slices of N- and P-type ma-

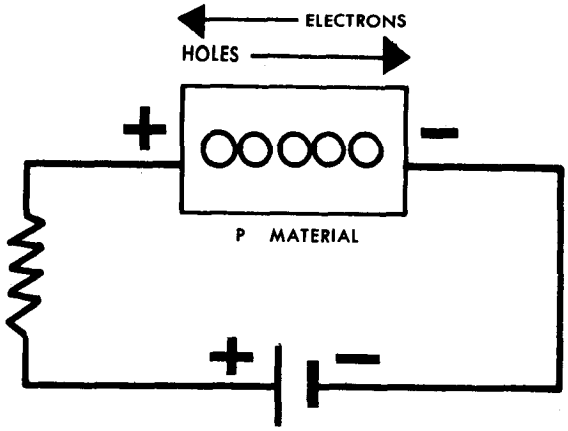


Fig. 45-16 Electron and hole movement through P material. *(Delco Remy, Division of General Motors.)*

terial together. The point where they join is called a *junction* (Fig. 45-17). Because unlike charges attract, a few electrons near the junction drift into the P material and fill the holes, thereby nullifying them as current carriers. A few holes drift into the N material, recombine with the electrons, and eliminate them as current carriers. Equilibrium is achieved when no holes or electrons can move across the (PN) junction, as shown in Fig. 45-17. The diode (which is the junction) is sealed and then bonded, epoxied, or attached to an insulated or grounded plate or housing. Earlier designed diodes have the junction positioned in a specially designed sealed case (Fig. 45-18).

Diode Action When a diode is connected in the circuit as shown in Fig. 45-19 (forward bias), the positive terminal of the battery connects to the P material and the negative terminal connects to the N material. With sufficient voltage difference, the electrons will flow from the negative side of the battery through the junction to the positive side of the battery because the holes in the P material repel, and the electrons in the N material repel from their terminals and move toward the junction. Usually only a fraction of the voltage is required to cause the holes and the electrons to move through the junction.

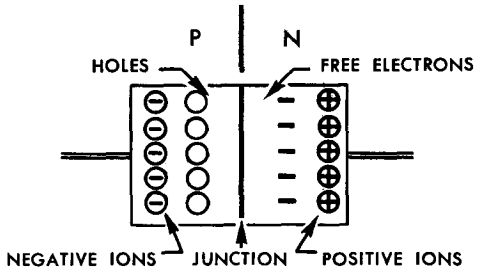


Fig. 45-17 Diode after the fusion process. *(Delco Remy, Division of General Motors.)*

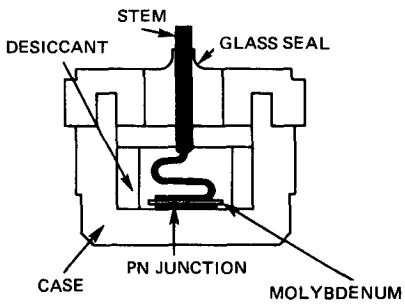


Fig. 45-18 Diode construction (PN). *(Delco Remy, Division of General Motors.)*

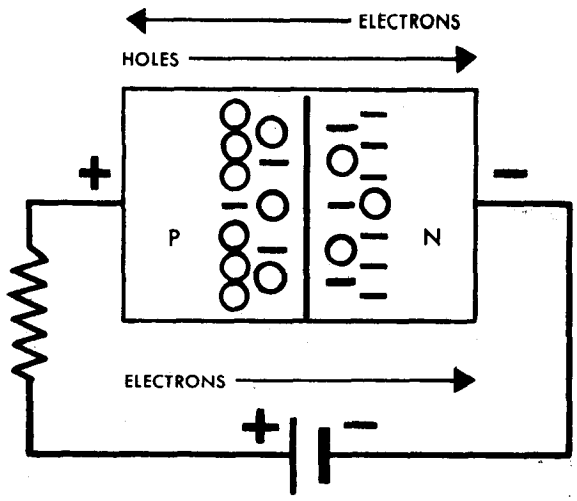


Fig. 45-19 Forward-bias connection. *(Delco Remy, Division of General Motors.)*

As soon as a hole enters the N material and recombines, an electron enters the P material. This forces an electron to leave the P material, creating a new hole, and a new electron to enter the N material.

When the battery is connected in reverse bias (reverse polarity), the negative terminal of the battery connects to the P material and the positive terminal connects to the N material. The holes are attracted toward the negative terminal and the electrons are attracted toward the positive terminal, causing the junction to void itself of current carriers, electrons, and holes. The junction becomes a high-resistance area. In short, a diode will allow a current flow when connected in forward bias, but will not allow a current flow when connected in reverse bias. *(NOTE: Some diodes will allow a very small current flow in reverse direction.)*

REVERSE-BIAS VOLTAGE When the reverse voltage is increased, say by using a 110-V tester or by using a battery charger with a selected voltage higher than the system voltage, the maximum reverse voltage may cause the diode to overheat and finally to destroy itself. When using a battery charger with a selected voltage higher than the maximum system charging voltage, the diode may also overheat and destroy itself. This destruction occurs because the covalent-bond structure breaks down and reverse current can flow freely through the diode. The diode system and the direction in which current is allowed to flow is shown in Fig. 45-20. Alternators and voltage regulators and other electrical components using positive and negative diodes are identified by symbols, as shown in Table 45-1.

Diode Rectification Diodes are used to change the induced ac current of the alternator into direct

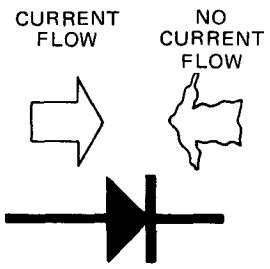


Fig. 45-20 Diode symbols. *(Delco Remy, Division of General Motors.)*

TABLE 45-1

DIODE IDENTIFICATION

Ground polarity of battery	Identification on diode in grounded heat sink	Insulated heat sink
Negative	−, Black, right-hand thread	+, Red, left-hand thread
Positive	+, Red, left-hand thread	−, Black, right-hand thread

current. They rectify (change) the alternating electric current into direct current by reversing the direction of alternate impulses. To utilize the full capacity of the alternator, six diodes are needed instead of three. Since three diodes give only half-phase rectification, one sine wave of each phase is not used because it cannot reach the battery.

To utilize each sine wave, each phase is connected to one positive and one negative diode (full-phase rectification). When connected in this sequence, six sine waves are rectified with each revolution of the rotor, and direct current flows into the battery. Current flow through each of the six sine waves is only for a fraction of a second during each stage of rectification. When the rotor passes under phases C and B, voltage is induced and current flows from junction C through the stator windings to junction B, through the positive diodes in the heat sink to the battery, from the battery to the negative diode, and to junction C (Fig. 45-21). The opposing voltage in the winding at junction A is in balance and, for a brief moment, in neutral. Note the current flows into the positive post of the battery.

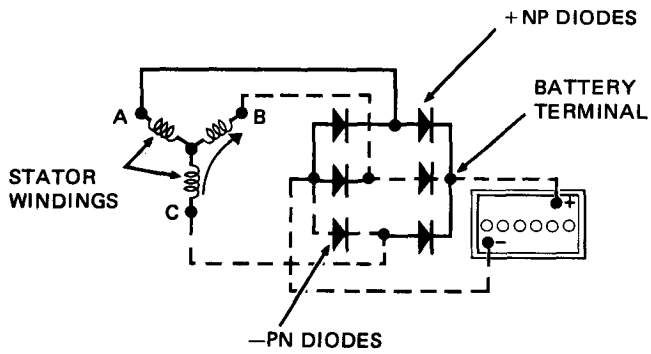


Fig. 45-21 Current flow, one sine-wave rectification (Y connection).

When the rotor has turned 60°, current flows irreversibly through the phase winding at junction A to junction B, to a positive diode in the insulated heat sink, and to the battery. In this stage, the phase winding at junction C is in neutral. The electric circuit is completed from the battery negative post through the negative diode junction A. The rectified voltage is by no means without pulsation, but for all practical purposes, it is smooth enough to be considered a non-pulsating dc voltage.

The current flow in a delta-connected stator does not correspond with that in a Y-connected stator. In a Y-connected stator, current is only conducted through two stator windings, whereas a stator connected in a delta circuit conducts current through all three stator windings (see Fig 45-22). The result is a higher current flow but not a higher voltage, in the delta circuit. For example, say an alternator with a Y-connected stator produces 60 A at 3000 rpm and a voltage of 16 V with a field current flow of about 2.5 A. If the same alternator stator is changed to a delta connection and is run at the same rpm and with the same field current and voltage, the output would be 103.8 A. This is because a delta-connected stator produces 0.73 A more than a Y-connected stator. (60 A × 0.73 = 43.8 A and 60 A + 43.8 A = 103.8 A.)

Alternator Cooling An alternator, like any device which converts energy, produces heat. It also picks up heat through radiation from the engine. This heat must be removed to protect the insulation, soldering, and diodes. Heat shields are sometimes installed to reduce heat radiation from the engine.

The cooling methods employed vary with alternator design. Fan cooling is the most common method. The fan is mounted on the rotor shaft behind the pulley and the cooling air is drawn from the slip-ring side (regulator side) through the alternator and out through the drive end-frame opening. The temperature of the cooling air should not exceed 140°F [60°C]. High-output alternators in the range of 150 to 300 A are oil-cooled. Newer designed alternators do not have external cooling fins.

Rectifier Bridge and Heat Sink When an alternator is operating, current flows through the diodes and causes heat. Semiconductors (diodes) lose their resistance to an opposing current flow when overheated. To ensure a safe diode operating temperature, three positive diodes are epoxied into the insulated heat sink and three negative diodes are epoxied into the ground heat sink. Together the heat sinks form the rectifier bridge (Fig. 45-23). When the

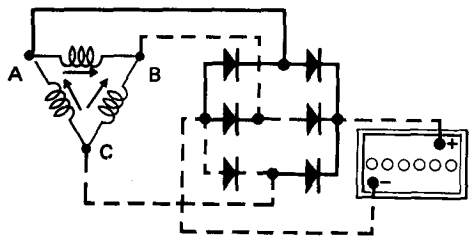
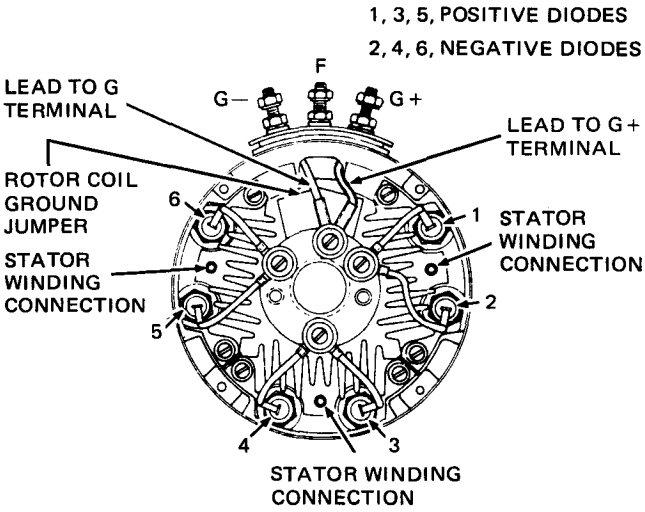


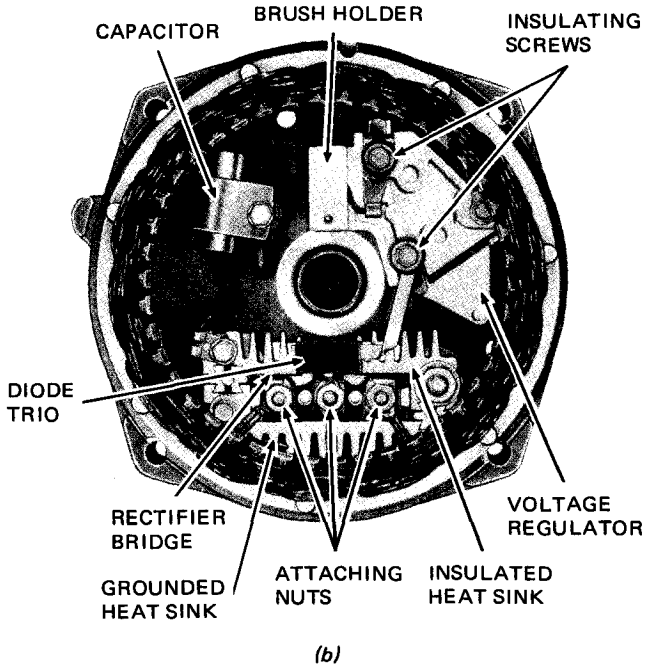
Fig. 45-22 Current flow, one sine-wave rectification (delta connection).

system has positive ground, the heat sink connections are reversed. Internally each set of diodes is connected back to back so that one negative and one positive diode are connected to one stator phase terminal connection. On other types of alternators, three positive and three negative diodes are pressed or screwed into two separate heat sinks, or the negative diodes are pressed or screwed into the end frame (Fig. 45-4, or as shown in Fig. 45-23*a*).

The insulated heat sink (negative ground) is connected to the alternator's battery-insulated terminal and the other heat sink is grounded to the alternator. When a two-wire system is used, the grounded heat sink is also insulated and connected to the alternator's ground terminal.



(a)



(b)

Fig. 45-23 Typical view of inside the end frame: (*a*) rectifier bridge *(Delco Remy, Division of General Motors.)*, (*b*) three individual heat sinks. *(Mack Trucks Canada Limited.)*

Two or three heat sinks are used to increase the cooling efficiency and make the alternator more versatile in that they can accommodate either battery polarity.

NOTE: The heat sink connected with the battery terminal must have the same polarity as the live side of the battery.

CHARGING SYSTEM SERVICE

Alternator Testing Prior to Removal (Remote-mounted Voltage Regulator) When the engine cranking speed is not adequate, the first step is to inspect the charging system. Test the batteries. Check all cables and wire connections for tightness and cleanliness and then make an alternator output test to determine whether the trouble is in the alternator or in the voltage regulator.

Before you proceed with the alternator output test, you must verify the type of alternator field circuit. Is it connected as an A or a B circuit? This information is contained in the service manual. *(NOTE: Alternators which have integrated voltage regulators are A circuit types.)* If no service manual is available, follow this general procedure: Disconnect the field wire(s) at the alternator and connect an ohmmeter as shown in Fig. 45-24. If the ohmmeter shows continuity, the field circuit is wired as an A circuit. If the ohmmeter shows no continuity, the field circuit is wired as a B circuit.

After determining the type of circuit, connect the test instruments as shown in Fig. 45-25.

NOTE: When the alternator is wired as an A circuit, you must also connect a jumper from one field terminal to ground the field circuit.

An example of an alternator test specification is given in Table 45-2.

After the instruments have been connected, run the alternator at an output of about 15 A for about 5

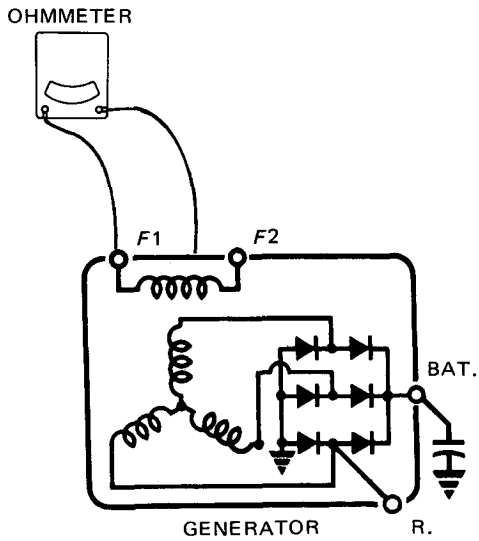


Fig. 45-24 Determining A or B circuit alternator.

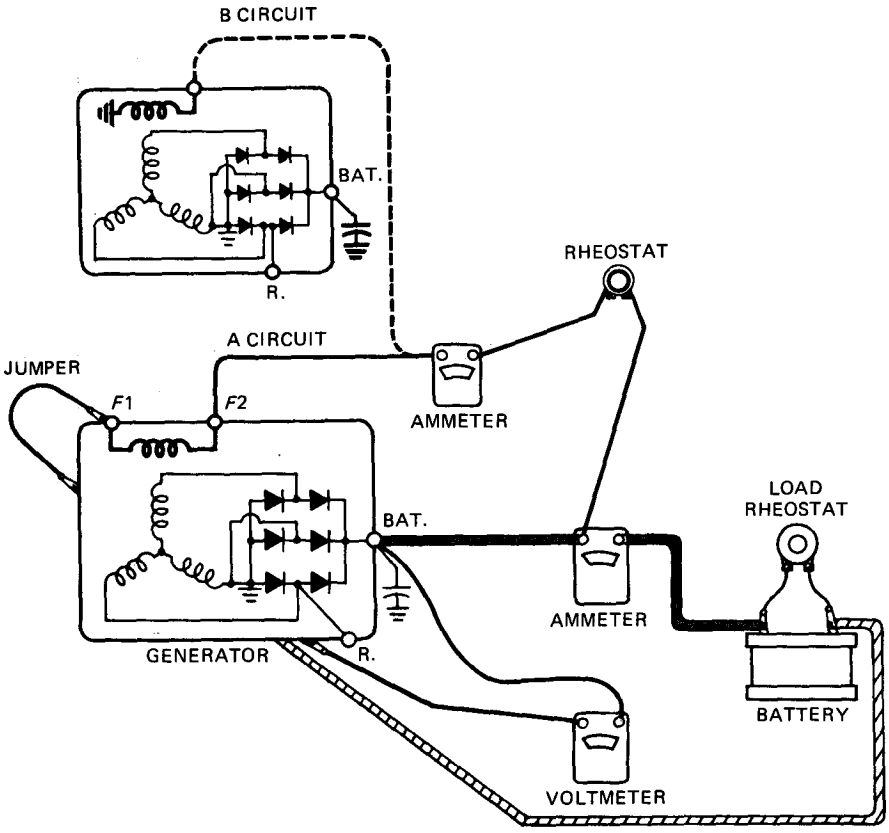


Fig. 45-25 Connections for testing A and B circuit alternator having remote-mounted voltage regulators.

TABLE 45-2

ALTERNATOR TEST SPECIFICATION

Vendor	Amperes at 15 V	Watts at 15 V	Field current, A, at 12 V, 75°F [23APC]	Cut-in-speed (alternator rpm)	Rated output speed (alternator rpm)	Belt width, in [mm]	Belt tension, lb [kg]	Brushes			
								Number used	Original length, in [mm]	Wear limit, in [mm]	Spring tension, oz [g]
Alternator	60	840	2.0–2.5	760	3300 cold 4100 hot	3/8 [9.53]	80–110 [36.29–49.94]	2	1/2 [12.70]	9/32 [7.14]	8–10 [226.8–283.5]

minutes to warm up the components. Then run it at about 760 rpm, and slowly remove the resistance to feed the field circuit. The alternator should show a current flow. Increase the alternator speed to 4100 rpm. Adjust the field rheostat so that the field current flow is between 2.0 and 2.5 A. Check the alternator speed constantly to maintain the recommended rpm.

Adjust the load rheostat, if necessary, to obtain the desired output (amperage). Check readings of the rpm, field current, voltmeter, and output ammeter. All gauges should indicate specified value or higher. If the current output is lower or the field current is higher, or the voltage is higher, the alternator must be disassembled and serviced.

Testing Alternator with Oscilloscope If your shop has an electronic engine tester (an oscilloscope), use it! It is an excellent instrument with which to locate the source of alternator trouble.

Connect the leads according to the manufacturer's recommendation. Set the instrument selectors to the proper positions. Run the alternator at the recommended speed, using the correct field current, voltage, and ampere output. The wave pattern on the oscilloscope will indicate the source of the alternator trouble.

Refer to Fig. 45-26. The alternator, when tested at 3500 rpm, showed 15.2 V, 30 A (Fig. 45-26*a*). When one positive diode during the test was open, grounded, or short-circuited, the current dropped 4.5 A because one sine wave wasn't used (Fig. 45-26*b* and *c*). The same ampere drop was registered when one negative diode was open, short-circuited, or grounded. The same tests were made at 1000 rpm, and the alternator output dropped from 10 to 9 A.

With the alternator running at the same speed and output, one stator winding was open. The output dropped to 22 A (Fig. 45-26*d*). When one stator winding was short-circuited, the output dropped to 24 A (Fig. 45-26*e*). However, when the stator was grounded, the output dropped to 18 A (Fig. 45-26*f*). At the same time as these tests were performed, the wave patterns throughout the tests were photographed. An open, grounded, or short-circuited stator

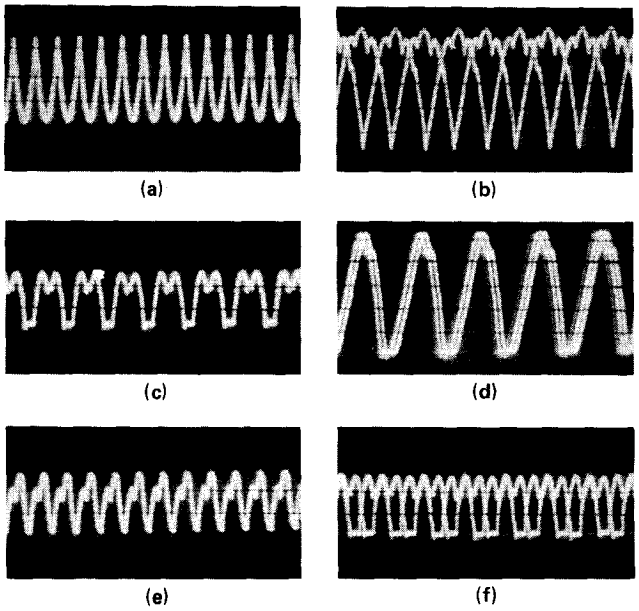


Fig. 45-26 Wave patterns on an oscilloscope: (*a*) three-phase output, (*b*) negative or positive diode open, (c) short-circuited or grounded positive or negative diode, (*d*) one phase open, (e) one phase short-circuited, (*f*) grounded stator winding.

at low alternator speed (1000 rpm) did not change the alternator output. When the R terminal of the alternator was grounded, the output dropped to 18 A because two sine waves were directed to ground.

Disassembling Alternator When the alternator performance is not to specification, or the brushes are to be replaced, it should be completely disassembled. Because there are so many varying alternator designs, it is not possible to outline a common disassembly procedure. However, the following are some typical steps to be taken and precautions to be noted:

1. Always clean the assembly thoroughly with compressed air before starting its service.
2. Chalk reference marks on the front and rear housing.
3. Remove the thru-bolts and use a screwdriver (in the slots provided) to separate the front from the rear housing.
4. Place a piece or tape over the bearing hole and onto the shaft bearing surface to protect them from dirt and damage.
5. To remove the front housing from the rotor, place the rotor in a vise having protected jaws and do not overtighten as this could distort the pole alignment. Use a proper puller to prevent damaging the pulley, the front housing, or the rotor.
6. If so equipped, remove the phase connector's voltage regulator, diode trio, and rectifier bridge.

Rotors The rotors of an alternator vary in design from a 2- to 16-pole piece construction. Most rotor assemblies include a laminated cover over which the field coil is wound. The coil ends are connected electrically to two slip rings. Two interlacing finger-type iron pole pieces are spaced evenly over the field coil and splined onto the rotor shaft (Fig. 45-27). A brush rides on each of the two slip rings connecting the field coil to the voltage regulator and to ground. When the coil is energized, the ends of the coil form a north and a south pole. The magnetic lines of force cause the left-rotor pole piece to become north and the right-rotor pole piece to become south. This creates alternating north and south poles which become six north and six south poles.

The rotor construction of earlier high-output alternators have heavy-gauge wire or copper ribbon wound onto individual pole shoes to create two south and two north poles. The newer high-output alternators are of the brushless design and are covered later in this unit.

Servicing a Rotor To check the serviceability of a rotor, first check the rotor for worn bearing surfaces and for a bent shaft. Either defect will reduce alternator output since either will bring the rotor closer to the stator, reducing the magnetic field strength and, subsequently, the output. Make certain the pole pieces are tight on the shaft and equally spaced because looseness reduces the magnetic field strength.

Check the slip rings. When the rings are rough, brush contact is reduced, and this lowers the field current and the output. If they are rough or out-of-round, the slip rings must be turned in a lathe to within 0.002 in [0.051 mm] of dial-indicator reading. The surface must be polished to a mirror finish with a 400-grain (or finer) polish cloth (see Fig. 45-28).

Testing Field Coil for Grounded, Open, or Short Circuit Adjust the ohmmeter by holding the ends of the test probes together, then turn the adjusting knob to set the needle to zero. When you test the field coil for a grounded circuit, hold one test probe of the ohmmeter against the rotor shaft or pole piece and the other against either of the slip rings (Fig. 45-29). If the field coil is not grounded, the ohmmeter will not move from its infinite position.

When you test the field coil for an open or short circuit, or the field-coil resistance, hold one probe against each slip ring. If there is no open or short

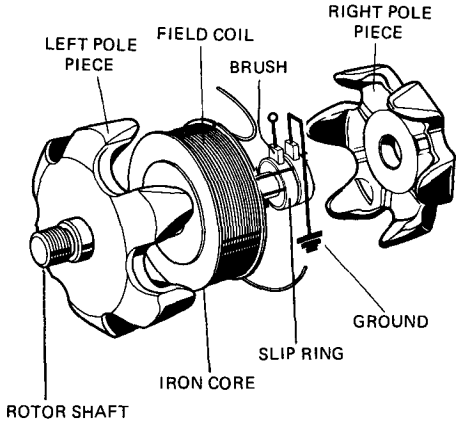


Fig. 45-27 Rotor construction. *(Delco Remy, Division of General Motors.)*

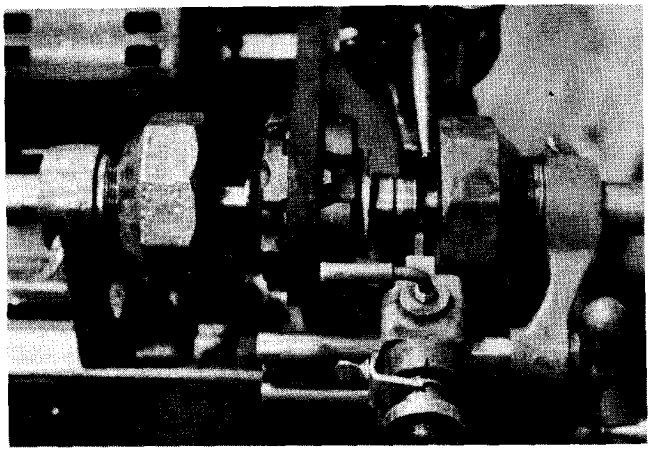


Fig. 45-28 Rotor installed into armature lathe.

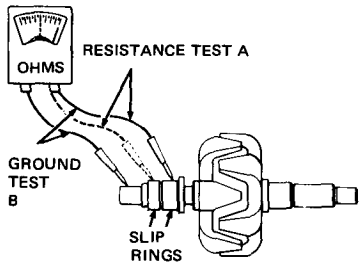


Fig. 45-29 Checking field coil A for short and resistance, B for ground.

circuit, the ohmmeter should indicate the resistance specified in the service manual.

Although the above methods are acceptable under certain circumstances, the current draw test is more reliable. The procedure is as follows: Connect the rheostat or carbon pile, ammeter, battery, and voltmeter to the rotor as shown in Fig. 45-30.

NOTE: Before you make the last battery connection, open the carbon pile (maximum resistance) and connect the leads to the sides of the slip rings to prevent damage to the brush contact surfaces.

Slowly reduce the resistance of the carbon pile until the voltmeter reaches its specified value. The ammeter at this time should indicate the specified amperage. If the ampere reading is above specification, the coil is short-circuited. If it is below specification, the coil has high resistance. In either instance the field coil must be replaced.

Bearing and Seal Replacement Whenever a major disassembly takes place, the bearings should be replaced. To replace the bearings of the drive end frame (front housing), remove the pulley shaft nut according to instructions in your service manual. Next, remove the pulley and fan from the shaft. Use an arbor press to push the rotor shaft from the drive end frame. Remove the retainer plate and push out the bearing and seal from the end frame.

To remove the bearing and seal from the slip-ring end frame or rear housing, first push out the plug. With the correct adapter, press out the bearing and the seal (from the outside to the inside). The adapter used must fit precisely within the bearing bore.

CAUTION Adequately support the end frame or housing to prevent it from being damaged when pressing the bearing in or out. To safeguard the end frame from damage, some manufacturers recommend heating the end frame in an oven to 250°F [121°C] when installing bearings in the end frame or housing.

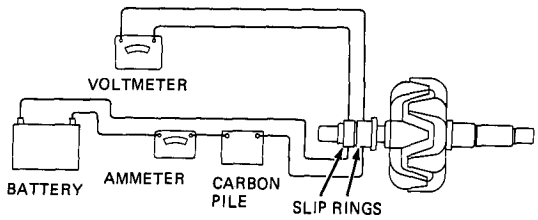


Fig. 45-30 Checking the field coil for open and short.

Alternator Brush-holder Assembly One of many different brush-holder assemblies is illustrated in Fig. 45-5. They all serve the same purposes: to position and hold the brush in sliding contact with the slip rings, to insulate the brush from the alternator frame, and to connect the brush with the regulator and/or with ground.

As illustrated, the brushes are small and the springs used are light since the brushes carry only field current.

Brush Replacement In view of the many differently designed alternators and brush-holder assemblies, there is no single procedure governing the replacement of brushes. In the absence of defined procedure, use your common sense. Brushes should be replaced when the alternator is serviced or when they are worn to half of their specified length. (Use a small steel ruler to measure the wear length.)

NOTE: Discoloration of a brush-holder assembly indicates overheating through a short or grounded circuit. You should, therefore, check the slip ring, brush spring, insulation, and field coil to determine the source of the short or grounded circuit.

Take care when inserting the brushes because they are easily broken. Make sure that they can move freely within the holders once inserted. After you place the brush-holder assembly in position, use an ohmmeter to determine if the terminals have continuity and to ensure that the assembly is not grounded. When the alternator is connected as a B circuit, one brush must be grounded.

Testing Stator The stator should be examined in detail. Begin by checking the stator leads and the point or points where the stator windings are soldered to each other. Check the laminated iron frame and the coils for looseness. If stator windings are discolored, they are short-circuited or grounded, and the stator must be replaced.

To test the stator winding for an open circuit, connect the test probe of an ohmmeter or test light between A and B, between A and C, and between B and C (Fig. 45-31*a*). If the test lamp fails to light during any of these tests, or if the ohmmeter fails to

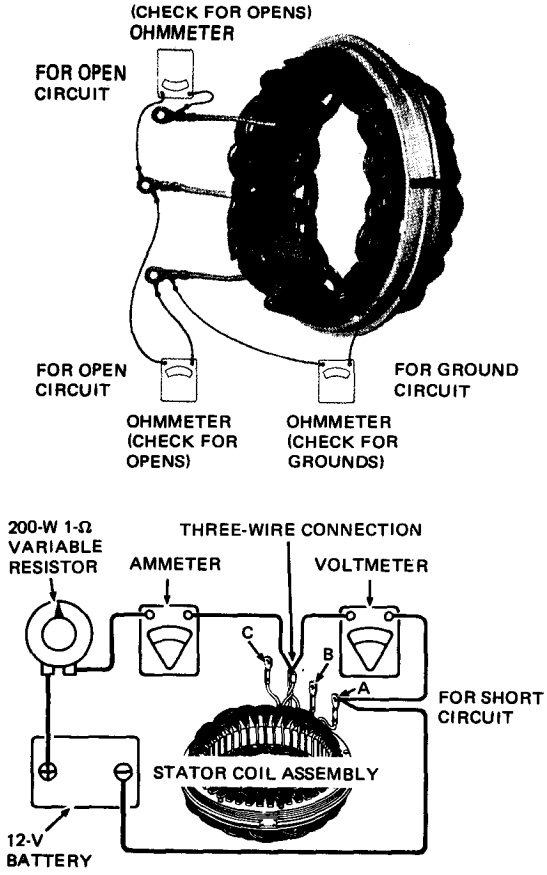


Fig. 45-31 Testing stator winding for short, open, and ground. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

show continuity, there is an open winding. The stator must then be replaced.

To test the stator for a grounded circuit, connect the test probe between A and the iron core, then between B and the iron core, and between C and the iron core. The test lamp should not light and the ohmmeter should show an infinity reading when the stator winding is not grounded.

If the alternator output is low and the above tests have not revealed the problem, there may be a short-circuited stator winding or perhaps a short circuit between two stator windings. Since neither of these defects can readily be detected, you may reassemble the alternator and run it on a test bench.

With the voltmeter, measure the voltage across each phase winding. If the three voltage readings are not essentially the same when the current flow is steady, the trouble is surely in the stator.

A more reliable test is to measure the current flow of each phase winding. Connect the battery and test instruments as shown in Fig. 45-31*b*. Open the variable resistor before making the last battery connection, then by turning the variable resistor knob clockwise, allow a voltage of 2 V to force current through the phase windings. Note and record the current flow. Repeat the test with the remaining two phase windings. The current flow through all phase windings must be within 0.02 of an ampere, otherwise the stator assembly must be replaced.

Testing Diodes To test individual diodes, connect one ohmmeter test probe to the diode lead and the other test probe to the diode case (Fig. 45-32). Take an ohmmeter reading, reverse the test probe, and again take the ohmmeter reading. If both readings are low, the diode is short-circuited, but if both are high, the diode has an open circuit. If one reading shows high resistance and the other low resistance, the diode is reusable.

To test the diodes in the heat sink or in the slip-ring end frame, you must remove the stator winding leads from the diodes (or on some models, the stator winding leads from the rectifier bridge). Remove the capacitor and the rectifier bridge connector to the battery terminal since it is impossible to determine which diode is faulty. For instance, when one diode is grounded, short-circuited, or open, the current of the test light or ohmmeter always follows the path of least resistance, which in this case is through the stator winding and/or through the damaged diode.

Testing Rectifier Bridge Testing a rectifier bridge is similar to testing individual heat sinks. To test the diodes in the grounded heat sink (Fig. 45-32), connect the negative ohmmeter probe to the heat sink body or the ground, and the positive lead to each of the three flat metal connectors (or on some models to the terminals), to ensure good contact. Observe and record the ohmmeter reading. It should show an infinity reading. Next, reverse the ohmmeter connection and touch the negative probe of the ohmmeter to each of the three diode terminals. Observe and record the reading. It should show a low reading. If both ohmmeter readings of one diode are high, one of the diodes is open. If both readings are low, one of the diodes is grounded or short-circuited. If the first reading was infinity and the second reading was low, the diodes in the grounded heat sinks are reusable.

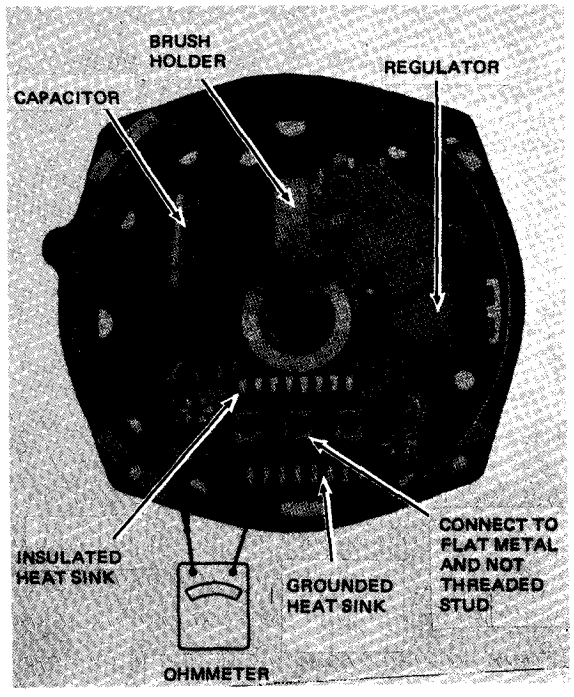


Fig. 45-32 Testing rectifier bridge diodes. *(Delco Remy, Division of General Motors.)*

To test the insulated heat sink side of the rectifier bridge, connect the positive ohmmeter probe to the bridge body or to the grounded heat sink and touch the negative probe to each of the three flat metal connectors or terminals. You should have an infinity ohmmeter reading. Reverse the ohmmeter test probes and then connect the negative probe to the bridge body or to ground, and touch the positive probe to each of the three flat metal connectors or terminals. In all three connections you should obtain a low reading.

PURPOSE AND TESTING OF DIODE TRIO A diode trio is used in conjunction with an integrated voltage regulator circuit. Its purpose is to rectify the current directed to the voltage regulator. *(NOTE: It is a half-sine-wave rectification.)*

There are three diodes within the diode trio (Fig. 45-33). The single long connector is used to connect the diode trio to the voltage regulator and the three short connections are used to connect the diode trio with the three-stator phase windings. To test the diode, connect the negative ohmmeter probe to the long lead (voltage regulator) and touch each stator lead with the positive ohmmeter probe. You should obtain at each stator lead a low-resistance reaction. Next, reverse the ohmmeter probes and with the negative probe touch each stator lead. You should obtain a high reading.

CAUTION When soldering (or unsoldering) the stator lead to the diode, use a pair of pliers as a heat insulator to prevent overheating the diode.

Diode Replacement When you replace a diode, be careful not to damage the heat sink or the new diode. Use special tools manufactured for this purpose.

Support the heat sink and then press the damaged diode out and the new diode in. Never "drive" them in or out as this would damage the heat sink or end frame.

When you replace a diode which is threaded into the heat sink, remember that negative diodes have right-hand threads and positive diodes have left-hand threads.

To make removal of the diode easier, cut the diode leads with a diagonal cutter. Immerse the heat sink in hot water or place it in an oven and heat it to about 150°F [66°C], then remove it. Coat the threads of the new diode with a silicone grease and torque it to specification. The silicone grease and the proper torque ensure a good diode circuit.

Always test the newly installed diode before resoldering. Solder the leads in a position where they do not interfere with the other components. Use a pair of pliers as a heat sink to avoid damaging the diode.

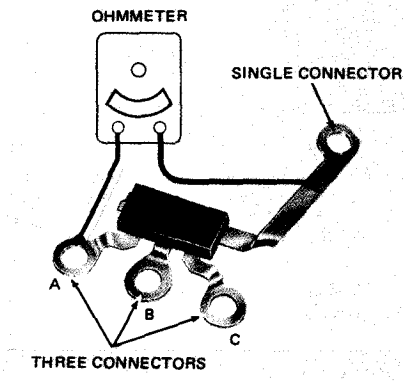


Fig. 45-33 Testing diode trio. *(Delco Remy, Division of General Motors.)*

Reduced Output due to Heat Sink or Rectifier Bridge Failure Any deterioration of the heat sink or components related to the heat sink can affect alternator output. For example, although a broken heat sink does not instantly affect the output of an alternator, it can cause the temperature to rise beyond the limit which is safe for a diode, and, therefore, destroy the diode in the heat sink. Poor or broken insulation between the rectifier bridge and/or the heat sink and the slip-ring end frame can send current partly to ground, reducing the current flow to the battery. The same is true when the battery terminal is partly grounded. An ohmmeter or test light can be used to check the insulator heat sink and battery terminal for a short or grounded circuit and for continuity.

Transit Condenser and Diodes Most alternators have either a condenser (capacitor) or diode to protect the rectification diodes against high transit voltage and to aid in radio noise suppression (Fig. 45-32). These diodes or condensers should, therefore, be checked to prevent either a short circuit or part of the alternator output from going to ground. When the condenser or diode has an open circuit, no current output is lost because there is no circuit to ground.

To test the condenser for series resistance, capacity, and leakage, use a condenser tester as shown in Fig. 45-34. When you test for series resistance, the meter reading should be in the dark bar at the right-hand end of the scale. When you test for leakage, the reading should be in the dark bar at the left-hand end of the scale. To test the capacity of the condenser, take a meter reading and compare it with your specification. It should match the microfarad reading of the test specification.

Reassembling Alternators The following are some points to be noted during assembly and precautions which should be taken before reassembly:

1. Make certain that all components or parts are clean and that the insulators, washers, and grommets are not damaged.
2. Fill the drive-end-frame (rear housing) bearing to the correct level with only the recommended grease.
3. Make certain the lip seal and/or felt seals are placed in the correct position.
4. Use the appropriate adapters to press components or parts into position. When assembling the front housing to the slip-ring end frame (rear housing), hold the brushes by inserting a wire in the hole provided for this purpose.
5. Place the fan and pulley on the shaft after making certain that the blades are not bent or twisted.

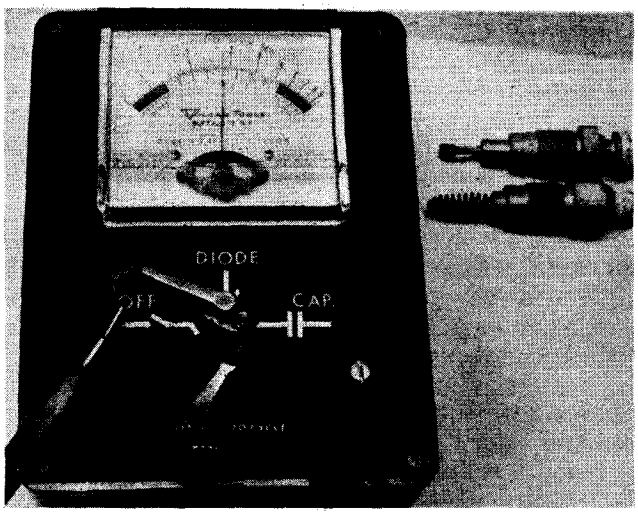


Fig. 45-34 Testing capacitor.

6. Tighten the shaft nut to the recommended torque, using the same procedure for removing the shaft nut.
7. Clean the bearing surface of the rotor shaft on the slip-ring side before sliding the assembly over the rotor and onto the drive end frame.

CAUTION If a lip seal is used, take care not to damage it.

8. Align the housing's reference marks. Install and tighten the thru-bolts but make sure the rotor turns freely.
9. Since the reservoir can be filled with grease before or after assembly, depending on alternator design, it should be checked so that the grease is not forgotten.
10. Remove the wire which holds the brushes away from the slip ring.

After an alternator has been serviced, its performance must be tested. This can be done on an alternator test bench, or after installation, but prior to being connected into the charging circuit.

Questions

1. Describe how the rotor (rotating field) is constructed and how the field is excited.
2. What would a discolored stator core indicate?
3. Explain why a 60-A alternator reaches its limitations of approximately 68 A and 19 V?
4. What is the major difference in the current flow between rectification of a Y and a delta alternator?
5. Why must the stator leads be disconnected from the heat sinks or rectifier bridge before testing the diodes?
6. What is the advantage of having either a delta-wound or Y-wound stator winding?
7. Why is it important to know which diodes are in the insulated heat sink?
8. Why can an alternator be driven in either direction and operate at high speed?
9. Outline the procedure of an alternator output test.
10. What is the difference between an A and a B circuit?
11. Three things which increase the voltage being induced in the stator are: increasing the strength of the magnetic field, increasing the speed of rotor rotation, and (*a*) increasing regulator setting; (*b*) increasing speed of stator rotation; or (*c*) increasing number of conductors in stator.
12. In many alternators, defective field windings require (*a*) stator replacement, (*b*) regulator replacement, or (*c*) rotor replacement.
13. The three components which could affect alternator output are: (*a*) armature, rotor, and transistors; (*b*) stator, field windings, and armature; or (*c*) stator, fields, and diodes.
14. To make an alternator output test of a B circuit (*a*) disconnect the regulator and connect terminal F to the battery terminal with a jumper wire; (*b*) install a new regulator to check the alternator; (*c*) disconnect the regulator and connect terminal F to ground; or (*d*) connect terminal F to ground at the regulator.

UNIT 46 • VOLTAGE REGULATORS AND INTEGRAL CHARGING SYSTEM

VOLTAGE REGULATOR COMPONENTS

To protect the battery and the accessories against high voltage, the alternator voltage must be controlled. This is done by using a voltage regulator which varies the current flow to the field-coil (rotor). Although vibrating points and transistorized regulators may still be in service, they have long been replaced by transistor regulators.

A transistor regulator consists primarily of resistors, capacitors (condensers), diodes, and transistors. It is a completely electronic unit; therefore it is durable and efficient. It safely allows a high field current flow, and it has a longer service life than the vibrating contact regulator. An equally important feature is the ease with which it can be tested, adjusted, and serviced.

Resistors Resistors used in transistor regulators vary in material and shape (Fig. 46-1). Their purpose may be one of the following, or a combination of any or all: (1) to reduce current flow (calculable by Ohm's law), (2) to stabilize voltage, and (3) to reduce voltage

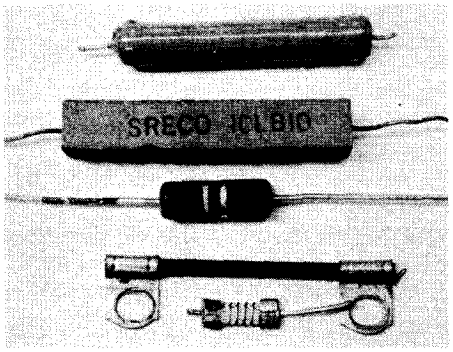


Fig. 46-1 Typical resistors.

(also calculable by Ohm's law). (See Ohm's Law, Unit 37.)

Capacitors Capacitors, also called *condensers,* may be used to store electricity, and/or to equalize system voltage which varies when the transistor is switched on or off (see Fig. 46-2). They are used to assist in switching a transistor on and off and to prevent excessive heat from developing within the transistor.

A capacitor, when placed in a circuit as shown in Fig. 46-3*a*, will receive a charge when the switch is closed. The capacitor voltage will increase from zero to battery voltage, at which time the current flow stops. When the switch is reversed, the capacitor will discharge until all stored energy is dissipated by the resistor (Fig. 46-3). Note the symbols used for resistors and condensers.

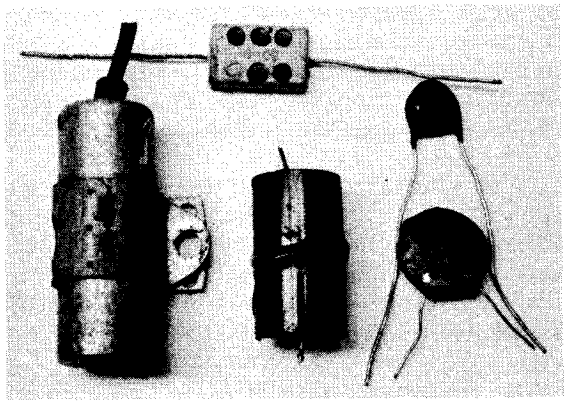


Fig. 46-2 Typical capacitors.

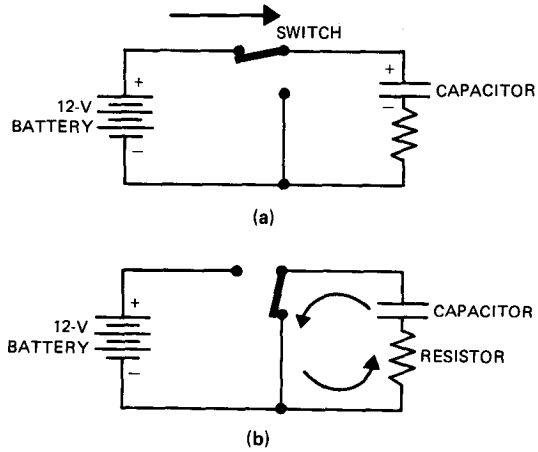


Fig. 46-3 Switch action and current flow of a capacitor when (*a*) charging and (*b*) discharging. *(Delco Remy, Division of General Motors.)*

Zener Diodes A zener diode is a special diode used to switch a transistor on and off. It reacts to a predetermined system voltage. The symbol used to identify the zener diode is shown in Fig. 46-4.

This specially designed diode can safely conduct current flow in reverse bias when the reverse voltage reaches a value of, say, 8 V. When the reverse voltage is below 8 V, the diode will not conduct current. This factor has been made possible by doping the silicon with more atoms having three electrons in their outer orbit when P-type material is required or by doping the silicon with more atoms having five electrons in their outer orbit when N-type material is required. The number of added atoms determines the voltage at which the current can flow. Unlike a conventional diode, this diode will not overheat and destroy itself.

Transistors A transistor is somewhat of a magnetic switch and, at the same time, an amplifier. However, it only allows a larger current flow (from the emitter to collector) when the emitter-to-base circuit is complete.

