TM 10-570

WAR DEPARTMENT

TECHNICAL MANUAL

THE INTERNAL COMBUSTION ENGINE

February 4, 1941

TECHNICAL MANUAL

THE INTERNAL COMBUSTION ENGINE

CHANGES } No. 1

WAR DEPARTMENT,
WASHINGTON, January 27, 1942.

TM 10–570, February 4, 1941, is changed as follows:

FIRING ORDER OF CYLINDER — "V-TYPE" ENGINE	FIRING ORDER OF CYLINDER — "IN-LINE" ENGINE	ONE COMPLETE CYCLE															
		2 REVOLUTIONS OF CRANKSHAFT — 720°															
		1-REVOLUTION OF CRANKSHAFT 360°								1-REVOLUTION OF CRANKSHAFT 360°							
		½ REV. 180°				½ REV. 180°				½ REV. 180°				½ REV. 180°			
		1ST. STROKE DOWN				2ND. STROKE UP				3RD. STROKE DOWN				4TH. STROKE UP			
		45°	45°	45°	45°	45°	45°	45°	45°	45°	45°	45°	45°	45°	45°	45°	45°
1R	1	P	P	P	P	E	E	E	E	I	I	I	I	C	C	C	C
1L	6	C	C	P	P	P	P	E	E	E	E	I	I	I	I	C	C
4R	2	C	C	C	C	P	P	P	P	E	E	E	E	I	I	I	I
4L	5	I	I	C	C	C	C	P	P	P	P	E	E	E	E	I	I
2L	8	I	I	I	I	C	C	C	C	P	P	P	P	E	E	E	E
3R	3	E	E	I	I	I	I	C	C	C	C	P	P	P	P	E	E
3L	7	E	E	E	E	I	I	I	I	C	C	C	C	P	P	P	P
2R	4	P	P	E	E	E	E	I	I	I	I	C	C	C	C	P	P

P—POWER; E—EXHAUST; I—INTAKE; C—COMPRESSION
R OR L INDICATES RIGHT OR LEFT BANK OF CYLINDERS

FIGURE 17.—Eight-cylinder engine.

[A. G. 062.11 (12–16–41).] (C 1, Jan. 27, 1942.)

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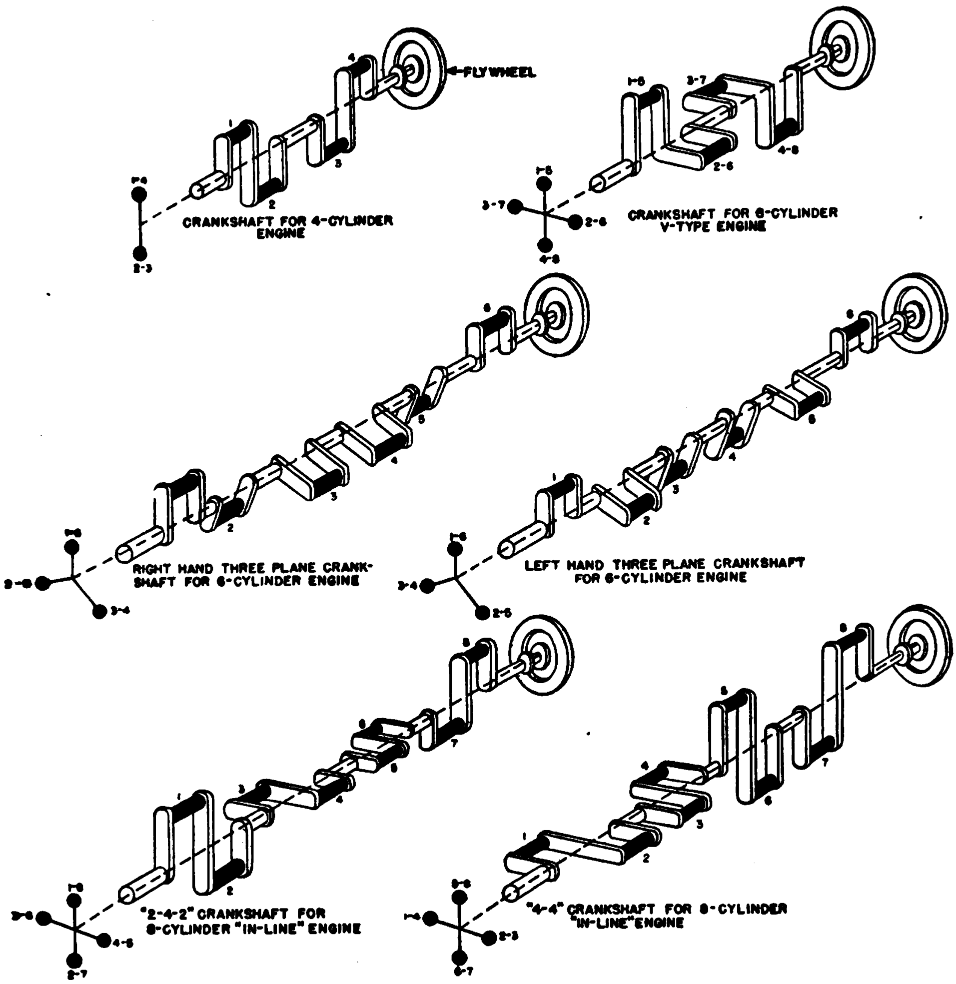