A transistor is made from a PN or NP junction by fusing one or more P- or N-type materials to it (see Fig. 46-5). The left P or the left N material is called the *emitter;* the N or P material at the right is the *collector.* On larger type transistors, either the case

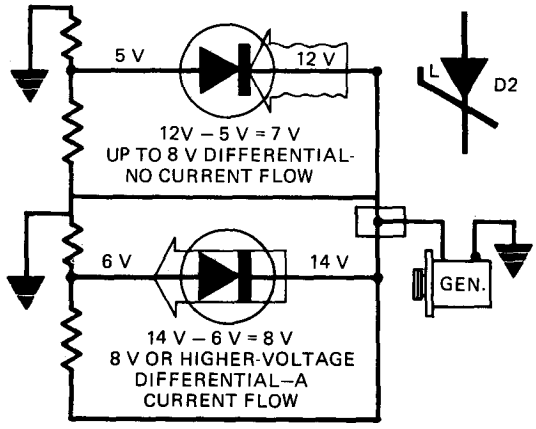


Fig. 46-4 Zener diode symbols. *(Delco Remy, Division of General Motors.)*

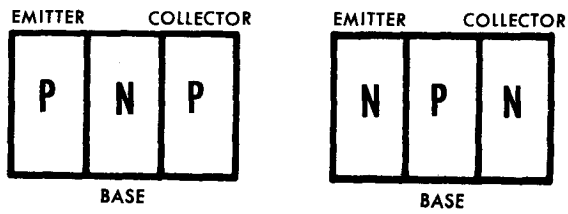


Fig. 46-5 Transistor construction. *(Delco Remy, Division of General Motors.)*

is the emitter (NPN) or the base (PNP) is one connection and the transistor stems are the other two connections.

The smaller transistors have three-wire leads, that is, the base, the emitter, and the collector. The emitter-to-base diode is always in forward bias; the base-to-collector diode is always in reverse bias; the base and collector connections are always to the same system polarity. Both the PNP and NPN transistors perform in essentially the same manner but their polarity is different. *(NOTE: NPN transistors are used in the new voltage regulators.)*

The unusual operating characteristics of a transistor are based on the potential difference between the base and the collector, and the base and the emitter. When the base potential is closer to the collector potential, the ratio of current flow between the emitter-base and the emitter-collector is higher, and the ratio will decrease by moving the base potential toward the emitter. When the emitter and collector potential are equal, there is no current flow.

TRANSISTOR OPERATION When a diode is placed in forward bias into a simplified field circuit, and the circuit is completed by closing the switch (or through a voltage relay or zener diode), field current will flow (Ohm's law) from the positive terminal of the battery, through the field coil, diode, and switch, to the negative terminal of the battery.

When you replace the diode with an NPN transistor, the current flow (indicated by arrows in illustrations) remains the same but something rather unexpected happens (refer to Fig. 46-6*b*): From the illustration you can see that 5 A enter the emitter, 4.8 A leave the collector, and a current of only 0.2 A flows in the emitter-base circuit. The current flow (see arrows) using an NPN transistor is from the base to the emitter and from the collector to the emitter (Fig. 46-6*a*).

The holes created in the emitter by the departing electrons travel directly into the collector because of velocity, and some holes at the emitter-base junction combine with electrons and neutralize. However, the number which combine is quite small because of the potential difference between the emitter-collector and the emitter-base is usually less than 5 percent.

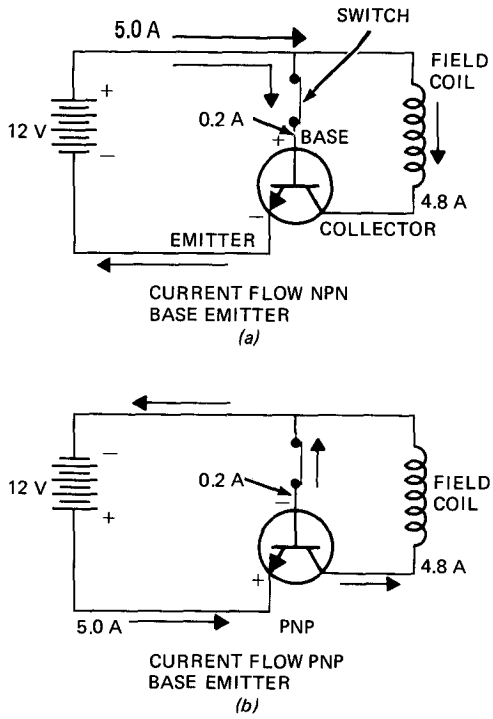


Fig. 46-6 Simplified field coil circuit: (*a*) NPN transistor, (*b*) PNP transistor. (Note symbol and arrow.)

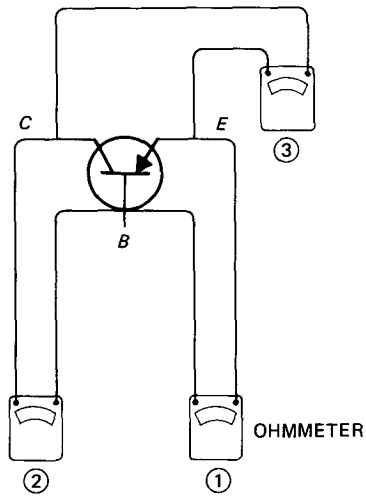


Fig. 46-7 Testing a transistor.

Testing a Transistor Whether a transistor is of an NPN or a PNP design, testing involves two diodes (Fig. 46-7). First, connect one ohmmeter to the emitter and base, observe the reading, and then reverse the ohmmeter probes. (1) You should have one infinity and one low ohmmeter reading. Then connect one ohmmeter probe to the collector and one to the base. Note the reading. Reverse the ohmmeter probes—you should have one infinity and one low reading. (2) Next, connect one ohmmeter probe to the emitter and the other one to the collector. Note the reading, then reverse the probes. You should have, for both test connections, a high resistance reading. *(NOTE: If one reading is only slightly lower than the other, this is acceptable.)* When the transistor tests out as outlined above, it is reusable.

Transistor Regulator Transistor regulators are superior to transistorized regulators as follows: They are solid state (fully electronic) and therefore not sensitive to vibration. They allow precise voltage control since they can switch a transistor on and off as few as 10 times per second or as many as 7000 times per second and thus alter the voltage across the field-coil winding. They can be adjusted quickly and easily. They are protected from external damage and are less affected by heat. Most relevant to mechanics is the fact that they are easy to test and to adjust.

Two types of voltage regulators are used. One has microminiature electronic parts and uses a printed circuit to connect the parts. This regulator cannot be serviced. It must be replaced. The second is a small compact assembly which can be serviced by replacing the defective parts (Figs. 46-17 and 46-18).

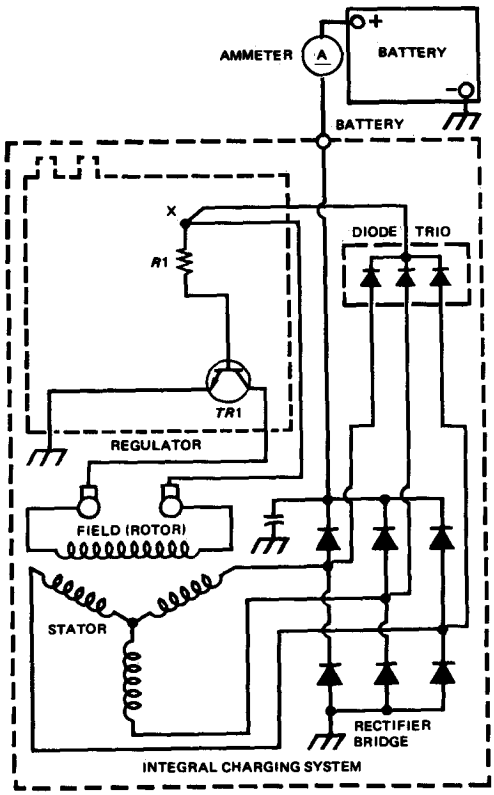


Fig. 46-8 Action when transistor is switched on.

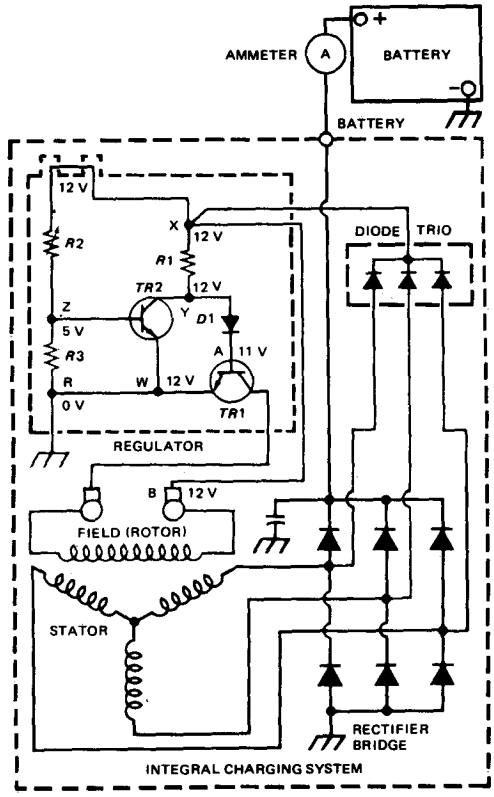


Fig. 46-9 Action when transistor *TR1* is switched off. *(Delco Remy, Division of General Motors.)*

Transistor Regulator Design The basic circuit which connects the battery to the field coil is shown in Fig. 46-8. It consists of the transistor *TR1* and resistor *R1*. The resistor *R1* has a resistance of about 220 Ω and is used to limit the base-emitter current flow. *TR1* is used to switch the field current on or off.

When the rotor is rotated, maximum field current (which depends on the resistance of the field coil and the applied voltage) flows from the stator winding, through the diode trio, where it is rectified, through the resistor *R1*, through the base-emitter of *TR1*, then to ground and to each of the stator windings. Current also flows from junction X over the right-hand brush and slip ring, through the field coil, slip ring, and brush, through the emitter-collector, then to ground and back to the stator windings.

To switch off *TR1* and thereby stop the field current flow, transistor *TR2*, two resistors *R2* and *R3*, and a diode *D1* are placed into the circuit as shown in Fig. 46-9. The base of *TR2* is connected to Z. The collector is connected to junction W and the emitter to junction Y. *TR2* is used to open and close the base circuit of *TR1*. The two resistors are used to reduce the voltage potential at junction Z. Diode *D1* is placed between the junction Y and the base of *TR1*. It prevents a reverse current flow and reduces the base-emitter voltage by about 1 V. As the alternator output voltage increases (say to 12 V), this voltage increase also occurs at junctions Y and W (when disregarding the voltage drop through the resistor *R1*). However, at points *A* and *B* the voltage is only 11 V when nullifying the resistance of *TR1*, and at point *Z* it is only 5 V because of the voltage drop caused by resistor *R2*. As a result: (1) the emitter-base and (2) the emitter-collector circuit of *TR2* are completed to ground. (3) This induces 12 V at junction W. (4) With the higher voltage present at point *W*, the base-emitter circuit of *TR1* is in reverse bias and therefore causes *TR1* to switch off.

To switch *TR1* on again to produce a field current flow, a zener diode *D2* is placed into the emitter-base circuit of *TR2* (Fig. 46-10). If the zener diode breakdown voltage is 8 V, it will not conduct current when the output voltage is at or below 14 V because there is 14 V at junction Y opposing 6 V from junction Z (base). This causes a voltage potential of 8 V at point *Z*. Transistor *TR2* then switches off, *TR1* switches on, and current flows in the base-emitter circuit of *TR1* since there is now 0 V at junction W. Current again flows through the field winding.

To switch *TR1* off again, the voltage output must be increased to at least 14.1 V. As the alternator voltage increases it also occurs at point *B* and at junctions Y and W. The voltage at junction Z is then 6.05 V and at point *C* 8.05 V. With 8.05 V at point *C*, the zener diode conducts current, causing *TR2* to switch on and *TR1* to switch off, decreasing the charging voltage. As soon as the charging voltage reaches 14 V, *TR2* switches off and *TR1* switches on because 8 V are present at point *C*, thus preventing the zener diode from conducting current. As stated previously, the switching cycle may be as few as 10 times per second or as many as 7000 times per second to maintain a charging voltage of 14.1 V.

To protect the transistor against high inductive current flow from switches, solenoids, or the induced voltage of the field coil when the transistor is switched off, diode *D3* is placed in the regulator circuit (Fig.

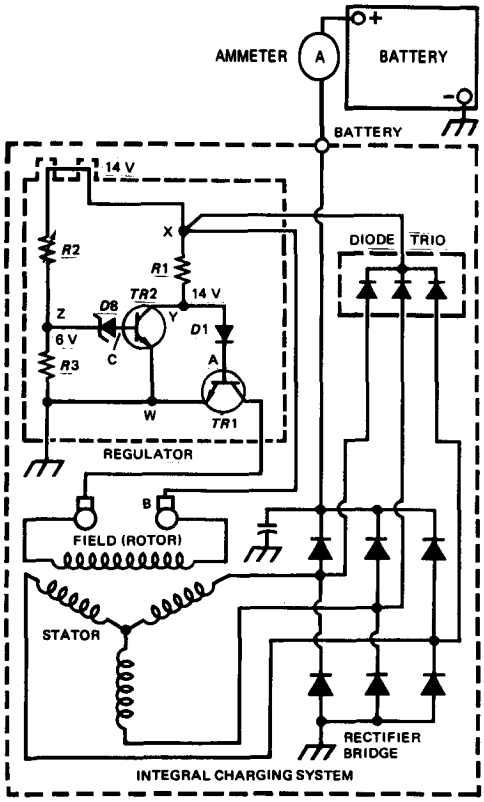


Fig. 46-10 Zener diode inserted. *(Delco Remy, Division of General Motors.)*

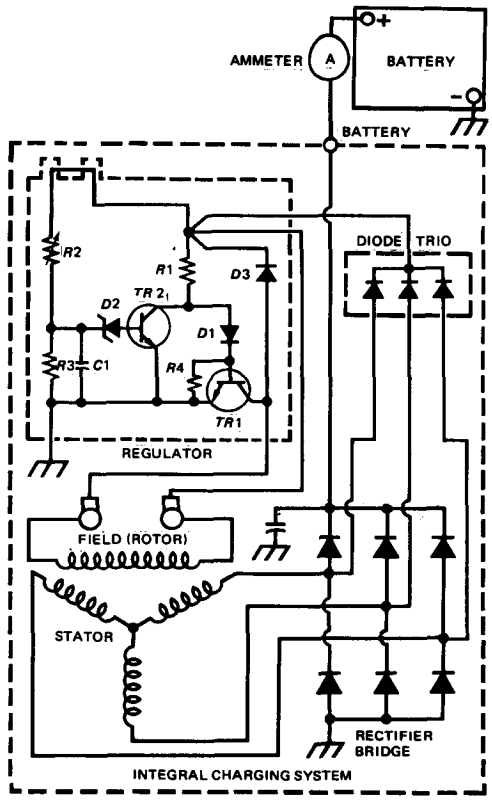


Fig. 46-11 Added components to protect the regulator. *(Delco Remy, Division of General Motors.)*

46-11). Diode *D*3 diverts the inductive current created by the reverse induced voltage back to the field coil over the diode trio, rectifier bridge, and stator windings, to ground, thereby protecting the transistor.

Since the charging voltage increases (because the resistance decreases) as the temperature under the hood exceeds approximately 80°F [26.6°C], it is essential to reduce the charging voltage in order to protect the battery against overcharging. It is equally important to increase the voltage when the temperature drops below 80°F [26.6°C] to prevent it from undercharging. The special resistor *R*2 is constructed to increase in resistance with an increase in temperature, thereby reducing the potential voltage at the junction Z. This allows the zener diode to conduct current at a slightly lower voltage, thereby lowering the charging voltage to about 13.7 V. Resistor *R*4 is used to prevent the occurrence of small current leakage through the emitter-collector of *TR*1 due to high temperature. The filter capacitor *C*1 is used to stabilize the system voltage of *R*3 as the voltage varies from maximum to nearly zero while the transistor *TR*1 is switched on and off.

Indicator Lamp Circuit Alternators which are used on farm tractors and on smaller motortrucks may use an indicator lamp circuit instead of an ammeter. It is also called a *three-wire system* (see Fig. 46-12). Terminal No. 1 of the voltage regulator is connected over the parallel indicator lamp and resistor to the ignition switch. The parallel connection reduces the total resistance to allow a higher field current flow as this causes a quicker voltage buildup when the switch is turned on to start the engine.

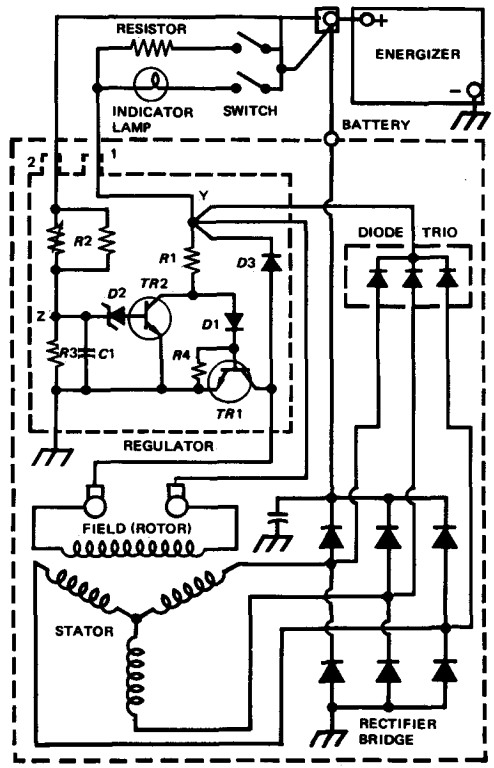


Fig. 46-12 Alternator circuit using an indicator light. *(Delco Remy, Division of General Motors.)*

Current flows from the battery through the switch, the resistor, and light indicator to No. 1 terminal and onto junction Y. From this point on, the current flow through the field coil and voltage control is the same as outlined above under Transistor Regulator Design.

No. 2 terminal is directly connected to the battery at all times to relay battery voltage to point Z in order to achieve precise voltage control. *[NOTE: Because of the high resistance in* R2 *and* R3*, the current drain (when the engine is not operating) is minute.].* When the rotor is rotating and the alternator voltage output exceeds that of the battery open voltage, this additional voltage is also present at the left- and right-hand sides of the ignition switch and causes the indicator light to go out. If the voltage output reduces below the battery potential, the light will glow again because the voltage at the left-hand side of the ignition switch is then lower than on the right-hand side.

Adjustable Voltage Regulator Alternators with an output of around 100 A may use a regulator having an external adjustment to vary the maximum output voltage. These alternator stators can be in a Y connection or, as shown in Fig. 46-13, in a delta connection. When the latter stator connection is used, only a single connection from the diode trio to the field coil is made and the protection diode *D2* is in parallel with the field-coil windings. Battery voltage is relayed onto junction X and onto the series resistors 5, 6, 2, and 3. The voltage-regulating device consists of two resistors placed between the junction X and junction C and in series with *R2* and *R3*. A movable contact arm is positioned over the two resistors. The arm can be placed externally with a screwdriver in three different positions. As shown in Fig. 46-13, no additional resistance is added to the series circuit and the output voltage may reach 14.4 V. When the arm is placed in the No. 2 position, one resistor is added to the series circuit, lowering the potential at junction Z and the output voltage is reduced to, say, 14.2 V. When the arm is placed in position No. 3, two resistors are added, thus reducing the potential at junction Z even more, to cause an output voltage perhaps as low as 14 V. *(NOTE: The two parallel resistors* R2 *react in the same way as the temperature-sensitive resistor* R2 *in Fig. 46-10.)*

Newer designed alternators which have an R terminal use the terminal to supply half-system voltage (7 V) for a 12-V system to the electronic tachometer and/or hourmeter. The current flow and voltage control is the same as previously outlined above under Transistor Regulator Design.

Brushless Alternators To cope with the higher current demand placed on today's alternators, manufacturers have designed alternators without the conventional (slip ring and brushes) field current connection. They are commonly called *brushless-type alternators.* All their rotating and nonrotating components, including the bearings, are larger in size. The voltage regulator is within the alternator and part of the alternator circuit's integral charging system. One of the many brushless alternators is shown in Fig. 46-14*a* and *b*. It has an output of 140 A for a 12-V system and an 80-A output for a 24-V system. It is totally sealed because it uses engine oil as its cooling medium. Oil enters near the rectifier bridge area, and flows there through a small hole in the rear housing to the rotor and stator compartment. From there it drains back into the engine return oil gallery. The regulator compartment is not separately sealed since no damage will occur should some oil get onto the regulator parts. As mentioned previously, high-output alternators have the delta connection.

Some of the differences between the alternator shown in Fig. 45-5 and the brushless alternator shown in Fig. 46-14 are: The brushless alternator is oil-cooled and has no slip ring; its rotor is permanently magnetized; its field coil is fastened to the rear housing and extends into the bore of the rotor; its voltage regulator internal component connections have changed slightly; and resistors, capacitors, diodes are additional features (Fig. 46-14*b*).

NOTE: TR1 *in Fig. 46-14 is a special transistor allowing a high current flow; resistor* R2 *is a potentiometer (small variable resistor). Also note that battery voltage is always present at junctions A, B, and D. The current drain through the series resistors* R1 *and parallel resistors* R2 *and* R3 *is minute because of the high resistance.*

The brush and brushless alternators operate in the same manner to produce current except that the

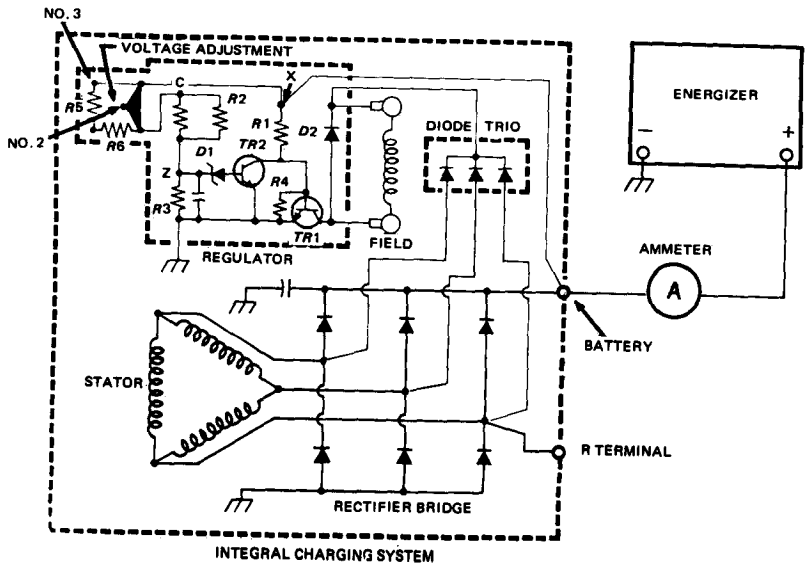


Fig. 46-13 Integral charging system circuit. *(Delco Remy, Division of General Motors.)*

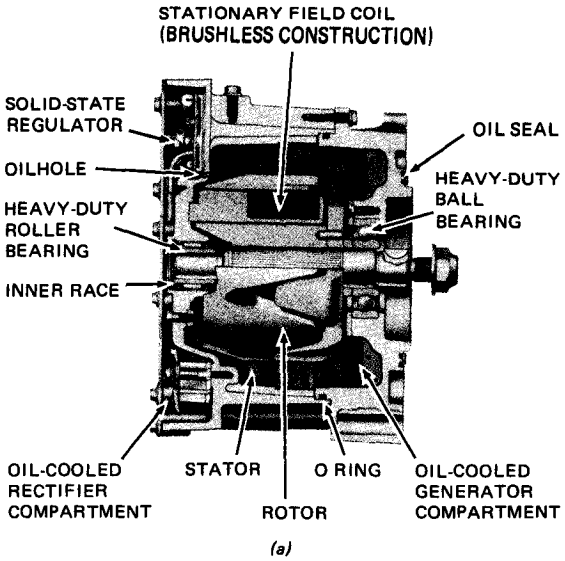


Fig. 46-14 (*a*) Sectional view of a brushless alternator using engine oil as its coolant media; (*b*) wiring diagram of the alternator. *(Delco Remy, Division of General Motors.)*

brushless alternator has only one rotating part, which is the rotor.

Voltage Regulator Design and Regulation When the engine is operating (Fig. 46-14*b*), current flows from the stator windings over the rectifying bridge, over junction E to the positive post of the battery, through the battery, and then from its negative post back through the rectifier bridge to the stator windings. The field current flows from junction E to junction A, through resistor *R*6 to the emitter-base of *TR*1, to ground. (Ground means the stator windings.) Current also flows from the stator windings, through the diode trio, to junction F, through resistor *R*8, and to the base-emitter of *TR*1 to ground. The combined voltage switches on *TR*1 and field current flows from junction F through the field coil and the emitter-collector of *TR*1 to ground. At the same time current also flows from junction D to the capacitor *C*1 (charging it), and through resistors *R*1, *R*2, and *R*3 to ground. This places a voltage of about 5 V at junction G. As the alternator output voltage increases and as the voltage at junction H reaches 8.05 V, the zener diode *D*4 conducts current, and the emitter-base current is completed through the zener diode *D*4 and resistors *R*2 and *R*3 to ground. Now the base-emitter circuit of *TR*1 becomes reverse bias (remember, diode *D*5 reduces the voltage) and the transistor *TR*1 switches off, reducing the output voltage. As the output voltage at point *H* reaches 8 V, zener diode *D*4 blocks the current flow, which causes *TR*2 to switch off and *TR*1 to switch on again.

Capacitor *C*1 is used to protect the rectifier diode from high transient voltage and surpresses radio interference. Resistor *R*5 prevents current leakage through *TR*2 at high temperatures. Diode *D*5 is used to reduce the voltage and to prevent high transit voltage from the field coil from flowing to *TR*1 when the field current is stopped. Resistor *R*7, capacitor *C*3, and resistor *R*4 are used to switch the transistor *TR*1 and *TR*2 on and off more quickly.

Testing the Integral Charging System The majority of charging system problems are made known to the operator by the engine's slow cranking speed or by overcharged batteries. To locate the malfunction, you should first make a few basic (but often overlooked) checks. Check tension on the drive belt(s) and the pulley(s) for their overall condition. Check and test the batteries and if necessary charge them. Measure the open voltage and voltage drop of the battery connections and the voltage drop at the ammeter, key switch, and fuel and/or the oil pressure switch. Do not overlook testing the ground circuit between the integrated charging system and the batteries.

If these checks prove negative, there is obviously a more complex problem to be resolved. Several approaches will be pursued in the next few paragraphs, but first you should be cautioned not to inadvertently incur additional malfunctions. For instance, take care while testing or checking not to polarize the alternator. Do not short across or ground any alternator terminal. Do not operate the alternator without the connecting wires or the test instruments fastened to the terminals. Do not reverse the battery polarity. Both the alternators and the batteries must have equal polarity. (This also holds true when using booster batteries to aid starting.)

Assume you have a charging system using two- or three-wire connections (excluding the R terminal; see Figs. 46-11 through 46-13). Assume also that the alternator produces a low ampere output or that the voltage is low or the indicator light is not working satisfactorily. Under these circumstances, when the indicator light is not glowing with the key switch at the "on" position (engine not operating), check for the following: a burned out lamp bulb, high resistance between lamp and socket, broken No. 1 wire, high contact resistance at the alternator No. 1 terminal, key switch or circuit breaker, or a damaged circuit breaker. Use a voltmeter to check the voltage and voltage drop, or simply remove No. 1 terminal from the alternator and momentarily touch a ground. This will cause the lamp to glow if the indicator lamp and circuit are in satisfactory condition.

If the indicator lamp glows with the key switch in the "off" position, there may be a short circuit between the No. 1 and No. 2 terminals. Check the ter-

minals and the wire-end insulation. If the indicator lamp glows but goes out as you remove the No. 1 wire from the alternator, the problem is in the rectifier bridge and it must be replaced.

Next, turn the key switch to the "on" position but do not start the engine. If applicable, use a jumper wire to bridge the fuel or oil pressure switch. Proceed as follows: (1) Connect the positive voltmeter lead to No. 1 terminal and the negative voltmeter lead to ground; (2) Connect the positive voltmeter lead to No. 2 terminal and the negative lead to ground; (3) connect the positive voltmeter lead to the BAT. terminal of the alternator and the negative lead to ground. All three voltmeter readings should be equal to the open battery (or batteries') voltage. If the readings do not coincide, locate the excessive resistance by using a voltmeter to measure the voltage drop at the various circuit connections and switches.

If the problem has not yet been resolved, then proceed further by connecting the positive lead of the voltmeter to the alternator's battery terminal and the negative lead to ground. Start the engine and operate it at half-throttle. Turn on all accessory circuits and observe the voltmeter reading. If the voltmeter exceeds 15 V in a 12-V system, 30 V in a 24-V system, or 39 V in a 32-V system, no further tests should be made because the output voltage is too high and the alternator or voltage regulator is defective.

On the other hand, if the voltage is below the recommended operating range (see Table 46-1) increase the engine rpm to high idle. If this does not increase the voltage, then it is possible that the batteries need to be recharged, that the voltage is adjusted too low, or that the alternator is defective.

However, if the voltage reading shows zero, there may be an open circuit within the alternator, a damaged voltage regulator, burned-out field coils or stator windings, or a burned-out rectifier bridge. The diode trio may be damaged or the rotor demagnetized. If the alternator is of the slip-ring design, the zero reading may be due to broken, damaged, or shorted brushes, or to damaged slip rings. In each of the above cases, the alternator must be serviced and repaired.

Assume that the voltage is low, but the checks previously outlined proved to be satisfactory. You might then disconnect the battery ground cable and connect the test instruments and battery as shown in Fig. 46-15. *(NOTE: These connections are applicable to all integral charging systems, with additional connections for systems with two- and three-wire connections.)*

Operate the engine at half-throttle to stabilize the temperature of the charging system components and then operate it at high idle. Turn the carbon pile knob clockwise to increase resistance so that maximum

TABLE 46-1

System voltage, V	Rated voltage, V	Operating rating, V
12	14.0	13.0–15.0
24	28.0	26.0–30.0
32	37.5	33.0–39.0

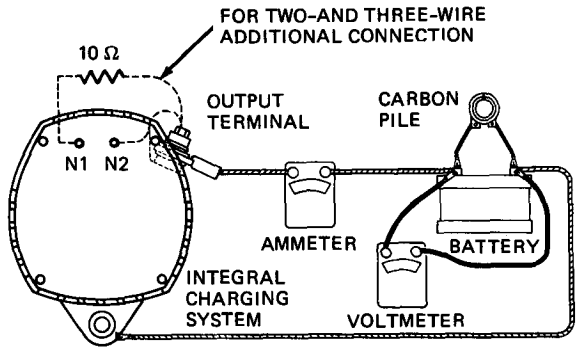


Fig. 46-15 Alternator test connection. *(Delco Remy, Division of General Motors.)*

alternator ampere output is achieved. Meanwhile, note the ammeter reading. If the amperage reading is at rated output (or within 10 A of it), the alternator performance is satisfactory. If the voltage at this stage is low, say 12.9 V, and the batteries of the motor vehicle or truck-tractor are low in charge, adjust the voltage regulator and increase the voltage by 0.2 V.

If the alternator is designed with the ability to ground the field coil, you may, at this point, insert a small screwdriver into the slot in the rear housing so that it contacts a small tap on the brush holder. This grounds one field coil end and takes the regulator out of the circuit. The maximum field current will then flow through the field-coil winding and the alternator will produce maximum output (which is about 10 percent above rated amperage and voltage).

To adjust the output voltage of an oil-cooled alternator, stop the engine and hold a drain can below the alternator end cover. After the oil has drained into the can, remove the cover and then, with a screwdriver, turn the potentiometer screw 10° clockwise to raise the voltage, or 10° counterclockwise to lower it. Place a new gasket between the rear housing and cover. Insert and tighten the cover screws and repeat the test. (See material earlier in this unit on voltage adjustment for another adjustment method.)

Integral Charging System Service When the alternator does not perform within the specification range, remove it from the motor vehicle. Follow the removal procedures outlined in the service manual and take all the necessary precautionary measures. After the alternator is removed, thoroughly clean its external surface and then remove the end cover (or the rear housing). The system will appear similar to those illustrated in Figs. 46-16 and 46-17. You are now ready to make the first test. Connect one ohmmeter probe to the single diode trio lead and the other probe to ground. The ohmmeter should show an infinity reading. If this is not the case, the diode trio is grounded. On alternators using brushes, test the brush holder for ground by connecting one ohmmeter probe to ground and the other to the brush holder. The ohmmeter should show an infinity reading and if it does not the voltage regulator is grounded probably because the insulators located on the screws which hold the regulator to the front housing are broken or otherwise damaged. Next, remove the three stator

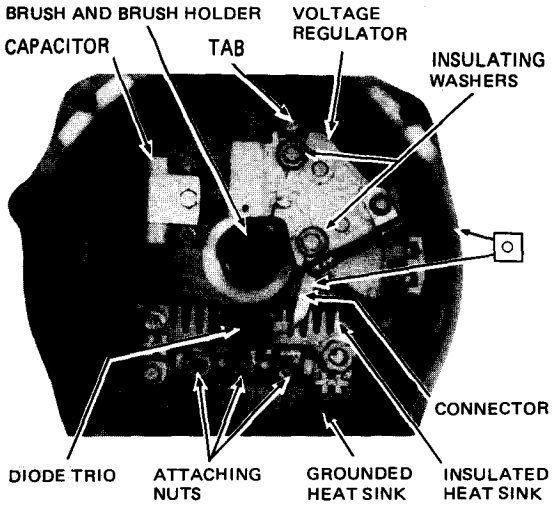


Fig. 46-16 View onto rear of alternator, end cover removed. *(Delco Remy, Division of General Motors.)*

leads, the diode trio, the output terminal connection, the R terminal connection, and the field connection from the rectifier bridge. Remove the field leads from the voltage regulator (Fig. 46-17). If applicable, remove the capacitor and then test the stator coil windings, the diode trio, and the capacitor, as previously outlined.

To check the field-coil resistance, connect the ohmmeter as shown in Fig. 46-17*a*, and compare the resistance indicated on the ohmmeter against the manual specifications. If the ohmmeter reading is lower than specified, the field coil has a short. If the ohmmeter reads zero, the field coil is grounded. If the ohmmeter reads infinity, the field coil has an open circuit. To verify a grounded field coil, connect the ohmmeter as shown in Fig. 46-17*b*. When the field coil is grounded, the ohmmeter reads zero, and if not grounded the ohmmeter needle is in the infinity position.

To check the insulated battery and R terminal, connect one ohmmeter probe to the battery terminal lead and the other to ground. The ohmmeter should indicate an infinity reading. If it does not, the terminal insulation is damaged and therefore grounding the terminal bolt. Repeat this test procedure to check the R terminal but connect one probe to the R terminal instead of the terminal battery lead.

Voltage Regulator Service As a rule voltage regulators cause very little charging trouble but there are occasions during servicing of other components when the regulator is inadvertently damaged. For instance, when a terminal is grounded, the battery polarity reversed, and ac welding is done on the motor vehicle without removing battery connections, the voltage regulator, resistor, diodes, or transistor may burn out. This condition will be noticeable by discoloration of the burned-out parts, by loose solder, or by printed circuit damage.

To check the voltage regulator components, remove the screws and then lift the regulator from the

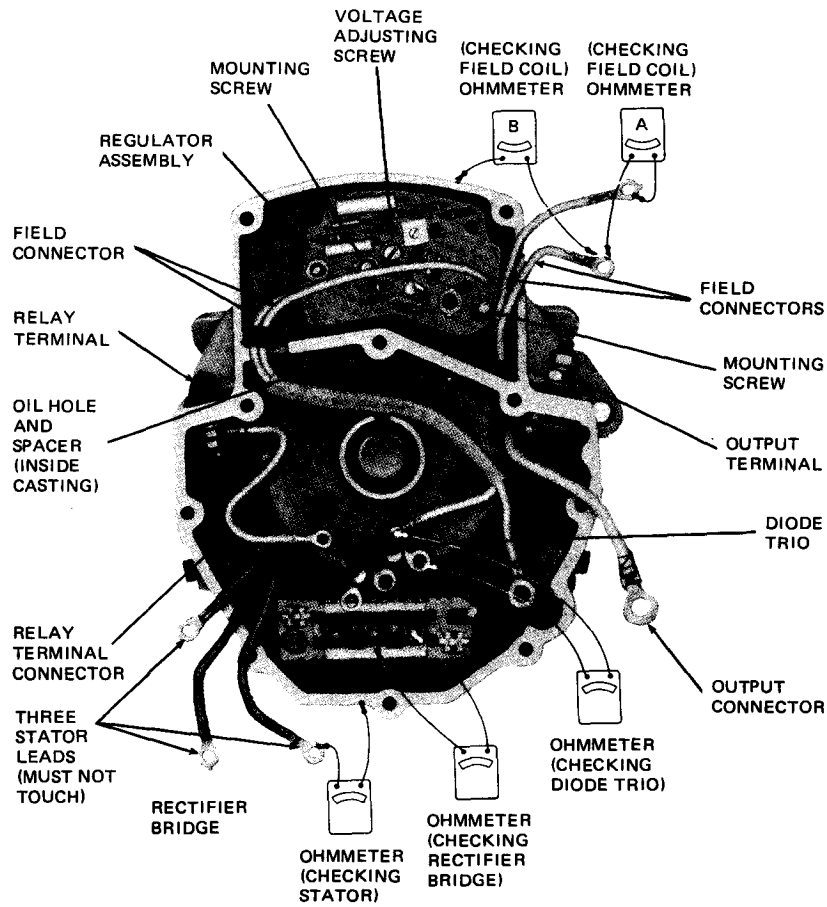


Fig. 46-17 View onto rear of alternator, end cover removed. *(Delco Remy, Division of General Motors.)*

front alternator housing. After the sealing compound is removed, the front and rear views will be similar to those shown in Fig. 46-18. *(NOTE: The various color rings around the resistor are used to identify the resistance in ohms.)*

Because of the interaction of the resistor, capacitors, diodes, and transistors, only certain components become defective because they are exposed to a high reverse polarity. They are *TR*1 and *TR*2, resistor *R*2, capacitor 2, and diode 5.

Start the regulator examination by checking for a broken or interrupted printed circuit, or discolored components. If the damage is severe, it is advisable to replace the regulator. If not, remove the screw from *TR*1 and with a screwdriver pry it loose from the panel board, then use an ohmmeter to test *TR*1, *TR*2, and diode 5. *(NOTE: You must scratch fairly hard with the ohmmeter probe to break through the transparent coating which is applied to all exposed metal on the regulator.)* Next, connect the ohmmeter as shown to *R*2 and then turn the adjusting screw clockwise and counterclockwise. The ohmmeter reading should change if resistor *R*2 is in good condition. Next, connect the ohmmeter to capacitor 2. Note the resistance, then reverse the ohmmeter lead and again note the resistance. You should have one infinity and one low ohmmeter reading if the capacitor is in good condition. When no defective components have been found, test the remaining resistors. Use the color chart to determine their resistance value. Next, check *C*1 and *C*2 and diode 4. If no defects are found, replace the regulator. To replace defective components, use a 50-W soldering gun but make certain when resoldering that no solder flows to the adjacent printed circuit.

When the regulator is repaired, install *TR*1, place silicone grease on both sides of the mica, and then push *TR*1 into the panel board holes and install its hold-down screw. Apply a silicone rubber sealing compound around the components to secure them, vibrationproof, to the panel board. Reinstall the regulator, complete the alternator assembly, and retest and adjust the voltage.

CAUTION When bench-testing an oil-cooled alternator, it should not be operated for more than 6 seconds at maximum output; otherwise it could self-distruct.

Remagnetizing a Rotor When a brushless alternator is disassembled, the rotor is often demagnetized in the process and consequently it must be remagnetized. To remagnetize the rotor, connect a jumper wire to the battery terminal and momentarily touch the R terminal. This causes a current flow through the regulator and field coil to ground and magnetizes the pole pieces to their correct polarity

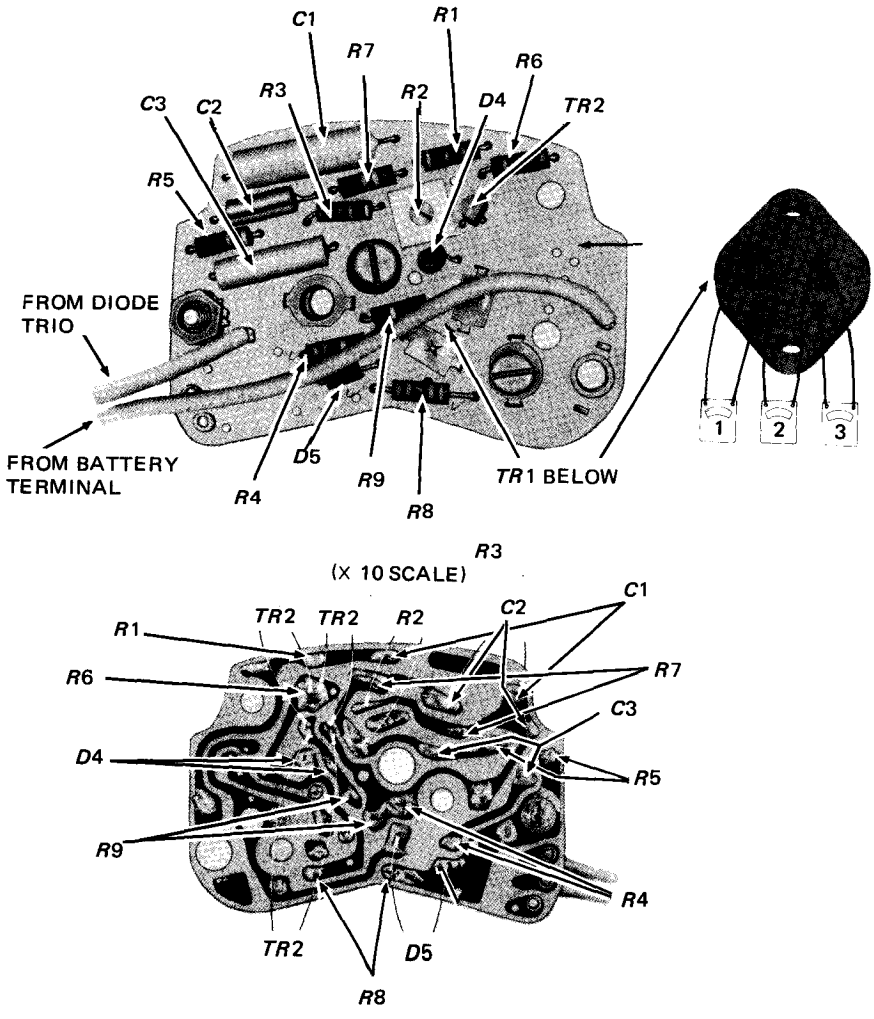


Fig. 46-18 Testing voltage regulator. *(Delco Remy, Division of General Motors.)*

Alternators Using Remote-mounted Regulators Alternators with an output of 150 A or more are commonly mounted directly to the engine and the voltage regulator is externally mounted. Direct mounting is necessary because they require a driving power of 3 or 4 kW and this power load would be difficult to carry over drive belts. The reason the alternator is mounted separately is that the operating temperature of the alternator is around 200°F [93.3°C] and the voltage regulator does not perform satisfactorily at this temperature. The alternators are usually of the brushless A-type design and their stators are connected either Y or delta.

The remote-mounted voltage regulator uses the basic components and circuit connections shown in Fig. 46-14. However, to protect the system and the voltage regulator against high voltage, one zener diode, several resistors, and a fuse are added. To aid heat dissipation, the voltage regulator housing is made with external cooling fins. *(NOTE: The testing procedure for this type of alternator is the same as that outlined for testing an A circuit alternator; see Alternator Testing Prior to Removal, Unit 45.)*

12/24-V Charging Systems As mentioned, the cylinder displacement of diesel engines has increased continuously over the years and more starting power is therefore required. The increased power has been achieved by using a 24-V cranking motor and a series-parallel switch so that the accessory circuits can operate on 12 V. Unfortunately, the series-parallel switch has a limited capacity to carry the very high current flow, which makes it less durable and shortens its service life. As a result manufacturers have designed transformer rectifiers (TR units) and have slightly modified their alternators so that the TR unit can be bolted to the alternator (see Fig. 46-19). The combined assembly, as a unit, provides an output of 12 V from the alternator and 24 V from the TR unit to charge battery C.

The TR unit consists of delta-connected primary

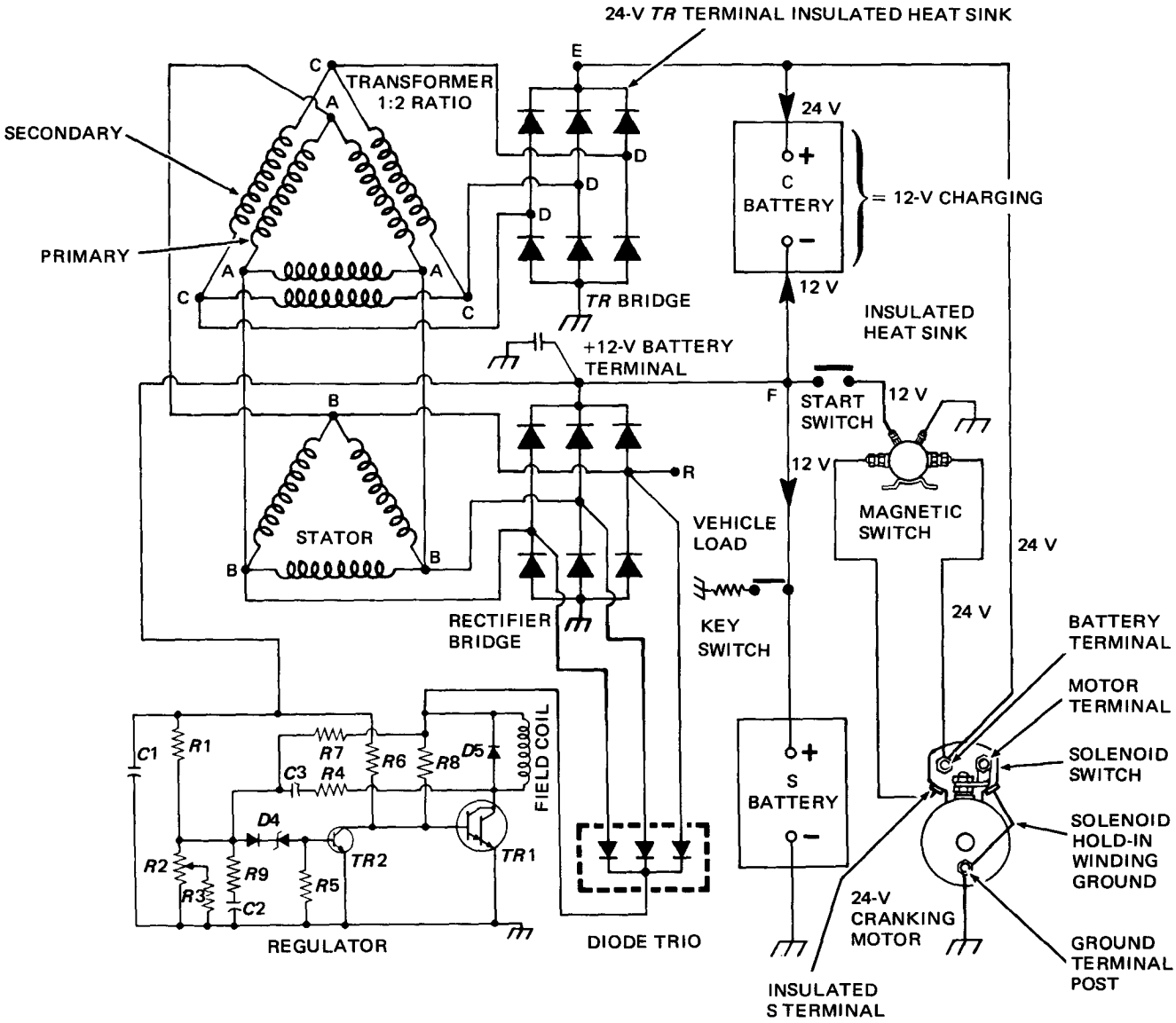


Fig. 46-19 Wiring diagram of an alternator with a *TR* unit and its cranking-motor circuit. *(Delco Remy, Division of General Motors.)*

and delta-connected secondary windings and a rectifier bridge. The transformer ratio is 1:2.

The primary windings are connected to each other at junction A and then to the stator windings at junction B. The secondary transformer windings are connected to each other at junction C and then to one pair (positive and negative) of diodes on the rectifier bridge at junction D. The insulated TR heat sink is connected to the 24-V terminal E and then to the positive battery post of battery C and to the battery terminal of the solenoid switch. The alternator's insulated heat sink is connected to the insulated battery terminal of the alternator and then to junction F, to the battery's C negative post, and to the battery's S positive post.

CRANKING OPERATION To start the engine, the operator closes the start switch, forcing 12 V from battery S through the magnetic switch pull-in winding, closing the cranking-motor actuating circuit. The current for the solenoid switch circuit and for cranking flows from the positive post of battery C to the battery terminal on the solenoid switch, to and over the magnetic switch disk to insulated terminal S, and through the pull-in and hold-in windings to ground. This action energizes the solenoid and the disk bridges, the battery, and the motor terminals of the solenoid switch. The current then flows from the battery terminal over the disk to the motor terminal, through the field and armature windings to the insulated ground terminal post, to ground, and into the negative post of battery S.

CHARGING OPERATION When the engine is operating, current from the 12-V alternator terminal enters the positive battery post of battery S, leaves its negative post, re-enters the alternator, and returns to the stator windings. At the same time, current from the stator windings (point *B*) enters the primary windings at point *A*, causing an ac current to flow within the primary windings. The changing ac current flow creates a changing magnetic field and with every magnetic field change in the primary coil windings the magnetic lines of force cross the secondary coil windings. This induces a voltage into the secondary coil windings and creates an ac current flow.

The ac current from junction C is directed to junction D of the rectifier bridge, where it is rectified and directed to the 24-V terminal, charging the C battery. The voltage regulator senses the cemf of battery S and regulates the voltage between 13.9 and 14.2 V.

Because there are twice as many coil loops in the secondary windings as there are in the primary windings, the voltage is doubled and the current is reduced by half. For example, if the regulated voltage is 14 V then the secondary voltage is 28 V. However, when transforming to a higher voltage (in this case double), the current is reduced by half. For instance, say maximum alternator output is 80 A, then 40 A is directed to the TR unit and 40 A is directed to the 12-V alternator terminal. The 24-V terminal would therefore have a maximum of 20 A. This figure would be true if the current flow in the TR unit did not have to encounter resistance and also current loss due to transforming.

12/24-V Charging System Service When either battery is overcharged or undercharged, check and test the batteries, the battery cables, and the wire connections. Do not forget to check the drive belt tensions. If this does not resolve the problem, check the output voltage at the 12- and 24-V terminals as you would test the voltage of a conventional alternator. If the output voltages are above or below specified operating range, remove the battery ground cable and then remove the TR unit. Remove the attaching screw and pull the TR unit slightly away from the rear housing so that you can remove the primary transformer lead connections from the alternator rectifier bridge. (Retighten the nuts.) After the TR unit is removed, the alternator becomes a conventional alternator and is to be tested, checked, and serviced as previously outlined. When the alternator is serviced and tested, and the voltage adjusted, but no defects are found, you must then test the TR unit. To check the rectifier bridge of the TR unit, first remove the secondary transformer leads from the rectifier bridge and then test the rectifier bridge (see A, Fig. 46-20). If the bridge is in satisfactory operating condition, next check the secondary and primary transformer coils for ground and for a short circuit. *(NOTE: An open circuit cannot be tested with an ohmmeter because the coils are delta-connected.)*

To check the primary transformer coils for ground, connect one ohmmeter probe to ground and the other probe to each one of the three terminals (see B, Fig. 46-20). Each test should show an infinity reading. In the same manner test the secondary transformer coils. Once again each test connection should show an infinity reading (see D, Fig. 46-20).

To check for a short circuit in the transformer coils, connect the ohmmeter probe to one primary and one secondary transformer end (see C, Fig. 46-20). If there is no short, the ohmmeter will indicate an infinity reading.

If the malfunction has not yet been found, install the TR unit to the alternator and make the following connections: Connect (1) an ammeter in series with the 24-V TR terminal, (2) a voltmeter to the 12- and 24-V terminals and to ground, and (3) a carbon pile across battery C. Start the engine, warm up the charging components, and then perform an alternator output test. The voltage at the 24-V terminal should be twice that of the 12-V terminal, and the ammeter should not show less than 5 A, nor should it exceed one-quarter of the maximum alternator ampere rating. If any of these connections result in a discrepancy reading, you may assume that one or more of the secondary and/or the primary transformer coils have a short and the transformer assembly must be replaced.

Installing Alternators Before you install an alternator, check the drive and driven sheaves (pulleys). *(NOTE: The drive belts are matched sets. Do not replace only one belt, replace them as a set.)* Make certain the battery ground cable is disconnected when installing the alternator. Always use the correct washers and bolts so that the alternator fits snugly to its mounting brackets.

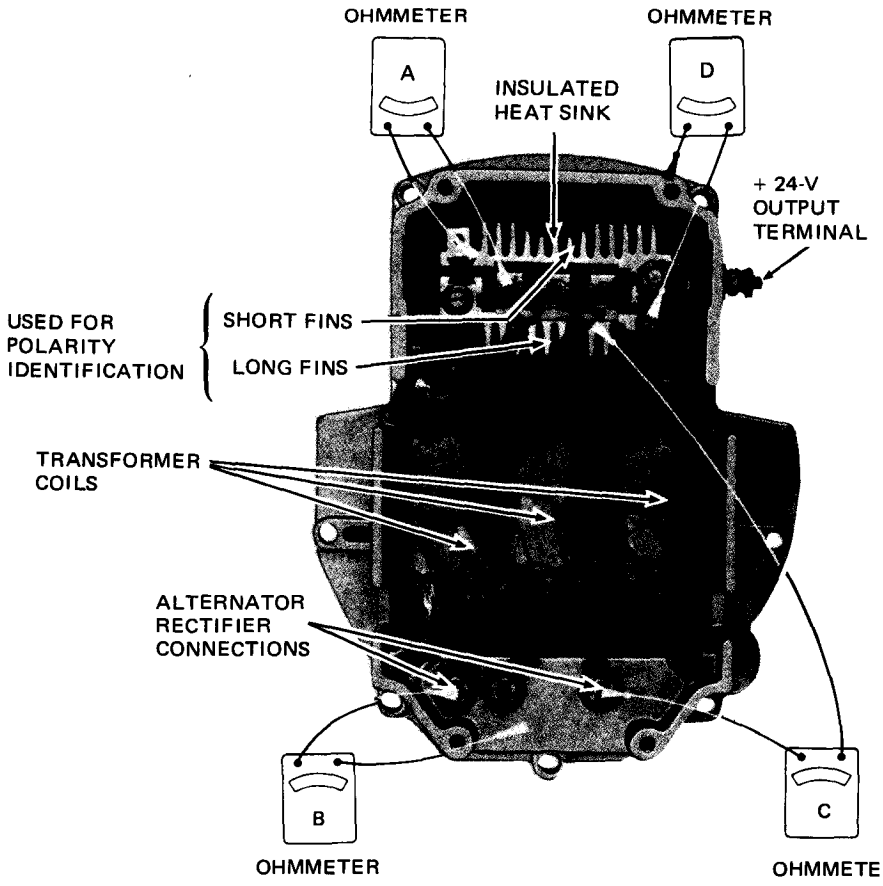


Fig. 46-20 Testing transformer coils and rectifier bridge. *(Delco Remy, Division of General Motors.)*

Check alignment of pulleys. Any misalignment must not exceed 1/16 in [1.59 mm] for each 1 ft [30.48 cm] between pulley centers.

Install belt(s), but do not roll or pry belts over pulleys. Once the belts are installed, tighten them and lock the adjustment. Then measure the belt tension, as shown in Fig. 46-21, or with your index finger (in the middle of the free belt span), push the belt straight downward. Correct belt tension is specified in Table 46-2.

After you have adjusted the belt to the correct tension, torque all mounting bolts to the specified values and connect the battery (and R terminal wire, if used) to the alternator. Connect the battery ground cable.

NOTE: If the drive belts are new, check the tension 1 hour or so after operation because they tend to loosen (stretch) slightly and may need readjustment. Recheck them again after 8 hours of operation, and thereafter at least every 5000 miles [8045 km] or 150 hours of operation. Do not use any kind of belt dressing.

Belt Cleaning Remove oil or grease from the drive belts as soon as detected so that it will not penetrate them. Remove the belts from the engine. Clean both sheaves and belts with a nonflammable solvent or cleaner. Occasionally soap and water may be used, but they are not as effective as a solvent cleaner.

CAUTION Never attempt to clean belts when the engine in running and never use a flammable solvent.

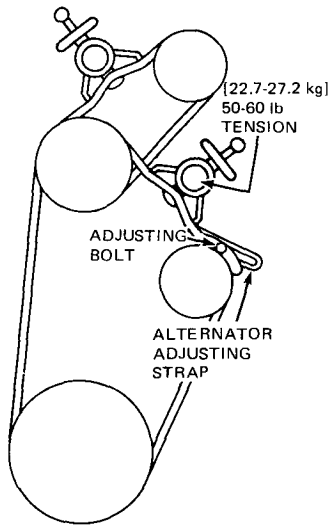


Fig. 46-21 Measuring belt tension. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

TABLE 46-2

CORRECT BELT TENSION

Belt width, in [mm]	Deflection per foot [per 30.48 cm] of span, in [mm]
1/2 [12.7]	13/32 [10.3187]
11/16 [17.4625]	13/32 [10.3187]
3/4 [19.05]	7/16 [11.1125]
7/8 [22.225]	1/2 [12.7]
1 [25.4]	9/16 [14.2875]

Questions

1. Why are resistors used in transistor regulators?
2. List the three functions of a (condensor) capacitor.
3. What is the major difference between N and P material?
4. Explain why a diode conducts current in only one direction.
5. Outline the procedure to test a transistor for an open and a short circuit.
6. Outline the procedure to test a diode for an open and a short circuit.
7. Explain how the test instruments are connected to perform an A and a B circuit alternator output test (remote-mounted regulator).
8. Outline the procedure to check the field coil of a brushless alternator.
9. Refer to Fig. 46-11. Would the alternator output be affected when one diode has a short circuit?
10. A precaution to be observed when soldering diode leads is (*a*) to avoid overheating during soldering; (*b*) to heat high enough to get a good connection in the diode; or (*c*) not to damage the insulation.
11. A major advantage of the transistor regulator is that the transistor (*a*) permits a lower field current; (*b*) permits a higher field current; or (*c*) eliminates the need for a cutout relay.
12. A transistor permits a current to flow when the base circuit is (*a*) open, (*b*) connected to field, (*c*) grounded, or (*d*) carries current.
13. The diode in an ac alternator performs two functions. One is to rectify, the other is (*a*) to act as a cutout relay; (*b*) to change the ac current to dc current; or (*c*) to change the current flow.
14. List the order in which the field current flows through the alternator shown in Fig. 46-11 when the battery is in a low-charge state.
15. What are the advantages of an integral charging system over a conventional charging system (that is, where the voltage regulator is not part of the alternator)?
16. In order to determine if the alternator or regulator of a Delco integral charging system is faulty, which test must you make? Outline the procedure to make this test.
17. Why is the voltage first stepped up to 24 V and then rectified to direct current of a 12/24-V charging system alternator?
18. How would you increase the output voltage of the alternator shown in Fig. 46-13 if the voltage regulator were set too low?

UNIT 47 • INSTRUMENT GAUGES AND THEIR CIRCUITS

To alert the operator to any adverse engine or auxiliary system operating condition, several gauges and/or indicator lights augment the instrument panel. On stationary and small engines a minimum of four gauges are used, namely, the engine oil pressure gauge, engine coolant temperature gauge, fuel level gauge, and an ammeter or indicator light.

The sender for the oil pressure gauge is screwed into the engine's main oil gallery, the temperature sender is screwed into the water manifold or thermostat housing, and the fuel level sender is fastened in the (main) fuel tank.

Current for the three circuits is directed from the cranking-motor terminal over the ammeter to the key switch. When the switch is turned to the "start" or "run" position, each individual circuit receives its current from the key switch, over a circuit breaker or fuse, from where it then flows to the gauge, to the sender, and then to ground.

OPERATION OF OIL-PRESSURE-INDICATING CIRCUIT

When the key switch is in the "on" position, a fixed current flows through the left-hand coil winding of the pressure gauge to ground, and through the right-hand coil winding, through the variable resistor (in the sender unit), and through the sliding contact to ground. When the engine oil pressure is high, the diaphragm curves upward and moves the sliding contact to the left, thereby reducing the resistance and causing a higher current to flow. This increases the magnetism in the right-hand coil winding and causes the pressure gauge needle to move to the right, thus indicating the higher oil pressure. When the oil pressure decreases, the diaphragm straightens and causes the sliding contact to move to the right, thereby increasing the resistance and reducing the current flow. This action reduces the magnetism in the right-hand coil winding which, in turn, causes the gauge needle to move to the left (Fig. 47-1).

OPERATION OF TEMPERATURE-INDICATING CIRCUIT

The temperature gauge is of the same design as the oil pressure gauge except that it has different coil windings and scale calibration. The sending unit is a bimetal arm which acts simultaneously with the sliding contact on the (variable) resistor wire. If the bimetal arm is heated, it warps to the right, and if it cools down to ambient temperature, it warps to the left. The bimetal arm responds to the temperature changes and increases or decreases resistance by sliding its arm on the resistor wire to the left or to the right, thereby varying the current flow and magnetic

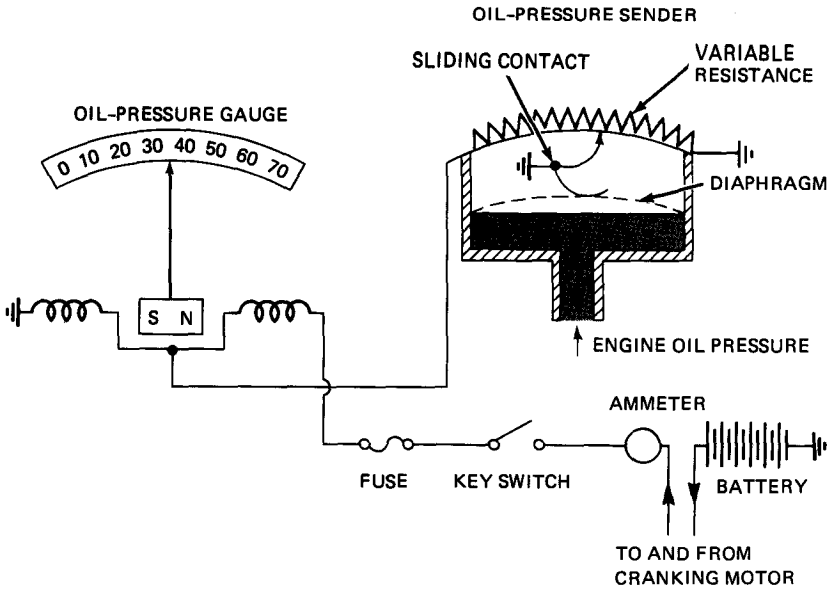


Fig. 47-1 Basic oil pressure gauge circuit.

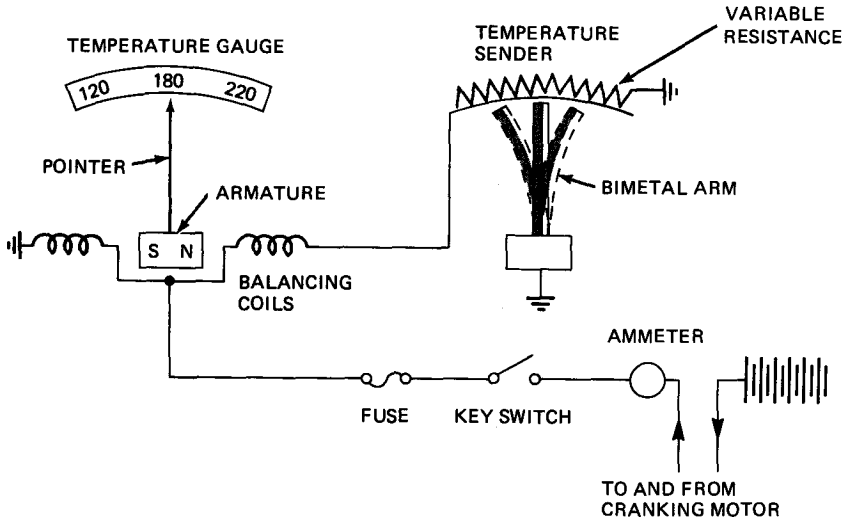


Fig. 47-2 Basic temperature-indicator circuit.

strength of the right-hand coil in the temperature gauge (Fig. 47-2).

OPERATION OF FUEL-LEVEL-INDICATING CIRCUIT When the key switch is in the "on" position, current flows through the coil winding (in the fuel level gauge) to the variable resistor (sender), and over the sliding contact to ground. If the fuel tank is empty (float down), the sliding contact moves through the float and arm so that the total resistance of the variable resistor is placed into the fuel-level-indicating circuits. Consequently the current flow is low, and therefore the coil winding produces very little heat. As a result, the bimetal strip warps to the left and mechanically moves the fuel gauge needle to the "empty" position. When the fuel tank is full, the float has risen, thus moving the sliding contact, and all resistance of the variable resistor is removed. This results in a higher current flow, which produces maximum heat from the coil winding; therefore, the bimetal strip warps to its maximum right-hand postion, thus moving the gauge needle to the "full" position (Fig. 47-3).

Additional Circuits Motortrucks, motor vehicles, or wheel loader-backhoes have additional circuits to relay more information to the operator about the system's operating condition. These circuits (see Fig. 47-4) are the air-filter restrictor circuit, engine oil-filter restrictor circuit, cool-level-indicator circuit (not connected), and a tachometer/hourmeter circuit (not shown).

The engine oil-filter restrictor sender is a pressure switch screwed into the filter housing. As the oil pressure drops across the filter because of the filter restriction, the switch closes. The current then flows over the switch contacts to ground and the warning light glows.

On a naturally aspirated engine, the air-filter restrictor sender is screwed into the intake manifold and on turbocharged engines it is screwed to the air cleaner outlet housing. The switch closes when the

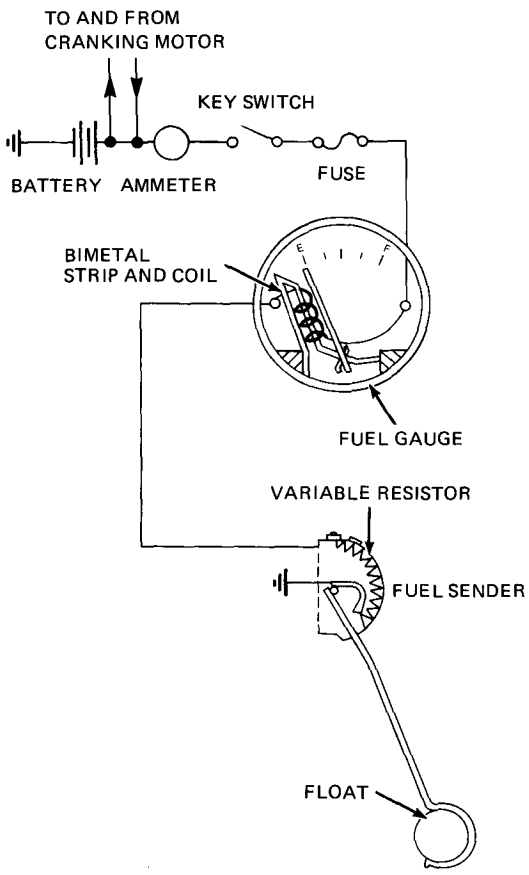


Fig. 47-3 Basic fuel level circuit.

intake air pressure drops, because of a restricted air filter, to 20 inH_2O [50.8 cmH_2O] (water). This closes the indicator light circuit to ground.

The coolant level sender is screwed into the top tank of the radiator and the switch closes its circuit to ground when the sensing unit of the switch is not surrounded by coolant.

The tachometer is a solid-state rpm indicator. It receives its ac current (7 V) from the alternator R terminal.

Testing If one or more of the above listed circuits fail to function, or register incorrectly, check *all* circuit connections, not only those which "appear" to be malfunctioning. (Do not omit the battery connections.) *[NOTE: The identifying numbers opposite the conductors indicate (1) the wire color, and (2) the relevant service manual test procedure to be followed (Fig. 47-4).]*

If no loose or damaged connections are found, proceed to check and test the batteries. If necessary, service any batteries and then measure the open battery voltage. Turn on the key switch and with a voltmeter measure the voltage at the cranking motor (No. 1), harness connection (No. 1), key switch (Nos. 1 and 5), panel connector (No. 5), circuit breaker control (No. 11), panel board (No. 11), and panel board connector (No. 2). The voltage registered at each test point should coincide with the open battery voltage. However, a drop of 0.2 V on the No. 2 panel board connector is acceptable because of the numerous connections. If an open circuit is found, check the 40-A circuit breaker.

TEST EXAMPLE Assuming that the fuel gauge does not operate correctly but the above tests check out satisfactorily, then proceed as follows: First of all check the fuel level in the tank and, if it is at a low unregisterable level, add some fuel. Disconnect the two wires from the fuel sender, then connect an ohmmeter to the sender terminals. The ohmmeter should read between 1 and 90 Ω, according to the fuel level in the tank. If the ohmmeter reads zero or infinity, replace the sender.

If the sender checks out, turn the key switch on, connect a voltmeter across the harness connector, and measure the voltage drop (No. 8). If this checks out, connect a voltmeter to the Nos. 2 and 14 panel board connectors. Battery voltage should register; if it does not, remove the instrument board and check the connections on the fuel level gauge. If the connections are good, then obviously it is the gauge which is defective and it must be replaced. *(NOTE: Most other circuits are protected through a circuit breaker and also by a diode which guards the circuit against induction current flow.)*

Engine Shutdown Systems Engines which function without an operator, such as industrial power units and some marine engines, are equipped with a protection system. This system when actuated stops the engine whenever a low oil pressure, high coolant temperature, or low coolant level occurs. Some engines are additionally equipped with an overspeed governor or switch. The system components and circuits, of course, vary relative to the type of engine, that is, whether it is a two- or four-cycle engine and according to the type of fuel system used. For example, a Detroit two-cycle diesel engine includes a fuel pressure switch and the shutdown system energizes the solenoid switch. The purpose of this switch is to release the air shutdown latch and thereby block the airflow to the cylinders. On four-cycle engines the solenoid moves the fuel-injection-pump throttle or fuel rack to the shutoff position. On Cummins engines, however, the shutdown is achieved by de-energizing the PT fuel pump solenoid, thus shutting off the fuel flow to the injectors.

A basic shutdown system for a four-cycle engine is comprised of the components shown in Fig. 47-5. The oil pressure sender switch is screwed into the main oil gallery, the temperature switch is screwed into the water manifold (before the thermostat), the coolant level switch is screwed into the top tank of the radiator, and the overspeed governor is attached to the fuel-injection pump or fuel pump, or (as shown in Fig. 47-5) an electronic shutoff system is used. A permissive start switch is used to bypass the open oil pressure switch during engine cranking, or the oil pressure switch has a manual override switch. On a Cummins engine the oil pressure sender switch is normally closed and opens when the rated oil pressure is reached. The other three sender switches are normally closed, but open when the set temperature or the coolant drops below the sensing probe or when the engine overspeeds.

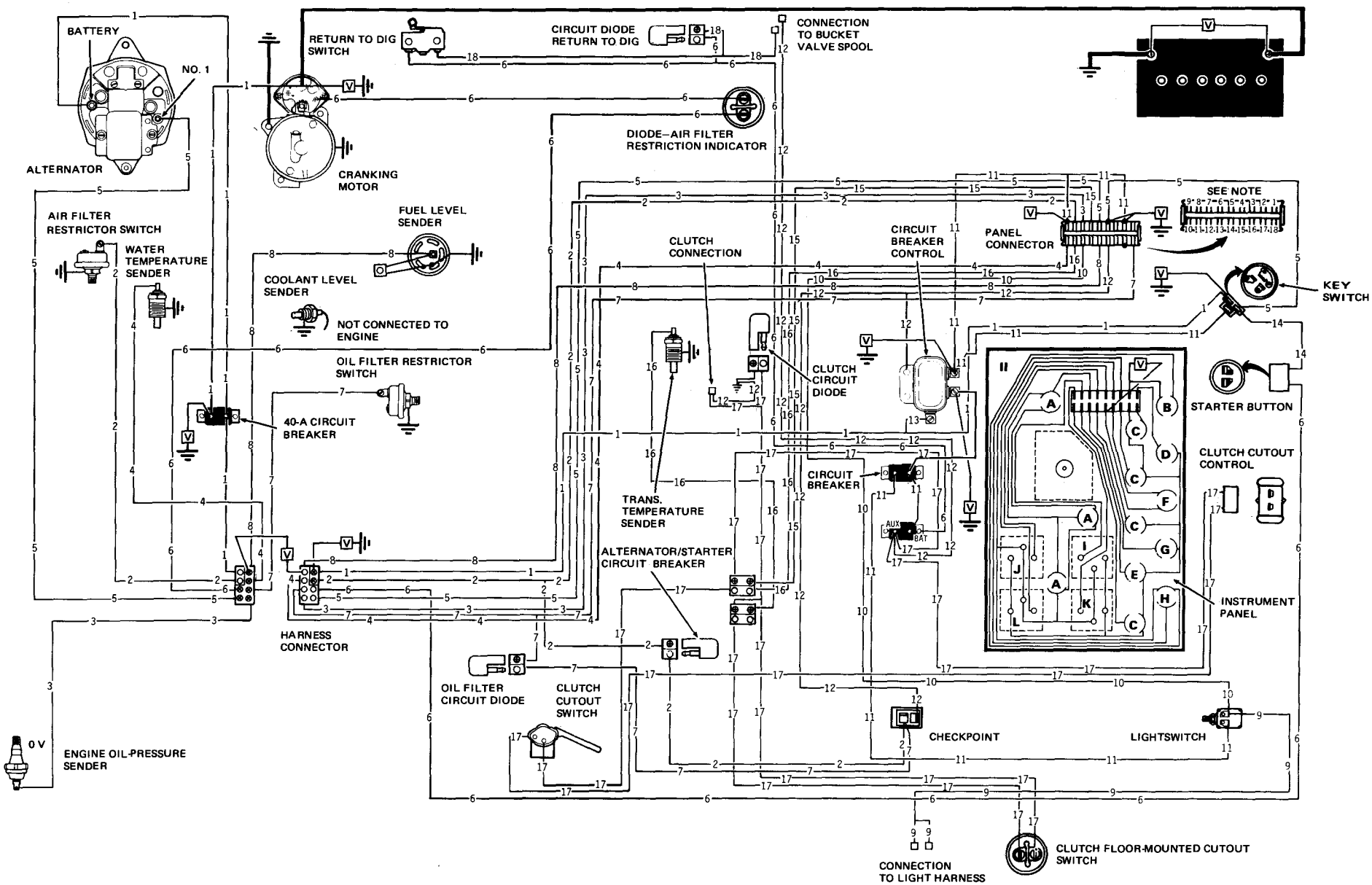


Fig. 47-4 Wiring diagram of a wheel leader-backhoe. A—illumination light, D—oil filter, E—air cleaner warning light, F—alternator warning light, G—engine oil pressure warning light. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

NOTE: TERMINAL NUMBERS ARE STAMPED ON THE INSTRUMENT CLUSTER PLUG. THESE NUMBERS DO NOT CORRESPOND TO THE WIRE NUMBERS.

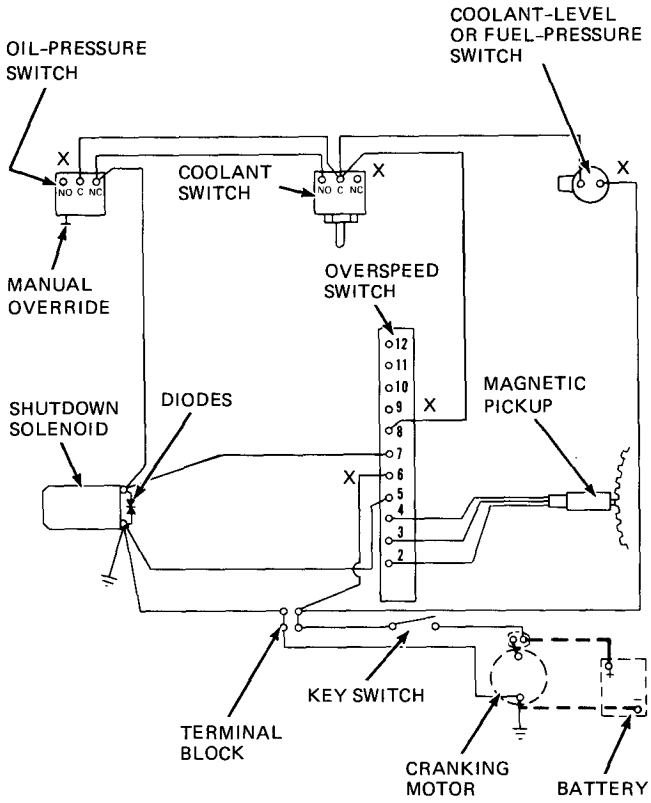


Fig. 47-5 Basic shutdown system. *(Caterpillar Tractor Company.)*

On other four-cycle engines the oil pressure sender switch and the other switch positions are reversed (open) because on these engines the shutdown solenoid is energized whereas on a Cummins engines it is de-energized.

OPERATION (CUMMINS ENGINE) When the key switch is in the "on" position, battery voltage is at the points marked *X* and the oil pressure switch is open. The other three (above-mentioned) switches are closed; therefore, the fuel solenoid switch in the PT fuel pump is de-energized, blocking the fuel flow. To start the engine, the key switch is placed in the start ("S") position, or the oil pressure override switch is actuated. This energizes the PT fuel solenoid and opens the check valve. When the operator pushes the start button switch, cranking commences. When the engine is running, the oil pressure opens the oil pressure switch. After about 15 seconds the operator can then move the key switch or the override switch to the run position. This places the oil pressure shutdown switch into the shutdown circuits.

A test procedure for the shutdown system is not outlined in this text because of the numerous switch variations and circuit connections. Refer to the applicable service manual in regard to servicing and testing.

When the engine overspeeds, the overspeed governor flyweights force the switch open, or if the frequency of the magnetic pickup is high enough, the zener diode conducts current and causes the overspeed switch to open the circuit, de-energizing the fuel solenoid. When the cooling level drops below the sensing probe of the cooling level switch, it opens. When the coolant temperature rises above 205°F [96.1°C], its switch opens, or when the oil pressure drops below safe operating pressure, its switch opens. In all cases the shutdown circuit de-energizes the fuel solenoid valve and stops the fuel flow to the injectors (Cummins). On other engine shutdown systems, when one switch is closed it energizes the shutdown circuit, and the shutdown solenoid moves the throttle lever to the no-fuel position, or releases the air shutdown latch stopping the intake airflow, or moves the fuel rack to the no-fuel position.

Questions

1. Name the minimal instrument gauges on a diesel engine instrument board.
2. Outline the reaction of the oil pressure gauge when the engine oil pressure drops, say, by 15 psi [103.5 kPa].
3. List the major differences between a temperature circuit and the fuel level circuit in regard to the sender and gauges.
4. Why is the air filter restrictor gauge on a turbocharged engine not located in the intake manifold?
5. Explain how you would test the oil-filter-restrictor-indicator circuit when there is a malfunction, for example, if the light continues to glow after the oil filter has been changed.
6. What is the purpose of a shutdown system?
7. Why are the shutdown senders on a Cummins engine connected in series?
8. List the three methods by which the operation of an engine is actually stopped when the shutdown system is actuated.

SECTION 6
SHOP EQUIPMENT
UNIT 48 • HAND TOOLS

To quickly and accurately diagnose and repair a component that is not functioning correctly, you must understand how the unit operates and know the law that governs its behavior. It is also necessary for you to know which hand tools and shop tools to use, and how to use them. Although it may be possible for you to haphazardly repair a component with the first available tool, only the correctly designed and selected tool will ensure that the job is done flawlessly and safely.

Selection of Hand Tools The most important advice you can be given at the beginning of your career is to purchase top-grade tools. These are made from high-quality steel and manufactured to precision. Special consideration is given to balance so that the tool will feel comfortable in your hand. Since you, the mechanic, must work with your tools daily, balance is of paramount importance.

The initial cost of even a minimum number of tools is high but the accompanying warranty guarantees satisfaction and many years of service. It is better, in the long run, to start with a few carefully selected tools that will take care of your most common needs and then to gradually build up to a complete (high-quality) set.

Care of Tools Your tools should always be cleaned before you return them to your toolbox. Ideally, each type of tool should have its own tray or drawer, primarily to protect the tools but also to allow you to locate them quickly.

Always place the most commonly used tools in the most accessible box drawer. Make certain that your tool box is large, sturdy, and if possible, equipped with casters. Hammer handles should always be tight and of the proper length. Your chisels, punches, and screwdrivers should be kept sharp and dressed at all times. Be proud of your tools; they contribute immeasurably to your livelihood.

Punches A *punch* is a forged steel tool variably shaped at one end (Fig. 48-1). It is used to drive a pin, bolt, or other fastener in and out of a hole. The working end may be sharp or blunt, tapered or cylindrical, or it may have a cutting edge.

A punch is classified according to its specific use; for example, the *starter punch* is used to start an object moving, whereas the *drift punch* is used to complete the job. A *center punch* is used to make a center before drilling or to show alignment of components. An *alignment punch* is used to align holes and thereby facilitate insertion of bolts, etc., or to line up parts for assembly work. A *hole punch* is used to make holes in gasket material.

A *prybar* can be defined as a forged steel tool tapered at one end, flat and angled at the other, and tempered over its total length. A prybar can be used as an alignment punch on one end while the other end can be used as a lever to move, remove, or lift components.

Files One of the oldest tools is the *file*. Every mechanic should have an assortment of files to fit, prepare, or shape a component when restoring its serviceability. This does not mean that as a mechanic you must posses one of each of the very many files used in your trade, but you should at least acquire the files shown in Fig. 48-2.

A file is a tool with cutting ridges made from hardened steel for forming or smoothing surfaces. It is usually used on metal. In the trade a file is described by its shape or its specific function, that is, flat file, mill file, round file, etc. Each of these files is made in bastard, single, or double cut. Bastard files are the least used as they are too coarse for filing many

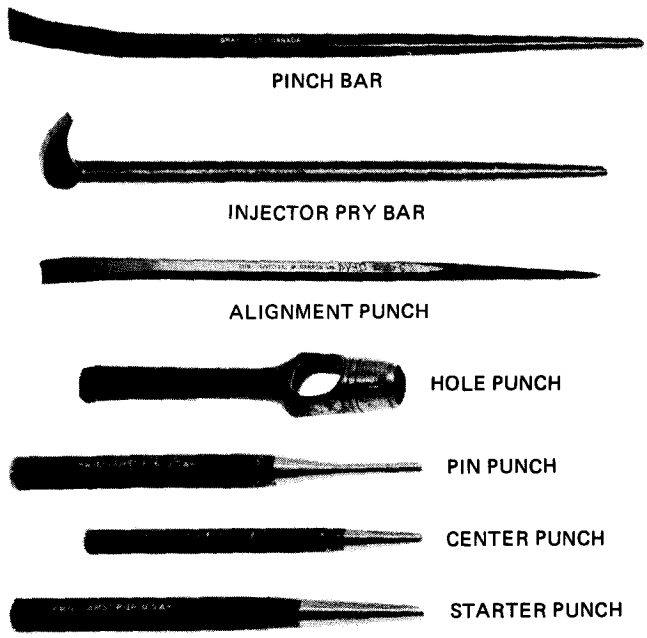


Fig. 48-1 Punches.

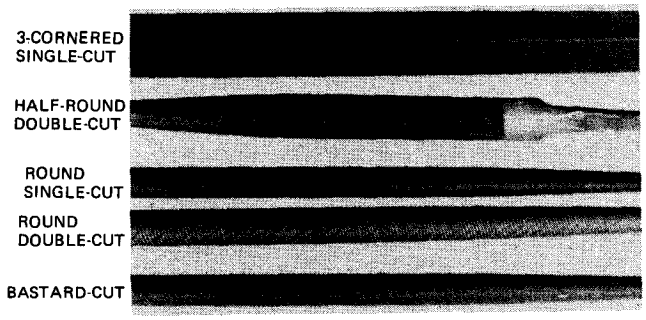


Fig. 48-2 Files.

surfaces, especially the faces of flanges. Double- or single-cut files are more applicable.

Pointers for Selecting and Using Files

1. Be certain to select the appropriate file. The incorrect file may ruin the component.
2. Fit the file with a handle so that the point of the tang will not pierce your hand.
3. Grasp the file firmly. Stand balanced with your left foot forward so that your right hand is square and parallel to the object being filed.
4. Push the file down and forward with a gentle force. On the return stroke, lift the file from the object to prevent excessive damage to the file cut.
5. Clean the file frequently with a file cleaner or a piece of wood to produce a smooth surface.
6. Fill the cut with chalk as this prevents particles from sticking in the file cuts and increases the effectiveness of the file.

Screwdrivers The screwdriver is often misused by many tradesmen because of its capacity to substitute as a prybar or chisel. Every mechanic should have a variety of screwdrivers varying in type and size to accommodate the many different screw recesses. The screwdrivers most popular in the diesel mechanics trade are shown in Fig. 48-3. It is advisable to have a similar set of screwdrivers for the socket drive to permit working in tight quarters.

Pointers for Using Screwdrivers

1. Keep standard screwdrivers dressed. This can be done by grinding and dressing with a file (see Fig. 48-4).
2. Use a screwdriver only for the purpose for which it is designed. Do not use it as a scraper, chisel, or prybar.
3. Select the proper size screwdriver (appropriate to the screw) to avoid damage to the screw head recesses. This will also ensure troublefree removal of the screw, or when tightening, will help to achieve the proper torque.
4. Hold the components so that the screwdriver cannot slip and pierce your hand or body.
5. When you work on electrical equipment, make certain that the ground cable is disconnected. If the cable cannot be disconnected, be sure to use an *insulated* screwdriver.
6. When loosening a tight screw, exert a heavy downward force and then use both hands while applying a strong twisting effort. A sharp blow with a hammer on the head of the screw will also help to loosen it, as will the application of penetrating oil or moderate heat.

Hacksaws The *hacksaw* is seldom used by diesel mechanics, but there are times when it is indispensable. When buying a hacksaw, select one with a 12-in [30.5-cm] fixed frame. This will give you a stable blade when sawing and thereby reduce the number of blade replacements. Keep spare blades with 18, 24, and 32 teeth per inch so that you will have the proper blade when needed. Buy good quality blades. They may be more expensive, but they will last much longer.

Pointers for Using Hacksaws

1. Carefully select the blade according to the job to be done. A properly selected blade will have at least two teeth in contact with the surface being sawed and will be coarse enough to give good chip clearance. Be sure the teeth point away from the handle.
2. Test the metal with the first or last teeth of the hacksaw blade, otherwise you may inadvertently ruin the entire set of teeth.
3. Use your thumb to guide the blade until the cut is started at the desired location. Apply sufficient pressure so that the blade begins to cut immediately.
4. Use the entire length of the hacksaw blade and enough force to ensure effectiveness.
5. When the kerf is deep enough to guide the blade, the saw should be lifted or raised lightly on the back stroke to reduce wear on the teeth.
6. If you break a hacksaw blade, start a new cut. Since a new blade has more set than a worn one, continuing on the original cut could jam or break the blade.
7. Protect the hacksaw and blades during storage so that the teeth will not be damaged.

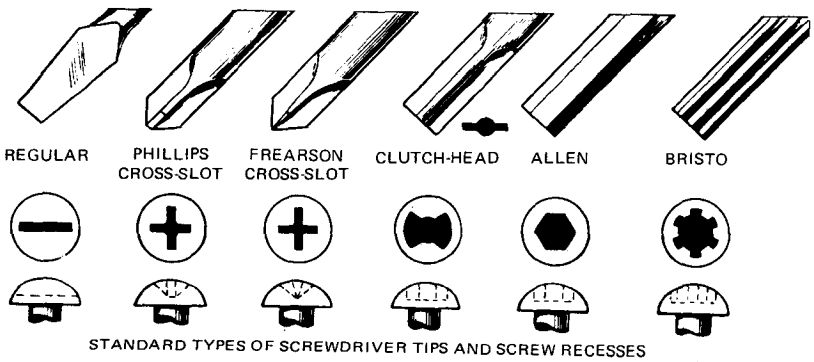


Fig. 48-3 Screwdrivers.

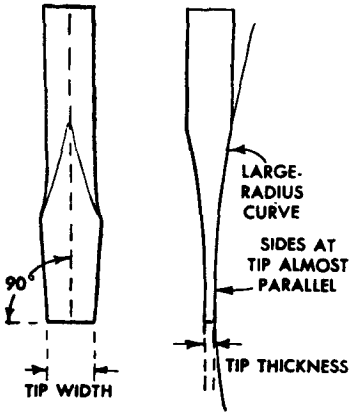


Fig. 48-4 Dressing a screwdriver.

In addition to the ordinary saw it is handy to have a jab saw or junior hacksaw. These can reach into areas and be functional where no other saw can operate.

Pliers As a diesel engine mechanic you would be almost helpless without *pliers*. Furthermore, you need all the types shown in Fig. 48-5. At times you will require specially designed pliers if you are to hold, cut, bend, or remove various snap rings and hose clamps. The name of the pliers will usually indicate to you their shape and specific use.

Pointers for Using Pliers

1. Select pliers to suit the job.
2. Do not use pliers to cut spring steel or steel harder than the pliers themselves, otherwise the jaws may be permanently damaged.
3. Never use pliers to tighten bolts, nuts, or fittings as this will damage the fastener.
4. Never use pliers as a jumper cable as this could result in burned hands when the high current flow heats the pliers.

Hammers *Hammers* differ in type and style throughout the trades. The most commonly used hammers in the diesel mechanic's trade are the ball-peen, plastic, bronze, or lead-tip hammers.

How to Use Hammers Hammers are rated and described according to their shape, the material from which they are made, and the weight of the head without the handle. Although the hammer is a simple tool, there is a right and a wrong way to use it:

1. The hammer should be gripped near the end of the handle to increase the length of the lever arm and thereby the force of the blow.
2. The hammer should be parallel to the object being struck to ensure contact with its full face. This distributes the force of the blow over the entire surface of the hammer face, minimizing damage to the edges of the hammer and to the object being struck. The novice has a tendency to grip the hammer too close to the head. This is known as *choking* and reduces the blow force.
3. The head of the hammer must fit very tight to the handle so that it cannot fly off and endanger other workers.

The taper in the hammerhead, known as the *eye*, tapers from the center in both directions. The handle is secured to the head by driving in a steel wedge or wedges into that end of the handle. Care must be taken to ensure that the wedges remain tight so that the head does not become loose.

When working in dry or heated areas, hammer handles have a tendency to dry out and become loose. This may be corrected by periodically immersing the hammerhead in water overnight.

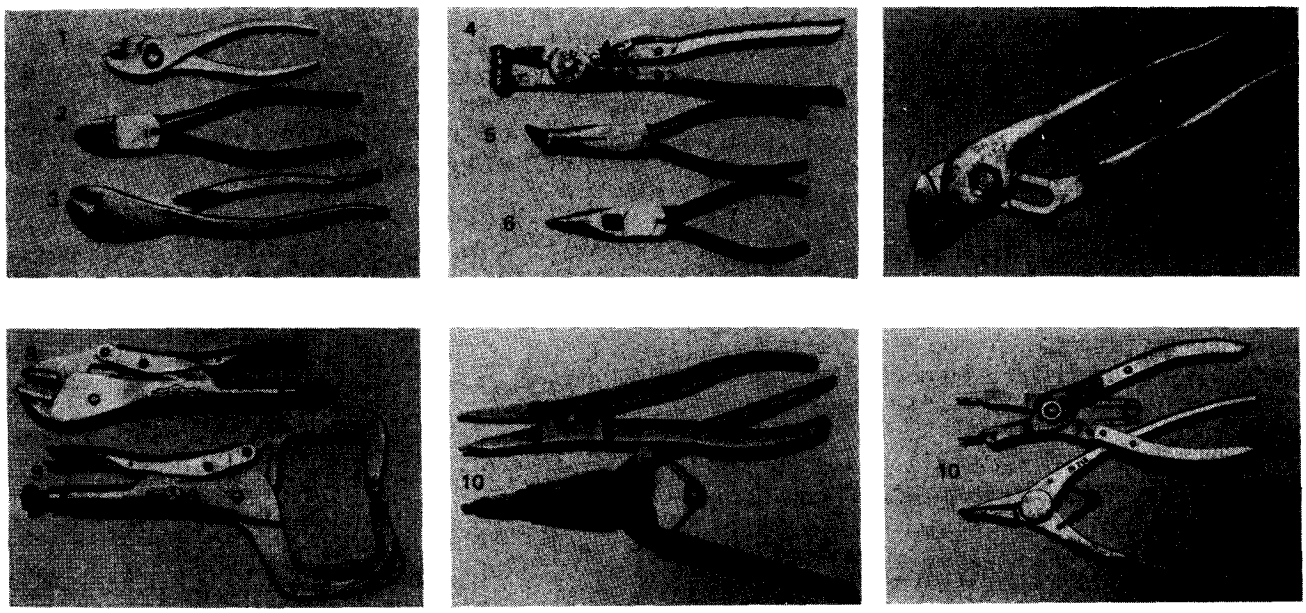


Fig. 48-5 Pliers: (1) combination pliers, (2) diagonal cutter, (3) angle-nose pliers, (4) hose-clamp pliers, (5) bent-needle-nose pliers, (6) needle-nose pliers, (7) interlock joint pliers, (8) vise grip, (9) vise gripclamp, (10) various snap ring pliers.

Never use the heel of the hammer handle to bump or drive components into position as this can split the handle. Do not use a second hammer as a punch. The wooden handle may split and cause bodily injury. The peen end of hammers is used for riveting and tapping out bolt holes when making a gasket.

Sledge hammers used for heavier work also come in different weights and shapes. They are described as single- and double-jack sledge hammers.

Cold Chisels A *cold chisel* can be defined as a forged steel tool with a hardened wedge-shaped cutting edge at one end. Although hand-operated chisels are still the most common, an increasing number of pneumatically and electrically operated chisels are now being marketed.

The size of a chisel is determined by the distance across the cutting edge; manufacturers have not yet standardized lengths. A cold chisel must be hard enough to cut metal without its edge breaking down and at the same time be capable of withstanding heavy hammer blows. To meet both these requirements, only a short portion of the wedge end is hardened and tempered.

Chisel Cutting Angle The cutting angle of a flat chisel is determined by the hardness of the material to be cut. For general-purpose work, an angle of 60° to 70°, is preferred. With softer metal (such as copper or brass) the angle may be increased to 45°.

When you grind the chisel, take great care to prevent the cutting point from overheating because that will remove the hardness of the cutting edge.

Other types of cold chisels handy to have in your toolbox are the cape, the round-nose cape, and the diamond-point chisels. These are used to cut narrow grooves of various shapes.

Combination, Box-end, and Open-end Wrenches One wrench suitable for almost any job is the combination wrench (see Fig. 48-6). Nevertheless you may require wrenches varying in size from ¼ to 1½ in [6 to 39 mm] and also metric wrenches. The combination wrenches give you the advantage of having a 15° offset box-end wrench on one end and a 15° angled open-end on the other end. Seldom used are the box-end, open-end, angle-head open-end, or ratcheting box-end wrenches. However, you should have a set of double-end, single-hex, flank-drive flare-nut wrenches when working on fuel-injection equipment. Also for fuel-injection equipment, you may need a tappet wrench set because standard-type open-end wrenches are too thick.

Another wrench you will often need is the flex-head wrench since it can be used in small areas at various angles.

Pointers for Using Combination and Other Wrenches

1. Use your wrenches only to tighten or loosen bolts, nuts, and fittings. Do not use them in place of another tool.
2. Select the wrench that is most suited to the job.
3. Hold the wrench head parallel to the nut, bolt, or fitting to be tightened or loosened to prevent the wrench from slipping.
4. When you use an open-end wrench, make certain that the longest and widest side carries the torque, otherwise the wrench may spread and slip.
5. Do not use an extension or pipe to increase torque. It may either slip or break the wrench.

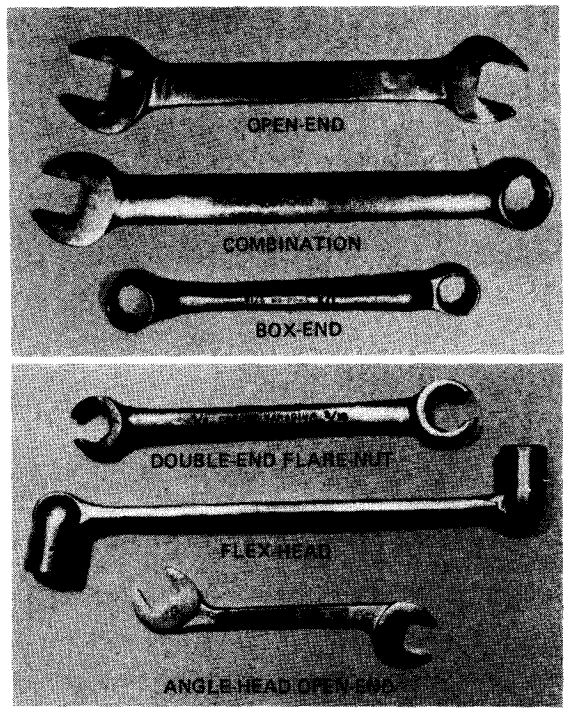


Fig. 48-6 Wrenches.