NOTE: RIGHT AND LEFT HAND REFERS TO ARRANGEMENT OF THROWS AND NOT TO DIRECTION OF ROTATION

FIGURE 19.—Crank throw arrangements most commonly used.

[A. G. 062.11 (12-16-41).] (C 1, Jan. 27, 1942.)

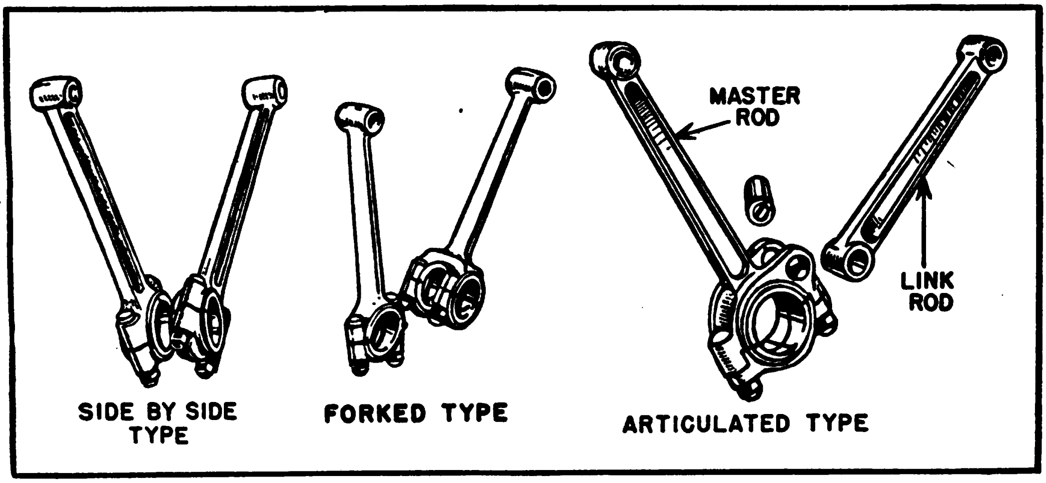

FIGURE 39.—Connecting rods used in V-type engines.

[A. G. 062.11 (12-16-41).] (C 1, Jan. 27, 1942.)

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:

E. S. ADAMS,
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The Adjutant General.

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WAR DEPARTMENT,
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THE INTERNAL COMBUSTION ENGINE

Prepared under direction of
The Quartermaster General

285007°—41——1

SECTION I

ENGINE TERMINOLOGY

1. Definitions.—For purposes of clarity and uniformity the following terms and definitions will be used in this manual when discussing the internal combustion engine:

Articulated.—Parts joined by a pivot in such a way that one part will transfer movement through the other.

Axis.—A center line; a line about which something rotates or about which it is evenly arranged.

Babbitt.—A soft metal alloy used in plain bearings.

Back pressure.—The result of resistance to the normal flow of gases and liquids.

Bore.—The interior diameter of an engine cylinder. (*See* Stroke.)

Brake horsepower (b. hp.).—Amount of net available power produced by an engine as measured at the crankshaft. (*See* Horsepower.)

British thermal unit (B. t. u.).—A unit for measuring heat. One British thermal unit equals 778 foot-pounds of work (or energy). It represents the heat required to change the temperature of 1 pound of water through 1° F.

Bypass.—A separate passage which permits a liquid or gas to take a course other than that normally used.

Calorific value.—Heat value of fuel.

Centrifugal force.—The force acting on a rotating body which tends to throw it away from the center of its rotation.

Cetane rating.—A system of numbers indicating the ignition quality of Diesel fuels.

Chamfer.—A beveled edge or corner.

Check valve.—A device that permits passage of a fluid or gas in one direction only. It stops (or checks) flow if movement is reversed.

Clearance.—The space between a moving and a stationary part. Clearance is usually allowed between two surfaces to provide for expansion and contraction and for lubrication.

Clearance volume (compression volume).—The amount of space confined within the engine cylinder and cylinder head when the piston is at its top dead center position.

Cooling system.—The group of units that carries off and dissipates the unused heat absorbed by the cylinder block, cylinder head, pistons, and valves.

Combustion chamber.—The space within and above a cylinder in which the fuel mixture is compressed and burned.

Compression.—To be pressed into smaller space; to be condensed or reduced in size or volume.

Compression pressure.—The amount of pressure resulting from the compression stroke of a piston when it has reached top dead center. Usually stated in pounds per square inch.

Compression ratio.—A ratio expressing the extent to which a fuel mixture or air charge is compressed. It is a relationship between clearance and displacement volumes and is found as follows:

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

For example: The compression ratio for a 3½- by 5-inch cylinder having a piston displacement of 48.105 cubic inches and a clearance volume of 12.026 cubic inches would be $\frac{48.105+12.026}{12.026}=5$. This means that the original charge would be reduced or compressed to one-fifth of its original volume.

Concentric.—Having a common center.

Condensation.—The process by which a vapor is reduced to a liquid.

Contraction.—Becoming smaller in size; usually, in metals, a result of cooling or a lowering of temperature.

Cycle.—A series of events, operations, or movements that repeat themselves in an established sequence.

Cylinder in-block.—A group of cylinders cast as one piece.

Detonation.—A knock in an engine resulting from the too rapid burning of a fuel in the combustion chamber.

Displacement volume. (*See* Piston displacement.)

Dynamic balance.—The balance of a body which is rotating or in motion.

Eccentric.—A circle not having the same center as another within it; a device mounted off center for converting rotary motion into reciprocating motion.

Energy.—Capacity for doing mechanical work.

Energy, kinetic.—Energy due to motion.

Energy, potential.—Energy due to position.

Engine.—A machine that produces power to do work, particularly one that converts heat into mechanical power. The term "engine" should be used in referring to the power plant of a motor vehicle, and the term "motor" should be used in connection with electric motors.

F-*head.*—Used to describe an engine with one set of valves (usually intake) placed overhead and the other (usually exhaust) in the side of the cylinder block.

Fit.—Fit may be considered as the desired clearance between the surfaces of machine parts.

Foot-pound.—The work done in lifting 1 pound 1 foot; a measurement of torque, force, or work. When used in connection with torque, the expression is sometimes changed to read pounds-feet.

Friction.—The action between two bodies in contact, which opposes movement between them.

Friction horsepower (f. hp.).—The power lost within the engine due to its internal friction.

Heat.—A form of energy.

Horsepower.—A unit for measuring power. It is the rate at which work is done. One horsepower is 33,000 foot-pounds per minute. (*See* Brake horsepower; Friction horsepower; Indicated horsepower.)