Socket Wrenches Without a complete socket wrench set in ⅜- and ½-in drives, your mechanic's toolbox is not complete. Also if the work you intend to do requires the larger size bolts and nuts, then you must invest in a ¾-in drive and perhaps a metric socket set.

Socket wrenches of various designs are among the greatest time- and work-saving tools you can have in your possession (Fig. 48-7). Ninety percent of all tightening and loosening of nuts and bolts, etc., can be made with a socket wrench or socket adapter and handle. Learn to use these tools to their fullest capacity.

How to Use Socket Wrenches First use a speed or sliding T handle to spin the bolt or nut tight.

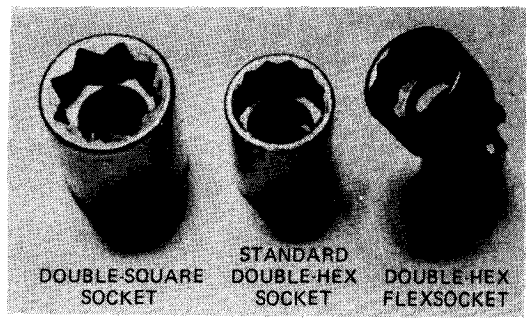


Fig. 48-7 Socket wrenches.

Then use a ratchet, flex handle, or the sliding T handle (with or without ratchet adapter) to tighten the nut or bolt (Figs. 48-8 and 48-9). If you have to work at an angle, use either the flex handle or a universal joint or swivel socket. Take advantage of the extension bar to swing the handle freely, but avoid too long an extension. Make use of the various socket attachments to improve and speed up your work (Fig. 48-10).

Pointers for Using Socket Wrenches

1. Select the correct socket size and most suitable handle.
2. Avoid using a socket as a driver or the handle as a prybar.
3. Use an impact socket and extension when using an impact wrench.
4. Support the socket to secure engagement, and pull on the handle or wrench to loosen or tighten nuts, etc.
5. When pushing the handle or wrench is the only possible method to loosen or tighten the nut or bolt, push with the palm of your hand.
6. Work with care. If the wrench slips it can cause serious injury.

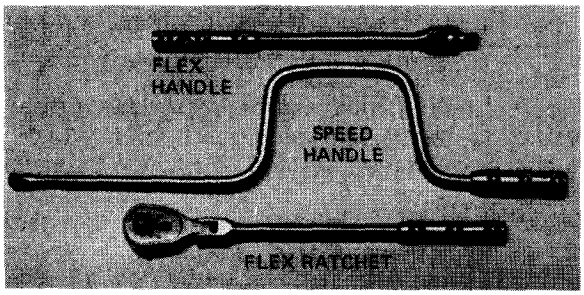


Fig. 48-8 Handles and ratchet for socket wrenches.

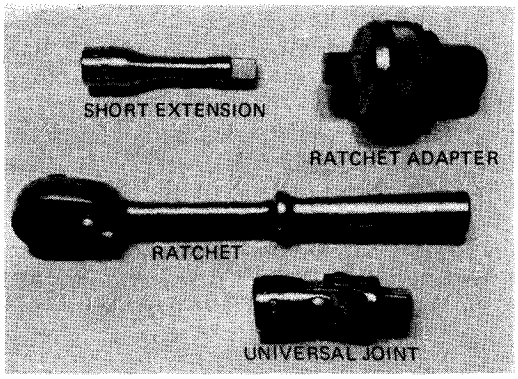


Fig. 48-9 Handles and adapters for socket wrenches.

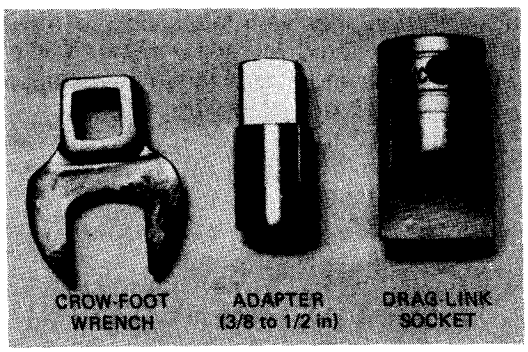


Fig. 48-10 Socket attachments.

Torque Wrenches A torque wrench is a tool which measures the resistance to turning (referred to as *torquing*). This tool is comparable to a micrometer, dial indicator, or any other accurate measuring device.

As a diesel mechanic it is essential that you have a torque wrench, or that one is available to you, since every bolt or nut on a diesel engine must be torqued to the manufacturer's exact specification. As you know, torque is based on the principle of the lever, that is, distance times force equals the movement or torque about a point measured at 90° to the direction of force.

TYPES OF TORQUE WRENCHES There are many types of torque wrenches of varying shapes. Some are direct-reading and others have a sensory signaling mechanism that warns the mechanic the moment the predetermined torque is reached. Sensory torque wrenches also incorporate a direct-reading scale and, therefore, may be used as either direct-reading or signaling models.

Torque wrenches are calibrated to read in pound-inches, pound-feet, or for special applications, in newton-meters. Your employer should have a torque wrench with a combination scale in pound-feet and newton-meters, varying in torque range.

TORQUE-WRENCH DESIGN AND OPERATION The torque wrench adapts the principle of Hooke's law. This law in effect states that, within the boundary of the norm, steel will bend in proportion to the amount of load it carries. In other words, a 1-lb [0.45-kg] load creates, for example, a 1-in [25.4-mm] deformation of a steel spring. This increases to a 2-in [50.8-mm] deformation with a 2-lb [0.90-kg] load, and so on. This ratio law of 1 in to 1 lb remains constant until the stress in the spring has exceeded the norm, the norm being bound by the elastic limit of the spring. Past this point, the spring attains a permanent set. Even complete removal of the load will not bring back the original shape.

The spring itself (measuring element) can be a single beam, double beam, or coil. It is attached between the drive square and the pivot handle a precise length in relation to the scale. The handle is pivoted, in some cases, to ensure a fixed length and to maintain a 90° angle to the centerline of the torque wrench. The pointer is directly or indirectly attached to the socket-drive square and is thereby connected to the bolt or nut. Because the scale is attached to the handle, it bends with it when force is applied. It moves underneath the pointer and thereby permits a direct torque reading.

How to Use Torque Wrenches Proper use of a torque wrench is of vital importance when a specific torque is to be achieved. Many small mistakes may be made when using a torque wrench with the result that:

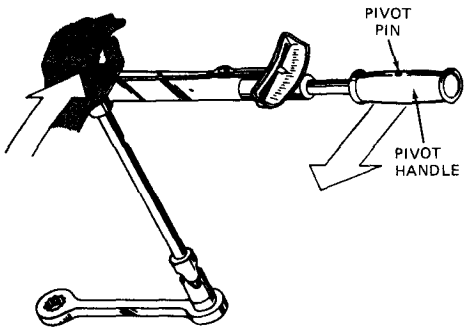


Fig. 48-11 Proper method of supporting a torque wrench. *(International Harvester Company.)*

1. A connection may remain loose or may become loose.
2. Loss of water, oil, or entrance of air and dirt may occur.
3. Flanges and rod bearings may be destroyed because of overtorquing and undertorquing.
4. Wear of components may be accelerated.

Hold the pivot handle so that as you pull on it. the handle will float on the pivot pin (Fig. 48-11). The handle end may contact the yoke in the process of pulling it, but as long as you do not alter its position, this will not affect the accuracy. However, an error in torque will result if you change the 90° angle of direction of force or if you change the distance by extending the handle.

As an example, if you change the lever length from 12 to 10 in, or from 12 to 14 in, but continue to apply the same force (say 100 lb), the torque-wrench readings would be

$$T = 12 \times 100 = 1200 \text{ lb·in}$$
$$T = \frac{12 \times 100}{12} = 100 \text{ lb·ft } [135.5 \text{ N·m}]$$

When altered to 10 or 14 in:

$$T = \frac{10 \times 100}{12} = \frac{500}{6} = 83.6 \text{ lb·ft}$$
$$T = \frac{14 \times 100}{12} = \frac{700}{6} = 116.6 \text{ lb·ft } [157.9 \text{ N·m}]$$

When the centerline of the torque wrench has been extended by the use of an extension or an adapter (Fig. 48-12), the following formula will apply:

$$T = \frac{TS \times (L1 + L2)}{L1} = \frac{100 \times (12 + 6)}{12} = 150 \text{ lb·ft } [203.2 \text{ N·m}]$$

where T = torque, lb·ft
TS = torque scale, lb
$L1$ = torque-wrench frame, in
$L2$ = extension or adapter, in

Or if you know the recommended torque is 100 lb·ft, the torque-wrench scale reading may be found by using the following formula:

$$TS = \frac{T \times L1}{(L1 + L2)} = \frac{100 \times 12}{(12 + 6)} = 66.66 \text{ lb·ft } [90.3 \text{ N·m}]$$

Pointers for Using Torque Wrenches

1. By selecting a torque wrench of the appropriate size and range, the accuracy of the torque-wrench reading is improved. A good rule of thumb is to select a torque wrench with a capacity adequate for a working range within the central two quarters of the scale.
2. When the torque range is limited to 100 lb·ft [135.5 N·m] and you are required to torque a nut to 150 lb·ft [203.25 N·m], use an extension of the same length as the torque wrench. This gives you double lever length and, therefore, your torque scale also doubles to 200 lb·ft [271 N·m]. (See Fig. 48-12.)
3. Clean the threads of both components thoroughly, or restore the threads when necessary. Remove water, oil, or dirt for the hole.
4. Check the manufacturer's specifications to determine whether a antiseize lubricant should be used or whether a dry torque is recommended.
5. When the rundown resistance is high because of a self-locking device or a damaged thread, take the resistance measurement at the last rotation and add it to the specified torque.
6. Follow the manufacturer's recommended sequence when tightening. First, torque each bolt to half of the desired torque. Then tighten the bolts to the three-quarter point. Finally, torque each bolt to the specified torque. The important point here, of course, is not to completely torque a bolt in one movement. If sequence procedures have not been outlined by the manufacturer, then you should start tightening from the center in a circular or diagonal pattern to the outside.
7. To check the torque, use the breakaway method. This means you should loosen the fastener and take a reading. The difference between this reading and your applied torque should be about 10 percent.
8. When retorquing, loosen the fastener, and then torque to specification. This method is important because a torque reading from a static position of the fastener is usually higher than the torque of the original tightening.
9. When using a torque multiplier, multiply the ratio by the scale reading to determine the torque of the fastener.
10. It is advisable to rest your palm on the drive square to equalize the force you apply to the handle. Failure to support the head end of the torque wrench will result in the socket rocking off the fastener.

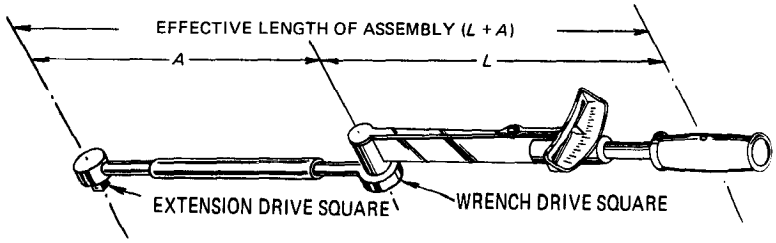


Fig. 48-12 Making a torque wrench multipurpose and multirange. *(International Harvester Company.)*

Hex-head and Multispline Wrenches As previously mentioned, you will require hex-head and multispline wrenches in both inch and metric sizes to loosen or tighten set screws and cap screws. Both sizes are used on fuel-injection equipment (Fig. 48-13).

Pipe and Adjustable Wrenches Both of these wrenches are useful tools, but they should be used only for the purposes for which they were designed. The pipe wrench, for instance, was designed to hold, tighten, or loosen round stock. It should never be used on bolts, studs, or nuts. An adjustable (crescent) wrench should only be used to loosen a bolt, nut, or fitting when no other wrench fits.

Pointers for Using Pipe Wrenches

1. Select the appropriate size pipe wrench for the job.
2. Do not use a pipe over the handle for additional leverage as the stress may damage your wrench.
3. Use only a pipe wrench with sharp jaws; otherwise it could slip.
4. Adjust the wrench so that the object to be torqued is held by the center area of the jaws.
5. To prevent lost motion or slippage at the beginning of the turn, press the adjustable jaw against the object. This ensures that the wrench will bite and hold at once.

Pointers for Using Adjustable Wrenches

1. Use an adjustable wrench only when other wrenches are not available. This wrench is prone to slip.
2. Adjust its jaws tight to the fastener.
3. Apply the force so that the fixed jaw will carry most of the torque.

Stud Removers Special tools have been designed to remove studs quickly and easily. The most common stud removers are shown in Fig. 48-14. Note that the collet type, when properly applied, will not damage the thread or bend the stud, whereas the wedge type may do so.

How to Use Collet-type Stud Removers

1. Screw the tapered collet onto the stud.
2. Slide the housing over the collet and tighten the nut. This will draw the collet into the housing and lock the puller tightly onto the stud.

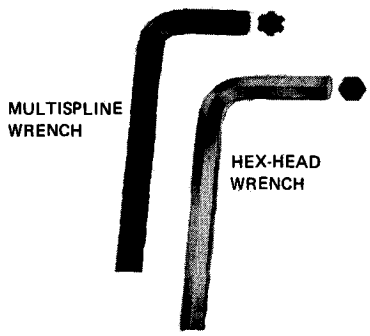


Fig. 48-13 Wrenches used to tighten and loosen set screws and cap screws.

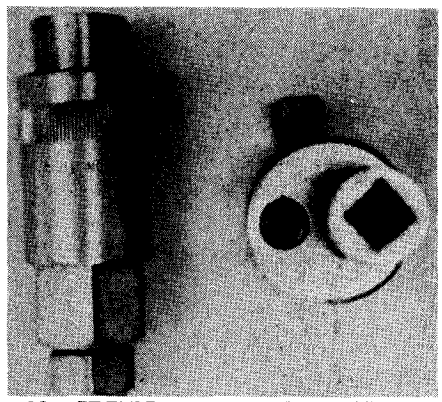


Fig. 48-14 Typical stud removers.

3. Use a wrench, preferably an impact wrench, to remove the stud.

How to Use Wedge-type Stud Removers

1. Slip the wrench over the stud and push the wedge into the bore until it contacts the stud. As the wrench is turned, friction forces the wedge tight against the stud, holding the stud extractor to the stud bolt.
2. To install the stud, follow the same procedure, but push the wedge in from the other side. When no stud removal tools are available, simply screw two nuts onto the stud, jam them tight, and then use a wrench on the lower nut to remove it. To install the stud, use the upper nut. Make sure the nuts are tight to prevent slippage and resulting thread damage.

Removing Broken-off Bolts, Studs, or Screws

A simple (but not always successful) way to remove a stud broken above or below the surface is to use a center punch and hammer. Gentle tapping in counterclockwise direction may force out the broken stud, etc. As soon as part of the stud extends above the surface, take hold of it with a pair of pliers or vise grip and work it back and forth to loosen it. Removal is sometimes speeded up by a hard hammer blow on the object or by the application of penetrating oil or moderate heat.

Some other methods of removing a bolt, stud, or screw when the center punch or pliers cannot remove it, are: (1) weld a nut to the broken bolt or screw, (2) cut a slot with a hacksaw and then use a screwdriver to remove the bolt, (3) file the protruding part so that an adjustable wrench can be used to remove the bolts.

Many different types of extractors are on the market to remove bolts, screws, taps, or pipes which have broken off at or below the surface (Fig. 48-15). Some extractors are more effective than others; nevertheless, to remove any such bolt, nut, etc., a hole must be drilled into it and the extractor then forced or threaded into the hole.

Pointers for Removing Broken-off Bolts, Studs, or Screws

1. Blow the hole or surface clean. Use goggles to protect your eyes. It is a good practice to apply penetrating oil to the broken studs, etc., and allow it to soak into the threads before attempting to remove them.

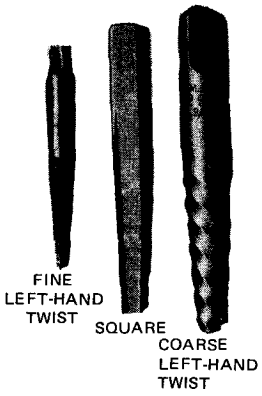


Fig. 48-15 Taper-bit screw extractors.

2. Center-punch the stud, etc., and drill a pilot hole. If it is broken below the surface, be sure to use the correct size guide so that the hole is correctly centered (Fig. 48-16).
3. Enlarge the hole sufficiently to insert the extractor tool. It is wise to drill the hole over the total length of the stud to reduce stress on the threads.
4. When using extractors similar to those shown in Fig. 48-15, you must drive the extractors into the drill hole, and then turn them counterclockwise to remove the threaded stud, screw, etc.
5. If you use the extractor shown in Fig. 48-16, you must tap the extractor lightly after you have inserted it into the drilled hole, and then turn it counterclockwise to remove the threaded stud, screw, etc.

Tap Extractors Many times during your employment as a mechanic you may break a tap. It is possible to remove the broken tap by heating it to take out the temper. After this, the procedure previously outlined should be followed.

Work carefully when restoring the threads with a tap because the tap or threads are easily damaged.

CAUTION Do not blow out a broken stud, tap, etc., with a cutting torch because particles of the molten metal will fuse with the threads, leaving them difficult to restore.

Twist Drills Although twist drills are always to be found in the shop tool crib, you can save yourself many steps, and much time, by having a small kit of your own. They are manufacturered in many different designs and sizes, but those most useful to the diesel mechanic are the high-speed conventional twist drills of the straight- or tapered-shank design.

The effectiveness of any tool or instrument largely depends on your own performance and the manner in which you have prepared the tool. Any twist drill can cut effectively if you have sharpened it to suit the material to be drilled. You must also take into consideration the speed at which it will operate in relation to the size of the drill and the material to be drilled. Proper and adequate lubrication is another essential factor.

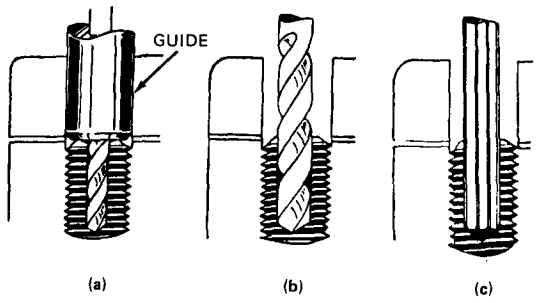


Fig. 48-16 Procedure for extracting a stud that breaks below the surface: (*a*) center punch stud and drill pilot hole, (*b*) enlarge hole, (*c*) insert extractor.

Drill Sizes Standard drill sizes may be measured in inches or millimeters. Taper-shank drills in fractional inch sizes run from ⅛- to 1¾-in diameter by increments of sixty-fourths, to 2¼-in diameter by increments of thirty-seconds, and to 3½-in diameter by increments of sixteenths. Straight-shank drills run in increments of sixty-fourths up to 1¼-in diameter, in increments of thirty-seconds up to 1½ in, and in increments of sixteenths up to 2-in diameter.

Sizes smaller than ⅛-in diameter are not regularly made with tapered shanks but rather with straight shanks. They are made in so-called "jobbers" lengths ranging from 1/64 to ½-in diameter in increments of sixty-fourths. Jobbers drills are shorter than regular drills. This lessens the risk of breakage.

Both straight and tapered shanks are available in letter size drills from A (0.234-in diameter) to Z (0.413-in diameter). Straight-shank drills are available in wire gauge or number sizes from No. 80 to No. 1 (0.0135- to 0.2280-in diameter).

Metric size drills are available in 0.75- to 77-mm diameter [0.0295 to 3.0315 in].

Drill Sharpening The importance of correct repointing (sharpening) of twist drills cannot be too strongly emphasized. A drill, no matter how well designed and heat-treated, will not drill the desired hole if it is point-ground incorrectly. It is safe to say that by far the largest percentage of failures experienced in drilling is due to incorrect repointing of drills.

As a general rule it is not possible to accurately resharpen a drill by hand. To restore them to maximum efficiency, drills should be resharpened on drill-grinding machines designed for this purpose. This is especially true of drills over ⅜ in [9.52 mm] in diameter. However, if the drill is ½ in [12.7 mm], you will, after practice, be able to sharpen it using only a drill gauge.

Procedure for Drill Sharpening Use a soft, medium-grain grinding wheel for pointing drills. Before the drill is ground, the wheel face should be dressed to ensure that it is flat and sharp. Drills should be ground on the wheel face, not on the side. All point grinding should be done dry. If during grinding the drill inadvertently becomes too hot, it should never be cooled in cold water. It should be allowed to cool of its own accord. A sudden cooling is almost sure to produce grinding checks.

When you are repointing a drill, four features must be carefully considered: point angle, lip relief, cutting edges, and web thinning.

DRILL POINT ANGLE The proper point angle is measured from the cutting edges to the axis of the drill. The angle should correlate with the material being drilled. A point angle of 118° (Fig. 48-17*a*) is normal for the average class of work, but take note that this angle is generally increased with increased hardness of the material being drilled. For example, a point angle of 136° is recommended for manganese steel (Fig. 48-17*b*), while for wood, fiber, and similar materials, a point angle of 60° is recommended, (Fig. 48-17*c*). However, there are certain circumstances where a smaller drill (¼ in or 6.35 mm, and less) must be used and therefore such a drill with a point angle of 136° is marketed for these occasions.

LIP RELIEF (CLEARANCE) In order that the points may have effective cutting edges, the heel, or part of the drill point behind each cutting edge, is removed. This lip clearance may vary from 12 to 15°. If the clearance angle is greater, it weakens the cutting edge; if it is smaller, there may not be sufficient clearance to allow the cutting edge to enter the work. Consequently the drill may split down the center. The angle of clearance at the center or chisel point should be about 130° (Fig. 48-18).

CUTTING EDGES The two cutting edges of a drill must be angled identically with the centerline of the drill. In other words, while the point angle may vary a trifle one way or the other, the variation must be uniform in regard to both cutting edges. A difference in angle will cause one edge to take a larger cut and, consequently, put an unequal strain on the two cutting edges. If the cutting edges are of unequal length (Fig. 48-19), the chisel point will be off-center even though the point angle may be uniform on both edges. This condition will cause the drill to cut oversize.

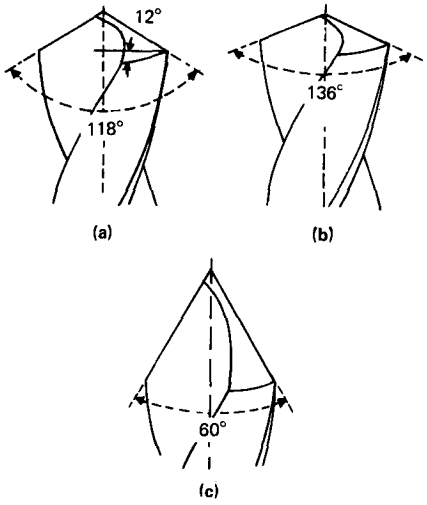


Fig. 48-17 Twist-drill point angles for (*a*) the average class of work, (*b*) manganese steel, (*c*) wood, fiber, and similar materials.

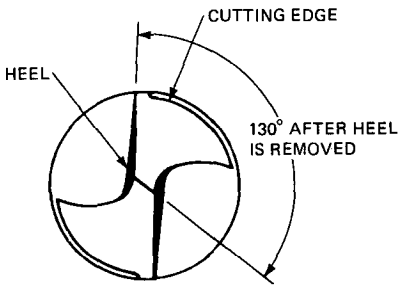


Fig. 48-18 Lip relief (top view) before removing the heel.

WEB THINNING As the web of a drill usually increases in thickness toward the shank, a web-thinning operation becomes necessary when the drill has been shortened by repeated grindings. This operation is essential in order to minimize the pressure required to make the drill penetrate. This point-thinning operation must be carried out equally on both sides of the web in order to ensure that the web will be central. Care must also be taken to see that the point thinning is not carried too far up the web, thereby weakening the drill. As a general rule, a web thickness, at the drill point, of approximately one-eighth the drill diameter is recommended. Figure 48-18 shows a drill with the web thinned correctly.

Drill Speeds The speed of a drill (the rate at which the periphery of the drill moves in relation to the workpiece) is expressed in surface feet per minute (sfm). For convenience, this sfm is best converted to revolutions per minute (rpm). The correct rpm of a twist drill depends upon the diameter of the drill, the type of steel from which a drill is made, the type of material being drilled, the quality of the hole desired, the way in which the workpiece is set up or held, and the quality of the machine itself.

To calculate the rpm of a drill, use the formula

$$\text{rpm} = \frac{4 \times \text{cutting speed}}{\text{diameter of drill}}$$

Recommended Cutting Fluids for Drilling, Reaming, and Tapping Perhaps even more important than twist speed is the cooling action while drilling. If the drill is not properly cooled with the recommended cooling fluid, the cutting edge of the drill will wear faster and the hole surface will harden. Table 48-1 lists recommended cutting fluids to be used with various metals.

Reamers The reamers which you will use for servicing a diesel engine are of the straight, tapered, and adjustable designs (Fig. 48-20). They are a multiple-tooth cutting tool and are used for hole sizing or

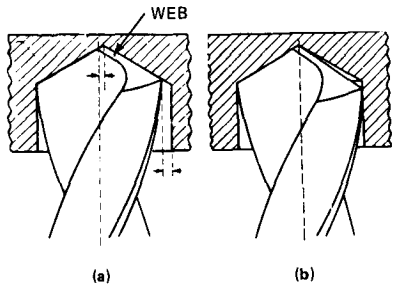


Fig. 48-19 Results of incorrect cutting edges: (*a*) cutting edges of unequal length, (*b*) cutting edges with unequal angles.

TABLE 48-1

CUTTING FLUIDS

Metal	Drilling	Reaming	Tapping
Mild and medium steel	Soluble	Lard oil	Lard oil
Tool steel	Soluble	Lard oil	Lard oil
Brass and bronze	Dry	Soluble	Dry
Copper	Soluble	Soluble	Soluble
Aluminum	Kerosene	Lard oil	Soluble
Cast iron	Dry	Dry	Lard oil

Note: Soluble oil is generally used 1 part oil to 40 parts water.

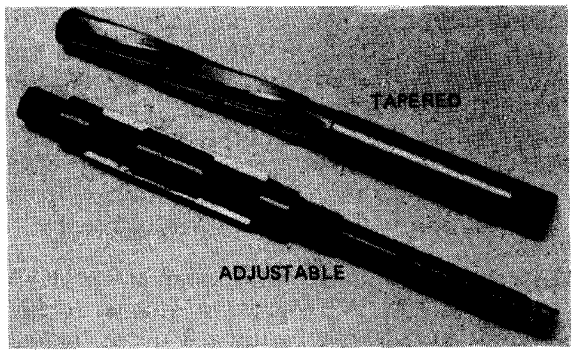


Fig. 48-20 Reamers.

smoothing. With this tool the diameter of an existing hole can be increased by 0.003 to 0.030 in [0.0762 to 0.762 mm].

Reaming does not improve the angular alignment of drilled holes; rather it tends to follow the direction of the existing hole. It is, therfore, essential to make certain that the hole is drilled and located accurately before reaming. The drill should be correctly sharpened to prevent it from wandering.

Pointers for Using Reamers

1. Select the reamer to suit the job. When an adjustable reamer is used, adjust it to the drilled hole size *plus* 0.002 in [0.05 mm].
2. Lubricate the hole with cutting oil and insert the reamer.
3. Maintain a 90° angle to the hole. Gently turn the reamer clockwise. *Never* turn the reamer counterclockwise because this will chip the edges of the reamer. Make only small cuts from 0.001 to 0.002 in [0.025 to 0.005 mm].
4. Store your reamers in a container or some well-protected place when they are not in use.

Cleaning Tools for Parts The first step in service maintenance procedure is to superficially clean the components to be serviced. This speeds up the repair job and prevents foreign matter from entering the components during disassembly. It is important to clean components thoroughly after disassembly so that they can be examined visually to determine the cause of failure.

Pointers for Using Cleaning Tools

1. Use only approved cleaning solvent (never gasoline) and keep all containers labeled. Keep the solvent tank covered when not in use.

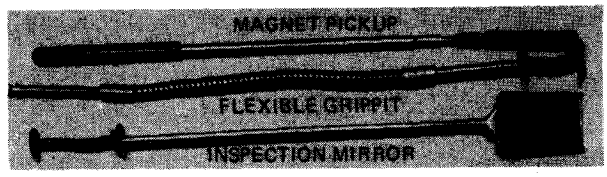


Fig. 48-21 Mechanic's helpers.

2. When cleaning with caustic solution, use rubber gloves.
3. Always protect your eyes, especially when using hand- or power-operated wire brushes. Special protection shields are available for this purpose.
4. When using a scraper to remove gasket material (or any type of dirt) always keep your free hand *behind* the scraper.
5. Take care when using compressed air to remove foreign material, because it has great impact force.

Mechanic's Helpers In every vocation there are certain "tricks of the trade." In mechanics, speed and performance are very often aided by miscellaneous gadgets known as *mechanic's helpers*. For instance, suppose you lose a bolt in an engine and know only vaguely where it has dropped. With such helpers as an inspection mirror and a magnetic pickup or flexible grippit, you can retrieve the bolt easily (Fig. 48-21). A mechanic's stethescope can save time when trying to locate or diagnose any abnormal engine sound, noise, or knock. The screw starter is another useful device which will start a screw that cannot be hand-started.

Questions

1. What factors should be considered when purchasing a set of tools?
2. What safety precautions must be taken when using a punch or chisel?
3. Name the three most common punches and state their applications.
4. Why should you *never* use a file without a handle?
5. Why should you lift the file on the return stroke?
6. Describe how to dress a ½-in regular screwdriver.
7. What safety precautions must be taken when using a screwdriver?
8. Why should you start a new cut after a hacksaw blade breaks?
9. What must you consider when selecting a hacksaw blade?
10. List a number of safety precautions which should be taken when using a hammer.
11. Describe how to restore the cutting edge of a chisel.
12. When is a speed handle used?
13. List a number of occasions when a pipe wrench is required.
14. Describe how to remove a stud bolt with a wedge-type stud remover.
15. Describe how to sharpen a twist drill to drill a hole into a broken grade 8 stud bolt.

16. Which wrench is used on a hollow-head screw: (*a*) open, (*b*) box, (*c*) torque, or (*d*) Allen?
17. Wrench sizes are governed by the (*a*) thread length, (*b*) length of the bolt, (*c*) width of the bolt head across the flats, or (*d*) width of the bolt head across the corners.
18. Diamond-point chisels are used to (*a*) cut V-shaped grooves, (*b*) cut round-shaped grooves, (*c*) cut square-shaped grooves, or (*d*) cut hardened nuts and bolts.
19. The number of threads per inch on a hex bolt can be determined by a (*a*) radius gauge, (*b*) screw thread micrometer, (*c*) thread pitch gauge or (*d*) acme screw thread gauge.

UNIT 49 • SHOP TOOLS

The range and variety of shop tools available to you depends, of course, on the shop in which you are working. However, there are some tools which are standard in all service shops.

Steam Cleaner The most efficient way to clean assembled engines or components is with a steam cleaner—dry cleaning is not nearly as effective. All steam cleaners, whether portable or stationary, operate on the same principle. Water, mixed with a cleaning solution, is forced under controlled pressure through a heating coil. It then passes into a special hose and out through a handle-type nozzle. The heating coil is located in an open furnace where it is heated by an oil or gas burner. By controlling the burner flame (and in some steam cleaners, the water flow), the desired temperature is regulated to produce a wet steam.

Pointers for Using Steam Cleaners

1. Steam-clean in an isolated area where there is good ventilation because steam will cause oxidation. Protect all compartments which could be damaged by the steam. Close all openings to prevent the entry of water or foreign matter.
2. Make certain that any electrical equipment is grounded properly.
3. Check supplies of fuel, water, and cleaning solution before igniting the steam-cleaning unit.
4. Wear safety gloves and goggles.
5. Make sure that the object to be cleaned is raised off the ground to ensure better cleaning.
6. Ensure that the water flow from the nozzle is free of air before you ignite the fuel, otherwise steam pockets will form in the heating coil. Steam pockets can prevent water from flowing and cause damage to the coil.
7. Adjust the flame heat to the desired steam pressure by controlling the fuel flow.
8. Vary the nozzle distance to achieve the greatest cleaning action.
9. When the object is clean, shut off the supply of solution first and, a short time later, shut off the fuel valve.
10. Do not try to wash the object with cold water because this will increase the possibility of corrosion.
11. Do not shut down the steam cleaner until cool water leaves the nozzle. This will help to prevent damage to the heating coil.
12. When you are done, clean the work area and store the equipment carefully, especially the hose and electrical wires.

Hot Tank The most efficient way to clean individual components is the hot-tank method. This method is increasing in popularity because of its effectiveness. The cleaning solution is simply a mixture of water and caustic soda which is heated to a temperature of 200°F [93°C]. There are many hot-tank cleaning solutions on the market, but close attention should be paid to manufacturers' warnings. Some solutions are irritating to the skin and some are very poisonous. Eye protection must *always* be worn.

Pointers for Using Hot Tanks

1. Follow the manufacturer's operating instructions regarding the solution to be used.
2. Protect your hands with rubber gloves. Shield your face.
3. Lower the components gently into the tank to avoid splashing.
4. After the component has been removed from the hot tank, wash it thoroughly to remove all the solution.
5. Finally, the clean component must be protected from surface oxidation. Either immerse it in an oil solution or use an air-operated spray oiler.

Cold Tank As a temporary measure, any container and cleaning solvent may be used to clean components. However, inferior containers can, in time, contaminate the solution and reduce its cleaning power.

There are many well-designed cold-tank cleaners available which guarantee an excellent cleaning job. An example of one is shown in Fig. 49-1. This cold tank consists of two separate compartments which hold 6 gal [22.71 L] of solution. One side can be used as a soaking tank. This cleaner also has a filter element, hydraulic pump, and a spray nozzle to clean areas which are difficult to reach.

Pointers for Using Cold Tanks

1. Use a recommended solvent with a high flash point. Never smoke or approach the tank with an open flame or spark.
2. Clean parts or components with a scraper or wire brush before placing them in the solution.
3. Keep the solution and tank clean. Change the filter and the fluid regularly to prevent damage to the pump and electric motor.

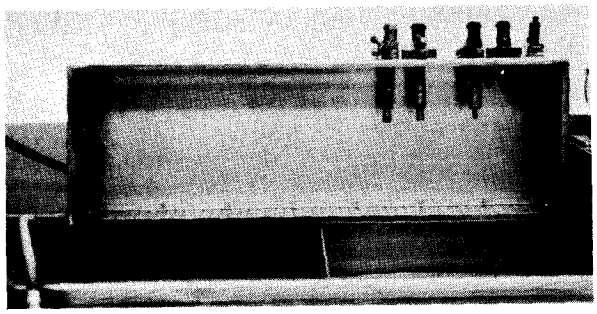


Fig. 49-1 Two-sectional cold tank with built-in pump and filter element.

4. Keep the tank lid closed when not in use to prevent accidental explosion.
5. Protect you hands with rubber gloves or wash your hands thoroughly after the cleaning job is completed.
6. Always wear eye protection.

Sonic Cleaner A sonic cleaner is ideal for cleaning smaller parts and components such as the injection equipment.

Lubrication- and Fuel-supply Tools The type of lubrication-supply tools used will depend on the type of service your workshop supports. However, the equipment illustrated in Fig. 49-2 is standard.

SPRING- AND PISTON-TYPE OILERS Suction guns and grease guns are tools used in the lubrication of component parts during assembly. Suction guns are used for both draining and refilling filters, gear cases, and cylinders. Grease guns may be hand- or power-operated. Various grease guns with the necessary adapters are shown in Fig. 49-2.

Pointers for Using Grease Guns
1. Select the correct coupling to complement the grease fittings.
2. Use an extension when necessary to ensure proper coupling fitting.
3. Clean and examine the grease fitting before you push the coupling on.
4. Check the specifications for both low- and high-pressure grease guns to prevent overgreasing.
5. When you remove the coupling, try to use a straight pull. Do not twist because this will damage the coupling tang and seal.
6. Wipe off the excess grease.

Lubrication and Fuel Dispenser Time will be saved and cleanliness will be ensured if the service shop has a separate dispenser for each liquid used. The dispensers may be hand- or power-operated.

When using air-operated lubrication- or fuel-supply tools, be sure to use a pressure regulator, moisture-separator, lubricator, and nylon retrocoil airhose.

Be sure to set the regulator to the recommended pressure to avoid damage to valve, piston, and seals.

Glass Blaster Some workshops use a glass-blasting cleaning tool to quickly remove rust, paint scale, or any other surface coating. This tool operates on the principle of air, controlled by a valve, flowing into and around a venturi. Small glass beads or pearls are drawn into the stream of air and forced through a specially designed blasting gun against the surface to be cleaned. By regulating the airflow, the amount of air and glass pearls impinging on the surface is readily controlled.

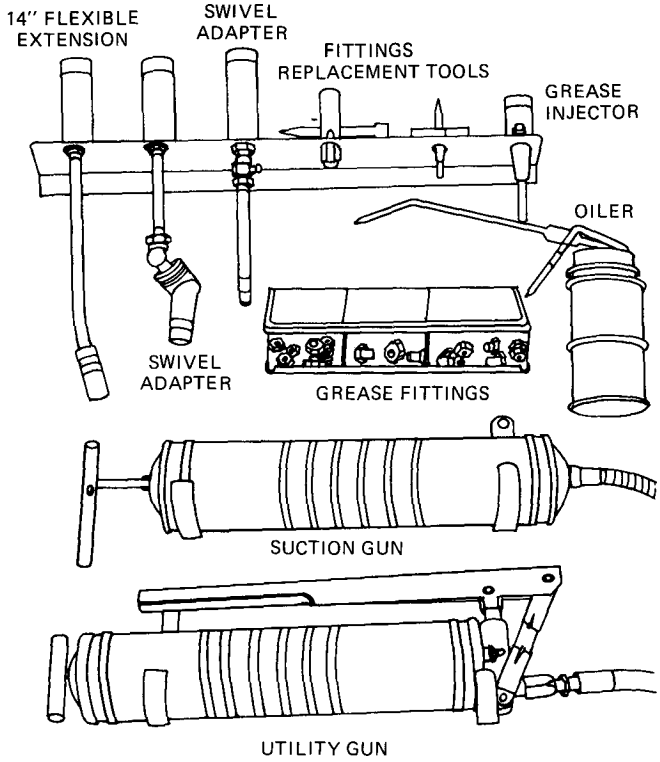


Fig. 49-2 Standard lubrication equipment.

Pointers for Using Glass Blasters
1. Make certain that the air pressure is adjusted to the specified pressure and that the component to be cleaned is dry and free of dirt and grease.
2. Be sure that the recycling filter is clean.
3. Use masking tape to protect all surfaces which are not to be cleaned.
4. Do not accidentally spray the glass cabinet's window. Such action will damage the surface of the glass and reduce your visibility.
5. Upon completion of the cleaning operation, make sure that all the glass dust is removed from the components.

Hydraulic Jacks Statistics indicate that most accidents in a service shop are related to lifting, pushing, or pulling. In the majority of instances these accidents could have been avoided if normal safety rules had been obeyed. The following common-sense rules should always apply:

1. Do not overestimate your own strength. Do not lift or carry more than safety boards recommend.
2. When you lift a load, make certain your back is straight and your legs are bent. Let the strength of your legs help you lift the weight.
3. Make sure that the load you are about to carry does not obstruct your vision.

4. Do not twist your body while lifting or carrying a load (move your feet in a straight-line position).
5. When you lift sharp-cornered objects, use work gloves to protect your hands. It is wise to remove finger rings as they could catch on some protrusion and cause injury.

HAND, FLOOR, AND PORTABLE JACKS Mechanically, hydraulically, and air-operated jacks are designed to make lifting easier. You should be aware of their full capacity. It is even more important that you know the recommended procedures for using them.

Pointers for Using Hydraulic Jacks

1. Always clean the floor and surrounding area before you use a floor jack or portable crane.
2. Select the jack which suits the particular lifting situation.
3. In the interest of safety, position the jack in the correct location. For instance, never place a jack under an oil pan, radiator, clutch housing, or any other area which could cause component damage or unsafe lifting conditions.
4. Place the jack square to the component to be lifted and use a suitable saddle or head to ensure safe lifting.
5. Lift only as high as necessary and support with safety stands or cross blocking. *Never* work on or under an object which is supported *only* by a jack, crane, or any other lifting device.
6. Before you place safety stands under the object, make certain that the stands can hold and support the load. In some cases it is wise to place wood between the jack or stand and the object to be lifted. This will increase friction and prevent slippage.
7. Never remove the jack or lift an object from the block until you have checked that the work area is clear.
8. When using a portable crane, block and tackle, or chain hoist, lower the load as much as possible before moving it into position.
9. Never leave the load hanging unprotected while you are lowering it into position. It may release accidentally.
10. Always use the correct type of lifting cable, chain, or manila rope. Never use a synthetic rope.

Hydraulic Presses A floor or portable hydraulic press is essential to any service shop because of its versatility. It can be a real time-saver when gears or hubs are to be removed. Also, the controlled force on the object being pushed or pulled is evenly distributed, thereby eliminating shock load and vibration.

Pointers for Using Hydraulic Presses

1. Before you use a hydraulic press, clear the surrounding area of any obstructions.
2. Adjust the table to a suitable working height. Secure it firmly and make certain that there is slack in the winch cables.
3. Support the object being pulled or pushed by using a pulling attachment or accessory. Remember that the center of the hydraulic ram must be in the center of the object to be pulled or pushed.
4. Screw out the extension and bring it in contact with the object. Apply moderate pressure and check the alignment.
5. Bearings, gears, or any other component or part which can break during press action should be wrapped with a shop towel so that you are protected in case the component shatters.
6. In order to prevent damage to the pressed-out component (which may eject with great force), let it fall into a pail of sawdust or onto a slab of wood.

Pullers and Attachments Nearly all service shops possess some type of puller set with attachments. Figure 49-3 shows some of the more common

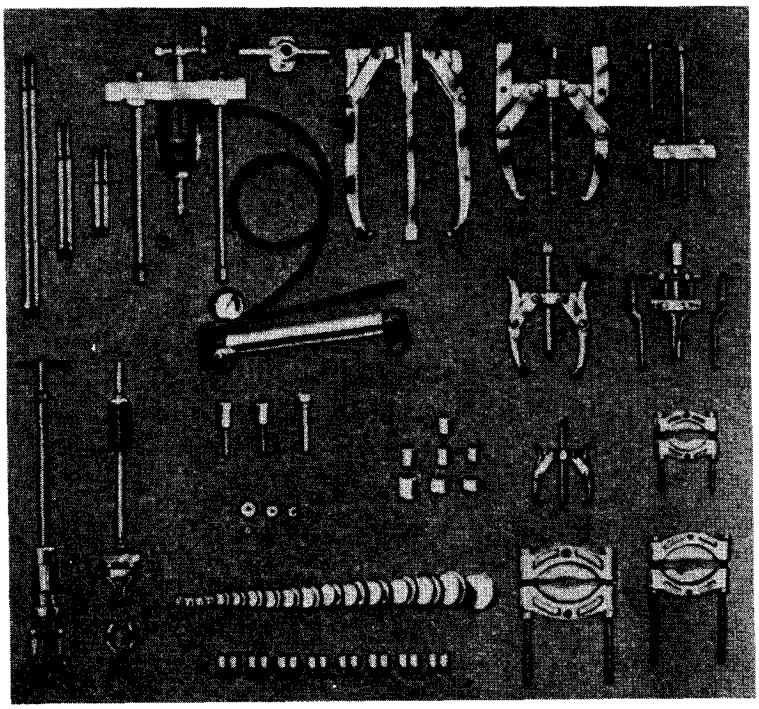


Fig. 49-3 Typical pullers and attachments. *(Owatonna Tool Co., Tools and Equipment Div.)*

pullers. Never substitute a punch, hammer, or prybar for a puller. By using the wrong tool, the job will take longer and you may damage the component.

Tool manufacturers have designed a great variety of pullers and attachments to take care of the three basic pulling problems: pulling gear-bearing pulleys, etc., out of shafts (either to replace them or to get at other worn-out parts); pulling press-fitted internal bearing cups, retainers, or oil seals out of a housing; and pulling shafts out of a housing.

One of the major difficulties when removing or installing press-fitted parts is getting a firm grip on the parts themselves. Precision gears, bearings, races, etc., whether very small or very large, are pieces of delicately machined steel. They must be gripped in a manner that will not damage them, yet the grip must be firm enough to prevent the puller from slipping off. Unfortunately these parts are often located in places which are extremely difficult to reach.

The proper grip is not the only aspect of pulling. Force is equally important. Not only do you need enough force to remove press-fitted parts that may be frozen or rusted in place, but the force must be applied properly. The pull, for instance, must be perfectly straight. If a gear, bearing, or bearing cup is cocked by an improperly applied pulling force, it will be damaged during removal or may become impossible to remove.

Some basic methods of gripping and pulling bearings, gears, pulleys, etc., are shown in Fig. 49-4. Figure 49-5 shows how to grip and pull bearing races and retainer seals, and Fig. 49-6 illustrates how to grip and pull shafts.

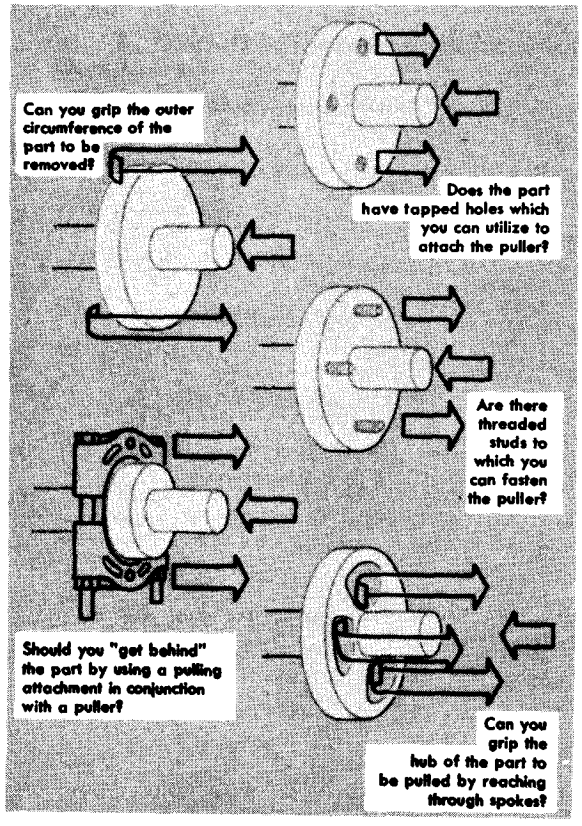


Fig. 49-4 Pointers for gripping and pulling gears, bearings, wheels, etc. *(Owatonna Tool Co., Tools and Equipment Div.)*

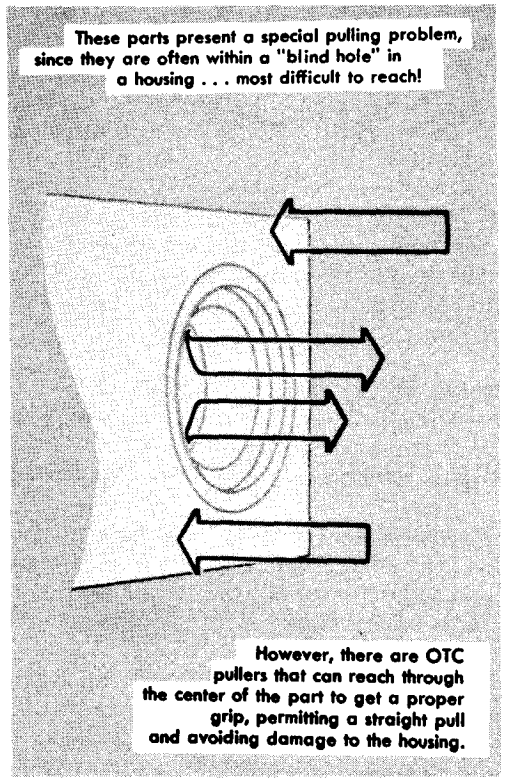


Fig. 49-5 Pointers for gripping and pulling bearing races, retainers, seals, etc. *(Owatonna Tool Co., Tools and Equipment Div.)*

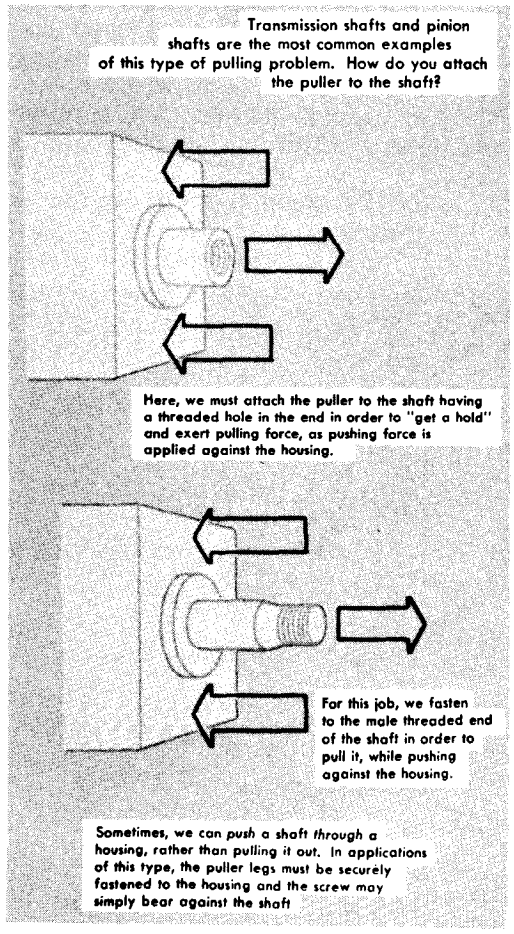


Fig. 49-6 Pointers for gripping and pulling shafts. *(Owatonna Tool Co., Tools and Equipment Div.)*

How to Select the Right Puller

1. Analyze the areas of resistance, or areas of press fit. They can vary greatly between seemingly similar jobs.
2. Select a pulling screw which is at least half as large in diameter as the shaft of the object to be pulled. When using a hydraulic puller, the maximum force exerted, in tons, should be 7 to 10 times the diameter of the shaft in inches (see Table 49-1).
3. Select the proper shaft protector or step plate. Determine which puller type will best grip the part. Perhaps a combination of pullers may be required.
4. The puller you select must have a reach equal to, or larger than, the corresponding dimension of the object to be pulled.
5. Measure the width of the part to be pulled. It will indicate the puller spread requirement. A puller with proper reach and spread will usually be strong enough. When in doubt, always use the next largest size. A larger size may be needed for rusted parts or when the area of resistance is large.