Hydraulics.—The science of using liquids under pressure to do work.

I-*head* (*valve-in-head*) *engine.*—Designates an engine with its valves placed in the cylinder head directly above the cylinder bore.

Impeller.—The rotating part of a blower or pump which imparts motion to air or a liquid by forcing it outward from the center of the part.

In-block.—Two or more cylinders cast as one piece, i. e., 2, 4, 6, 8 cylinders cast "in-block."

Indicated horsepower (*i. hp.*).—Total power developed by the engine; or brake horsepower (b. hp.) added to friction horsepower (f. hp.) Example: If an engine tested at 2,000 revolutions per minute develops 34 b. hp. and 26 f. hp., it would be rated as having 60 i. hp. at 2,000 revolutions per minute.

Inertia.—The property of a body which causes it to persist in a state of rest or in uniform motion.

In-line.—Indicates that all the cylinders of an engine, starting at the front with No. 1, then No. 2, etc., are in the same plane and in sequence within the cylinder block. Other blocks are known as V-type, radial type, etc.

Integral.—The whole made up of parts; constituting an essential part of a complete unit or assembly.

Journal.—The finished part of a shaft or axle which rotates in or against a bearing.

L-*head.*—Designates an engine with all the valves, cams, lifters, and other moving parts in and on one side of the cylinder block.

Mechanical efficiency.—The ratio between the brake horsepower (b. hp.) and the indicated or total horsepower (i. hp.)

Misfire.—The failure of an engine to fire regularly or to complete its cycle of operation.

Momentum.—The quantity of motion in a moving body.

Octane rating (number).—The antiknock rating given a gasoline; obtained by comparison with a standard or reference fuel.

Oscillate.—To move or swing back and forth with a pendulumlike motion.

Otto cycle.—A cycle of four events which occur in a gasoline engine in the following order: intake, compression, power, and exhaust.

Piston displacement.—The amount of space displaced during one stroke of a piston. For total piston displacement of all cylinders of an engine, use the following formula:

$$D^2 \times .7854 \times S \times N = \text{piston displacement}$$

D^2 is diameter or bore squared or multiplied by itself (as 5×5); this result is then multiplied by the constant .7854 (the area of cylinder 1 inch in diameter); this result by S, the stroke of the piston in inches; and this result by N, the number of cylinders.

Example: What is the piston displacement of four cylinders, 4-inch bore and 5½-inch stroke?

Procedure:

$4 \times 4 = 16$ or D^2

$16 \times .7854 = 12.566$ square inches.

12.566 square inches × 5½ inches = 69.113 cubic inches in 1 cylinder.

69.113 cubic inches × 4 cylinders = 276.5 cubic inches in 4 cylinders.

Poppet valve.—A valve having a disk-shaped head mounted on a stem that guides the valve head onto its seat. This type of valve is used almost exclusively in automotive engines.

Ports.—Openings in a cylinder block (or sleeve) for intake, exhaust, water, oil, etc.

Potential.—Ability to exert energy; expressed electrically by voltage.

Power.—The rate of doing work.

Power plant.—The engine.

Radial.—Radiating from a common center, as the spokes of a wheel.

Reciprocating.—A back and forth (or up and down) linear motion, such as the action of pistons in the engine.

Rectilinear motion.—Motion in a straight line.

Rotary.—Revolving or circular. Rotary motion is considered the opposite of linear reciprocating (up and down or back and forth) motion in power transfer.

R. P. M.—Revolutions per minute.

SAE.—Society of Automotive Engineers, a technical organization that advocates standardization of parts and nomenclature and performs scientific research on automotive matters.

Seat (valve).—That part of the combustion chamber upon which the valve face rests.

Shim.—Spacer (usually metal) used to regulate the fit or clearance between two objects, such as bearings.

Sleeve valve.—The ports or slots (valves) cut into sliding cylinders (or sleeves) of an engine which open and close by moving up and down to admit the fuel mixture or to expel the exhaust gases.

Static balance.—The balance of a body at rest.