Pointers for Using Pullers

1. Make sure you have sufficient work space when preparing a large pulling job.
2. Lubricate the pulling screw and the center of the step plate or shaft protector to reduce friction.
3. Check for alignment and grip after the slack has been taken up.
4. When necessary, use penetrating oil or moderate heat for rusted parts or when the area of resistance is large.

CAUTION Be prepared in event the object being pulled ejects with great force.

Bushing Inserter and Removing Tools Bushing inserting and removing tools are essential to every diesel service shop to ensure proper bushing removal and installation. They can also be used for the installation of oil seals and many other press-fitted components.

Electric Hand and Bench Drills Although hand or bench drills are routinely used in conjunction with a twist drill, to drill holes, they can also be used for a variety of other purposes. They may be used as the power source for a wire brush or a rotary file, or as a hole-cutter saw. Bench drills and slow-speed hand drills can also be used as the power source to rotate reamers, taps, and dies. Learn to use these tools to their maximum capacity.

TABLE 49-1

HYDRAULIC-PULLER FORCE RELATED TO SHAFT DIAMETER

Shaft diameter, in	OTC hydraulic-puller ton range
0–2	17½
2–3½	30
3½–5½	50
5½–10	100

Pointers for Using Hand and Bench Drills

1. Secure the object to be drilled so that it cannot rotate with the twist drill, should the twist drill grab. A vise should be used whenever possible.
2. Make sure that your work clothes are buttoned up so that they cannot be caught in the drill.
3. Make sure that you use a three-prong plug connector. *Never* use power tools if your feet are wet.
4. Make sure that the twist drill is sharpened properly and the hole to be drilled is center-punched.
5. Whenever possible select the correct speed. Alternatively, you can start with a slow speed and light feed and gradually increase both until the twist drill forms the correct chips. Usually the most efficient operation results from a heavy feed and moderate speed.
6. Use cutting oil to prevent surface hardening. This is also useful in cooling the twist drill. Cooling it makes the cutting operation easier and helps to retain the cutting edge. The use of a cutting fluid will improve the hole finish and the cooler chips will minimize the danger of burns. Use kerosene, kerosene and lard oil, or soluble oil when drilling aluminum or bronze. For cast iron, use soluble oil or air pressure. When drilling holes in steel, tool steel, or steel forgings, use soluble oil or mineral lard oil.

Hand and Floor Bench Grinders and Hand Sanders Grinding or sanding is the harsh rubbing action by the abrasive face surface of the grinding wheel or disk as it rotates against the object to be ground. The abrasive grains actually cut chips out of the component being ground.

Selection of Grinding Wheels Grinding wheels and sanding disks come in many different sizes and shapes to meet a multitude of demands. Your concern, however, is with abrasive grains which suit the various types of metals you will be handling. The two types of abrasive grains are aluminum oxide and silicon carbide.

Grinding wheels are identified by a color code. The regular aluminum oxide grinding wheel is red. It is acceptable for grinding all types of steel. The special aluminum oxide wheel is white. Although it is not as tough as the regular grinding wheel, it is used to grind tools and high-speed steel. The regular silicon carbide is green and is used to grind cast iron, brass, copper, and aluminum.

The object to be ground determines the grain size to be used. It is advisable to have one coarse and one medium grinding wheel for the bench grinder. You can grind most soft materials with the coarse grinding wheel and most hard materials with the medium grinding wheel.

Testing and Mounting Grinding Wheels Before mounting a grinding wheel, test the wheel for damage by inserting (through the center hole) a screwdriver and tapping the wheel every 45° around its circumference. An undamaged wheel will give a clear metallic tone. If it is cracked, there will be a dull sound.

When mounting the wheel, make sure that the flanges are undercut and that the wheel goes easily onto the spindle. Do not force the wheel onto the

spindle; instead, scrape the bushing hole to a larger size. After installation or after the wheel becomes loaded, glazed, or out-of-round, the wheel should be dressed with a star wheel dresser. Work the dresser freehand, but always use the work rest to support the dresser. Adjust the work rest as close as possible to the wheel. The maximum distance should not exceed ⅛ in [3.18 mm]. This will prevent the work from being caught between the wheel and the rest.

Pointers for Using Grinders or Sanders

1. Wear safety goggles at all times when performing any operation with a sander or grinder.
2. Make sure that all safety equipment (such as guards) is in place.
3. Hold the work securely. Do not let the work hammer or hit against the grinding wheel; otherwise the wheel may explode.
4. Keep your shirt sleeves buttoned or rolled up. Avoid all personal contact with the moving wheel.
5. Stand to one side when starting the grinder. Allow the wheel to reach full rpm before using it.
6. Do not grind on the side of the wheel unless it was manufactured for that purpose.

Bench Vise Each mechanic should have a vise in his or her working area to save unnecessary steps. The vise (Fig. 49-7) is the proverbial workhorse. Without it, many service jobs would be very difficult or even impossible.

Pointers for Using Bench Vises

1. Keep the vise clean and securely supported on the workbench. Check that the jaws are tightened.
2. Do not expose the jaws of the vise to excessive heat. *Never* use the vise as an anvil.
3. Do not use an extension over the vise handle. Do not use a hammer to increase jaw force. The latter can break the spindle, nut, or jaws.

Impact Wrenches Impact wrenches should be standard equipment in every service shop as time- and labor-saving devices. Whether they are air- or electrically operated will depend on the type of service the workshop performs. Many mechanics do not use the impact wrench to its fullest advantage. You will find it a most useful tool even if only to tighten or loosen a few bolts or nuts.

Pointers for Using Impact Wrenches

1. Keep this tool in good operating condition by using an airline filter and oiler.

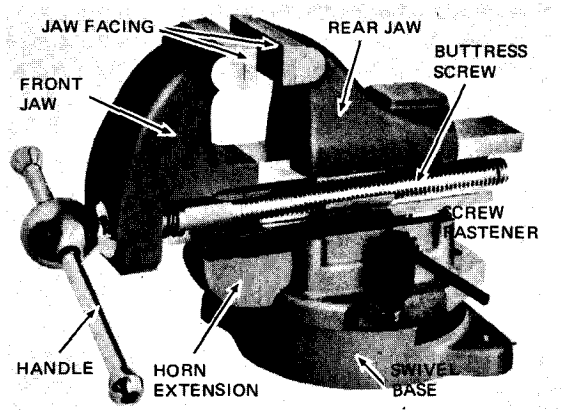


Fig. 49-7 Bench vise.

2. When possible, use a recoil airhose for safer and easier operating and handling.
3. Use only impact sockets and extensions.
4. When using an air-impact wrench, adjust the air-valve regulator to achieve the desired torque.

Questions

1. List the safety precautions you must take when using a steam cleaner, a hot tank, and a solvent cleaner.
2. List the safety precautions you must take when using a grease gun.
3. What safety precautions must you take when using a floor jack, a chain hoist, and a portable crane hoist?
4. Describe how to operate a frame shop press. What safety precautions must be taken while operating it?
5. What factors govern the selection of the correct puller?
6. List the safety precautions you must take when using a hand drill, a bench drill, a hand sander, a grinder, and a bench grinder.
7. Give the color code of the grinding wheel which is best suited for aluminum and tool steel.
8. List the reasons why a new grinding wheel should be tested before being installed; a new grinding wheel should be dressed after installation.
9. List the circumstances under which you should *not* use the aid of a vise.
10. List the safety precautions to be taken when using an impact wrench.

UNIT 50 • MEASURING TOOLS

All service and repair jobs require analysis, diagnosis and measurement, to determine the cause of the trouble. After disassembly, a regular series of steps are repeated to determine each component's serviceability. When you reassemble and install components to the engine, you must make exact measurements to ensure proper operation.

It is obvious then, that knowing how to use and read the various measuring tools is of vital importance. All measuring tools used by you (with the exception of the protractor) measure distance in inches or thousandths of an inch [millimeters or hundredths of a millimeter]. It is essential for you to be able to interpret both measuring scales.

Selection and Care of Measuring Tools Earlier in this textbook it was suggested that for lasting accuracy and performance you should buy only high-quality tools. This statement is even more relevant when buying measuring tools. Also, careful handling and proper storage cannot be overemphasized. Measuring tools are delicate instruments and their precision is quickly affected by mishandling or improper storage. Any such tools which are not in constant use should be kept lightly oiled. A padded box or cloth wrapping will help minimize exposure to atmospheric air and thereby prevent oxidation.

The following measuring tools, although not precision instruments, should be among the essential tools for your toolbox. The main items are the 6- or 12-in steel rule, straightedge, feeler gauge, divider, and inside and outside calipers. You should also have access to spring scales and screw pitch gauges.

Reducing Common Fractions Dimensions used on engine or fuel-injection systems or assembly operations are given in terms of common fractions or decimals. As it is often necessary to change common fractions into decimals or vice versa, you should memorize the following formula: divide the numerator by the denominator.

For example, to change 3/8 to a decimal:

- Divide the numerator 3 by the denominator 8.
- Place a decimal point after the 3.
- Locate the decimal point in the quotient.
- Add as many zeros as are needed to obtain a quotient which can be rounded off to the required number of decimal places.
- Divide. The result is the decimal equivalent of the common fraction 3/8.

```
0.375
8)3.000
  24
  60
  56
  40
```

Reducing Decimal Fractions to Common Fractions

- Write the number after the decimal point as the numerator of a common fraction.
- Write the denominator as 1 with the same number of zeros after it as there are digits to the right of the decimal point.
- Reduce the resulting fraction to lowest terms.

For example, to change 0.3125 to a common fraction:

- Write number after the decimal point as the numerator: 3125.
- Determine the denominator: 1 + 4 zeros = 10000.
- Reduce the fraction to lowest terms:

3125/10000 = 5/16.

6-in Steel Rules The steel rule should have English measurements in thirty-second and sixty-fourth graduations on one side and metric measurements in half-millimeter graduations on the other side.

Straightedge As its name inplies, a *straightedge* is used to check the surface of the flywheel, cylinder head, or a manifold flange for flatness. Handle this tool with care. Do not use it for any other purpose than that for which it was designed.

Feeler Gauge A *feeler gauge* or *thickness gauge* is a fixed distance measuring gauge with its thickness marked in thousandths of an inch or hundredths of a millimeter. It is wise to have a set of no-go feeler gauges as well as a standard set and a millimeter set (Fig. 50-1).

Screw Pitch Gauge A most useful tool to quickly determine the pitch of various threads is the *screw pitch gauge.* Each of its folding leaves has teeth corresponding to a definite pitch. By matching the teeth with the thread on the work, the correct pitch can be read directly from the leaf.

Calipers and Dividers *Calipers* are used to measure chambers, cavities, bores, grooves, flanges, or shafts (Fig. 50-2). The distance between the caliper points is then measured with a rule. For even greater precision, measurements can be made with a micrometer (see the section on Micrometers later in this unit). A *divider* is different from a caliper in that it has

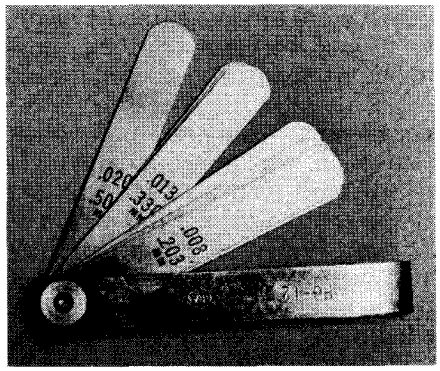


Fig. 50-1 Feeler gauge marked in hundredths of a millimeter and thousandths of an inch.

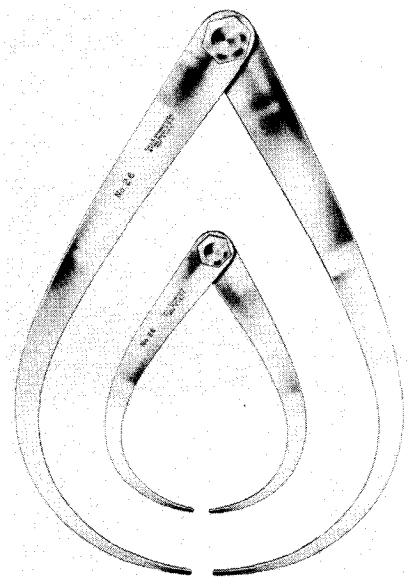


Fig. 50-2 Outside calipers. *(The L.S. Starrett Co.)*

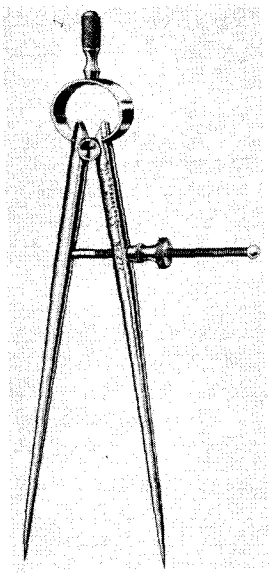


Fig. 50-3 Divider. *(The L.S. Starrett Co.)*

pointed legs and therefore is a handy tool for layout work, surface measurements, etc. (Fig. 50-3).

Protractor A combination square, combination set, and bevel *protractor* are among the most useful tools you can have if your work demands the measuring of levels and angles during engine installation.

How to Use Protractors To measure an object for its horizontal installation, hold the square head on the surface to be measured. The air bubble in the spirit-filled glass tube will indicate if the object is parallel to the horizontal. To find the exact measurement of this angle in degrees, lay the protractor on the surface to be measured and then turn the degree ring so that the air bubble is in the middle of the two graduation marks. The graduation scale on the protractor head will show the tilt of the object in degrees and minutes.

Spring Scale When deciding whether to purchase a spring scale, remember that a graduation in pounds and ounces [kilograms] is useful when measuring torque or the resistance of a spring.

Precision Measuring Tools The most common adjustments to components are in measurements of thousandths or ten-thousandths of an inch [or in hundredths or thousandths of a millimeter]. The instruments with which you can measure such precision are the micrometer, the dial indicator, and the vernier caliper.

Micrometers All micrometers have an accurately ground screw which rotates in a fixed nut (spindle nut in Fig. 50-4). This opens and closes the distance between two measuring faces on the ends of the anvil and spindle or between the spindle and the object, or between one fixed and one movable spindle. The pitch of the screw is 1/40 in or 40 threads per inch. With one complete revolution of the thimble, the spindle will move outward or inward precisely 0.025 in. The sleeve is divided by vertical lines into 40 equal parts that correspond to the numbers of threads on the spindle; each vertical line designates 0.025 in. For faster and easier reading, the manufacturers of micrometers have made the vertical lines of three different lengths. Every fourth line, which is the longest line, designates 0.100 in. For example, the line mark "1" represents 0.100 in, and the line mark "2" represents 0.200 in. Every short line represents 0.025 in, and every middle length line represents 0.050 in.

As you can see from Fig. 50-4, the thimble is beveled. It is divided into 25 equal parts with each line representing 0.001 in. Rotating the thimble from one of these lines to the next line will move the screw and spindle longitudinally 0.001 in.

For speedier reading, every fifth graduation (on the thimble) has a longer line and is numbered 0, 5, 10, and so on. Therefore, when the thimble is rotated from No. 0 to No. 15, the spindle has moved 0.015 in or, when the thimble has made a complete revolution, the spindle has moved 0.025 in.

How to Read Outside Micrometers Graduated in Thousandths of an Inch (0.001 in) To read the micrometer graduated in thousandths of an inch (0.001 in), multiply the number of vertical divisions visible on the sleeve (past the 0 mark) by 0.025. Add to this the number on the thimble which coincides with the longitudinal line on the sleeve. As an example see Fig. 50-5.

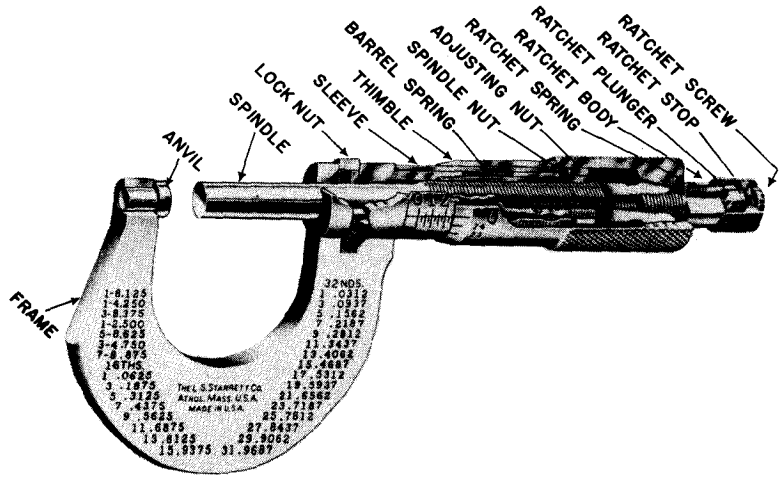


Fig. 50-4 Cutaway view of a micrometer. *(The L.S. Starrett Co.)*

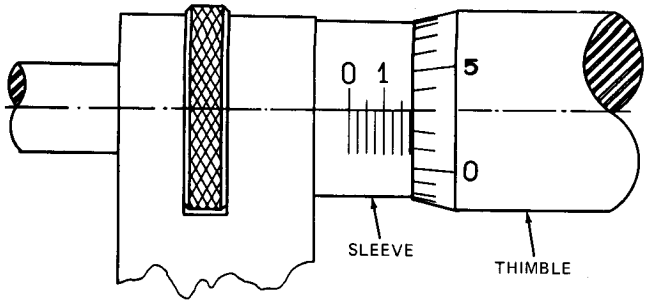


Fig. 50-5 Reading a micrometer graduated in thousandths of an inch. *(The L.S. Starrett Co.)*

- Seven lines are visible. Multiplying 7 by 0.025 equals 0.175 in.
- The third line of the thimble coincides with the longitudinal line on the sleeve. Therefore, multiplying 3 by 0.001 equals 0.003 in.
- Adding 0.175 to 0.003 equals 0.178 in.

There is a second method to determine the micrometer reading shown in Fig. 50-5.

- Read the last number on the sleeve: 0.100 in.
- Multiply each additional line shown on the sleeve by 0.025: 3 × 0.025 = 0.075 in.
- Read the number which coincides with the longitudinal line on the sleeve: 3 = 0.003 in.
- The total reading is 0.100 + 0.075 + 0.003 = 0.178 in.

How to Read Outside Micrometers Graduated in Ten-thousandths of an Inch (0.0001 in) Micrometers graduated in 0.0001 in are similar to those which are graduated in 0.001 in except they have a vernier graduation scale on the sleeve (Fig. 50-6). The vernier scale consists of 10 divisions on the sleeve, which occupy the same space as 9 divisions on the thimble. Therefore the difference between the width of one of the 10 spaces on the vernier scale and one of the 9 spaces on the thimble is one-tenth of a division on the thimble, or one-tenth of 0.001 in which is 0.0001 in.

To read a micrometer graduation of 0.0001 in, you must first obtain the 0.001-in reading, then check which line on the vernier scale coincides with the line on the thimble. If it is the line "1," add 0.0001 in. If it is the line marked "2," add 0.0002 in. If it is the line marked "3," add 0.0003 in, and so on.

In Fig. 50-6, the number 2 line on the sleeve is visible, representing 0.200 in. Two additional lines are visible, each representing 0.025 in, totaling 0.050 in. The longitudinal line on the sleeve lies between 0 and 1 on the thimble, indicating 0.000 in. *(NOTE: It must also be added when it reads more.)* The seventh line on the vernier scale coincides with a line on the thimble representing 0.0007 in. The total equals 0.2507 in.

How to Read Micrometers Graduated in Hundredths of a Millimeter (0.01 mm) The design of a micrometer graduated in 0.01 mm is similar to the micrometer graduated in thousandths of an inch. The only differences are: (1) The spindle screw has a 0.5-mm pitch and, therefore, one complete revolution of the thimble moves the screw and spindle 0.5 mm. (2) The thimble is graduated equally in 50 divisions with every fifth line numbered from 0, 5, 10, to 50. Therefore, each graduation on the thimble is equal to one-fiftieth of ½ mm, or 0.01 mm. Two complete turns of the thimble will move the spindle 1 mm.

The procedure for reading a metric micrometer is the same as for reading a micrometer graduated in thousandths of an inch. For example, to read a metric micrometer, you add the total reading in millimeters visible on the sleeve to the reading in hundredths of a millimeter indicated by the graduation on the thimble which coincides with the longitudinal line on the sleeve.

Refer to Fig. 50-7. The 5-mm graduation is visible, thereby representing 5 mm. There is one additional 0.5 mm line visible, representing ½ mm. Line 28 on the thimble coincides with the longitudinal line on the sleeve. Each line represents 0.01 mm and the total is 0.28 mm. Therefore, the aggregate total reading for this example is 5.78 mm.

Inside Micrometers As the name suggests, the inside micrometer is capable of measuring distance between two inside surfaces. The inside micrometer has the same micrometer head as the outside micrometer and, therefore, is read in the same manner.

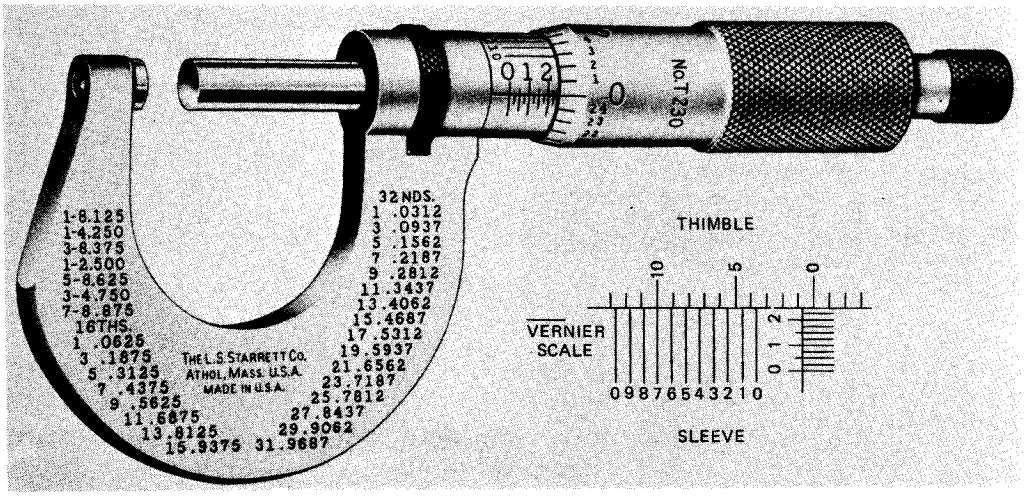


Fig. 50-6 Reading a micrometer graduated in ten-thousandths of an inch. *(The L.S. Starrett Co.)*

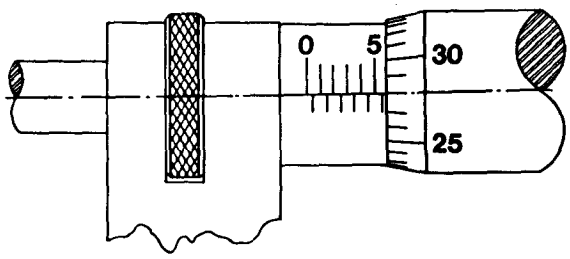


Fig. 50-7 Reading a micrometer in hundredths of a millimeter. *(The L.S. Starrett Co.)*

Micrometer Depth Gauge The micrometer depth gauge is used to measure the distance between two surfaces. You will notice from Fig. 50-8 that the micrometer head is the same as the inside and outside micrometers. However, the anvil is moved and enlarged to a precision-ground and lapped base. The numbers on the sleeve start from the right and the graduation numbers on the thimble start from below the 0 mark.

How to Read Micrometer Depth Gauges Graduated in Thousandths of an Inch (0.001 in) When the thimble is turned in a clockwise direction so that the bevel edge reaches the left 0 mark of the sleeve and the thimble 0 mark is in longitudinal line on the sleeve, the rod in then precisely 1, 2, 3 in, etc. (depending on the rod length) from the base. Conversely, when the thimble is turned counterclockwise so that the bevel edge of the thimble reaches the right 0 mark of the sleeve, and the thimble 0 mark is in longitudinal line on the sleeve, the rod is then precisely flush with the base or 1, 2, in, etc., depending on the rod length used. This, of course, is assuming that the micrometer is properly adjusted.

When you turn the thimble one complete revolution in a clockwise direction, the rod will extend exactly 0.025 in. When you turn five complete revolutions, the rod will extend exactly 0.125 in.

To read a micrometner depth gauge in 0.001 in, multiply the last concealed division on the vertical scale by 0.025 in and add to this the number of 0.001 in indicated by the lines on the thimble which coincide with the longitudinal line of the sleeve.

Refer to Fig. 50-8. The concealed number on the sleeve is 8, which represents 0.800 in. There are two additional lines not visible (each line representing 0.025 in); $2 \times 0.025 = 0.050$ in. The 0 on the thimble coincides with the longitudinal line on the sleeve, which means no additional thousandths of an inch measured. Therefore the micrometer reading is $0.800 + 0.050 + 0.000 = 0.850$ in.

Pointers for Using Micrometers

1. Check the micrometer for accuracy by using the gauge stock provided for that purpose.
2. Clean the surfaces to be measured as well as the anvil and spindle before attempting any measurement.
3. Balance the micrometer with two or three fingers so that it is parallel to the object to be measured. Use your other hand to lightly support the micrometer head.
4. Do not force the spindle against the object to be measured. The micrometer or object should slide through without restriction.
5. Use the ratchet stop to ensure proper force. Move the object to be measured back and forth between the anvil and spindle when making the final ratchet stop adjustment. Then lock the spindle so that the spindle cannot move out of adjustment.
6. When using a micrometer depth gauge, use only two fingers across the base so that you can feel when the rod contacts the surface to be measured.

Dial Indicators *Dial indicators* are used to measure distance of movement in thousandths, half-thousandths, or hundred thousandths of an inch or to measure a millimeter, hundredths or thousandths of a millimeter (Fig. 50-9). Your workshop should have indicators scaled in both inches and millimeters for measuring such things as the movement of timing gears, fuel-injection pump plungers, the straightness of a valve stem, or the travel of the fuel rack. The face of the dial indicator should be of the balanced type, that is, both positive and negative graduations. The

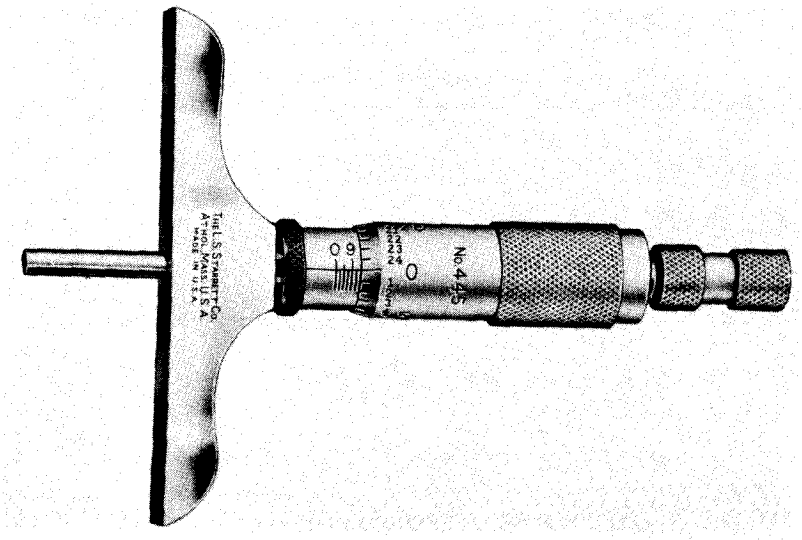


Fig. 50-8 Micrometer depth gauge. *(The L.S. Starrett Co.)*

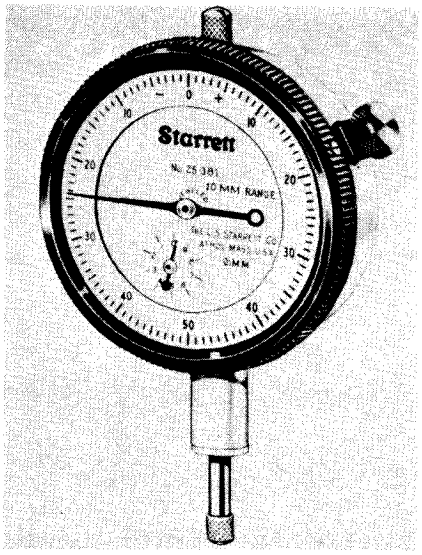


Fig. 50-9 Balance-type dial indicator graduated in hundredths of a millimeter. *(The L.S. Starrett Co.)*

measuring range should be at least 1 in. A dial indicator without an attachment can seldom be used to measure movement unless it is to check the roundness of bores or of cylinders. Many mounting attachments and contact points of various designs are needed to install the dial indicator correctly in order to make a precise measurement.

Special Dial Indicators Special dial indicators do not differ from any other dial indicators except that they are mounted on their own specially designed base to suit some particular purpose.

CYLINDER AND OUT-OF-ROUND GAUGES Cylinder gauges and out-of-round gauges are ideal measuring instruments when your service work includes reboring or regrinding cylinders and connecting rods or rebuilding unit injectors. They readily determine taper, out-of-roundness, or concentricity of the nozzle tip (Fig. 50-10).

DIAL DEPTH GAUGE The dial depth gauge is a useful tool to have when servicing fuel-injection pumps because it can quickly and accurately measure plunger lift, head clearance, or fuel-rack travel. As you can see from Fig. 50-11 the dial face is of the continuous type.

Pointers for Using Dial Indicators

1. Make certain that you have selected the best mounting attachment and a suitable contact point.
2. Make certain that the dial indicator and base are firmly attached and that the measuring rod is parallel to the object being measured.
3. Check that the rod, spindle, and dial needle move freely and that the dial range is adjusted so that the full movement of the object can be measured.
4. Always turn the dial face so that the zero line is placed over the dial needle.
5. Take at least two readings. Move or turn the object against its stop or end of travel to ensure the accuracy of measurement.

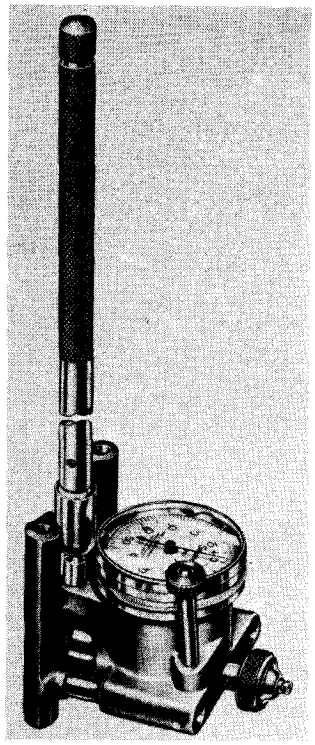


Fig. 50-10 Cylinder gauge. *(The L.S. Starrett Co.)*

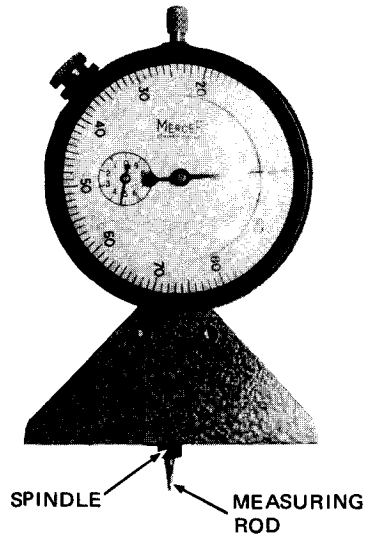


Fig. 50-11 Dial depth gauge.

6. Store the measuring tool in a protective case. Do not oil the spindle or gear mechanism.
7. When you measure with a cylinder gauge, always lock the locking mechanism before you move the tool from the cylinder because this clamps the adjustable contact points. These points are synchronized with the indicator needle. Remeasure with a micrometer the exact diameter you have measured with the cylinder gauge.

Vernier Calipers The *vernier caliper* differs from the vernier micrometer both in construction and in its principle of operation. The reading on the vernier caliper is not obtained by the relationship between the pitch of a screw and the movement of the thimble

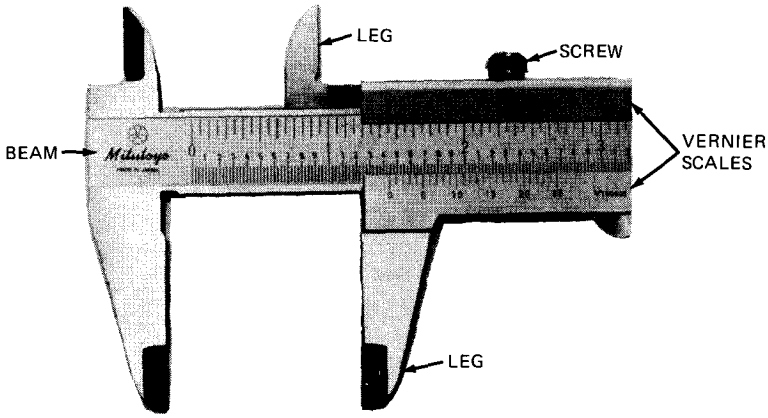


Fig. 50-12 Vernier caliper graduated in 1/25 and 1/16 in.

as it is on the vernier micrometer. Instead, the vernier caliper's legs are slid into position and accurately adjusted for measurement by means of a fine screw which moves a sliding leg on a beam or bar. The measurement is then determined by adding the reading on the beam and the graduation on the vernier scale (Fig. 50-12).

Vernier calipers are designed to measure inside and outside dimensions in thousandths of an inch or hundredths of a millimeter. By varying the standard design, the vernier caliper can also be made to measure height and depth.

The beam of the tool is graduated in inches, and each is divided into 20 or 40 equal parts representing 1/20 or 1/40 in, respectively, (or equal to 0.050 or 0.025 in).

Every second or fourth division is longer and is numbered to represent 0.100 in. The vernier scale has 50 or 25 divisions which correspond with either 49 or 24 divisions on the beam.

How to Read 50-division Calipers If you set the tool so that the 0 line on the vernier scale coincides with the 0 line on the bar, the line to the right of the 0 of the vernier will differ from the line to the right of the 0 on the bar by 0.001 in, the second line by 0.002 in, and so on. The difference will continue to increase by 0.001 in for each division until the line 50 on the vernier scale coincides with line 49 on the bar. When you read the tool, note how many inches and how many 0.100 in and 0.050 in that the 0 mark on the vernier scale is from the 0 mark on the bar. Then note the number of divisions on the vernier scale from the 0 to a line which exactly coincides with a line on the bar.

For example, refer to Fig. 50-13. An outside measurement has been made and the measurement is locked in. The two legs are exactly 1.464 in apart because the 0 mark on the vernier scale is past the 1.000-in graduation line and 9 additional divisions to the right are visible. (Multiply 9 × 0.050 = 0.450 in.) The fourteenth line on the vernier scale coincides with a line on the bar which equals 0.014 in. When you add the reading on the bar to the vernier reading, you will obtain the exact measurement: 1.000 + 0.450 + 0.014 = 1.464 in.

How to Read 25-division Metric Vernier Calipers The difference between the English and metric vernier caliper is that the bar on the metric vernier is graduated in centimeters, millimeters, and half-millimeters. The vernier gives a final reading of 1/5 mm (equal to 0.02 mm). Apart from this, the same principles apply when reading metric measurements as when reading English measurements.

For example, the result of a measurement made with a metric vernier caliper is shown in Fig. 50-14. The 0 mark on the vernier scale is past the 40-mm graduation mark on the bar. Also, three divisions are visible to the right: 3 × 0.5 mm = 1.5 mm. The ninth line on the vernier scale coincides with a line on the bar. Therefore, 9 × 0.02 mm = 0.18 mm. When you add the reading of the bar to the vernier reading, you will have the exact measurement: 40.00 + 1.50 + 0.18 = 41.68 mm.

Pointers for Using Vernier Calipers

1. Clean the legs and check the tool for accuracy.
2. Clean the objects to be measured and slide the movable leg close to the surface. Lock it with the right-hand screw to the bar and have light tension on the left-hand screw.
3. Be certain that the legs are parallel to the object to be measured and do not force the legs together.
4. Adjust the leg with adequate force so that the object just sits between the two legs. Then lock the reading in.

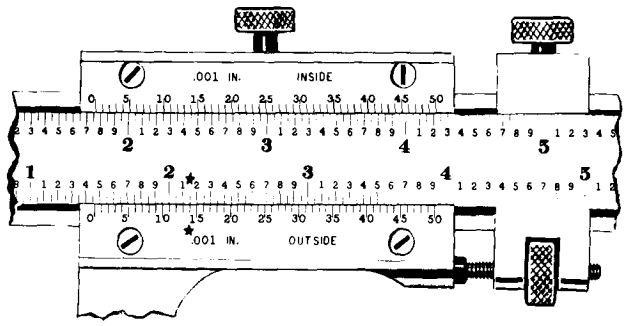


Fig. 50-13 Reading a vernier caliper. *(The L.S. Starrett Co.)*

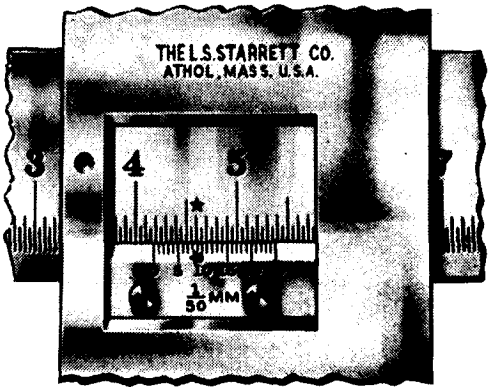


Fig. 50-14 Reading a metric 25-division vernier. *(The L.S. Starrett Co.)*

Hole and Telescopic Gauges *Hole* and *telescopic gauges* are used to determine hole size or to check a hole for taper or out-of-roundness (Fig. 50-15). The tool itself only fixes the distance between the two surfaces. A micrometer or a vernier caliper is needed to measure the distance.

How to Use Hole and Telescopic Gauges Hole gauges are used to measure openings up to a ½-in diameter, whereas telescopic gauges will measure up to a 6-in diameter. Each gauge has the ability to measure over a fixed distance, for example, a hole gauge from 0.300 to 0.400 in and a telescopic gauge from 0.700 to 1.250 in.

To use a hole gauge, insert the gauge into the hole and adjust the split ball by means of the knurled knob so that the two sides of the split ball contact the surface lightly. With the telescopic gauge, the contact plunger expands to the hole size. When you feel the plunger touch the sides of the hole, lock the plunger by turning the knurled knob. Withdraw the gauge, and with a micrometer or vernier caliper, measure the distance across the two contact points.

Speed Indicator A *speed indicator* (*hand tachometer*) is used to measure the rotating speed of a shaft in either direction. The outer dial plate is graduated from 0 to 100, reading from left to right, or vice versa. Each graduation represents one revolution of the spindle. Therefore, one complete revolution of the large dial indicates 100 revolutions. The small dial has 50 groove lines on its face, each representing 100 revolutions. Therefore, one complete revolution of the small dial indicates 5000 revolutions.

How to Use Speed Indicators Select a tip suitable for the desired application and push it gently onto the spindle. Set the raised point on the inner dial to 0. Position the indicator tip on the rotating object. (The rotating inner dial can be prevented from turning by firmly pressing on the raised knob.) Release the knob, and for the count of 1 minute, allow

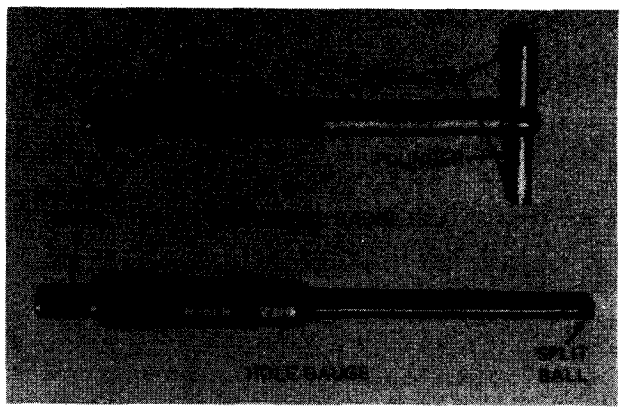


Fig. 50-15 Telescopic and hole gauges.

the rotating disk to turn to record the number of revolutions. Read the inner and outer dials.

Questions

1. What line on the thimble of the micrometer will be aligned with the zero reference line when the reading of the micrometer is 2.071 in?
2. What is the fractional equivalent of 3.750 in expressed in its lowest terms?
3. What will be the finished size of a crankshaft bearing journal when ground 0.020 in undersize if the original size was 2.0625 in?
4. Which of the following can be used to measure inside diameters: outside micrometer, telescope gauge and outside micrometer, measuring hole gauge, or small-hole gauge and ruler?
5. Which of the following turns when the thimble of a micrometer is turned: hub, spindle, anvil, or sleeve spindle nut?
6. Which of the following is the analogous term for step-type feeler gauges: angle step gauges, no-go gauges, spark plug gauges, or go and no-go gauges?
7. List the things you would do to take care of your measuring tools.
8. What are the decimal equivalents of $1\frac{1}{32}$, $\frac{13}{64}$, and $\frac{9}{16}$?
9. For what measurements can a feeler gauge be used?
10. Explain how to measure the camshaft diameter of a turbocharger.
11. Explain how to measure a camshaft-bearing bore using an inside micrometer.
12. Explain how to measure the depth of a gear-pump housing using a micrometer depth gauge and by using a dial-indicator depth gauge.
13. List the steps you must take to mount or fasten a dial indicator to measure the runout of a flywheel or the end play of a shaft.
14. What carelessness during installation or mounting would lead to a false reading of the dial indicator?
15. What measuring advantage does a vernier caliper have over a micrometer?
16. Explain how to measure a valve guide using a hole gauge and a micrometer.

UNIT 51 • FASTENERS, TAPS, AND DIES

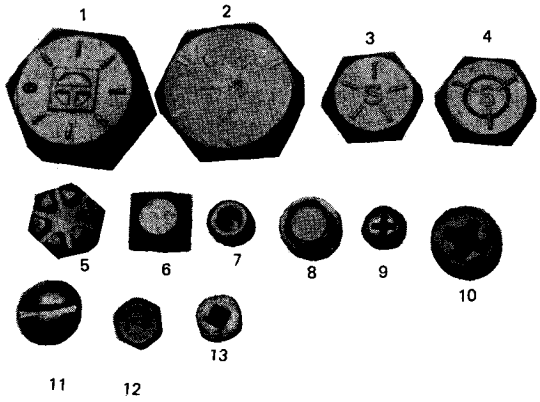
Two metals can be joined together by three basic methods: (1) welding (brazing or soldering), (2) riveting, and (3) using threaded fasteners (screws, hex bolts, and nuts). The latter method is the most advantageous because the two metals can be taken apart without being damaged.

A bolt is used to join two metals when there is room to screw a nut onto the end of the bolt. The bolt is inserted through the holes, then a nut is screwed onto the bolt's threaded end and torqued to force the metals together.

A screw is used to join two pieces of metal when one side is inaccessible and therefore a nut could not be threaded onto the bolt. The screw is inserted through one hole and threaded into the other hole and the metal pieces are forced together as the screw is being torqued.

Stud bolts have threads on both ends. They are used when a bolt or screw would not provide satisfactory clamping force.

Classification and Identification of Bolts and Screws The dimension and design of almost every bolt and screw meet SAE standards. There are a number of ways to categorize the different bolts and screws. One way is by the head design of the bolt or screw (see Fig. 51-1).



1. Hex bolt—exceeds SAE grades, tensile strength 180,000 psi [1,241,064 kPa]
2. Hex bolt—grade 8, tensile strength 150,000 psi [1,034,220 kPa]
3. Hex bolt—grade 7, tensile strength 133,000 psi [917,008.4 kPa]
4. Hex bolt—grade 5, tensile strength 120,000 psi [827,376 kPa]
5. Self-locking hex bolt
6. Square-head bolt
7. Socket-head bolt
8. Hexagon-washer-head bolt
9. Round-head machine screw
10. Oval-head-trim machine screw
11. Thrust-head machine and tapping screw
12. Hexagon-reset-head machine and tapping screw
13. 100° flat-head machine and tapping screw

Fig. 51-1 Bolt and screw head designs.

NOTE: Because you cannot screw an English bolt into a metric threaded hole or vice versa, straight metric conversions of bolts, screws, nuts, threads, etc., are not always useful and will not be listed in this unit. However, both the English and metric systems of measurement use the same method of categorizing bolts and screws.

Special Screws One of many special screws is the set screw. It is used to hold collars and gears, etc., in position. As you can see from Fig. 51-2, the head and point designs vary to suit specific applications.

Other special bolts and screws are shown in Fig. 51-3. These specially designed heads and shanks provide an exact alignment and ensure interference-free connection fastenings.

The thrust head screw, round head, step bolt, countersunk, square neck, ripped neck, and cartridge bolts are used where appearance and smoothness are important.

Self-tapping Screws *Self-tapping screws,* with various head and thread designs, are most commonly used on sheet metal work. Because of the thread design, tapping screws cut their own threads into a drilled or punched-out hole.

Size of Bolts and Screws Another way in which to identify a bolt or screw is by its size. The size of a bolt or screw is measured by the bolt diameter. The diameter of hex-head bolts, cap screws, and studs is measured in fractions of an inch starting with ¼ in and increasing by sixteenths up to ⅞ in. From ⅞ in, it increases to 1½ in, in ⅛-in increments. Bolts and screws of less than ¼-in diameter are classified by a numbering system from 0 to 14, for example, No. 0 = 0.001-in diameter and No. 14 = 0.024-in diameter. Some bolts and screws are numbered from 0 to 24, and these range from 0.060 to 0.371 in.

Bolt and Screw Length Bolt and screw lengths are measured from the extreme end to the bearing surface of the head. Bolts and screws of diameters up to 2½ in increase in length by ¼ in. From 2½ to 6 in, they increase in length by ½ in.

Bolt and Screw Thread Series and Pitch The thread series and pitch are directly related: The thread series governs the pitch. *Pitch* is defined as the distance from a point on a screw thread to a corresponding point on the next thread, measured parallel to the axis. The pitch of a bolt or screw can

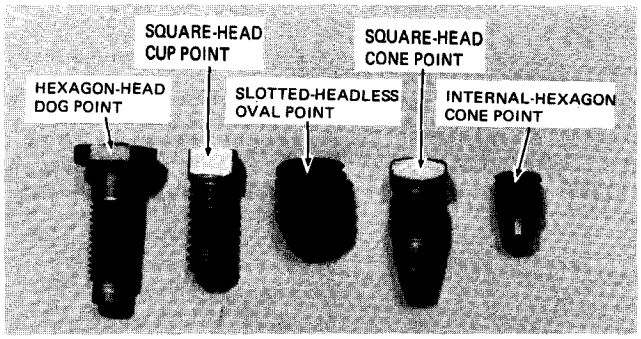


Fig. 51-2 Setscrews.