Stress.—The forces exerted on, within, or by a body during either tension or compression; the opposing reaction of the interior elements of a body against forces tending to deform them.

Stroke.—The length or distance a piston travels up or down inside a cylinder.

T-*head.*—Used to describe an engine that has the intake valves on one side of the cylinder and the exhaust valves on the other.

Taper.—To make smaller gradually toward one end; a gradual reduction of size in a given direction.

Tappet (valve lifter).—That portion of a valve operating mechanism which rides against the cam and lifts the valve or push rod. It can usually be adjusted for valve stem clearance.

Temperature.—The intensity (or degree) of heat.

Thermodynamics.—The theory of changing heat into mechanical work.

Thrust.—A stress or strain tending to push anything out of alinement.

Tolerance.—An allowable variation in dimensions. For example: A standard measurement of 0.025 with a tolerance of minus 0.003 or plus 0.003 indicates that dimensions of 0.022 or 0.028 are allowed.

Torque.—A twisting or wrenching effort. Torque is the product of force multiplied by the distance from the center of rotation at which it is exerted. For example: A force of 40 pounds applied on the end of a 1-foot pipe wrench would be 40 (pounds) × 1 (foot) or 40 foot-pounds of torque. Similarly, 40 pounds of force exerted on the end of a 2-foot pipe wrench would be 40 (pounds) × 2 (feet) or 80 foot-pounds of torque. This indicates why it is easier to unscrew a pipe coupling with the 2-foot wrench than with the 1-foot wrench—the torque incident to the 2-foot lever (wrench) is greater.

Torsion.—The deformation in a body caused by twisting.

V-*type.*—Two rows (or banks) of engine cylinders arranged in V-form. Any other object having a V-shape, such as a V-block.

Vacuum.—Result of reducing atmospheric pressure.

Valve lifter (tappet.)—(*See* Tappet (valve lifter).)

Valve seat.—That part of the combustion chamber upon which the valve face rests.

Velocity.—The rate of motion or speed of a body at any instant; usually measured in miles per hour or feet per second or minute.

Vibration damper.—A device to regulate the torsional (twisting) vibration of a multiple cylinder engine crankshaft.

Viscosity.—Internal resistance to flow; the fluid body of a liquid.

Volatility.—Ability of a liquid to vaporize or turn into a gas.

Volumetric efficiency.—The ratio of the volume of air or fuel charge actually taken into the cylinder to the volume of the piston displacement—the greater the volumetric efficiency, the greater the weight of air or fuel charge taken into the cylinder.

Work.—The use of energy to overcome resistance.

SECTION II

PRINCIPLES OF OPERATION

2. General.—*a.* An engine may be described as a machine that uses power to do work, particularly one that converts some form of energy, especially heat, into mechanical power. An internal combustion engine is one which obtains its power by the combustion or burning of fuel in a confining space—its cylinders.

b. In gasoline engines of the type commonly used for automotive purposes, mechanical power is generated from the potential chemical energy of the fuel used. The engine, acting as a pump, draws the fuel mixture (air and gasoline) from a device known as a carburetor into the cylinder. The gasoline in the ideal mixture is highly vaporized or atomized and is in the proportion of about 1 part of gasoline to 15 parts of air by weight. After this vaporized mixture is drawn into the cylinder it is compressed to a fractional part of its original volume and then ignited. The mixture burns and forms water vapor and carbon dioxide. This burning raises the gases to a high temperature, and since heating a confined gas increases its pressure, the gases of combustion exert extremely high pressures on the piston of the engine, giving to it a rectilinear motion and allowing the gases to expand. This motion is converted into rotary motion by means of a connecting rod and a crankshaft.

3. Work.—*a.* Any applied effort which overcomes a resistance or results in objects being lifted or moved is work. Thus, if you turn a crank, lift a chair, or slide a table across the floor you are doing work. The time it takes to move an object is also involved in work. A man could unload a ton of bricks in an hour by handling them one at a time whereas a power crane could be used to lift the whole load at one time.

b. (1) In each instance the same amount of work was accomplished but the crane did it in a fraction of the time. This indicates a greater ability to do work. Work is done when the man, figure 1 ①, exerts force through distance in turning the wrench to tighten the nut on a bolt.

(2) In figure 1 ② the bicycle rider exerts a force downward against the pedal, making the sprocket turn, which moves the chain and re-

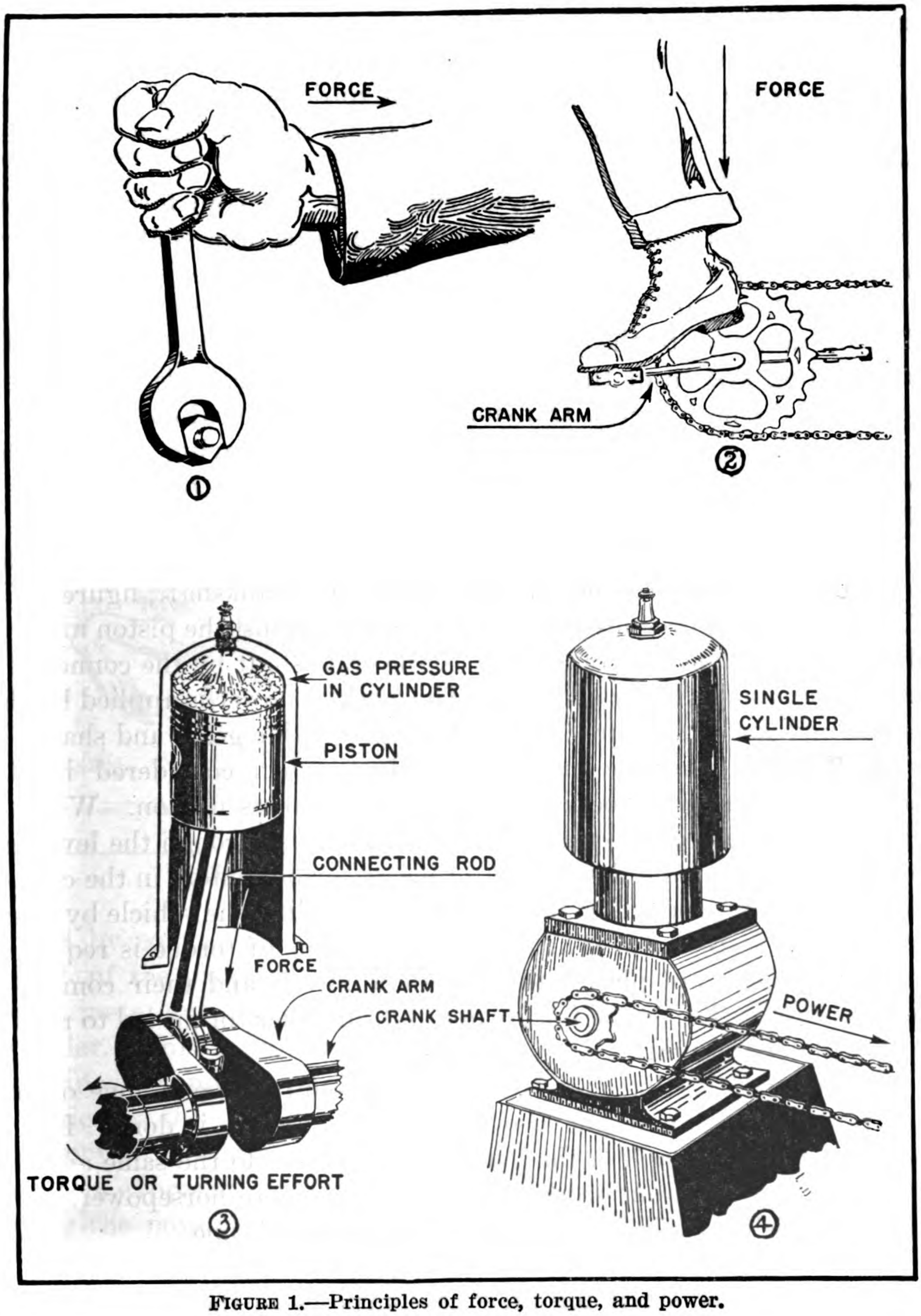


FIGURE 1.—Principles of force, torque, and power.