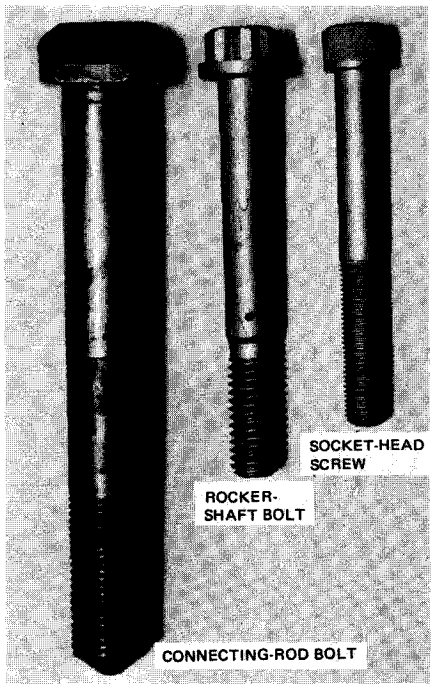


Fig. 51-3 Special bolts and screw.

be measured with a thread gauge by comparing the various blades which have different pitches with the threads of the bolt or screw.

The *thread series* of a bolt or screw identifies the number of threads per inch which are equal to the number of pitches per inch. Although there are about 24 different thread series used in industry, you need only be concerned with those commonly used on diesel engines or related machines (see Table 51-1).

1. (U)NC (American National Coarse Thread Series)
2. (U)NF (American National Fine Thread Series)
3. (U)NEF (American National Extra Fine Thread Series)
4. N (American National, 8-, 12-, and 16-Pitch Series)
5. NPGF [American Standard Tapered Pipe (Dryseal)]

There is a difference between the American National Coarse Thread Series and the Unified Standard. Figures or letters on the bolt head are used to identify Unified Standard bolts. In the Unified System of screw thread limits, the term *Class of Fits* once applied to the assembly characteristics of mated parts. The term *Class of Thread* now indicates only the limits of one component and does not imply that the mating part need necessarily be made to the corresponding class of limits. In fact, any class of internal thread may be used to assemble with any class of external thread so long as the assembly meets the requirements of the end product.

Thread Classes and Grade Marking The Unified Screw Thread System includes three classes of external threads, 1A, 2A, 3A, and three classes of internal threads, 1B, 2B, 3B. Associated with these three classes will sometimes be found two of the old American National classes 2 and 3, formerly called *fits*.

The tensile strength of a bolt, screw, or stud is graded by the numbering system 1, 2, 4, 5, 7, and 8. Grades 5, 7, and 8 are identified on the head (see Fig. 51-1). *(NOTE: Grades 1, 2, and 4 have no identification markings because of their low tensile strength.)*

It is obvious, then, that when ordering screws and bolts from the parts department or tool room, you should specify the head design, the bolt size, the bolt length, the thread series, and the bolt grade. The class or fit will most commonly be 2A or 2B unless you require the bolt, screw, or nut specially designed for a particular purpose.

Metric Fasteners Most fuel-injection equipment is manufactured with the international metric 60° thread. The identification of a metric thread is simple because the diameter and the pitch are used to identify the bolt, screw, or nut.

As you can see from Table 51-2, most bolts, screws, or studs are produced in three pitches which are about equal to (U)NC, (U)NFC, (U)NEF.

Metric bolts, screws, and studs are also graded by a numbering system, but the identification marks for grades, 5, 7, and 8 are a cross, a square, and a triangle, respectively.

Washers *Lock washers* are able to hold the nut and bolt in position because the energy of the spring or the multitooth lock washer bites into the surface when the screw, nut, or bolt is tightened. Although *flat washers* serve many purposes, their main functions are to act as a seal or to allow more even distribution of the bolt-head force.

Pointers for Using Bolts, Studs, and Screws

1. Select the proper thread, series, size, length, and class. If any one of these factors is incorrect, the bolt, stud, or screw will fail as a fastener.
2. Under all circumstances tighten the bolt to a precise torque and sequence.
3. Use the correct lock washer and flat washer.

Causes of Bolt or Cap-screw Failure Bolts and screws, like any other components, can eventually become ineffective because of varying circumstances. Listed below are some of the causes of their ineffectiveness and/or deterioration.

1. Excessive residual tension (adds to the stress on the bolt or screw)
2. Improper torque, improper grade, or improper in-

TABLE 51-1

ENGLISH BOLT AND SCREW THREAD SERIES AND PITCH

Nominal size of wrench, in	Basic diameter, in	Nominal size of screw and bolt, in	(U)NC	(U)NF	(U)NEF	(U)N8	(U)N12	(U)16	NPTF size, in	NPSF threads per inch
	0.060	0		80					1/16	27
	0.073	1	64	72					1/8	27
	0.086	2	56	64					1/4	18
	0.099	3	48	56					3/8	18
	0.112	4	40	48					1/2	14
	0.112	4	32*	36*					3/4	14
	0.125	5	40	44					1	11 1/2
	0.138	6	32	40					1 1/4	11 1/2
	0.164	8	32	36					1 1/2	11 1/2
	0.190	10	24	32					2	11 1/2
	0.216	12	24	28	32				2 1/2	8
	0.242	14	20*	24*					3	8
3/16	0.1875	3/16	24*	32*						
7/16	0.2500	1/4	20	28	32					
1/2	0.3125	5/16	18	24	32					
9/16	0.3750	3/8	16	24	32					
5/8	0.4375	7/16	14	20	28					
3/4	0.5000	1/2	13	20	28		12			
13/16	0.5625	9/16	12	18	24		12			
15/16	0.6250	5/8	11	18	24		12			
1 1/16	0.6875	11/16	11*	16*						
1 1/8	0.7500	3/4	10	16	20		12	16		
1 5/16	0.8750	7/8	9	14	20		12	16		
1 1/2	0.1000	1	8	12	20	8	12	16		
1 11/16	1.1250	1 1/8	7*	12*	18	8	12	16		
1 7/8	1.250	1 1/4	7*	12*	18	8	12	16		
2 1/16	1.3750	1 3/8	6*	12*	18	8	12	16		
2 1/4	1.5000	1 1/2	6*	12*	18	8	12	16		
2 1/2	1.750	1 3/4	5*			8	12	16		
2 5/8	2.000	2	4 1/2*			8	12	16		

Note: * Denotes nonstandard.

TABLE 51-2

METRIC BOLT AND SCREW THREAD SIZE AND PITCH

Size, mm	Pitch, mm	Size, mm	Pitch, mm
1.6	0.35	6	0.8, 0.75, 1.00
1.7	0.35	8	0.75, 1.00, 1.25
1.8	0.35	9	1.00, 1.25
2.0	0.4	10	1.00, 1.25, 1.5
2.2	0.45	12	1.00, 1.25, 1.5
2.3	0.4	13	1.75
2.5	0.45	14	1.00, 1.25, 1.5
2.6	0.45	16	1.5
3.0	0.5	18	1.5, 2.00, 2.5
3.5	0.6	20	0.5
4	0.5, 0.7		
5	0.5, 0.7, 1.00		

stallation (creates stress changes which in time lead to fatigue and failure)

3. Exposure to extreme heat (reduces tensile strength of bolts)

4. Improper mating of fastener components (causes decarburization and stripping of the nuts and bolts)

5. Cracked or dished washers (cause the fasteners to fail)

6. Improper material, heat treatment, or excessive hardness (causes the head to pop off or the nut to crack)

7. Excessive vibration (causes fracture failure)

Dies The dies shown in Fig. 51-4 are used to cut external threads. When it is necessary to cut large pitch threads, adjustable (split) or two-piece dies are recommended to ensure a clean cut.

How to Cut External Threads

1. Select an adjustable die which has the desired dimension and thread series. For instance, it might be 1/2 in (U)NF.

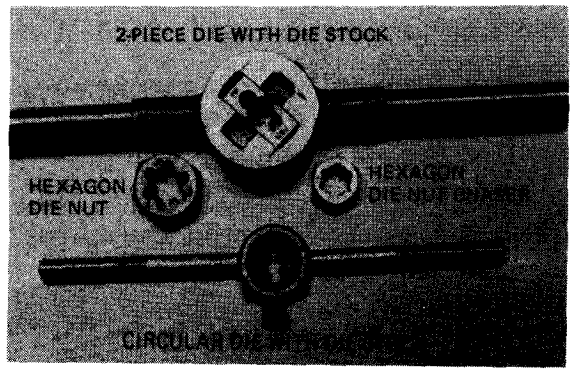


Fig. 51-4 Dies used to cut external threads.

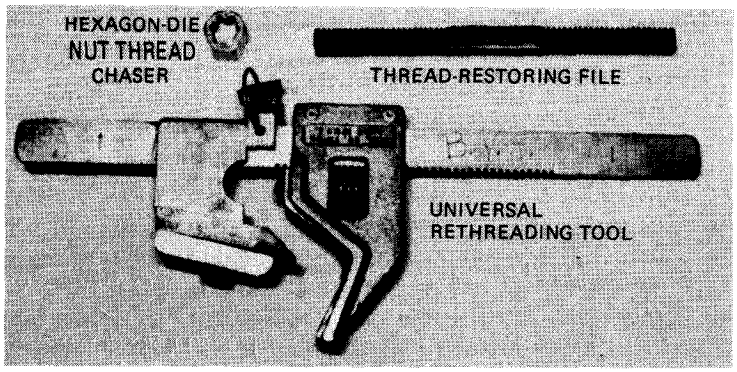


Fig. 51-5 Tools used to restore external threads.

2. Insert the die in the die stock with its full thread toward the die-stock shoulder. Enlarge the diameter with the adjustable screw. Then use the setscrew to lock the die into the die stock.
3. Make certain that the round stock is of ½-in dimension and that the end is chamfered about 4°. This will ensure easier starting.
4. Use the lubricant recommended for drilling.
5. Cut the thread by turning the die stock. While turning, push down with a moderate force. Make certain that you maintain a 90° angle to the round stock.
6. Cut the thread by turning the die stock at slow speed. Keep the die stock well lubricated. Do not reverse rotation because this may break the thread. If it becomes necessary to turn backward, only turn the width of one land, then start cutting again.
7. After you have cut the desired thread length, remove and adjust the die, then repeat the cutting procedure. Check the thread fit with a nut or die to make sure that it has the proper tolerance.

Restoring External Threads There are many ways in which an external thread can be damaged. To restore a damaged thread, you can use a rethreading die or a thread file (see Fig. 51-5). However, in both cases you are limited to a 7 or 8 thread series, whereas the universal rethreading tool shown in Fig. 51-5 is not limited to size or to thread series.

Nuts and Internal Threads *Nuts* of various thread series, size, grade, class, and design are used with bolts and studs. Some of the most common nuts are shown in Fig. 51-6.

Palnut locknuts and *jamnuts* are used to lock a nut to a bolt or stud after the first nut has been properly positioned or tightened. *Slotted* or *castle nuts* are used where thread friction and a lock washer are not sufficient to prevent the nut from coming loose. A cotter pin properly installed will prevent the nut from coming loose.

Self-locking nuts are widely used (see Fig. 51-7). They are designed principally to increase thread friction. This is done (1) by using a nylon insert or nylon collar, (2) by distorting the threads by cutting a vertical slot in the upper one-third of the nut and shrinking its dimension slightly, or (3) by flattening the upper one-third of the nut to a slightly smaller dimension than the lower two-thirds of the nut (see Fig. 51-8).

Nut Grade The standard grades are Nos. 2, 5, or 8. A grade marking is only required for a No. 5 or No. 8 nut. Grade No. 5 is identified by a dotted point on one corner and a radial line at the corner located 120° clockwise from the corner with the dot. Grade No. 8 nut is marked with a dot at one corner and a radial line at the corner located 60° counterclockwise from the corner with the dot.

Hand Taps As a minimum requirement you should understand the differences among the standard *hand taps* you will be using when servicing diesel engine

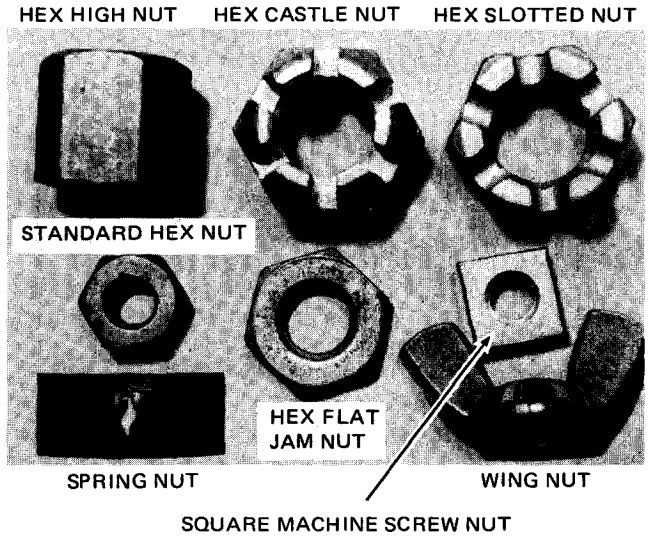


Fig. 51-6 Various types of nuts.

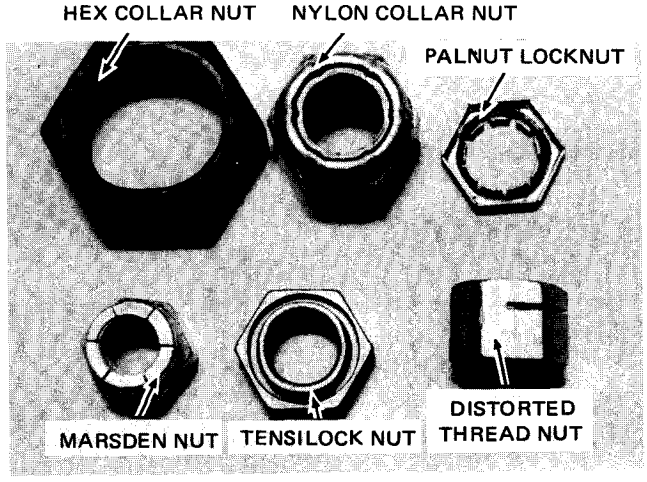


Fig. 51-7 Various types of self-locking nuts.

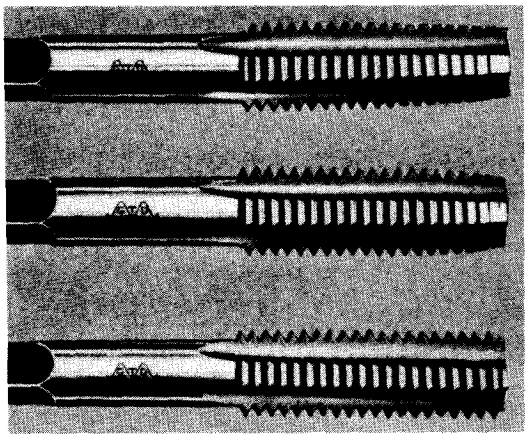


Fig. 51-8 Hand taps. *(Greenfield Tap and Die Corp.)*

components. Hand taps used for cutting English and metric threads are supplied in sets of three of equal size. The set includes a *taper tap, plug tap,* and *bottoming tap* (Fig. 51-8).

Series taps are used to tap deep holes. They may be either open or blind. They are similar in general dimension to taper, plug, and bottoming hand taps, but they differ from the latter in that each tap cuts only a certain percentage of the thread. This divides the tapping strain among the three taps and lessens the possibility of tap breakage.

Pointers for Hand Tapping Tapping a hole follows the drilling of that hole. Three types of holes can be drilled into an object, as shown in Fig. 51-9. If possible, avoid drilling a blind bottoming hole because it is difficult to tap.

When hand tapping a hole, you should consider a drill size which will give you 60 to 70 percent thread depth. You should be aware that thread depth is the major cause of tap breakage. A bolt inserted in an ordinary nut which has only 50 percent thread will break before stripping the threads. Remember, also, that a 100 percent thread depth is only 5 percent greater in strength than a 75 percent depth.

1. Use a tap drill size chart (see Conversion Tables) or the following formula to determine theoretical maximum and minimum drill sizes for average conditions. For example, ¼-in (U)NC thread:

Maximum drill size basic thread outside diameter =

$$0.250 - \frac{3}{8 \times \text{no. of threads}}$$

Maximum drill size =

$$0.250 - \frac{3}{8 \times 20} = 0.250 - 0.01875 = 0.231 \text{ in}$$

Maximum drill size basic thread outside diameter =

$$0.250 - \frac{1}{2N}$$

Minimum drill size =

$$0.250 - \frac{1}{2 \times 20} = 0.250 - 0.025 = 0.225 \text{ in}$$

2. Make certain that the drill is properly sharpened. A dull drill can create an egg-shaped hole which will result in an uneven thread depth (Fig. 51-10).
3. Dull drills or the lack of lubricant can cause surface hardening. As a result you will find it hard to start the tap, or you will round over the threads, or the tap may break altogether.
4. Blow out the drilling chips from the bottom of the hole.

CAUTION
Use goggles.

5. Use the taper or No. 1 tap to ensure a straight start.
6. Lubricate the area you are cutting with the proper lubricant. [See Recommended Cutting Fluids for Drilling, Reaming, and Tapping (Unit 48).]
7. Select a tap wrench which will hold the tap securely.
8. Using both hands, turn the tap in a clockwise direction as far as possible. Periodically remove the tap to clear out the swarf of metallic particles and repeat the procedure.
9. When it is necessary to tap in both a clockwise and counterclockwise direction to break the chips, do not reverse the tap more than the width of one land.
10. Frequently clear out the chips when tapping a bottom hole. This will prevent tap breakage caused by the impact of the tap on the chips.
11. When you tap a bottom hole, fill the hole with lard. This will force the chips out as the tap is turned in.
12. When you tap a pipe thread, use a pipe reamer before threading. Remember that the diameter of the pipe tap increases at a rate of ¾ in/ft.

Rivets Except for the friction clutch or for sheet metal work, the rivet method is very seldom used to fasten diesel engine components. Nevertheless, you should be thoroughly familiar with the various types of rivets and methods of riveting.

Methods of Riveting Some of the more common riveting methods are shown in Figs. 51-11 and 51-12. Although there is no established rule regarding the most suitable rivet, it is wise to use solid rivets when

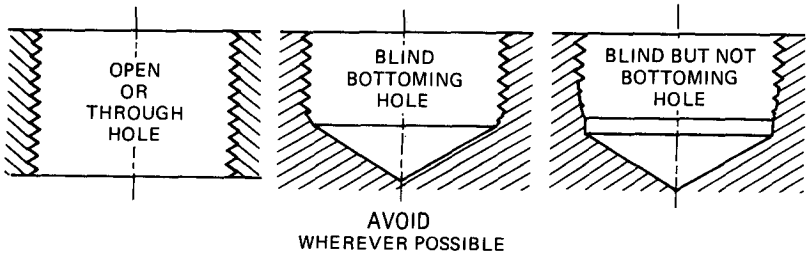


Fig. 51-9 Types of holes that can be drilled in tapping. *(Greenfield Tap and Die Corp.)*

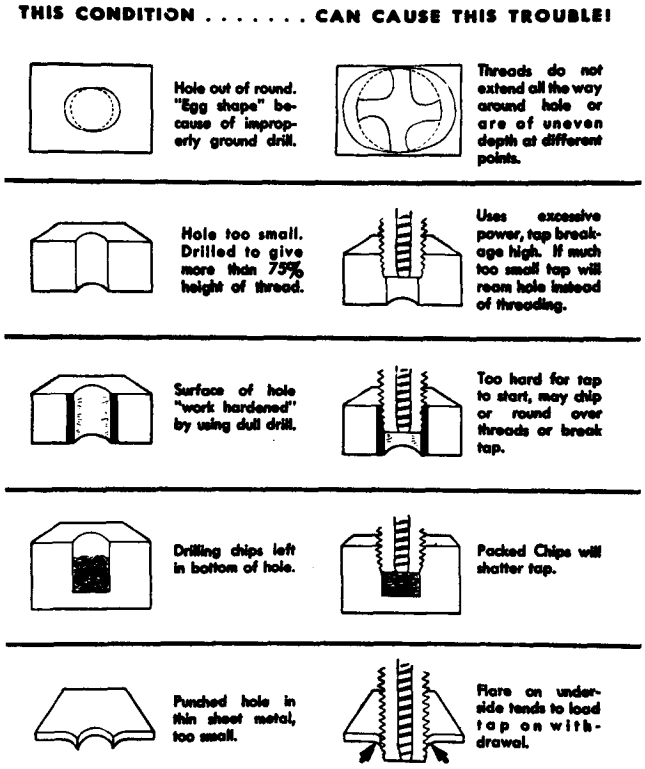


Fig. 51-10 How faulty drilling can cause tapping troubles. *(Greenfield Tap and Die Corp.)*

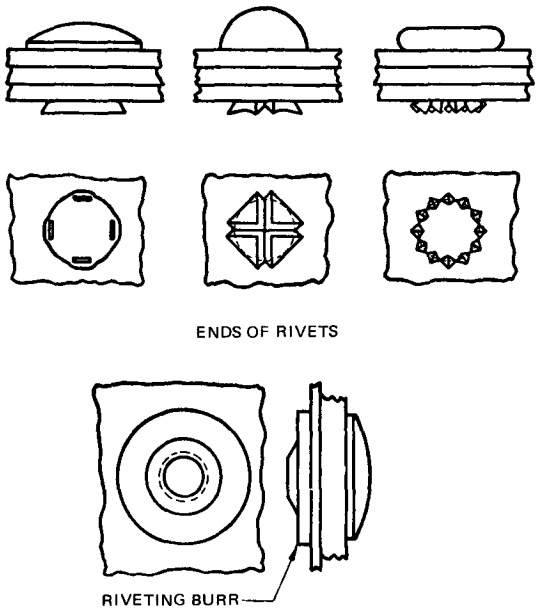


Fig. 51-11 Staking method of riveting.

maximum strength is needed. Semitubular rivets can be used if tensile or fatigue strength is not a major concern.

Impact riveting refers to the use of a hardened die and a buck. By striking the die repeatedly with a hammer, the head is formed (Fig. 51-12).

Squeeze riveting is similar to impact riveting except that it is essential to apply a steady force on the die to form the head.

Staking riveting refers to deforming the rivet material at one or more points with a sharp tool in order to force the metal at these points tight against the mating parts (Fig. 51-11).

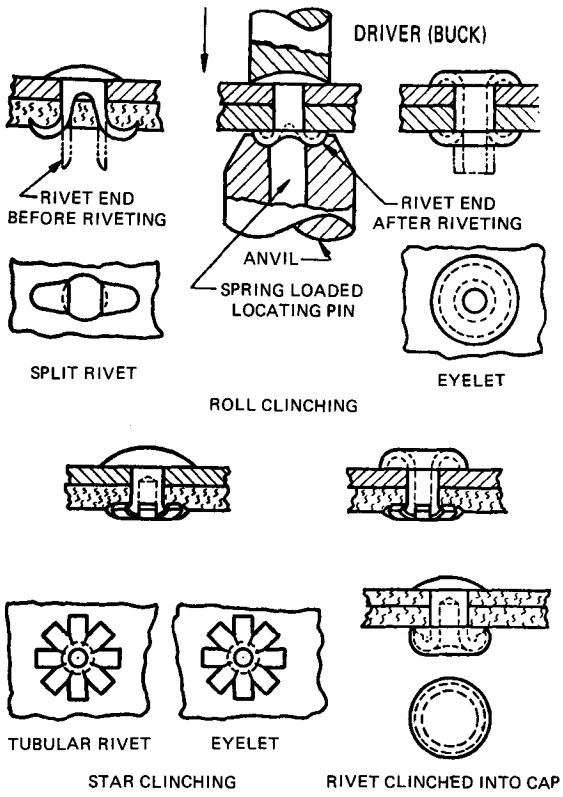


Fig. 51-12 Clinch riveting.

Clinch riveting is the most common. This method of riveting involves the forcing of a die against the opening end of a semitubular rivet to form a star- or roll-clinch cap against the material to be fastened (Fig. 51-12).

Pointers for Riveting

1. Select the most suitable rivet and material for the job.
2. The rivet should protrude by the amount of its diameter. It should fit in the hole snugly.
3. Keep the two joining surfaces tightly together at all times.
4. For soft or resilient materials, use the die which forms a star clinch.
5. Do not use a split rivet with clutch facings.
6. When possible, change every rivet so that the heads alternate from side to side.

Locking Devices Locking devices used to lock, hold, or position a pulley or gear are woodruff keys, splines, pins, snap rings, metal lock plates, and lock wires (Figs. 51-13 and 51-14).

Woodruff keys or *square keys* are used to position a component to a shaft or tapered shaft when moderate strength is required. For greater strength, or when it is necessary for a shaft gear or pulley to move lengthwise, *multisplines* are used.

The most common pins and snap rings you will encounter are those shown in Figs. 51-13 and 51-14. Each is used under special circumstances to hold the component in position.

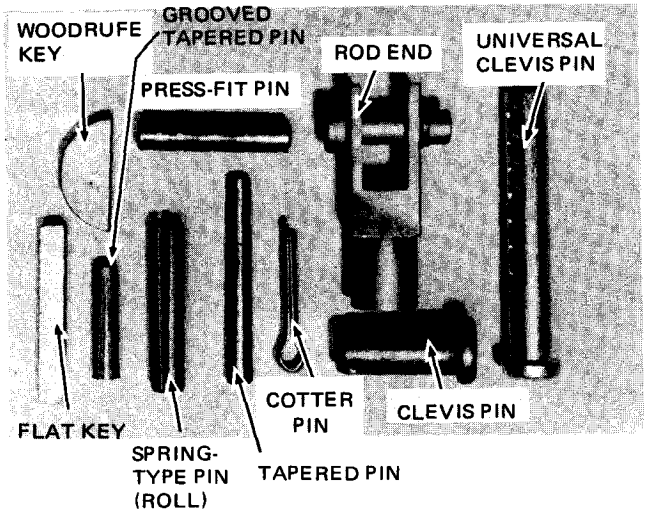


Fig. 51-13 Various types of locking devices.

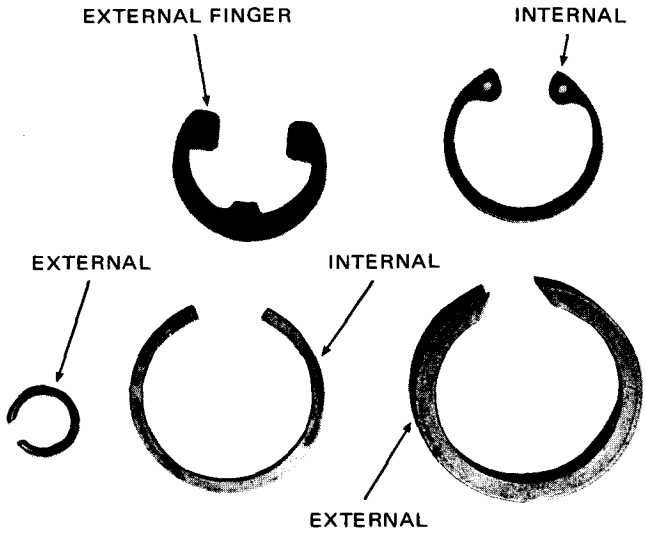


Fig. 51-14 Various types of snap rings.

Metal Wire Locks A metal lock, or wire lock, is used when a self-locking cap screw or nut is inadequate. Both methods will prevent the cap screw or bolt from loosening. The correct locking method for installing flat metal locks is shown in Fig. 51-15.

CAUTION
Never reuse a metal lock.

Pointers for Using Different Locking Devices
1. Always use a new cotter pin of the proper length and dimension. Use the special cotter keys for engine clutches and connecting rods.
2. Use new self-locking pins to prevent premature failure.
3. Check splines, keys, and keyways for wear.
4. Make certain that the setscrew is seated and locked properly.

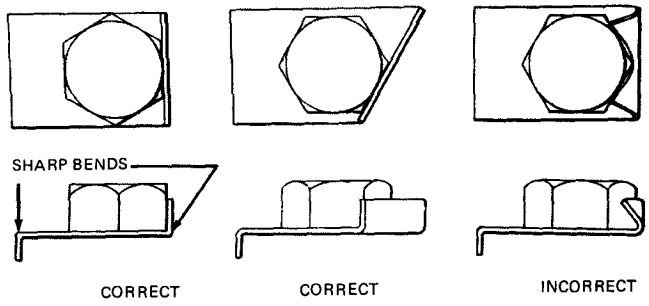


Fig. 51-15 Installing flat metal locks.

5. Do not substitute an internal snap ring for an external one.
6. When you install a snap ring, make certain that its diameter and thickness are the correct size and that it is inserted properly in the groove.

Questions

1. What is the difference between a hex bolt and a screw?
2. What does a thread gauge measure?
3. Between what two points is the length of a bolt measured?
4. Which types of thread series are most commonly used on diesel engines?
5. Name two major causes for bolt or cap screw fatigue and failure.
6. What is the difference between a die and a tap?
7. When it becomes necessary while cutting a thread to turn the die backwards, why must it be turned only the width of one land?
8. Name the standard grades of nuts.
9. Why should you never reuse a self-locking nut?
10. Before drilling a hole for a tapping, what must be considered?
11. When fastening by riveting, what must you know in order to select the correct rivet?
12. Why, in some instances, is a lock plate used instead of a lock washer?
13. When a nut is tightened, it tends to (*a*) expand its threads; (*b*) pull inward at the center; (*c*) bulge outward at the center; or (*d*) none of the above.
14. The strain on a loose bolt is (*a*) the same as when it is tight; (*b*) less than when it is tight; (*c*) greater than when it is tight; or (*d*) chiefly on the nut.
15. What is the official name for coarse thread? (*a*) SAE, (*b*) unified coarse, (*c*) unified national coarse, or (*d*) NF.
16. A die is a special type of tool that (*a*) is easily damaged; (*b*) repairs and makes male threads; (*c*) should be used only by an expert; or (*d*) makes threads stronger than new.
17. A headless fastening device threaded at both ends is a (*a*) screw, (*b*) bolt, (*c*) stud, or (*d*) pin.
18. Which nut is secured with a cotter pin? (*a*) slotted nut, (*b*) acorn nut, (*c*) Palnut locknut, or (*d*) hex nut.

SECTION 7
BREAK-IN, TROUBLESHOOTING, AND TUNEUP

UNIT 52 - CHECKS AND ADJUSTMENTS BEFORE STARTING THE ENGINE

Need for Break-in A new or rebuilt engine must be operated for a certain period of time (*break-in*) under various speeds and load conditions to remove high spots from the moving components and allow mating surfaces to acquire a full seat. During this time errors in the assembly, in the torque value of the mounting bolts, or in the adjustment can be detected and promptly corrected. The engine should also be tested and adjusted *after* the break-in period to ensure faultless performance.

Preparation Prior to Break-in Run To prepare the engine for its break-in run, secure and align it to the dynamometer test stand, then proceed:

1. Connect the dynamometer drive shaft strictly in accordance with manufacturer's instructions.
2. Connect the exhaust and intake pipings to the engine.
3. Connect the water supply and return hoses to the cooling tower.
4. Connect the throttle and shutoff lever or electric wire to the shutoff solenoid.
5. Connect the batteries but make certain you have corrected battery voltage and ground polarity.
6. Depending on dynamometer cooling arrangement, you may have to remove the thermostat.
7. Connect a mercury manometer to the intake manifold or to the air box (to measure turbocharger boost pressure and/or blower pressure.)
8. Connect a pyrometer to the exhaust manifold (to measure the exhaust temperature). Connect a water manometer to the exhaust-manifold outlet (to measure the exhaust back pressure).
9. Connect a temperature gauge to the inlet water manifold (to measure the coolant temperature).
10. Connect a pressure gauge to the main oil gallery (to measure the oil pressure). Position a temperature gauge as recommended by the engine manufacturer (to measure the oil temperature).
11. Connect a water manometer to the crankcase in accordance with the procedure recommended by the engine manufacturer (to measure piston blowby) (Fig. 52-1).
12. Connect a fuel-pressure gauge, or a flowmeter, to the fuel manifold (to measure fuel pressure and/or flow.)
13. Connect the fuel supply and return line to the engine.

Before you start the engine, proceed as follows:

1. Check the coolant-system hose connection, and adjust coolant flow if necessary.

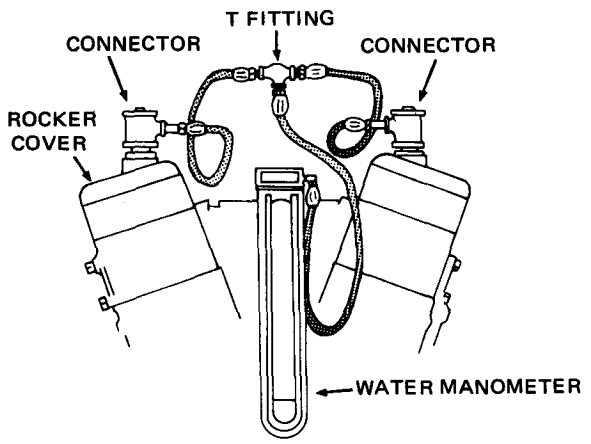


Fig. 52-1 Schematic view of water manometer connection to check blowby.

2. Check the drive belts and make any adjustments that are required.
3. Adjust the valves. Check the injection pump timing or the injector timing, or the injector adjustment.
4. Fill the crankcase to the correct level, with the oil specified by the engine manufacturer. *(NOTE: Check the dip stick first because its markings are different.)* Connect an oil priming pump as recommended (to the primary oil filter, gear case, or main oil manifold).
5. Lubricate the cranking motor and alternator bushings or bearings, if required.
6. Prime the fuel-injection system when necessary.
7. If the engine is equipped with a turbocharger, remove the oil-inlet line and lubricate the bearings according to the engine manufacturer's recommendation.
8. Connect the battery ground cable.
9. Pressurize (prime) the lubrication system to about 40 psi [275.8 kPa] using a power primer or a hand primer. Then set the throttle to the no-fuel position. If the throttle is equipped with a decompression lever, place it in the "on" position. Crank the engine for a minimum of 20 seconds while maintaining (with the priming pump) a minumum pressure of about 20 psi [137.9 kPa]. Disconnect the oil primer assembly.
10. If not previously done, open the coolant supply to the engine and to the dynamometer. Then check all plugs, tubings, fittings, hoses, and connections for coolant leaks.
11. Disconnect the turbocharger inlet air hose and oil-return line and set the throttle at idle speed. *(NOTE: If the engine is equipped with a compression release, pull the release while cranking the engine for a short period of time. Release the compression lever, and then continue cranking the engine until it starts.)*
12. If the engine fails to start within 30 seconds although the cranking speed reaches 150 to 200 rpm, check the fuel supply, the transfer pump, or the manifold pressure. If they are not faulty, bleed the low- and high-pressure systems. If a glow plug circuit is used, check the wiring and the glow plugs.
13. Once the engine starts, observe the compressor wheel. It must not rub or bind. Check the turbocharger return-oil drain. Oil should flow from the hose within the time specified in the engine service manual. If oil flows within the specified time, reconnect the oil drain hose. If oil does not flow, then stop the engine and correct the problem. At this time check the compressor wheel. It should coast freely to a stop.

Break-in Run Each engine manufacturer gives dynamometer test specifications or charts which present concise data regarding rpm, load, temperatures, and pressures (Table 52-1).

CAUTION Never shut the engine down immediately after a run-in phase. Allow it to cool down. During the run-in phases, or for the first 100 hours of operation, do not operate the engine below 1000 rpm or idle it over a long period of time. The oil level must be checked and the level corrected after each run-in phase. The oil pressure must be checked repeatedly and must remain constant at all load and speed conditions. The oil temperature must not exceed 225°F [107°C] and the cooling temperature must not exceed 200°F [93°C] or drop below 160°F [71°C].

A run-in specification example is shown in Table 52-1. To perform the run-in, start the engine, operate it at 800 rpm, and observe the oil pressure and coolant flow. Check for coolant, oil, and fuel leakage. Stop the engine, if necessary repair the leak area, recheck the oil level, and add more oil if necessary. Then again start the engine, operate at phase 1 load and rpm, and check the blowby, oil temperature, coolant temperature, and boost pressure. If the oil pressure drops below 50 psi [344.7 kPa] or if the oil pressure is too high (above 70 psi [482.6 kPa]), stop the engine and correct the problem. When the problem is corrected, operate the engine under phase 2 run-in conditions. Should the crankcase blowby increase, reduce the load and rpm to phase 1 level. If the blowby stabilizes, operate the engine again under phase 2 run-in conditions. After phase 2 run-in, stop the engine, check the oil level, and start phase 3 run-in. After 15 minutes if there is no increase in blowby and/or increase in oil and coolant temperatures, stop the engine, recheck the oil level, and check and/or adjust the valves. On Cummins engines you must also check and/or adjust the injectors. *(NOTE: On Detroit Diesel engines you must make a complete sequence of tune-ups, checks, and adjustments.)* After all adjustments have been made, start phase 4 run-in. If after 15 minutes the blowby is within specification,

TABLE 52-1

DYNAMOMETER TEST CHART

Engine model	hp at rpm	Rated hp at rpm (500-ft altitude)	Fuel rate, lb/hr	Air manifold pressure, in/Hg	Rating at altitude max.	Turbo	Crankcase pressure, in H_2O
XX	1050 at 2100	1050 at 2100	392/408	42/49	12,000		18

Phase 1 to temperature hp at rpm	Phase 2 15 min hp at rpm	Phase 3 15 min hp at rpm	Phase 4 15 min hp at rpm	Power check 5 min hp at rpm	Torque, ft/lb (500-ft altitude)
500 at 1575	700 at 2100	800 at 2100	900 at 2100	1005–1050 at 2100	2600/2630

Note: Turbocharged engines do not require fuel derating below altitude shown in column entitled "Rating at altitude max." Above maximum altitude, derate at each 1000 ft [304.8 m] additional altitude by 4 percent.

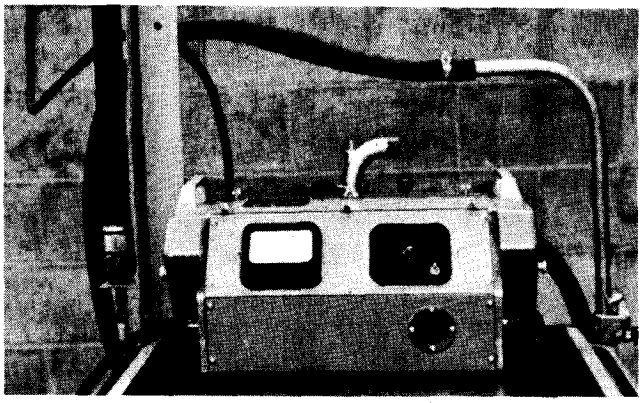


Fig. 52-2 Smokemeter connected to the engine.

the coolant and oil temperatures are stable, and the boost pressure is within specification, perform the 5-minute power check.

The next step is to measure the emissions. Always follow engine and/or smokemeter manufacturers' instructions when making this measurement. When the exhaust smoke exceeds the emissions specification, check the following: injection-pump timing, automatic advance operation, injector timing, or injector adjustment, governor and valve adjustment, blower or turbocharger boost pressure (Fig. 52-2) operation of the aftercooler, and aneroid or fuel ratio control.

Questions

1. Outline the preliminary preparatory steps to be taken before starting the run-in procedure.
2. (*a*) List the instruments required to check engine performance during the run-in. (*b*) List the components to which they are connected.
3. Which check must you make immediately after the engine has been started and is running at say, 1000 rpm?
4. Why should you *not* operate the engine at idle speed during the break-in run?
5. List the checks and adjustments you must make after the engine reaches operating temperature.
6. Why should an engine be allowed to cool down before it is shut off?

UNIT 53 • TROUBLESHOOTING AND TUNEUP

Tuneup Over 90 percent of engine problems and performance complaints can be prevented by a good maintenance program which includes engine tuneup at the intervals specified in the relevant service manual. An engine tuneup means checking the entire engine and its supporting systems for leaks, loose mountings, loose belts, a plugged radiator, etc. It also includes checking various adjustments, comparing them against the service manual specifications, and where necessary, making readjustments. (See material on tuneup procedures for Detroit Diesel engines in Unit 31; for Caterpillar engines in Units 32, 35, and 36, and for Cummins engines in Unit 33.)

NOTE: A tuneup can only be made when the engine is mechanically sound.

Troubleshooting A methodical approach to troubleshooting is needed if you are to solve the problems which you will face in your daily routine. In order to relate troubleshooting to as many different fuel-injection systems and engines as possible, only generalizations will be made in this unit.

To locate component failures or quickly isolate the cause of engine problems such as overheating, misfiring, and excessive smoking, or to determine why the engine is hard to start, etc., requires a thorough knowledge of the basic operating principles of the following systems: cooling, lubrication, intake, exhaust, fuel injection, and the accessory systems (cranking and charging). Good comprehension of the engine's construction and design is essential. In addition to theoretical knowledge, you must have the practical skill to test and measure engine performance, rpm, temperature, and pressure, etc., and the ability to evaluate results against service manual specifications.

Diagnosis The first step in solving engine problems is to narrow them down to only those systems which might be involved, determine the cause of the problem, and then decide how it can be prevented in the future.

Begin your evaluation by asking questions relevant to the problem. For instance, if the engine is hard to start or will not start, ask questions No. 1, 2, 4, 7, 8, 10, 11, and 13, listed below.

1. When was the trouble first noticeable?
2. Was this complaint or a similar problem recorded at any time?
3. Was the trouble noticeable at all speeds and load?
4. Did any unusual noise precede the trouble?
5. Has the cooling temperature increased?
6. Is the oil consumption normal?
7. When was the last maintenance check?
8. When was the last oil and filter change?
9. When was the cooling system last checked?
10. How does the engine respond to acceleration or deceleration?

11. Is there excessive exhaust smoke?
12. Does the engine start easily?
13. Does the engine hunt or surge at idle, high idle, or full load?

A wealth of information is available to you if the engine has a service record sheet to indicate which components or parts have been serviced or replaced.

Finally, a personal inspection should be made. During this appraisal you should check to determine if the engine is clean or dirty or if there are any external oil, coolant, or fuel leaks. Check the condition of the coolant, the fuel hoses or the tubings, the drive belts and pulleys. Determine if any components which are not standard have been added.

After gathering all data possible, analyze your findings in relation to the operating principles of the components concerned.

Engine Will Not Start When an engine fails to start (this is one of the most common complaints), it is often because the cranking speed is too low or because the ambient temperature is very low. Regardless of these two factors, first check the electrical system (see Units 38 to 47). When the ambient temperature is very low, always use No. 1 fuel and engine oil of the correct viscosity. Other factors which affect starting are referred to later in this unit.

Air-intake Restriction and Poor Compression When the air-intake system is restricted because of a plugged air cleaner, or when the engine has low compression because of a damaged or worn blower or turbocharger, worn or damaged rings and cylinder sleeves, or misadjusted or burned valves, you will notice the following:

- The engine is hard to start.
- It has lost power.
- The engine coolant temperature is below normal.
- The exhaust smoke has increased in density.
- The consumption of oil and fuel has increased.

You will also notice early formation of carbon on the valves and pistons, fuel may have diluted the engine oil, and the engine may run rough or vibrate excessively.

To check for a restricted air-intake system on naturally aspirated engines, connect a water manometer to the inlet manifold, and on the turbocharged engine, connect it to the inlet side of the compressor. Then operate the engine at high idle. The manometer reading must not exceed 2 inHg [5.08 cmHg] (Fig. 53-1).

To check the condition of the blower or turbocharger, connect a mercury manometer to the air box or intake manifold. Operate the engine at the specified speed and load and then compare the manometer reading with your service manual specification. (See Units 18 and 19 on blowers and turbochargers).

To determine piston-ring wear, check the blowby by connecting a water manometer to the appropriate component. Operate the engine at specified speed (load). Compare the blowby reading shown on the manometer against that specified in the service manual. If the blowby reading is within specification,

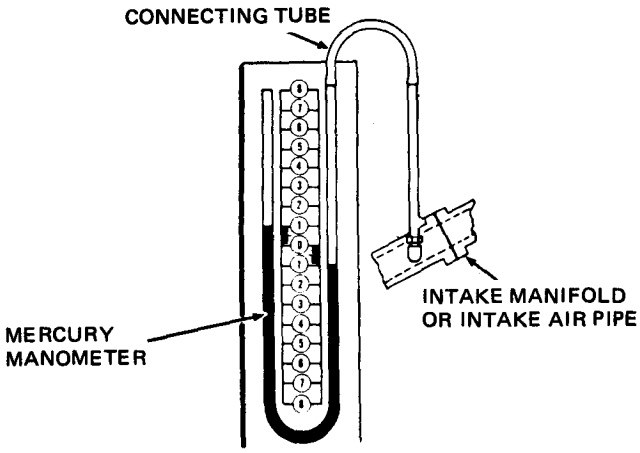


Fig. 53-1 Schematic view of mercury manometer (Hg) connection.

check the cylinder compression. (Compression check procedure varies somewhat among engine manufacturers.)

One recommended procedure is as follows:

1. Bring the engine oil to operating temperature.
2. Remove the injection line and the injector from the first cylinder head to be checked.
3. Clean the injector bore or sleeve with the recommended tool, but make certain that no carbon remains in the combustion space.
4. Crank the engine over for a few revolutions to blow out the carbon.
5. Place a new gasket in the bore, and then install and tighten the correct adapter with the gauge as shown in Fig. 53-2.
6. Operate the engine on three, five, or seven cylinders, at recommended rpm, until the pressure gauge stabilizes. Then read and compare the compression pressure with the specification shown in your service manual.

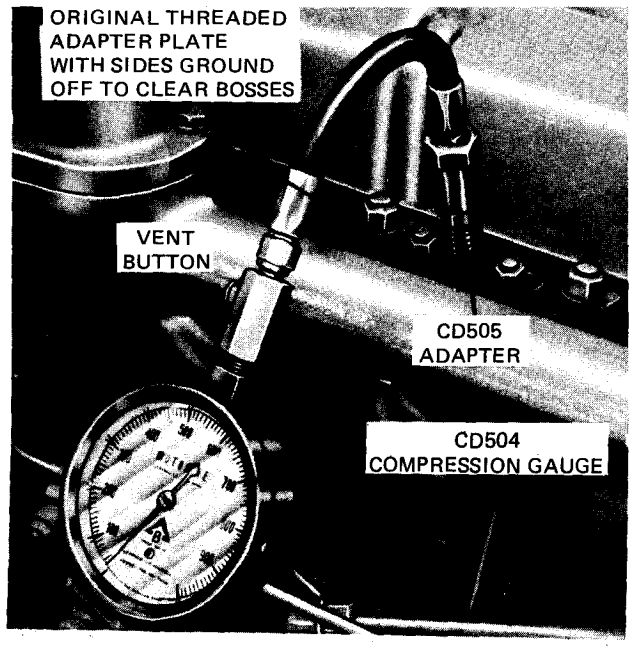


Fig. 53-2 Checking cylinder compression. *[J.I. Case Agricultural Equipment Division (TENNECO).]*

7. Check the remaining cylinders. The pressure variation should not be greater than 50 psi [344.7 kPa].

Air-intake Leaks When unfiltered air enters the cylinders, the engine may show a loss in power because of increased wear on the piston rings and the cylinder sleeve. Piston-ring wear causes poor compression, hard starting, and an increase in exhaust smoke density. (Effects of an air leak are more noticeable when a turbocharger is used.)

When the air leak occurs before the compressor, the compressor wheel will show dirt and excessive wear. If the air leak occurs after the compressor, the boost pressure will be lower and a hissing noise may be audible. Examine the compressor wheel and measure the boost pressure. To locate the leak, pressurize the intake system as explained in the section on air cleaners (Unit 18).

High Exhaust Back Pressure When the exhaust back pressure is high, the engine temperature will increase since more exhaust heat must be carried away by the cooling system. Furthermore, the engine power will decrease because of incomplete scavenging, the exhaust smoke will become denser, and the engine will probably run rough at idle speed. Other components that are affected because of high exhaust back pressure are the valves, injectors, and pistons. These components will show excessive carbon buildup and the lubricant will become contaminated.

To locate the cause of high exhaust back pressure, install a water manometer to the exhaust manifold, and measure the back pressure. If it is within specification, check the valve adjustment and/or the valve timing.

High Oil Consumption When the engine burns lubricant excessively after the run-in phase and no external leaks are present, you will notice that the oil soon becomes dirty, the engine temperature increases quickly, and the exhaust smoke is a bluish color.

To locate the cause of high oil consumption, first check the dipstick. An incorrect dipstick can result in too high an oil level (see Fig. 53-3). Check the oil pressure. If it is higher than specified because of a malfunctioning relief valve, excessive oil is thrown onto the cylinder wall. The oil cannot be controlled by the piston rings and, therefore, enters the combustion chamber. The result is the same when the incorrect grade or a poor quality of oil is used.

Check the lube oil and filter maintenance records. The filter and/or oil may not have been changed within the required intervals. Check the coolant level, the radiator pressure cap, and the drive belt(s). Either may have caused high engine temperature. Measure the blowby and cylinder compression. Check the crankcase breathers. When a breather is plugged, the crankcase pressure increases, forcing the oil through the gaskets and seals, and sometimes past the piston rings.

NOTE: Do not forget the air compressor. If its piston rings are damaged or worn there would be high oil consumption.

If none of the above tests have uncovered the cause of high oil consumption, the engine must be disassembled and the following components checked: valve guides, rocker shaft (position), piston rings and sleeve, main bearings, and connecting rod. Also check the camshaft bearings for excessive wear and/or clearance.

Low Oil-pressure Gauge Reading When the oil-pressure reading is lower than specified and the engine is noisy or knocks (see Engine Noise and Knocks later in this unit), instantly stop the engine to prevent additional damage.

Immediately check the crankcase oil level and check its color to determine if it is diluted. To ensure that the low pressure was not due to a damaged pressure gauge, recheck the oil pressure using a master gauge. If the oil pressure is actually low, drain the oil and remove the filters. Then check the filters and the crankcase for metal particles. If there are no metal particles present, check the oil pump and the pressure-relief valve.

Crankcase Oil Dilution

DIESEL FUEL When diesel fuel has diluted the engine oil, any one or more of the following may result: (1) A cylinder may misfire, (2) the engine may run rough, (3) the exhaust smoke may increase in density, or (4) the oil pressure may drop.

Misfiring can be caused by a sticky injector, the nozzle valve not seating properly, an incorrect spray pattern, an enlarged orifice, or insufficient compression.

Test for a malfunctioning injector. (The various procedures are described in Units 27, 31, 32, and 33.) Measure cylinder compression and blowby. Check the transfer-pump seal.

When the engine does not show any of the four symptoms outlined above, ask the operator when the oil and filters were last changed. Ask if the engine was operated while the engine was below recommended temperature or if it operated at idle speed over a long period of time.

When working on a Detroit Diesel engine, check the fuel jumper lines. They may be loose or broken. When working on a Cummins diesel engine check the injector O rings for damage.

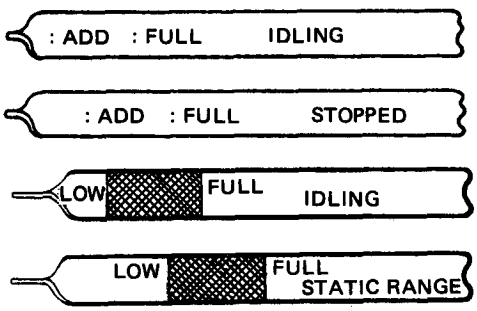


Fig. 53-3 Variations in dipstick markings. *(Allis-Chalmers Corp. Engine Division.)*

Sludge or Coolant When coolant has diluted the engine oil, you may notice increased engine temperature and creamy-textured oil. However, before you conclude that coolant has leaked into the crankcase, make sure the problem is not condensation.

Excessive condensation can be caused by operating the engine at a low ambient or low engine temperature, or running the engine at idle speed for a long period of time.

Engine oil can be diluted by coolant when there is a cracked cylinder head or block (due to overheating or freezing) or when there is a leaking cylinder-head gasket or a leaking cylinder-sleeve O ring.

To locate any of these leaks, remove the oil pan and clean the crankcase. Then lay a piece of white paper under the engine and allow it to stand overnight. The location of the coolant on the paper will indicate the area inside the block which you must examine.

If this method is unsuccessful in revealing cracks or the source of a leak, remove the water pump and the radiator hoses from the engine and seal the openings. Install an air hose with a pressure regulator to the cylinder block. Fill the engine with a strong solution of antifreeze. Operate the engine until the operating temperature is about 180°F [82°C], then pressurize the coolant system to about 40 psi [275.8 kPa]. Drain the oil and remove the oil pan. Then again check the cylinder block and crankcase for coolant leaks.

Engine Noise and Knock The source of engine noise or knock may or may not be easy to trace. The conditions under which the noise or knock is more easily found are when the engine is noticeably misfiring or operating irregularly, when there is excessive exhaust smoke, or when the coolant pump, cooling fan, compressor or alternator is noisy. Fairly obvious sources of knock are due to incorrect fuel being used.

More difficult to trace is the source of noise or knock due to piston "slap," broken piston rings or a broken piston pin, or a damaged camshaft bearing or follower. It is also difficult to locate the source of noise when the engine has one main or connecting-rod bearing excessively worn or damaged.

To locate a noise or knock caused by engine misfiring, loosen the high-pressure fitting or hold the injector down. If there is no change in the noise, then that particular cylinder is not at fault.

The following are some further hints which will help you locate engine knock:

- A loose wrist pin gives a sharp metallic rap at low speed and its noise decreases as temperature increases.
- A worn main bearing causes a dull knock when accelerating under a load, in contrast to a worn connecting-rod bearing which causes a noticeable dull knock at light load or idle speed, and decreases at full load.
- A worn piston makes a lighter sound than a worn connecting-rod bearing, and the noise may disappear as the engine warms up.
- A broken piston ring and/or land will give a sharp clicking noise throughout all speeds and load.

When the timing gears have too much backlash or the gears are loose on their shafts, they usually make a rattling noise. Timing gears having reduced backlash will whine.

Excessive Engine Vibration Determining the cause of engine vibration can be a time-consuming task unless the vibration is due to a misfiring cylinder, a damaged vibration damper, or loose or broken engine mounts or accessories.

However, when engine vibration is the result of accessories that vibrate at various frequencies (depending on their own malfunction) or because of their location, weight, and operating speed, a precise test instrument is necessary to measure the vibration and thereby determine its source.

Engine Overheating When an engine overheats, you may notice that it loses power (because it inhales less air by volume), and ignites too early. It may run rough, vibrate excessively, or knock. The density of the exhaust may have increased.

Many malfunctions or misadjustments can contribute to an overheated engine. To find the cause, proceed as follows:

1. Check the radiator hoses and coolant filter.
2. Check the adjustment and the operation of the thermostat fan and shutterstat.
3. Inspect the exterior of the engine for excessive dirt, grease, etc., and/or noticeable leaks.
4. Check the coolant level and the oil level.
5. If the radiator core is plugged or scaled, clean it and the engine (see Unit 20, "Cooling System").
6. Use an airflow meter to check the radiator for an airflow restriction and compare the reading with the service manual specification. For example, operate the engine at high idle and check the airflow at the fan hub area. It should be 50 to 100 ft/min [15 to 30.4 m/min]. At the fan blade area it should be 500 to 750 ft/min [152.4 to 228.6 m/min] and at the area outside of the fan blade it should be 700 to 1000 ft/min [228.6 to 304.8 m/min]. Check the radiator's pressure cap. The fan shroud should be positioned properly so that no vacuum pockets can build up.
7. Make certain the fan blades are not bent or broken. When a clutch-type fan drive is used, check its operation and adjustment.
8. Check the drive belts for correct tension.
9. Using an electronic temperature-measuring device install the sensing probe first at the radiator top tank, then at the coolant manifold, and then in the cylinder block. Compare your temperature readings with those in the service manual.

If the engine overheating problem is not yet uncovered, install a pressure gauge into the coolant and operate the engine at the recommended rpm. If the pressure is lower than specified the coolant pump may be worn, and if it is higher there may be an internal restriction. *(NOTE: The coolant-inlet pressure varies between engines and is within 5 to 10 psi [34.5 to 68.9 kPa] and the cylinder block pressure is within 10 to 40 psi [68.9 to 275.8 kPa].)*

To check the cooling system for aeration, install a liquid eye into the top radiator hose. Operate the

engine at high idle, and then check for air bubbles. Remove and test the thermostat if necessary (see Unit 20, "Cooling System").

When the injection system is the cause of the high temperature, the exhaust smoke is dense. Check the high-idle and idle speeds, the governor-to-fuel-rack adjustment, the injector-adjustment, injector timing, the fuel-injection-pump timing, and the aneroid adjustment.

Using a contact pyrometer, measure the exhaust temperature of each cylinder to determine those which vary from the average exhaust temperature (see Fig. 53-4).

To check the injection-pump timing and/or the operation of the automatic advance, use a diesel timing light. Install the specified transducer into the injection line (either at the injection pump or at the injector, depending on the transducer number) and make the necessary electrical connections (see Fig. 53-5). Before you start the engine, clean the timing marks and be sure you have the manufacturer's timing specifications at hand.

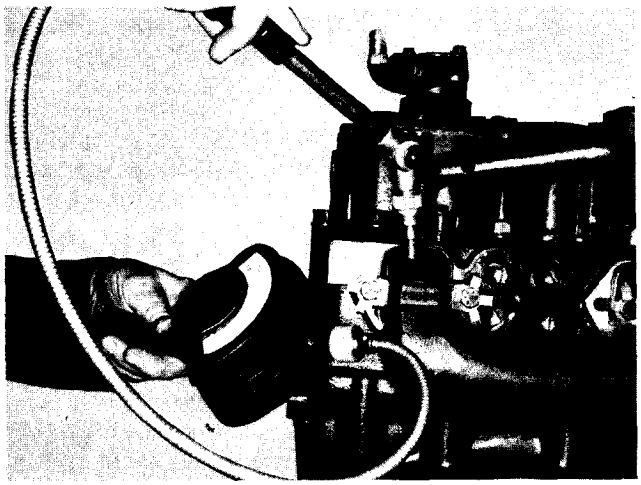


Fig. 53-4 Using a contact pyrometer to measure exhaust temperature of each cylinder. *(Cummins Engine Company, Inc.)*

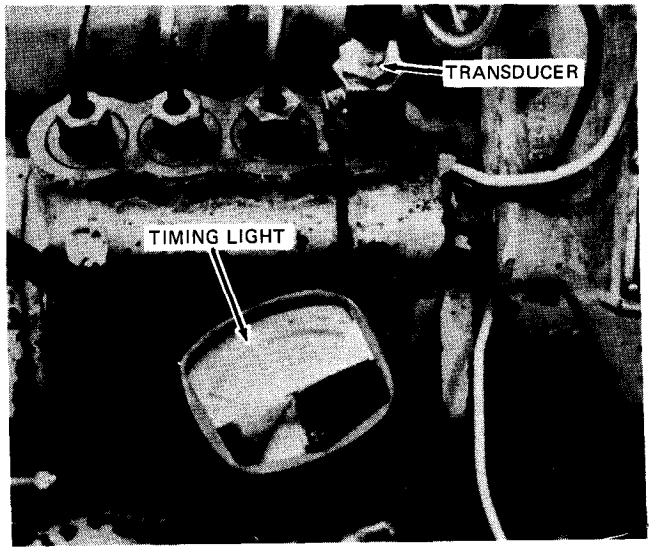


Fig. 53-5 Checking injection timing.

Start the engine and operate it at idle speed. Aim the flashing timing light at the timing marks. Synchronize the timing marks by using the knurled knob on the timing light. Read from the timing light scale the advance of the engine at idle speed. Increase the engine speed to the specified rpm to check the remaining advance points. (See the section on injector timing and adjustment in Units 31, 32, and 33.)

Engine Has Lost Power or Is Not Developing Full Power A reduction in engine power is usually coincidental with hard starting, increased exhaust smoke density, increased engine temperature, engine misfiring, or rough operating. Power loss or underdeveloped engine performance are constant customer complaints. Both usually are traced to the fuel-injection system. The fuel-injection system, however, is not always the source of the trouble; there are many other problem areas. Therefore, check and measure the intake system for restriction and the exhaust system for excessive back pressure. Use a smokemeter or a smoke chart to measure the density of the exhaust smoke. Check and measure the blower or turbocharger boost pressure. Check for a leaking intake manifold. Check the cylinder compression, valve adjustment, and/or valve timing. Check for a leaking cylinder head or head gasket.

When you suspect reduced power is due to damaged, worn, or misadjusted fuel-injection system components, your theory can quickly be proved or disproved. Check first for external fuel leaks. If none exist, check for restricted fuel hoses or tubings, damaged fittings, incorrect fuel-tank installation, or a malfunctioning shutoff valve. The fuel-tank filter and/or filler cap should also be checked. To check the fuel-inlet restriction and transfer-pump pressure, install a pressure gauge to the manifold or immediately after the transfer pump, and install a vacuum gauge before the transfer pump (Fig. 53-6). Then operate the engine. The inlet fuel restriction should not exceed 8 inHg [20.32 cmHg], and the transfer-pump pressure must be within specification.

To check for air in the fuel during engine operation,

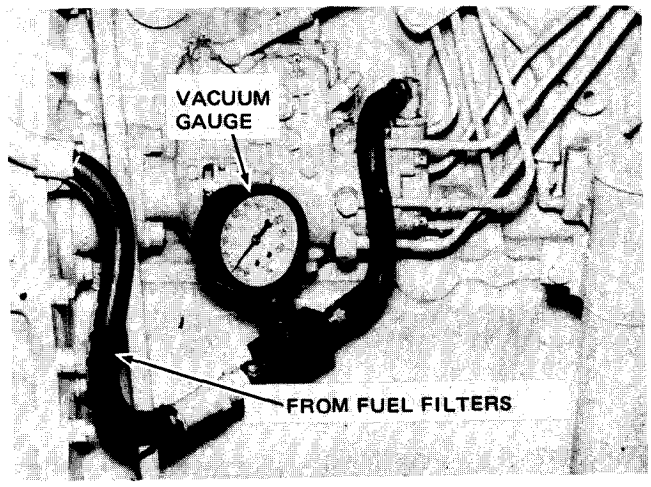


Fig. 53-6 Vacuum gauge installed to test fuel-inlet restriction. *(International Harvester Company.)*

install a liquid eye into the fuel line immediately before the transfer pump (to check the inlet side). If no air can be seen, install the liquid eye before the injection pump or manifold (to check the transfer pump and secondary filter). If the point of air entry occurs in any of these areas, it will be visible through the liquid eye.

When you check a Detroit Diesel engine for fuel-inlet restriction and the condition of the transfer-pump pressure, remove the return line at a suitable place after the restriction orifice and install a pressure gauge to the manifold. Then operate the engine at the specified rpm. Measure the return fuel flow and the manifold pressure. While measuring the return flow, check for the presence of air in the return fuel.

If the cause of engine power loss has not yet been discovered, check the injection-pump timing or the injector timing or adjustment. Check the adjustment of the governor and the control rack travel, the torque spring, or the stop-plate adjustment. If the engine is equipped with either an aneroid or fuel-ratio control, check its adjustment.

When the problem is still unsolved, check the opening pressure of the injectors. This can be done by removing the injectors from the engine and then testing them on the injector tester, or by connecting a suitable tester to the injector as shown in Fig. 53-7.

Engine Has Too Much Power Excessive power is a fairly rare complaint, but when it is reported you may notice any or all of the following: The engine rpm is above specification, the exhaust temperature is higher than normal, or the exhaust smoke is very dense.

NOTE: The exhaust temperature at maximum torque speed varies between 850 and 1200°F [455.4 and 648.9°C] depending on engine design.

To locate the cause of excessive power, check the governor-to-fuel-rack adjustment, the adjustment of the maximum-fuel stop, and the manifold boost pressure. (The wrong turbocharger may have been installed.)

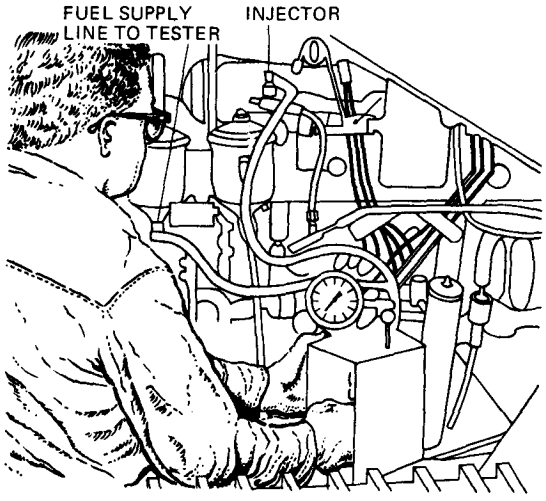


Fig. 53-7 Testing injector opening pressure while the injector is installed. *(International Harvester Company.)*

Diesel Exhaust Smoke A qualified mechanic can, by analyzing the exhaust smoke of a diesel engine, quickly evaluate the engine's performance and determine the source of trouble. Evaluation of engine trouble through the exhaust smoke should never be attempted when the engine is not at operating temperature or when the ambient temperature is below normal (70°F [21.1°C]). The combustion chamber under these conditions is not hot enough to completely burn all the fuel injected because the time lag is increased. This increased time lag causes late ignition and, depending on combustion temperature, produces grey to white exhaust smoke. It is advisable to test-drive the unit, to put a load on the engine using a chassis dynamometer, or to put a load on the engine using the torque converter of the power shift transmission so that you can analyze the exhaust smoke under all speeds and load.

Diesel exhaust smoke may be divided into three major groups: (1) liquid or cold exhaust smoke, which can range from grey to white, (2) hot or dense exhaust smoke, which can range from 20 to 100 percent density (see Fig. 53-8), and (3) blue exhaust smoke.

LIQUID EXHAUST SMOKE When an engine at operating temperature emits grey to white exhaust smoke, this indicates that part of the fuel in the combustion chamber has not been ignited. This may be caused by low compression as a result of broken piston rings or lands, leaking valves, or misadjusted valves. To determine the cause, check cylinder pressure, blowby, and valve adjustment. If the engine is misfiring, check the injector and/or the injector nozzles. There may be a leaking fuel nozzle, the opening pressure may be low, or the orifices may be enlarged. The injection timing may be late or the injectors may be misadjusted. Grey or white exhaust smoke also results from a very low fuel cetane rating, or from an excessive coolant leak into the combustion chamber.

HOT OR DENSE EXHAUST SMOKE Hot (dense) exhaust smoke indicates that the injected fuel has not burned completely. This may be due to reduced air in the cylinders or from overfueling.

CAUTION Never guess the density (percentage) of the exhaust smoke. Measure it with a smokemeter or compare it with a smoke scale (Figs. 52-2 and 53-8).

The smoke scale is divided into five groups ranging from 20 to 100 percent in density and is consistent with the Hartridge smokemeter scale. Although 40 percent density is permissible, it is near the upper range of the acceptable limit of emission control standards. If the exhaust becomes denser than 40 percent, check the intake system for restriction, and check the exhaust system for excessive back pressure. Check the blower or turbocharger boost pressure, the valve adjustment, the cylinder compression, and the blowby. Also check the coolant system and the oil level since both affect engine temperature.

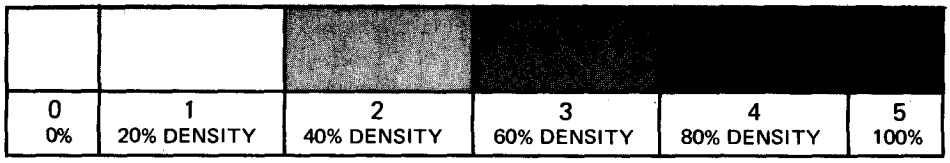


Fig. 53-8 Smoke chart. *(American Bosch, United Technologies Automotive Group.)*

When the excessive exhaust density is due to overfueling or early timing, check one or more of the following:

1. The adjustment of the aneroid or fuel-ratio control.
2. The injector timing, injector adjustment, or injection-pump timing.
3. Check the governor and the adjustment of the fuel control rack.
4. If necessary, check the opening pressure and the spray pattern of the injectors. Poor spray pattern and/or low opening pressure will reduce atomization and cause an increase in exhaust smoke density.

BLUE EXHAUST SMOKE When the smoke emitted is a mixture of blue and white (occasionally it may be completely blue), it indicates that the engine burns excessive oil.

When the exhaust is bluish, check the crankcase oil and the oil level. The oil may be too light for the ambient temperature or its level may be too high. In either case, excessive oil is thrown onto the cylinder walls and the piston rings cannot control it. Worn main bearings and connecting-rod bearings as well as excessive oil pressure can also cause oil to pass by the piston rings.

Check the cylinder compression and blowby. Do not forget to check the crankcase breather because a plugged breather can increase the crankcase pressure and force oil into the combustion chamber.

When an oil-bath cleaner is used, check its level. It may be too high, thus permitting oil to be drawn into the cylinders. Also, check the valve guides and valve seals for excessive wear. Worn guides or seals can permit oil to be drawn into the cylinder on the intake stroke.

Questions

1. How would you define the term "tuneup"?
2. List several unsatisfactory operating conditions which would call for a tuneup.
3. Why is it necessary to understand the operating principles of the various systems?
4. When servicing an engine, why should you seek information from the operator and from the engine service record?
5. What components would you check if the engine were hard to start but the cranking speed, compression, and timing checked out satisfactorily?
6. What symptoms would be noticeable if the camshaft gear were timed late by one tooth?
7. If the compressor on some Cummins engine was not timed, how would this affect the engine operation?
8. What components would you check when an engine overheats even though the coolant system and the injection system timing checked out satisfactorily?
9. List the components within the fuel-injection system of a Caterpillar compact-housing fuel pump which, if defective, could cause a reduction in power output.
10. Why, in your opinion, does an engine emit "cold smoke" prior to its reaching operating temperature?

CONVERSION TABLES

Well over 95 percent of the world's population already uses metric units of measurement or is converting to them. The tremendous advantage of the metric system lies in its simplicity and universality: All relationships between the various units of the metric system work in powers of 10, and unified symbols are used for each unit instead of a conglomerate of abbreviations.

Since many informative service manuals are still in use wherein the specifications are written in English units of measurement, the basic conversion charts have been included in this textbook to help you cope during this time of transition. These charts will provide you with a fast and easy means of converting from English to metric units of measurement, or vice versa.

For example, if you want to know the displacement in liters or cubic centimeters of a diesel engine having a displacement of 600 in^3 (cubic inches), select the capacity conversion table. Refer to the cubic inches entry in the left-hand column. The comparable amount in liters (L) and in cubic centimeters (cm^3) is shown to the right. If 1 in^3 equals 16.39 cm^3, then 600 in^3 equals 600 × 16.39 = 9834 cm^3. Likewise, if 1 in^3 equals 0.0164 L, then 600 in^3 equals 600 × 0.0164 = 9.84 L.

AREA CONVERSION

Unit	in^2	ft^2	yd^2	mi^2	cm^2	dm^2	m^2
1 in^2	1	0.0069	.....	....	6.452	0.06452	0.00064
1 ft^2	144	1	0.1111	0.0092	929	9.29	0.0929
1 yd^2	1296	9	1	0.0288	8361	83.61	0.8361
1 mi^2	....	27,878,400	....	1	....	....	2,589,998
1 cm^2	0.155	0.0017	.....	...	1	0.01	0.0001
1 dm^2	15.5	0.1076	0.01196	...	100	1	0.01
1 m^2	1550	10.76	1.196	...	10,000	100	1

BRITISH THERMAL UNITS (Btu)

1 Btu = 778.3 foot-pounds (ft · lb)
1 Btu = 107.5 meter-kilograms (m · kg)
1 Btu = 0.003931 horsepower-hour (hp · h)
1 Btu = 0.002928 kilowatthour (kWh)

CAPACITY CONVERSION

Unit	in^3	ft^3	U.S. liquid	U.S. gal	Imp. qt	Imp. gal	cm^3	dm^3	m^3	L
1 in^3	1	....	0.01732	....	0.01442	...	16.39	0.01639	.....	0.0164
1 ft^3	1728	1	29.92	7.481	24.92	6.229	.....	28.32	0.02832	28.32
1 yd^3	46,656	27	807.9	202	672.8	168.2	.....	764.6	0.7646	764.6
1 U.S. liquid qt	57.75	0.03342	1	0.25	0.8327	0.2082	946.4	0.9464		
1 U.S. gal	231	0.1337	4	1	3.331	0.8327	3785	3.785	0.003785	3.785
1 Imp. qt	69.36	0.04014	1.201	0.3002	1	0.25	1136	1.136		
1 Imp. gal	277.4	0.1605	4.804	1.201	4	1	4546	4.546	0.004546	4.546
1 cm^3	0.06102	....	.....	.....	.....	....	1	0.001	0.000001	0.001
1 dm^3	61.02	0.03531	1.057	0.2642	0.88	0.22	1000	1	0.001	1
1 m^3	61,023	35.31	1057	264.2	880	220	....	1000	1	1000
1 L	61.02	0.03531	1.057	0.2642	0.88	0.22	1000	1	0.001	1

LENGTH CONVERSION

Unit	in	ft	yd	mi (statute)	nmi	mm	cm	m	km	μm
1 in	1	0.08333	0.02778	....	....	25.4	2.54	0.0254	....	25.400
1 ft	12	1	0.3333	....	....	304.8	30.48	0.30488		
1 yd	36	3	1	....	....	914.4	91.44	0.9144		
1 mi (statute)	63,360	5280	1760	1	0.8684	....	....	1609.3	1.609	
1 nmi	72,960	6080	2027	1.152	1	....	....	1853.3	1.853	
1 mm	0.03937	3281×10^3	.....	....	....	1	0.1	0.001	....	1,000
1 cm	0.3937	4.716	14.148	....	....	10	1	100	....	10,000
1 m	39.37	3.281	1.094	....	....	1000	100	1	0.001	
1 km	39,370	3281	1093.6	0.6214	0.5396	10^6	100,000	1000	1	
1 μm	0.000039	....	....	....	....	0.01	0.0001	0.000001	....	1

PRESSURE CONVERSION

Unit	inH_2O	cmH_2O	inHg	cmHg	psi	kg/cm^2	atm	kPa
1 inH_2O	1	2.54	0.0735	1.866	0.0361			0.248
1 inHg	13.6	34.544	1	2.54	0.491	0.0345	0.0334	3.386
1 psi	27.7	70.104	2.036	5.171	1	0.0703	0.068	6.8948
1 kg/cm^2	393.73	1000.0	28.96	73.55	14.22	1	0.9678	101.28
1 atm	407.19	1033.0	29.92	75.96	14.70	1.033	1	....
1 kPa	4.01	10.18	0.295	0.750	0.145	0.026	....	....

WEIGHT CONVERSION

Unit	oz	lb	g	kg
oz	1	0.0625	28.35	0.02835
lb	16	1	453.59	0.45359
g	0.03527	....	1	0.001
kg	35.27	2.2046	1000	1

TORQUE CONVERSION

Unit	lb·ft	kg·m	N·m
1 lb·ft	1	0.1383	1.355
1 kg·m	7.233	1	9.80
1 N·m	0.738	7.233	....

POWER CONVERSION

Unit	hp	hp (metric)	ft · lb/s	kg · m/s	kW	W	Btu/min
hp	1	1.014	550	76.04	0.746	746	42.4
hp (metric)	0.986	1	542.5	75.00	0.736	736	41.8
ft · lb/s	.....	.....	1	0.30488	....	0.0226	0.001285
kg · m/s	.....	.....	3.281	1	....	0.0741	0.0042
kW	1.341	1.360	737.28	102.00	1	1000	56.8
W	0.00134	0.00136	0.737	0.102	0.001	1	
Btu/min	0.0236	0.0239	12.96	3.939	0.0176	17.6	1

PRESSURE VERSUS THE BOILING POINTS OF WATER (VARIOUS ALTITUDES)

Altitude					Boiling point of water	
ft	in	psi	inHg	kg/cm²	°F	°C
Sea level		14.69	29.92	1.032	212	100
1000	304.8	14.16	28.86	0.995	210.1	99
2000	609.6	13.66	27.82	0.960	208.3	98
3000	914.4	13.16	26.81	0.925	206.5	97
4000	1219.4	12.68	25.84	0.891	204.6	95.9
5000	1524.0	12.22	24.89	0.859	202.8	94.9
6000	1828.8	11.77	23.98	0.827	201.0	94.1
7000	2133.6	11.33	23.09	0.796	199.3	93.0
8000	2438.4	10.91	22.22	0.766	197.4	91.9
9000	2743.2	10.50	21.38	0.738	195.7	91
10,000	3048.0	10.10	20.58	0.701	194.0	90

FUEL CONSUMPTION FORMULAS

Fuel consumption (lb/hr) = specific fuel consumption [lb/(bhp)/(h)] × bhp

$$\text{Fuel consumption (gal/h)} = \frac{\text{specific fuel consumption [lb/(bhp)/(h)]} \times \text{bhp}}{\text{fuel specific weight (lb/gal)}}$$

Fuel specific weight (lb/gal) = fuel specific gravity × 8.34 lb

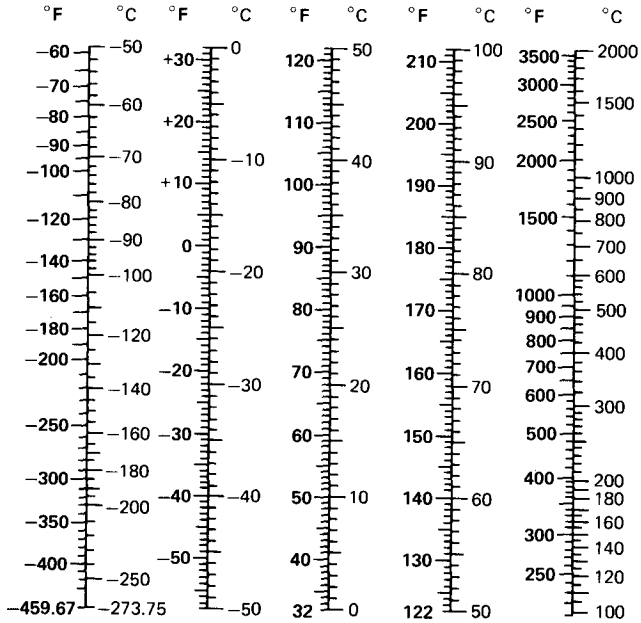
$$\text{Specific fuel consumption [lb/(bhp)/(h)]} = \frac{\text{fuel consumption (gal/h)} \times \text{fuel specific weight (lb/gal)}}{\text{bhp}}$$

$$\text{Specific fuel consumption [kg/(mhp)/(h)]} = \frac{\text{specific fuel consumption [lb/(bhp)/(h)]}}{2.24}$$

TEMPERATURE CONVERSION

°F = 9/5 × °C + 32

°C = 5/9 × (°F − 32)



BRAKE HORSEPOWER FORMULA

$$bhp = \frac{\text{torque (ft} \cdot \text{lb)} \times \text{engine rpm}}{5252}$$

CONVERSION FOR TEST STANDARDS

	Altitude, ft [m]	Barometric pressure, inHg [kg/cm²]	Ambient temperature, °F [°C]	Air density, %	Brake power, lb·ft/s[kg·m/s]
SAE	500 [152.4]	29.38 [746.25]	85 [29.4]	50	550.0 [76.04]
British	500 [152.4]	29.38 [746.25]	85 [29.4]	50	550.0 [76.04]
Din (German)	984 [300.0]	28.88 [733.55]	68 [20.0]	60	542.5 [75.00]
Metric	984 [300.0]	28.88 [733.55]	68 [20.0]	60	542.5 [75.00]
Sea level	Sea level Sea level	29.92 [759.97]	60 [15.55]	Dry air	*550.0 [*76.04]

* Standard ambient condition.

DECIMAL EQUIVALENTS OF MILLIMETERS

mm	in	mm	in	mm	in	mm	in	mm	in
0.01	0.00039	0.41	0.01614	0.81	0.03189	21	0.82677	61	2.40157
0.02	0.00079	0.42	0.01654	0.82	0.03228	22	0.86614	62	2.44094
0.03	0.00118	0.43	0.01693	0.83	0.03268	23	0.90551	63	2.48031
0.04	0.00157	0.44	0.01732	0.84	0.03307	24	0.94488	64	2.51968
0.05	0.00197	0.45	0.01772	0.85	0.03346	25	0.98425	65	2.55905
0.06	0.00236	0.46	0.01811	0.86	0.03386	26	1.02362	66	2.59842
0.07	0.00276	0.47	0.01850	0.87	0.03425	27	1.06299	67	2.63779
0.08	0.00315	0.48	0.01890	0.88	0.03465	28	1.10236	68	2.67716
0.09	0.00354	0.49	0.01929	0.89	0.03504	29	1.14173	69	2.71653
0.10	0.00394	0.50	0.01969	0.90	0.03543	30	1.18110	70	2.75590
0.11	0.00433	0.51	0.02008	0.91	0.03583	31	1.22047	71	2.79527
0.12	0.00472	0.52	0.02047	0.92	0.03622	32	1.25984	72	2.83464
0.13	0.00512	0.53	0.02087	0.93	0.03661	33	1.29921	73	2.87401
0.14	0.00551	0.54	0.02126	0.94	0.03701	34	1.33858	74	2.91338
0.15	0.00591	0.55	0.02165	0.95	0.03740	35	1.37795	75	2.95275
0.16	0.00630	0.56	0.02205	0.96	0.03780	36	1.41732	76	2.99212
0.17	0.00669	0.57	0.02244	0.97	0.03819	37	1.45669	77	3.03149
0.18	0.00709	0.58	0.02283	0.98	0.03858	38	1,49606	78	3.07086
0.19	0.00748	0.59	0.02323	0.99	0.03898	39	1.53543	79	3.11023
0.20	0.00787	0.60	0.02362	1.00	0.03937	40	1.57480	80	3.14960
0.21	0.00827	0.61	0.02402	1	0.03937	41	1.61417	81	3.18897
0.22	0.00866	0.62	0.02441	2	0.07874	42	1.65354	82	3.22834
0.23	0.00906	0.63	0.02480	3	0.11811	43	1.69291	83	3.26771
0.24	0.00945	0.64	0.02520	4	0.15748	44	1.73228	84	3.30708
0.25	0.00984	0.65	0.02559	5	0.19685	45	1.77165	85	3.34645
0.26	0.01024	0.66	0.02598	6	0.23622	46	1.81102	86	3.38582
0.27	0.01063	0.67	0.02638	7	0.27559	47	1.85039	87	3.42519
0.28	0.01102	0.68	0.02677	8	0.31496	48	1.88976	88	3.46456
0.29	0.01142	0.69	0.02717	9	0.35433	49	1.92913	89	3.50393
0.30	0.01181	0.70	0.02756	10	0.39370	50	1.96850	90	3.54330
0.31	0.01220	0.71	0.02795	11	0.43307	51	2.00787	91	3.58267
0.32	0.01260	0.72	0.02835	12	0.47244	52	2.04724	92	3.62204
0.33	0.01299	0.73	0.02874	13	0.51181	53	2.08661	93	3.66141
0.34	0.01339	0.74	0.02913	14	0.55118	54	2.12598	94	3.70078
0.35	0.01378	0.75	0.02953	15	0.59055	55	2.16535	95	3.74015
0.36	0.01417	0.76	0.02992	16	0.62992	56	2.20472	96	3.77952
0.37	0.01457	0.77	0.03032	17	0.66929	57	2.24409	97	3.81889
0.38	0.01496	0.78	0.03071	18	0.70866	58	2.28346	98	3.85826
0.39	0.01535	0.79	0.03110	19	0.74803	59	2.32283	99	3.89763
0.40	0.01575	0.80	0.03150	20	0.78740	60	2.36220	100	3.93700

SOURCE: The L.S. Starrett Co.

TUBE OD SIZES

in	mm
1/8	3.18
3/16	4.76
1/4	6.35
5/16	7.94
3/8	9.52
13/32	10.32
1/2	12.70
5/8	15.88
3/4	19.05
7/8	22.22
1	25.40
1 1/8	28.58
1 1/4	31.75
1 1/2	38.10
1 3/4	44.45
2	50.80

TAP DRILL SIZES FOR FRACTIONAL SIZE THREADS—75% DEPTH THREAD, IN—AMERICAN NATIONAL THREAD FORM

Tap size	Threads per inch	Diameter hole	Drill	Tap size	Threads per inch	Diameter hole	Drill
1/16	72	0.049	3/64	1/2	20	0.451	29/64
1/16	64	0.047	3/64	1/2	13	0.425	27/64
1/16	60	0.046	56	1/2	12	0.419	27/64
5/64	72	0.065	52	9/16	27	0.526	17/32
5/64	64	0.063	1/16	9/16	18	0.508	33/64
5/64	60	0.062	1/16	9/16	12	0.481	31/64
5/64	56	0.061	53				
				5/8	27	0.589	19/32
3/32	60	0.077	5/64	5/8	18	0.571	00/64
3/32	56	0.076	48	5/8	12	0.544	35/64
3/32	50	0.074	49	5/8	11	0.536	17/32
3/32	48	0.073	49				
				11/16	16	0.627	5/8
7/64	56	0.092	42	11/16	11	0.599	00/32
7/64	50	0.090	43				
7/64	48	0.089	43	3/4	27	0.714	00/32
				3/4	16	0.689	11/16
1/8	48	0.105	36	3/4	12	0.669	43/64
1/8	40	0.101	38	3/4	10	0.653	21/32
1/8	36	0.098	40				
1/8	32	0.095	3/32	15/16	12	0.731	47/64
				13/16	10	0.715	00/32
9/64	40	0.116	32				
9/64	36	0.114	33	7/8	27	0.839	27/32
9/64	32	0.110	35	7/8	18	0.821	00/64
				7/8	14	0.805	13/16
5/32	40	0.132	30	7/8	12	0.794	51/64
5/32	36	0.129	30	7/8	9	0.767	49/64
5/32	32	0.126	1/8				
11/64	36	0.145	27	15/16	12	0.856	55/64
11/64	32	0.141	9/64	15/16	9	0.829	53/64
3/16	36	0.161	20				
3/16	32	0.157	22	1	27	0.964	31/32
3/16	30	0.155	23	1	14	0.930	15/16
3/16	24	0.147	26	1	12	0.919	00/64
				1	8	0.878	7/8
13/64	32	0.173	17				
13/64	30	0.171	11/64	1 1/16	8	0.941	15/16
13/64	24	0.163	20	1 1/8	12	1.044	1 3/64
				1 1/8	7	0.986	63/64
7/32	32	0.188	12	1 3/16	7	1.048	1 8/64
7/32	28	0.184	13	1 1/4	12	1.169	1 11/64
7/32	24	0.178	16		7	1.111	1 7/64
15/64	32	0.204	6	1 5/16	7	1.173	1 11/64
15/64	28	0.200	8	1 3/8	12	1.294	1 19/64
15/64	21	0.194	10	1 3/8	6	1.213	1 7/32
1/4	32	0.220	7/32	1 1/2	12	1.419	1 27/64
1/4	28	0.215	3	1 1/2	6	1.338	1 11/32
1/4	27	0.214	3	1 5/8	5 1/2	1.448	1 29/64
1/4	24	0.209	4	1 3/4	5	1.555	1 9/16
1/4	20	0.201	7	1 7/8	5	1.680	1 11/16
5/16	32	0.282	9/32	2	4 1/2	1.783	1 00/00
5/16	27	0.276	J	2 1/8	4 1/2	1.909	1 00/00
5/16	24	0.272	I	2 1/4	4 1/2	2.034	2 1/32
5/16	20	0.264	17/64	2 3/8	4	2.131	2 1/8
5/16	18	0.258	F	2 1/2	4	2.256	2 1/4
				2 5/8	4	2.381	2 3/8
3/8	27	0.339	R	2 3/4	4	2.505	2 1/2
3/8	24	0.334	Q	2 7/8	3 1/2	2.597	2 00/32
3/8	20	0.326	21/64				
3/8	16	0.314	5/16	3	3 1/2	2.722	2 00/32
				3 1/8	3 1/2	2.847	2 00/32
7/16	27	0.401	Y	3 1/4	3 1/2	2.972	2 00/32
7/16	24	0.397	X	3 3/8	3 1/4	3.075	3 1/16
7/16	20	0.389	25/64	3 1/2	3 1/4	3.200	3 9/16
7/16	14	0.368	U	3 5/8	3 1/4	3.325	3 5/16
				3 3/4	3	3.425	3 7/16
1/2	27	0.464	15/32				
1/2	24	0.460	00/64	4	3	3.675	3 11/16

TAP DRILL SIZES FOR MACHINE SCREW THREADS—75% DEPTH OF THREAD

A bolt inserted in an ordinary nut, which has only one-half of a full depth of thread, will break before stripping the thread. Also a full depth of thread, while very difficult to obtain, is only about 5% stronger than a 75% depth.

These tables give the exact size of the hole, expressed in decimals, that will produce a 75% depth of thread, and also the nearest regular stock drill to this size. Holes produced by these drills are considered close enough for any commercial tapping.

$$\text{Diameter of tap} - \frac{0.974}{\text{no. threads per inch}} = \text{diameter of hole}$$

Tap size	Threads per inch	Diameter hole	Drill	Tap size	Threads per inch	Diameter hole	Drill
0	80	0.048	3/64	10	32	0.160	21
1	72	0.060	53	10	30	0.158	22
1	64	0.058	53	10	28	0.155	23
2	64	0.071	50	10	24	0.149	25
2	56	0.069	50	12	28	0.181	14
3	56	0.082	45	12	24	0.175	16
3	48	0.079	47	14	24	0.201	7
4	48	0.092	42	14	20	0.193	10
4	40	0.088	43	16	22	0.224	2
4	36	0.085	44	16	20	0.219	7/32
5	44	0.103	37	16	18	0.214	3
5	40	0.101	38	18	20	0.245	D
5	36	0.098	40	18	18	0.240	B
6	40	0.114	33	20	20	0.271	I
6	36	0.111	34	20	18	0.266	17/64
6	32	0.108	36	22	18	0.292	L
7	36	0.124	1/8	22	16	0.285	9/32
7	32	0.121	31	24	18	0.318	O
7	30	0.119	31	24	16	0.311	5/16
8	36	0.137	29	26	16	0.337	R
8	32	0.134	29	26	14	0.328	21/64
8	30	0.132	30	28	16	0.363	23/64
9	32	0.147	26	28	14	0.354	T
9	30	0.145	27	30	16	0.389	25/64
9	24	0.136	29	30	14	0.380	V

SOURCE: The L. S. Starrett Co.

GLOSSARY

ABDC Abbreviation for *after bottom dead center.*

Absolute pressure Gauge pressure plus atmospheric pressure.

Absolute temperature The temperature measured using absolute zero as a reference. Absolute zero is −273.16°C, or [469.69°F] and is the lowest point of temperature known.

Acceleration The rate of increase of velocity per time unit (i.e., seconds, minutes, hours).

Accumulator A device used for storing liquid under pressure (sometimes used to smooth out pressure surges in a hydraulic system).

Actuator A device which uses fluid power to produce mechanical force and motion.

Additive A matter which is added to improve fuel.

Advance To set the timing of the injection pump or injectors for an earlier injection.

Aftercooler A device used on turbocharged engines to cool air which has undergone compression.

Air bind The presence of air in a pump or pipes which prevents the delivery of liquid.

Air bleeder A device used to remove air from a hydraulic system. Types include a needle valve, capillary tubing to the reservoir, and a bleed plug.

Air cleaner A device (filter) for removing unwanted solid impurities from the air before it enters the intake manifold.

Air compressor A device used to increase air pressure.

Air-fuel ratio The ratio (by weight or by volume) between air and fuel.

Air gap The distance between two components.

Air pollution Contamination of the earth's atmosphere by pollutants such as smoke, harmful gases, etc.

Air starting valve A valve which admits compressed air to the air starter for starting purposes.

Align To bring two or more components of a unit into the correct positions with respect to one another.

Alloy A mixture of two or more different metals, usually to produce improved characteristics.

Allowance The difference between the minimum and the maximum dimensions of proper functioning.

Alnico magnet A magnet composed of aluminum (Al), nickel (Ni), and cobalt (Co).

Alternator An electromechanical device which produces ac current.

Alternating current (ac) An electric current that changes polarity.

Ambient temperature Surrounding air temperature.

Ammeter An instrument used to measure the rate of current flow in amperes.

Ampere (A) A unit of measurement defined as the current that 1 V can send through 1 Ω resistance.

Ampere-hour capacity (Ah) A measurement of the battery capacity to deliver a specified current over a specified length of time.

Angle Inclination of two lines to each other.

Angularity Having or being at an angle.

Aneroid A pressure-measuring device containing no liquid.

Anneal To toughen metals by heating and then cooling.

Annular In the form of an annulus; ring-shaped.

Annulus A figure bounded by concentric circles or cylinders (e.g., a washer, ring, sleeve, etc.).

Antifreeze A chemical added to the coolant in order to lower its freezing point.

API Abbreviation for *American Petroleum Institute.*

API gravity Gravity expressed in units of standard API (hydrometer).

Arc Portion of a curved line or of the circumference of a circle.

Arcing Electrons leaping the gap between the negative and the positive poles.

Armature The movable part of a relay, regulator, or horn or the rotating part of a generator or starter.

Asbestos A heat-resistant and nonburning organic mineral.

Aspirate To breathe (to draw out gas by suction).

ATDC Abbreviation for *after top dead center.*

Atmosphere The mass or blanket of gases surrounding the earth.

Atmospheric pressure (barometric pressure) The pressure exerted by the atmosphere, averaging 14.7 psi at sea level with a decrease of approximately ½ lb per 1000 ft of altitude gained.

Atom The smallest particle of an element.

Atomizer A device which disperses liquid (e.g., fuel) into fine particles (pulverized spray).

Attrition Wearing down by rubbing or by friction; abrasion.

Automatic valve A valve assisted by a spring, which is opened by a difference of pressure acting in one direction and closed by a difference in pressure acting in the opposite direction.

Auxiliary An aid to the main device which may only be used occasionally.

Babbit An antifriction metal used to line bearings, thereby reducing the friction of the moving components.

Backlash The distance (play) between two movable components.

Back pressure A pressure exerted contrary to the pressure producing the main flow.

Baffle A device which slows down or diverts the flow of gases, liquids, sound, etc.

Balanced valve A valve in which the fluid pressure is equal on both sides (i.e., the opening and closing directions).

Ball bearing A bearing using steel balls as its rolling element between the inner and outer ring (race).

Ball check valve A valve consisting of a ball held against a ground seat by a spring. It is used to check the flow or to limit the pressure.

Barometer An instrument which measures atmospheric pressure.

Basic size The theoretical or nominal standard size from which all variations are made.

Battery An electrochemical device that produces electric current.

Battery charging (See *Charge.*)

BBDC Abbreviation for *before bottom dead center.*

BDC Abbreviation for *bottom dead center.*

Bearing The contacting surface on which a revolving part rests.

Bearing clearance The distance between the shaft and the bearing surface.

Bell housing (clutch housing) The metal covering around the clutch or torque converter assembly.

Bendix-type starter drive (inertia starter drive) A type of starter drive that causes the gear to engage when the armature starts rotating and to automatically disengage when it stops.

Bernoulli's principle Given a fluid flowing through a tube, any constriction or narrowing of the tube will create an increase in that fluid's velocity and a decrease in pressure.

Blowby Exhaust gases which escape past the piston rings.

Blower A low-pressure air pump, usually of one rotary or centrifugal type.

Bond The holding together of different parts.

Boiling point The temperature at which a liquid begins to boil.

Bore A cylinder, hole, or the inside diameter of the cylinder or hole.

Bore diameter The diameter of a hole or cylinder.

Boring Enlarging the cylinders by cutting or honing them to a specified size.

Boring bar (cylinder) A tool used to machine the cylinders to a specific size.

Bosch metering system A metering system with a helical groove in the plunger which covers or uncovers ports in the pump barrel.

Bound electrons The inner-orbit electrons around the nucleus of the atom.

Boyle's law The absolute pressure which a given quantity of gas at constant temperature exerts against the walls of the containing vessel is inversely proportional to the volume occupied.

Brake horsepower (bhp) The usable power delivered by the engine.

Brake mean effective pressure (bmep) Mean effective pressure acting on the piston which would result in the given brake horsepower output, if there were no losses due to friction, cooling, and exhaustion. Equal to mean indicated pressure times mechanical efficiency.

Brake thermal efficiency Ratio of power output in the form of brake horsepower to equivalent power input in the form of heat from fuel.

Brazing The fastening of two pieces of metal together by heating the edges and then melting brass or bronze on the area.

Breather pipe A pipe opening into the crankcase to assist ventilation.

Brinnel hardness The surface hardness of a metal, alloy, or similar material according to J.A. Brinnell's method of measurement. A metal's surface is struck at a given force by a rigid steel ball of given diameter and the indentation is measured.

British gallon [Imperial gallon, gal (Imp.)] A gallon measurement of 277.4 in^3.

British thermal unit (Btu) Approximate definition: The amount of heat required to raise 1 lb of water 1°F. Exact definition: $1/180$ the amount of heat required to raise 1 lb of water from freezing to boiling at a standard atmospheric pressure.

Brush The pieces of carbon or copper that make a sliding contact against the commutator or slip rings.

BTDC Abbreviation for *before top dead center.*

Buoyancy The upward or lifting force exerted on a body by a fluid.

Burnish To polish or shine a surface with a hard, smooth object.

Bushing A metallic or synthetic lining for a hole which reduces or prevents abrasion between components.

Butane A hydrocarbon gas formed synthetically by the action of zinc or ethyl iodide. This gas becomes a liquid when under pressure.

Butterfly valve A valve in the venturi to control the airflow.