volves the rear wheel. The work done by the rider is used or consumed in overcoming the resistance of the bicycle to motion, in keeping it moving, or in overcoming gravity when going up hill.

c. It is an accepted fact that the total energy of the universe remains constant. Its form may change and its distribution may change, but it cannot be destroyed or created. For example, work is done in raising a book to a table top, but, by virtue of its position, the energy that has been stored in the book then enables it to do work. Likewise, heat energy stored in gasoline is liberated to do work when it is burned with oxygen.

d. An engine cannot create energy but it can transform the heat energy in a fuel into mechanical energy. In this process all the potential energy of a fuel is not used because no machine is 100 percent efficient. Some of the heat energy is lost in the exhaust gas, some is lost by radiation to the surrounding air, and some by conduction to the cooling system of the engine through cylinder walls, piston, etc. Some of the heat energy transformed into mechanical energy is used in overcoming the friction between the various moving parts of the engine. By this it is seen that the usable mechanical power delivered by the engine is only a part of the total heat energy supplied by the fuel.

e. In the automobile engine, the gasoline, by being burned in the cylinder, furnishes the power that rotates the crankshaft, figure 1 ③. The gas exerts a pressure or force downward against the piston making it move. The force is transferred to the crankshaft by the connecting rod which rotates the crankshaft. The work or power is applied by the chain and sprocket figure 1 ④, or through suitable gears and shafts.

4. **Torque.**—Torque or turning effort, when considered in the automotive engine, produces work when it causes motion. When a force is applied to the crank, figure 1 ③, it acts through the leverage of the crank arm and develops a torque or turning effort in the crankshaft. This turning effort does work in propelling the vehicle by overcoming its resistance. When a greater amount of torque is required, more cylinders are placed along the crankshaft and their combined effort is used. The desire for greater and smoother torque led to multiple cylinder engines.

5. **Power.**—*a.* Not only is the total amount of work done of importance in an engine but also the rate at which it is done. In the example in paragraph 3, the man and the crane do the same amount of work, but the crane works faster and uses more horsepower. The rate at which work is done involves the element of time.

b. Work is ordinarily measured in foot-pounds per second, but this unit is often too small for practical purposes so the larger unit of horsepower is used. Figure 2 illustrates the principle of horsepower. In this example the horse walks at the rate of 220 feet per minute and lifts a 150-pound weight. When these figures are multiplied it is seen that 33,000 foot-pounds per minute is the rate at which the horse is doing work. This rate is known as the horsepower.

c. The horsepower of an engine indicates the rate at which it is able to do work. This power can be determined in two ways. The total power released by burning a fuel in the cylinder can be determined by combining mathematically the area of the cylinder, the length of the piston travel or stroke, the number of working strokes per minute, and the effective pressure of the burning gases in the cylinder. This is known as indicated horsepower and is used for experimental and laboratory purposes. The other method is to attach a device to the engine, such as a dynamometer or a special brake horsepower tester, and measure the actual power developed. The result is expressed in terms of brake horsepower. This method of rating the power of an engine is the more practical of the two because it eliminates all mechanical and frictional losses from the result. A mathematical formula is used to calculate the taxable