Bypass filter An oil filter that only filters a portion of the oil flowing through the engine lubrication system.

Bypass valve A valve that opens when the set pressure is exceeded. This allows the fluid to pass through an alternative channel.

Cage A housing in which a valve operates and seats.

Calibrate To make an adjustment to a meter or other instrument so that it will indicate accurately its input.

Calipers A tool for measuring diameter, usually having curved legs and resembling a pair of compasses.

Calorie The amount of heat required to raise 1 g of water from 17 to 18°C.

Calorific value The amount of heat produced by burning one pound of fuel. (See *heating value.*)

Cam A rotating component of irregular shape. It is used to change the direction of the motion of another part moving against it, e.g., rotary into reciprocating or variable motion.

Cam follower (valve lifter) A part which is held in contact with the cam and to which the cam motion is imparted and transmitted to the pushrod.

Cam-ground A piston that is ground slightly oval but becomes round when heated.

Cam nose That portion of the cam that holds the valve wide open. It is the high point of the cam.

Camshaft A shaft with cam lobes.

Camshaft gear The gear that is fastened to the camshaft.

Capacitor An arrangement of insulated conductors and dielectrics for the accumulation of an electric charge with small voltage output.

Carbon One of the nonmetallic elements constituting fuel and lubricating oil.

Carbon dioxide (CO_2) A colorless, odorless gas which results when carbon is burned completely.

Carbon monoxide (CO) A colorless, odorless, poisonous gas which results from the incomplete burning of carbon.

Carbon pile Carbon disks or plates capable of carrying high current.

Carbon tetrachloride A colorless liquid, the fumes of which are toxic. Used in fire extinguishers and for cleaning.

Carburizing To combine or add to the metal the element carbon for hardening purposes.

Case-harden To harden the outer surface of metal to a given case or shell depth, while leaving the inner portion soft to absorb shocks and allow bending. (See *Carburizing.*)

Cavitation The formation of cavities in the fluid due to excessive speed of the activator resulting in the loss of efficiency in the pump.

Cells (battery) The individual (separate) compartments in the battery which contain positive and negative plates suspended in electrolyte.

Cell connectors The lead straps connecting the cell groups.

Celsius (centigrade) Thermometer scale on which the freezing temperature of water is 0°C and boiling temperature of water at atmospheric pressure is 100°C.

Center of gravity That point in a

body at which all its mass can be concentrated without allowing the effect of gravity.

Centigrade thermometer A thermometer with a centigrade scale.

Centrifugal force A force exerted on a rotating object in a direction outward from the center of rotation.

Centrifugal governor A governor which uses flyweight force to sense speed in order to control the amount of fuel supplied to the combustion chambers.

Centrifugal pump A pump using the centrifugal force produced by a rapidly rotating impeller to displace liquid.

Centrifuge A device with a rapidly rotating bowl which separates the impurities of a fluid by intense centrifugal force. It is one of the most efficient means known for purifying fuel and lubricating oils.

Cetane number The rating of a diesel fuel's ignition.

Chamfer (taper lead) The taper at the thread end of a tap or the throat of a die, made by cutting away the crests of the first few threads. This distributes the work of cutting over several threads and acts as a guide in starting the tap or die. The chamfer is relieved to facilitate cutting. The tap is classed as taper, second, or bottoming, according to the length of chamfer, which approximates the following:

- Taper tap: 4° per side
- Second tap: 8° per side
- Bottoming tap: 23° per side
- Nut taps: Approximately 75 percent of the thread length

Charge (battery) To force current (electrons) into a battery to restore it to a full state of charge.

Charles' law The physical law which states that the rise of temperature in all gases produces the same increase in volume if the pressure remains constant.

Check valve A valve which permits only one direction of flow.

Chemical change A change which alters the composition of the molecules of a substance, producing new substances with new properties.

Circuit (electric) A source of power. A path for current flow with one or more resistant units.

Circuitbreaker (lighting system) A device that opens the circuit when the current draw becomes excessive and closes the circuit when the current flow is reduced.

Circulating pump The term applied to cooling-oil pumps which give circulation of fluid.

Circumference The distance, or perimeter, of a circle. (π times the diameter.)

Clearance The space between two components.

Clearance volume The volume remaining above the piston when it is at TDC.

Closed cooling system A cooling system which is not exposed to the atmosphere.

Closed nozzle A fuel nozzle having a valve between the combustion chamber and the fuel chamber.

Clutch A device used to connect or disconnect the power input to the power output.

Clutch pilot bearing A small bushing, or ball bearing positioned in the crankshaft or flywheel.

Coil spring A spring-steel wire wound in a spiral pattern.

Color code Colored markings or wires to identify the different circuits.

Combustion The act or process that occurs during burning.

Combustion chamber The chamber in which combustion mainly occurs.

Combustion-chamber volume The volume of the combustion chamber (when the piston is at TDC) measured in cubic centimeters.

Combustion cycle A series of thermodynamic processes through which the working gas passes to produce one power stroke. The full cycle is: intake, compression, power, and exhaust.

Commutator A number of copper bars connected to the armature windings but insulated from each other and from the armature.

Compound A combination of two or more elements that are mixed together.

Compressed air Air that at any pressure in excess of atmospheric pressure is considered to be compressed.

Compressibility The property of a substance (e.g., air) by virtue of which its density increases with increase in pressure.

Compression The process by which a confined gas is reduced in volume through the application of pressure.

Compression check A measurement of the compression of each cylinder at cranking speed or as recommended by the manufacturer.

Compression gauge A test instrument used to test the cylinder compression.

Compression ignition The ignition of fuel through the heat of compression.

Compression pressure Pressure in the combustion chamber at the end of the compression stroke, but without any of the fuel being burned.

Compression ratio The ratio between the total volume in the cylinder when the piston is at BDC and the volume remaining when the piston is at TDC.

Compression release A device to prevent the intake or exhaust valves from closing completely, thereby permitting the engine to be turned over without compression.

Compression ring The piston rings used to reduce combustion leakage to a minimum.

Compression stroke That stroke of the operating cycle during which air is compressed into a smaller space creating heat by molecular action.

Compressor A mechanical device to pump air, and thereby increase the pressure.

Concentric Having the same center.

Condensation The reduction of a vapor or gas to a liquid state.

Condense To reduce from gas or vapor to liquid.

Condenser An arrangement of insulated conductors and dielectrics for the accumulation of an electric charge.

Conduction The transmission of heat through matter without motion of the conducting body.

Conductor Any material or device forming a path for the flow of electrons.

Connecting rod The rod joining the piston with the crankshaft.

Connecting-rod bearing The bearing used in the connecting-rod bore.

Constant-pressure combustion Combustion which occurs without a change in pressure. In an engine, this is obtained by a slower rate of burning than with constant-volume combustion.

Contamination The presence of harmful foreign matter in a fluid or in air.

Contour Outline.

Contract To reduce; to make smaller.
Control To regulate or govern the function of a unit.
Controlled port scavenging Scavenging method using ports which are controlled by valves in addition to the power piston.
Convection The transfer of heat through a liquid by motion of its parts.
Conventional According to the most common or usual mode.
Converge To incline to or approach a certain point; to come together.
Convolution One full turn of a screw.
Coolant A liquid used as a cooling medium.
Cooling system The complete system for circulating coolant.
Core The central or innermost part of an object.
Corrode To eat or wear away gradually by chemical action.
Corrosion The slow destruction of material by chemical agents and electromechanical reactions.
Corrosive Having the ability to corrode.
Counterbalance A weight, usually attached to a moving component, that balances another weight.
Counterbore A cylindrical enlargement of the end of a cylinder bore or bore hole.
Counterelectromotive force (cemf) The electromotive force (voltage) that opposes the applied voltage.
Countersink To cut or shape a depression in an object so that the head of a screw may set flush or below the surface.
Counterweight Weights that are mounted on the crankshaft opposite each crank throw. These reduce the vibration caused by putting the crank in practical balance and also reduce bearing loads due to inertia of moving parts.
Coupling A device used to connect two components.
Crankcase The casing which surrounds the crankshaft.
Crankcase scavenging Scavenging method using the pumping action of the power piston in the crankcase to pump scavenging air.
Crankpin The portion of the crank throw attached to the connecting rod.
Crankshaft A rotating shaft for converting rotary motion into reciprocating motion.
Crankshaft gear The gear that is mounted to the crankshaft.
Crank throw One crankpin with its two webs (the amount of offset of the rod journal).
Crank web The portion of the crank throw between the crankpin and main journal. This makes up the offset.
Crest The top surface joining the two sides of a thread.
Crest clearance Defined on a screw form as the space between the top of a thread and the root of its mating thread.
Critical compression ratio Lowest compression ratio at which any particular fuel will ignite by compression under prescribed test procedure. The lower the critical compression ratio the better ignition qualities the fuel has. (Gasoline engine, 4:1; oil engine, 7:1; diesel engine, 12.5:1.)
Critical speeds Speeds at which the frequency of the power strokes synchronize with the crankshaft's natural frequency or torsional damper. If the engine is operated at one of its critical speeds for any length of time, a broken crankshaft may result.
Crocus cloth A very fine abrasive polishing cloth.
Crowned A very slight curve in a surface (e.g., on a roller or raceway).
Crude oil Petroleum as it comes from the well (unrefined).
Crush A deliberate distortion of an engine's bearing shell to hold it in place during operation.
Current The flow of electrons passing through a conductor. Measured in amperes.
Cycle A series that repeats itself in the same sequence.
Cylinder The piston chamber of an engine.
Cylinder head The replaceable portion of the engine that seals the cylinder at the top. It often contains the valves, and in some cases, it is part of the combustion chamber.
Cylinder hone A tool used to bring the diameter of a cylinder to specification and at the same time smooth its surface.
Cylinder liner A sleeve which is inserted in the bores of the engine block which make up the cylinder wall.

Dead center Either of the two positions when the crank and connecting rod are in a straight line at the end of the stroke.
Deceleration Opposite of acceleration, that is, implying a slowing down instead of a speeding up. Also called *negative acceleration.*
Deflection Bending or movement away from the normal position, due to loading.
Deglazer A tool used to remove the glaze from cylinder walls.
Degree (circle) 1/360 of a circle.
Degree wheel A wheel marked in degrees to set the lifter height.
Depth of engagement The depth of a thread in contact with two mating parts measured radially. It is the radial distance by which their thread forms overlap each other.
Density The weight per unit volume of a substance.
Detergent A chemical with cleansing qualities added to the engine oil.
Detonation Burning of a portion of the fuel in the combustion chamber at a rate faster than desired (knocking).
Dial indicator (dial gauge) A precision measuring instrument.
Diaphragm Any flexible dividing partition separating two compartments.
Die (thread) A thread-cutting tool.
Diesel engine An internal-combustion engine having fuel injected into the combustion chamber near the end of the combustion stroke. The fuel is ignited by the heat of compression only.
Diesel index A rating of fuel according to its ignition qualities. The higher the diesel index number, the better the ignition quality of the fuel.
Differential pressure fuel valve A closed fuel valve with a needle or spindle valve which seats onto the inner side of the orifices. The valve is lifted by fuel pressure.
Dilution Thinning, e.g., as when fuel mixes with the lubricant.
Diode A device which allows current to pass but only in one direction.
Dipstick A device to measure the quantity of oil in the reservoir.
Direct-cooled piston A piston which is cooled by the internal circulation of a liquid.
Direct current (dc) Current that flows in one direction only.
Directional control valve A valve which selectively directs or prevents flow to or from specific channels. Also referred to as *selector valve, control valve,* or *transfer valve.*
Discharge A draw of current from the battery.

Displacement In a single-acting engine, the volume swept by all pistons in making one stroke each. The displacement on one cylinder in cubic inches is the circular area (in square inches) times the stroke (in inches).

Distillation Heating a liquid and then condensing the vapors given off by the heating process.

Division plate A diaphragm surrounding the piston rod of crosshead-type engine, usually having a wiper ring to remove excess oil from the piston rod as it slides through. It separates the crankcase from the lower end of the cylinder.

Double acting An actuator producing work in both directions.

Double flare A flared end of the tubing having two wall thicknesses.

Dowel A pin, usually of circular shape like a cylinder, used to pin or fasten something in position temporarily or permanently.

Dribbling Unatomized fuel running from the fuel nozzle.

Drill A tool used to bore holes.

Drill press A fixed machine to drive a tool in rotary motion.

Drive-fit A fit between two components, whose tolerance is so small that the two parts must be pressed or driven together.

Drop-forged Formed by hammering or forced into shape by heat.

Dry cell (dry battery) A battery that uses no liquid electrolyte.

Dry-charged battery A battery in a precharged state but without electrolyte. The electrolyte is added when the battery is to be placed in service.

Dry sleeve A cylinder sleeve (liner) where the sleeve is supported over its entire length. The coolant does not touch the sleeve itself.

Dual valves Refers to cylinders having two valves performing one function, e.g., two intake valves, two exhaust valves.

Dynamic balance Condition when the weight mass of a revolving object is in the same plane as the centerline of the object.

Dynamic pressure The pressure of a fluid resulting from its motion, equal to one-half the fluid density times the fluid velocity squared. In incompressible flow, dynamic pressure is the difference between total pressure and static pressure.

Dynamometer A device for absorbing the power output of an engine and measuring torque or horsepower so that it can be computed into brake horsepower.

Eccentric Circles which do not have the same center.

Edge filter A filter which passes liquid between narrowly separated disks or wires.

Efficiency In general, the proportion of energy going into a machine which comes out in the desired form, or the proportion of the ideal which is realized.

Electromotive force (emf) Forces that move or tend to move electricity.

Electrolyte A solution of sulfuric acid and water.

Element (battery) A group of plates—negative and positive.

Emulsify To suspend oil in water in a mixture where the two do not easily separate.

End play The amount of axial movement in a shaft that is due to clearance in the bearings or bushings.

Energize To make active.

Energy Capacity for doing work.

Engine displacement The volume each piston displaces when it moves from BDC to TDC times the number of cylinders.

Erode To wear away.

Ethylene glycol A compound added to the cooling system to reduce the freezing point.

Evaporative cooling system A cooling system in which the heat finally passes to the atmosphere by evaporation. This system may be either open or closed.

Excess air Air present in the cylinder over and above that which is theoretically necessary to burn the fuel.

Excite To pass current through a coil or starter.

Exhaust gas The products of combustion in an internal-combustion engine.

Exhaust analyzer (smoke meter) A test instrument used to measure the density of the exhaust smoke to determine the combustion efficiency.

Exhaust manifold A device which connects all the exhaust ports to one outlet.

Exhaust port The opening through which exhaust gas passes from the cylinder to the manifold.

Expansion ratio Ratio of the total volume when the piston is at BDC to the clearance volume when the piston is at TDC. (Nominally equal to compression ratio.)

Exhaust valve The valve which, when opened, allows the exhaust gas to leave the cylinder.

Eye bolt A bolt threaded at one end and bent to a loop at the other end.

Fahrenheit (°F) A designated temperature scale in which the freezing temperature of water is 32°F and boiling point 212°F (when under standard atmospheric pressure).

Fahrenheit thermometer A thermometer using a Fahrenheit scale.

Fatigue Deterioration of material caused by constant use.

Feeler gauge A strip of steel ground to a precise thickness used to check clearance.

Field The area affected by magnetic lines of force.

Field coil An insulated wire wound around an (iron) pole piece.

Fillet A curved joint between two straight surfaces.

Filter A device for cleaning or purifying fluid or air.

Finishing stone (hone) A honing stone with a fine grid.

Fire point Lowest temperature at which an oil heated in standard apparatus will ignite and continue to burn.

Firing order The order in which the cylinders deliver their power stroke.

Firing pressure The highest pressure reached in the cylinder during combustion.

Fit The closeness of contact between machined components.

Fixed displacement pump A type of pump in which the volume of fluid per cycle cannot be varied.

Flange A metal part which is spread out like a rim; the action of working a piece or part spread out.

Flank (side or thread) The straight part of the thread which connects the crest with the root.

Flank angles The angle between a specified flank of a thread and the plane perpendicular to the axis (measured in an axial plane).

Flare To open or spread outwardly.

Flaring tool A tool used to form a flare on a tubing.

Flash point The temperature at which a substance, usually a fluid, will give off a vapor that will flash or burn momentarily when ignited.

Flat crank A crankshaft in which one of the bearing journals is not round.

Flow control valve A valve which is used to control the flow rate of fluid in a fluid power system.

Flowmeter An instrument used to measure the quantity or flow rate of a fluid in motion.

Fluctuating Wavering, unsteady, not constant.

Fluid A liquid, gas, or mixture thereof.

Fluid flow The stream or movement of a fluid; the rate of a fluid's movement.

Fluid power Power transmitted and controlled through the use of fluids, either liquids or gases, under pressure.

Flute The grooves of a tap that provide the cutting rake and chip clearance.

Flux (magnetic) Magnetic force.

Flyball governor Conventional type of centrifugal governor commonly called a *mechanical governor.*

Flywheel A device for storing energy in order to carry the piston over a compression and to minimize cyclical speed variations.

Flywheel ring gear A circular steel ring having gear teeth on the outer circumference.

Foot-pound (ft·lb) The amount of work accomplished when a force of 1 lb produces a displacement of 1 ft.

Force The action of one body on another tending to change the state of motion of the body acted upon. Force is usually expressed in pounds [kilograms].

Force-feed lubrication A lubricating system in which oil is pumped to the desired points at a controlled rate by means of positive displacement pumps.

Forged Shaped with a hammer or machine.

Foundation The structure on which an engine is mounted. It performs one or more of the following functions; holds the engine in alignment with the driven machine; adds enough weight to the engine to minimize vibration; adds to rigidity of the bed plate.

Four-stroke cycle Cycle of events which is completed in four strokes of the piston, or two crankshaft revolutions.

Frame The main structural member of an engine.

Free electrons Electrons which are in the outer orbit of the atom's nucleus.

Free flow Flow which encounters negligible resistance.

Friction The resistance to motion due to the contact of two surfaces, moving relatively to each other.

Fuel mixture A ratio of fuel and air.

Fuel transfer pump A mechanical device used to transfer fuel from the tank to the injection pump.

Fuel valve A valve admitting fuel to the combustion chamber. In a more general sense, this term may also apply to any manual or automatic valve controlling flow of fuel.

Fulcrum The pivot point of a lever.

Full-floating piston pin A piston pin free to turn in the piston boss of the connecting-rod eye.

Full-flow oil filter All engine oil passes through this oil filter before entering the lubrication channels.

Gauge pressure Pressure above atmospheric pressure.

Gauge snubber A device installed in the fuel line to the pressure gauge used to dampen pressure surges and thus provide a steady reading. This helps protect the gauge.

Gallery Passageway inside a wall or casting.

Galvanic action When two dissimilar metals are immersed in certain solutions, particularly acid, electric current will flow from one to the other.

Gas Matter that has no definite form or volume, but instead tends to expand indefinitely.

Gasket A layer of material used between machined surfaces in order to seal them against leakage.

Gassing Hydrogen bubbles rising from the electrolyte when the battery is being charged.

Gate valve A common type of manually operated valve in which a sliding gate is used to obstruct the flow of fluid.

Gear-type pump A pump which uses the spaces between the adjacent teeth of gears for moving the liquid.

Generator An electromagnetic device used to generate electricity.

Gland A device to prevent the leakage of gas or liquid past a joint.

Glaze A smooth, glassy surface finish.

Glow plug A heater plug for the combustion chamber. It has a coil of resistance wire heated by a low-voltage current.

Governor A device for controlling the speed of a prime mover.

Gravity The force which tends to draw all bodies toward the center of the earth. The weight of a body is the resultant of all gravitational forces on the body.

Grid (battery) The lead frame to which the active material is affixed.

Grinding Removing metal from an object by means of a revolving abrasive wheel, disk, or belt.

Grinding compound Abrasive for resurfacing valves, etc.

Ground (battery) The battery terminal that is connected to the engine or the framework.

Growler A test instrument used for testing the armature of a starter or generator for open, short, and grounded circuits.

Half-moon key A fastening device in a shape somewhat similar to a semicircle (See *Key.*)

Heat A form of energy.

Heat exchanger A device used to cool by transferring heat.

Heating value Amount of heat produced by burning 1 lb of fuel.

Helical gear A gear wheel of a spiraling shape. (The teeth are cut across the face at an angle with the axis.)

Hone A tool with an abrasive stone used for removing metal.

Horsepower (hp) A unit of power equivalent to 33,000 ft·lb of work per minute (English) or 75 kg·m per second (metric). (See *Brake horsepower* and *Indicated horsepower.*)

Horsepower-hour (hp·h) A unit of energy equivalent to that expended in 1 hp applied for 1 hour. Equal to approximately 2545 Btu.

Hunting Alternate overspeeding and underspeeding of the engine caused by governor instability.

Hydraulics That branch of mechanics or engineering which deals with the action or use of liquids forced through tubes and orifices under pressure to operate various mechanisms.

Hydraulic governor A governor using fluid to operate the fuel control.

Hydrocarbon (HC) A compound of hydrogen and carbon. Petroleum and its derivatives are mixtures of various hydrocarbons.

Hydrogen One of the elements constituting fuel and lubrication oil.

Hydrometer A test instrument for determining the specific gravities of liquids.

Idling An engine running without load.
Ignition The start of combustion.
Ignition lag The time between start of injection and ignition.
Immersed To be completely under the surface of a fluid.
Impact wrench An air wrench or an electrically driven wrench.
Impeller A wheel or disk with fins.
Indicated horsepower (ihp) The power transmitted to the pistons by the gas in the cylinders.
Indicated thermal efficiency The ratio of indicated horsepower to equivalent power input in the form of heat from fuel.
Indicator An instrument for recording the variation of cylinder pressure during the cycle.
Indicator card A graphical record of the cylinder pressures made by an indicator.
Indirect cooled piston A piston cooled mainly by the conduction of heat through the cylinder walls.
Induction Using the magnetic field to impart electricity into an object which is not otherwise connected to the first ones.
Inertia That property of matter which causes it to tend to remain at rest if already motionless or to continue in the same straight line of motion if already moving.
Inhibitor Any substance which retards or prevents such chemical reactions as corrosion or oxidation.
Injection pump A high-variable-pressure pump delivering fuel into the combustion chamber.
Injection system The components necessary for delivering fuel to the combustion chamber in the correct quantity, at the correct time, and in a condition satisfactory for efficient burning.
Injector A device used to bring fuel into the combustion chamber.
In-line engine An engine in which all the cylinders are in a straight line.
Insert bearing A removable, precision-made bearing.
Insulator (electrical) A material that, under normal conditions, will not conduct electricity.
Intake manifold A connecting casting between the air filter or turbocharger and the port openings to the intake valves.
Intake valve The valve which when open allows air to enter into the cylinder.
Intercooler Heat exchanger for cooling the air between stages of compression.
Internal-combustion engine An engine that burns fuel within itself as a means of developing power.
Isochronous governor A governor having zero speed droop.

Jet A small hole in a carburetor passage to measure the flow of gasoline.
Jet cooling A method of passing cooling oil below the piston by means of a jet or nozzle.
Journal The portion of a shaft, crank, etc., which turns in a bearing.

Kelvin scale (K) A temperature scale having the same size divisions as between Celsius degrees, but having the zero point at absolute zero.
Key A fastening device wherein two components each have a partially cut groove, and a single square of square is inserted in both to fasten them together.
Keyway The groove cut in a component to hold the key.
Kilometer (km) A metric measurement of length equal to 0.6214 mile.
Kilowatt (kW) A unit of power equal to 1000 W.
Kilowatthour (kWh) A unit of electric energy.
Kinetic energy The energy which an object has while in motion.
Knocking A sharp pounding sound occurring periodically in an engine.
Knurling A method of placing ridges in a surface, thereby forcing the areas between these ridges to rise.

Lag To slow down or get behind; time interval, as in *ignition lag.*
Laminar A layer of fluid.
Laminar flow A smooth flow in which no crossflow of fluid particles occurs.
Land The projecting part of a grooved surface; for example, that part of a piston on which the rings rest.
Lap (lapping) A method of refinishing (grinding and polishing) the surface of a component.
Letter drills Drills on which the size is designated by a letter.
Line A tube, pipe, or hose which is used as a conductor of fluid.
Liner The sleeve forming the cylinder bore in which the piston reciprocates.
Linkage A movable connection between two units.
Liquid Matter which has a definite volume but takes the shape of any container.
Liter (L) A metric measurement of volume equal to 0.2642 gal (U.S.).
Live wire A conductor which carries current.
Load The power that is being delivered by any power-producing device. The equipment that uses the power from the power-producing device.
Load factor The mean load carried by an engine, expressed in percent of its capacity.
Load line A center line indicating the points of contact where the load passes within the bearing.
Load-line angle The angle of a load line with respect to the shaft center or bearing radial centerline.
Lobe The projecting part, usually rounded, on a rotating shaft.
Lubricant A substance to decrease the effects of friction, commonly a petroleum product (grease, oil, etc.).
Lubricator A mechanical oiler which feeds oil at a controlled rate.
Lug (engine) Condition when the engine is operating at or below its maximum torque speed.

Magnaflux A method used to check components for cracks.
Magnetic field The affected area of the magnetic lines of force.
Main bearing A bearing supporting the crankshaft on its axis.
Mandrel A mounting device for a stone, cutter, saw, etc.
Manual valve A valve which is opened, closed, or adjusted by hand.
Matter Any substance which occupies space and has weight. The three forms of matter are solids, liquids, and gases.
Mean effective pressure (mep) The calculated combustion in pounds per square inch (average) during the power stroke, minus the pounds per square inch (average) of the remaining three strokes.
Mean indicated pressure (mip) Net mean gas pressure acting on the piston to produce work.
Mechanical advantage The ra-

tio of the resisting weight to the acting force. The distance through which the force is exerted divided by the distance the weight is raised.

Mechanical efficiency (1) The ratio of brake horsepower to indicated horsepower, or ratio of brake mean effective pressure to mean indicated pressure. (2) An engine's rating which indicates how much of the potential horsepower is wasted through friction within the moving parts of the engine.

Mechanical injection Mechanical force pressurizing the metered fuel and causing injection.

Mechanically operated valve A valve which is opened and closed at regular points in a cycle of events by mechanical means.

Metal fatigue When metal crystallizes and is in jeopardy of breaking because of vibration, twisting, bending, etc.

Metering fuel pump A fuel pump delivering a controlled amount of fuel per cycle.

Metric size Size of a component, part, etc., in metric units of measurement (e.g., meters, centimeters).

Micrometer (mike) A precision measuring tool that is accurate to within one thousandth of an inch or one hundredth of a millimeter.

Micrometer (μm) One millionth of a meter or 0.000039 inch.

Millimeter (mm) One thousandth of a meter or 0.039370 inch.

Milling machine A machine used to remove metal, cut splices, gears, etc., by the rotation of its cutter or abrasive wheel.

Misfiring When the pressure of combustion of one or more cylinders is lower than the remaining cylinders, one or more cylinders have an earlier or later ignition than the others.

Mixed cycle Where fuel burns partly at constant volume and partly at constant pressure. Sometimes applied to the actual combustion cycle in most high-speed internal-combustion engines.

Molecule The smallest portion to which a substance may be reduced by subdivision and still retain its chemical identity.

Motor An actuator which converts fluid power or electric energy to rotary mechanical force and motion.

Multiviscosity oil An oil meeting SAE requirements.

Needle bearing A roller-type bearing in which the rollers are smaller in diameter than in length proportional to the race.

Negative terminal A terminal from which the current flows back to its source.

Neoprene A synthetic rubber highly resistant to oil, light, heat, and oxidation.

Neutron A neutral charged particle of an atom.

Newton's third law For every action there is an equal, opposite reaction.

Nitrogen oxide (NO_x) The combination of nitrogen and oxygen that occurs during the combustion process.

Nonferrous metals Any metals not containing iron.

North pole (magnet) The pole from which the lines of force emanate (thereafter entering the south pole).

Nozzle The component containing the fuel valve and having one or more orifices through which fuel is injected.

Number drills Drills on which the size is designated by a number.

Ohm (Ω) A unit of electrical resistance.

Ohmmeter An instrument for measuring the resistance in a circuit or unit in ohms.

Ohm's law The number of amperes flowing in a circuit is equal to the number of volts divided by the number of ohms.

Oil-bath air cleaner An air filter that utilizes a reservoir of oil to remove the impurities from the air before it enters the intake manifold or the compressor of the turbine.

Oil cooler A heat exchanger for lowering the temperature of oil.

Oil filter A device for removing impurities from oil.

Oil gallery A pipe-drilled or casted passage in the cylinder-head block and crankcase that is used to carry oil from the supply to an area requiring lubrication or cooling.

Oil pump A mechanical device to pump oil (under pressure) into the various oil galleries.

Oil pumping An engine condition wherein excessive oil passes by the piston rings and is burned during combustion.

Oil seal A mechanical device used to prevent oil leakage, usually past a shaft.

Oil slinger A special frame disk fastened to a revolving shaft. When the shaft rotates and oil contacts the disk, it is thrown outward away from the seal, and thus reduces the force on the seal lip.

Open circuit A circuit in which a wire is broken or disconnected.

Opposed piston engine An engine having two pistons operating in opposite ends of the same cylinder, compressing air between them.

Orderly turbulence Air motion which is controlled as to direction or velocity.

Orifice An aperture or opening.

Oscilloscope A device for recording wave forms on a fluorescent screen, proportional to the input voltage.

Oscillate To swing back and forth like a pendulum; to vibrate.

Output shaft The shaft which delivers the power.

Overhead camshaft A camshaft which is mounted above the cylinder head.

Overrunning clutch A clutch mechanism that transmits power in one direction only.

Overrunning-clutch starter drive A mechanical device that locks in one direction but turns freely in the opposite direction.

Overspeed governor A governor that shuts off the fuel or stops the engine only when excessive speed is reached.

Oversquare engine An engine that has a larger bore diameter than the length of its stroke.

Oxidation That process by which oxygen unites with some other substance causing rust or corrosion.

Packing A class of seal of flexible material used to seal two parts which move in relation to each other.

Paper air cleaner An air filter with a special paper element through which the air is drawn.

Parallel circuit An electric circuit with two or more branch circuits. It is wired so as to allow current to flow through all branches at the same time.

Pascal's law Pressure applied anywhere to a body of confined fluid is transmitted undiminished to every portion of the surface of the containing vessel.

Peen The thin end of a hammer head (opposite to the face).

Peening Flattening the end of a rivet, etc., using the force of a hammer.

Penetrating oil A special oil that aids the removal of rusted parts.

Perforate To make full of holes.
Periphery The external boundary or circumference.
Petroleum An oil liquid mixture made up of numerous hydrocarbons chiefly of the paraffin series.
Phosphor-bronze A bearing material composed of tin, lead, and copper.
Physical change A change which does not alter the composition of the molecules of a substance.
Pilot shaft A shaft position in or through a hole of a component as a means of aligning the components.
Pilot valve A valve used to control the operation of another valve.
Pintle-type nozzle A closed-type nozzle having a projection on the end of the fuel valve which extends into the orifice when the valve is closed.
Pipe In diesel applications, that type of fluid line, the dimensions of which are designated by nominal (approximate) inside diameter.
Piston A cylindrical plug which slides up and down in the cylinder and which is connected to the connecting rod.
Piston boss The reinforced area around the piston-pin bore.
Piston displacement The volume of air moved or displaced by a piston when moved from BDC to TDC.
Piston head The portion of the piston above the top ring.
Piston lands That space of the piston between the ring grooves.
Piston pin (wrist pin) A cylindrical alloy pin that passes through the piston bore and is used to connect the connecting rod to the piston.
Piston ring A split ring of the expansion type placed in a groove of the piston to seal the space between the piston and the wall.
Piston-ring end cap The clearance between the ends of the ring (when installed in the cylinder).
Piston-ring groove The grooves cut in the piston into which the piston rings are fitted.
Piston-ring side clearance The clearance between the sides of the ring and the ring lands.
Piston skirt The portion of the piston which is below the piston bore.
Piston speed The total distance traveled by each piston in one minute. The formula is: Piston speed-stroke (ft) × rpm × 2 or stroke (in) × rpm/6.
Pivot The pin or shaft on which a component moves.
Plate (battery) A flat, square, rigid body of lead peroxide or porous lead.
Play The movement between two components.
Plunger pump A pump which displaces fluid by means of a plunger.
Pneumatics That branch of physics pertaining to the pressure and flow of gases.
Polarity Can refer to the grounded battery terminal or to an electric circuit or to the north and south pole of a magnet.
Polarizing To develop polarization of the pole shoes in respect to battery polarity.
Polar timing diagram A graphic method of illustrating the events of an engine cycle with respect to crankshaft rotation.
Pole (magnet) Either end of a magnet.
Pole shoe A soft iron piece over which the field coil is placed.
Ports Openings in the cylinder block and cylinder head for the passage of oil and coolant. (Also exhaust-intake connection and valve openings.)
Port bridge The portion of a cylinder or liner between two exhaust or scavenging ports.
Port scavenging Introducing scavenging air through ports in the cylinder wall when they are uncovered by the power piston near the end of the power stroke.
Positive terminal The terminal which has a deficiency of electrons.
Potential energy The energy possessed by a substance because of its position, its condition, or its chemical composition.
Pour point The lowest temperature at which an oil will flow.
Power Rate of doing work.
Precision insert bearing A precision type of bearing consisting of an upper and lower shell.
Precombustion chamber A portion of the combustion chamber connected to the cylinder through a narrow throat. Fuel is injected into and is partly burned in the precombustion chamber. Heat released by this partial burning causes the contents of the precombustion chamber to be ejected into the cylinder with considerable turbulence.
Preloading Adjusting taper roller bearings so that the rollers are under mild pressure.
Press-fit (See *Drive-fit.*)
Pressure Force exerted per unit of area.
Pressure cap A special radiator cap with a pressure-relief and vacuum valve.
Pressure differential The difference in pressure between any two points of a system or a component.
Pressure lubrication A lubricating system in which oil at a controlled pressure is brought to the desired point.
Pressure-relief valve A valve that limits the maximum system pressure.
Printed circuit An electric circuit where the conductor is pressed or printed in or on an insulating material (panel) and at the same time is connected to the resistor, diodes, condenser, etc.
Prony brake A friction brake used for engine testing.
Proton The positively charged particle in the nucleus of an atom.
Prussian blue A blue pigment, obtainable in tubes, which is used to find high spots in a bearing.
Pulsate To move with rhythmical impulse.
Pulverize To reduce or become reduced to powder or dust.
Pump A device for moving fluids.
Pumping loss The power consumed by replacing exhaust gas in the cylinder with fresh air.
Pump scavenging Using a piston-type pump to pump scavenging air.
Push fit The part of the bearing that can be slid into place by hand if it is square with its mounting.
Push rod A rod used for transmitting cam motion to a rocker arm.
Pyrometer A temperature indicator used for comparing exhaust temperatures of the various cylinders.

Quench To cool heated steel or iron by thrusting it into water.
Quicksilver Metallic mercury.

Race (bearing) The inner or outer groove or channel bearing ring.
Raceway The surface of the groove or path which supports the balls or rollers of a bearing roll.
Radial Perpendicular to the shaft or bearing bore.
Radial clearance (radial displacement) The clearance within

the bearing and between the balls and races, perpendicular to the shaft.

Radial load A "round-the-shaft" load, that is, one that is perpendicular to the shaft through the bearing.

Radiator A heat exchanger in which cooling water gives up heat to the air without coming into direct contact with it.

Radius The distance from the center of a circle to its outer edge or the straight line extending from the center to the edge of a circle.

Ratio The numerical relationship between objects.

Rebore To bore out a cylinder to a size slightly larger than the original.

Reciprocating action A back-and-forth (alternating) movement.

Rectifier A device used to convert alternating current into direct current.

Regulator (electrical) An electromagnetic or electronic device used to control generator voltage.

Relay An electromagnetic switch which utilizes variation in the strength of an electric circuit to effect the operation of another circuit.

Relief valve An automatic valve which is held shut by a spring of correct strength. Excess pressure opens the valve and releases some of the gas or liquid. This valve is for protecting filters, air tanks, etc., from dangerous pressures.

Resistance (electrical) The opposition offered by a body when current passes through it.

Resistor A device placed in a circuit to lower the voltage, to reduce the current, or to stabilize the voltage.

Retard (injection timing) To set the timing so that injection occurs later than TDC or fewer degrees before TDC.

Reverse flush To pump water or a cleaning agent through the cooling system in the opposite direction to normal flow.

Rheostat A device to regulate current flow by varying the resistance in the circuit.

Ring expander A type of spring which is placed between the ring and ring groove to hold the ring with fixed force against the cylinder wall.

Ring groove A groove machined in the piston to receive the piston ring.

Ring job The service work on the piston and cylinder including the installation of new piston rings.

Rivet A soft-metal pin having a head at one end.

Rocker arm A first-class lever used to transmit the motion of the pushrod to the valve stem.

Rocker-arm shaft The shaft on which the rocker arms pivot.

Rockwell hardness A measurement of the degree of surface hardness of a given object.

Rod Refers to a connecting rod.

Roller bearing An antifriction bearing using straight (cupped or tapered) rollers spaced in an inner and outer ring.

Roller tappets (roller lifters) Refers to valve lifters having a roller at one end which is in contact with the camshaft and is used to reduce friction.

Roots blower An air pump or blower similar in principle to a gear-type pump.

Rope brake A friction brake used for engine testing.

Rotary blower Any blower in which the pumping element follows rotary motion, the centrifugal blowers being the exception.

Roughing stone (hone) A coarse honing stone.

Running-fit A machine fit with sufficient clearance to provide for expansion and lubrication.

SAE Abbreviation for *Society of Automotive Engineers.*

SAE horsepower (rated horsepower) Formula to determine power: bore diameter^2 × number of cylinders/2.5 = hp.

SAE viscosity numbers Simplified viscosity ratings of oil based on Saybolt viscosity.

Safety factor Providing strength beyond that needed as an extra margin of insurance against parts failure.

Safety valve (See *Relief valve.*)

Sand blast (glass blast) A cleaning method using an air gun to force the sand at low pressure (about 150 psi) against the surface to be cleaned.

Saybolt viscosimeter A container with a calibrated outlet tube for determining the viscosity of liquids. (This method is now obsolete.)

Saybolt viscosity The number of seconds necessary for 60 mL of liquid to pass through the outlet tube of a Saybolt viscosimeter under standardized test conditions.

Scale Precipitated hardness (salts) from water.

Scavenging The displacement of exhaust gas from the cylinder by fresh air.

Scavenging air The air which is pumped into a cylinder to displace exhaust gas.

Scavenging blower A device for pumping scavenging air.

Scavenging pump A piston-type pump delivering scavenging air to an engine.

Scraper ring An oil-control ring.

Screw extractor A device used to remove broken bolts, screws, etc., from holes.

Sealed bearing A bearing which is lubricated and sealed at the factory and which cannot be lubricated during service.

Seat (rings) Rings fitted or seated properly against the cylinder wall.

Semiconductor An element which is neither a good conductor nor a good insulator.

Sediment Solid impurities in a liquid.

Semifloating piston pin A piston pin which is clamped either in the connecting rod or in the piston bosses.

Separator (battery) A porous insulation material placed between the positive and negative plates.

Series circuit An electric circuit wired so that the current must pass through one unit before it can pass through the other.

Series-parallel circuit A circuit with three or more resistance units in a combination of a series and a parallel circuit.

Shaft horsepower Power delivered at the engine crankshaft. This term is commonly used instead of *brake horsepower* to express output of large marine engines.

Shim Thin, flat pieces of brass or steel used to increase the distance between two components.

Short circuit A circuit whose resistance is reduced in power owing to one or more coil layers contacting one another.

Shrink-fit A fit between two components made by heating the outer component so that it will expand and fit over the inner component. As the outer component cools, it shrinks and thereby fits tight to the inner component.

Shroud The enclosure around the fan, engine, etc., which guides the airflow.

Shunt A parallel circuit where one resistance unit has its own ground.

Shunt winding A resistance coil with its own ground.

Shutoff valve A valve which opens and thereby stops the flow of a liquid, air, or gas.

Silencer A device for reducing the noise of intake or exhaust.

Single-acting cylinder An actuating cylinder in which one stroke is produced by pressurized fluid, and the other stroke is produced by some other force, such as gravity or spring tension.

Sludge Deposits inside the engine caused by dust, oil, and water being mixed together by the moving components.

Snap ring A fastening device in the form of a split ring that is snapped into a groove in a shaft or in a groove in a bore.

Sodium valve A valve designed to allow the stem and head to be partially filled with metallic sodium.

Solenoid An electrically magnetic device used to do work.

Specific gravity The ratio of the weight of a given volume of any substance to that of the same volume of water.

Spline The land between two grooves.

Spool valve A hydraulic directional control valve in which the direction of the fluid is controlled by the means of a grooved cylindrical shaft (spool).

Spur gear A toothed wheel having external radial teeth.

Squish area The area confined by the cylinder head and flat surface of the piston when on compression stroke.

Stability The resistance of a fluid to permanent change such as that caused by chemical reaction, temperature changes, etc.

Starting air Compressed air used for starting an engine.

Starting-air valve A valve which admits compressed starting air to the cylinder.

Static electricity Electricity at rest; pertaining to stationary charges.

Staybolt A stress bolt running diagonally upward from the bedplate to the opposite side of the frame.

Steady flow A flow in which the velocity components at any point in the fluid do not vary with time.

Stethoscope A device for conveying the sound of a body (engine noise) to the mechanic.

Streamline flow A nonturbulent flow, essentially fixed in pattern.

Stresses The forces to which parts are subjected.

Stroboscope (timing light) An instrument used to observe the periodic motion of injection visible only at certain points of its path.

Stroke One of a series of recurring movements of a piston or the distance of such movement.

Stroke-to-bore ratio The length of stroke divided by the diameter of bore.

Stud A rod having threads on both ends.

Stud puller A device used to remove or to install stud bolts.

Stuffing box A chamber having a manual adjustment device for sealing.

Suction The process of producing a pressure differential (partial vacuum).

Suction valve Often used interchangeably with *intake valve.*

Sulfur An undesirable element found in petroleum in amounts varying from a slight trace to 4 or 5 percent.

Sump A receptacle into which liquid drains.

Sump pump A pump which removes liquid from the sump.

Supercharger An air pump driven by the engine which fills the cylinders with a higher pressure than atmospheric pressure.

Supply line A line that conveys fluid from the reservoir to the pump.

Surge A momentary rise and fall of pressure or speed in a system or engine.

Synchronize To make two or more events or operations occur at the proper time with respect to each other.

Synchronous Happening at the same time.

Synthetic material A complex chemical compound which is artificially formed by the combining of two or more compounds or elements.

Tachometer An instrument indicating rotating speeds. Tachometers are sometimes used to indicate crankshaft rpm.

Tap A cutting tool used to cut threads in a bore. (See *Chamfer.*)

Tap and die set A set of cutting tools used to cut internal and external threads.

Tapered roller bearing (See *Roller bearing.*)

Tappet The rocker arm.

Tappet noise The noise caused by excessive clearance between the valve stem and the rocker arm.

TDC Abbreviation for *top dead center.*

Temper The condition of a metal with regard to hardness achieved through heating and then suddenly cooling.

Temperature of compression The temperature of the compressed air charge in a power cylinder at the end of the compression stroke before combustion begins.

Temporary hardness Dissolved substances which precipitate out when water is heated.

Tension Stress applied on a material or body.

Terminal The connecting point (post) of a conductor.

Theory A scientific explanation tested by observations and experiments.

Thermal efficiency (See *Brake thermal efficiency* and *Indicated thermal efficiency.*)

Thermal expansion The increase in volume of a substance caused by temperature change.

Thermocouple The part of a pyrometer which consists of two dissimilar metal wires welded together at the inner end and held in a protective housing.

Thermometer An instrument for measuring temperature.

Thermostat A temperature-responsive mechanism used for controlling heating systems, cooling systems, etc., usually with the object of maintaining certain temperatures without further personal attention.

Throttling Reducing the engine speed (flow of fuel).

Thru-bolt Term usually applied to the stress rod passing through the engine frame to carry combustion stresses.

Throw The part of a crankshaft to which the connecting rod is fastened.

Thrust bearing (washer) A bearing or washer of bronze or steel which restrains endwise motion of a turning shaft, or withstands axial loads instead of radial loads as in common bearings.

Thrust load A load which pushes or reacts through the bearing in a direction parallel to the shaft.

Time lag of ignition (See *Ignition lag.*)

Timing gears Gears attached to the crankshaft, camshaft, idler shaft, or injection pump to provide a means to drive the camshaft and injection

pump and to regulate the speed and performance.

Timing marks (injection) The marks located on the vibration damper or flywheel, used to check injection timing.

Tolerance A fractional allowance for variations from the specifications.

Torque A force or combination of forces that produces or tends to produce a twisting or rotary motion.

Torque wrench A wrench used to measure the turning force being applied.

Torsional vibration The vibration caused by twisting and untwisting a shaft.

Transfer pump A mechanical device for moving fuel from one tank to another or bringing fuel from the tank to the injection pump.

Troubleshooting The act of analyzing, testing, and measuring the engine to remedy the cause of trouble.

Tube cutter A tube-cutting tool having a sharp disk which is rotated around the tube.

Tubing That type of fluid line whose dimensions are designated by actual measured outside diameter.

Tuneup The act of checking, testing, measuring, repairing, and adjusting the engine components in order to bring the engine to peak efficiency.

Turbine A series of curved vanes mounted on a shaft and actuated by the action of a fluid or gas under pressure.

Turbocharger An exhaust-gas-driven turbine directly coupled with a compressor wheel.

Turbulence chamber A combustion chamber connected to the cylinder through a throat. Fuel is injected across the chamber and turbulence is produced in the chamber by the air entering during compression.

Twist drill (See *Drill.*)

Two-stage combustion Combustion occurring in two distinct steps such as in a precombustion chamber engine.

Two-stroke cycle Cycle of events which is complete in two strokes of the piston or one crankshaft revolution.

Uniflow scavenging Scavenging method in which air enters one end of the cylinder and exhaust leaves the opposite end.

Unit injector A combined fuel-injection pump and fuel nozzle.

U.S. gallon [gal (U.S.)] United States gallon (231 in^3).

Vacuum A pressure less than atmospheric pressure.

Vacuum gauge A gauge used to measure the amount of vacuum existing in a chamber or line.

Valve Any device or arrangement used to open or close an opening to permit or restrict the flow of a liquid, gas, or vapor.

Valve duration The time (measured in degrees of engine crankshaft rotation) that a valve remains open.

Valve float A condition where the valves are forced open because of valve-spring vibration or vibration speed.

Valve grinding Resurfacing the valve face by a special grinding machine.

Valve guide A hollow-sized shaft pressed into the cylinder head to keep the valve in proper alignment.

Valve keeper (valve retainer) A device designed to lock the valve-spring retainer to the valve stem.

Valve lift The distance a valve moves from the fully closed to the fully open position.

Valve lifter (See *Cam follower.*)

Valve margin The distance between the edge of the valve and the edge of the face.

Valve oil seal A sealing device to prevent excess oil from entering the area between the stem and the valve guide.

Valve overlap The period of crankshaft rotation during which both the intake and exhaust valves are open. It is measured in degrees.

Valve rotator A mechanical device locked to the end of the valve stem which forces the valve to rotate about 5° with each rocker-arm action.

Valve seat The surface on which the valve face rests when closed.

Valve-seat insert A hardened steel ring inserted in the cylinder head to increase the wear resistance of the valve seat.

Valve timing The positioning of the camshaft (gear) to the crankshaft (gear) to ensure proper valve opening and closing.

Vaporization The process of converting a liquid into vapor.

Venturi A specially shaped tube with a small or constricted area used to increase velocity and reduce pressure.

Vibration damper A specially designed device mounted to the front of the crankshaft to reduce torsional vibration.

Viscosity The property of an oil by virtue of which it offers resistance to flow.

Viscosity index (VI) Oil decreases in viscosity as temperature changes. The measure of this rate of change of viscosity with temperature is called the *viscosity index* of the oil.

Volatile Evaporating readily at average temperature on exposure with air.

Volatility A measurement of the ease with which a liquid may be vaporized at relatively low temperature.

Volt (V) A unit of electromotive force that will move a current of one ampere through a resistance of 1 Ω.

Voltage Electrical potential expressed in volts.

Voltage drop Voltage loss due to added resistance cause by undersized wire, poor connection, etc.

Voltmeter A test instrument for measuring the voltage or voltage drop in an electric circuit.

Volume The amount of space within a given confined area.

Volumetric efficiency The difference between the volume of air drawn in on the intake stroke and the air mechanically entering the cylinder.

Water brake A device for engine testing in which the power is dissipated by churning water.

Water jacket The enclosure directing the flow of cooling water around the parts to be cooled.

Wet sleeve A cylinder sleeve which is about 70 percent exposed to the coolant.

Yoke A link which connects two points.

Zener diode A diode that allows current to flow in reverse bias at the designed voltage.

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