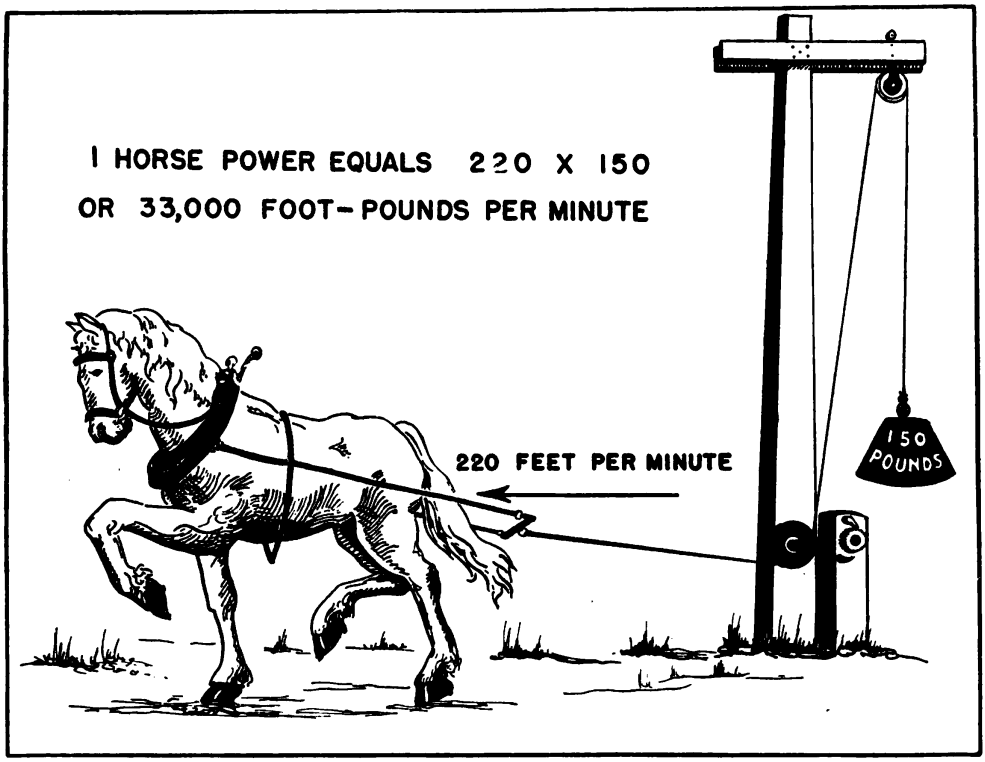


FIGURE 2.—Principle of horsepower and its value.

horsepower for licensing purposes. This is termed the SAE formula:

$$\text{horsepower} = \frac{(\text{bore of cylinder})^2 \times \text{number of cylinders}}{2.5}$$

Thus the horsepower of an eight cylinder engine having cylinders 3 inches in diameter would be $\frac{3 \times 3 \times 8}{2.5} = 28.8$ horsepower.

6. Fundamental principles.—*a.* Transforming the heat energy of a burning gas into mechanical energy in an internal combustion engine involves a basic law of physics known as Charles's law, which states that a gas under constant pressure will expand if its temperature is raised. If, however, a gas is heated during confinement, as it momentarily, is in an engine cylinder, it cannot expand externally so its pressure increases. It is this increased gas pressure acting evenly over the entire head of the piston that imparts motion to it and produces mechanical power.

b. In order to continue running and to deliver continuous power, an internal combustion engine must repeat over and over again a certain definite series of operations. Each operation is called an event, and each complete series of events, a cycle.

c. An example of the events that make up the operating cycle of an engine follows:

(1) Filling the cylinder with a correctly proportioned mixture of air and fuel is the first event. This is done by the piston moving downward toward the crankshaft and creating a vacuum or suction in the cylinder—the intake stroke.

(2) The second event is the compression of the air-fuel charge to a fractional part of its original volume by the upward stroke of the piston—the compression stroke.

(3) Next follow the burning of the compressed mixture, the liberation of heat energy, and the resulting expansion of the gases which forces the piston downward—the power stroke.

(4) The last event of the cycle is the expelling of the burned gases by the upward stroke of the piston, clearing the cylinder for a new charge of air and fuel—the exhaust stroke.

7. Four stroke Otto cycle.—*a.* Any gasoline engine that requires four strokes of the piston, two down and two up (consequently, two complete revolutions of the crankshaft), to complete a cycle of events is called a four stroke cycle engine. Since the four stroke cycle employed in the modern gasoline engine follows closely a ther-

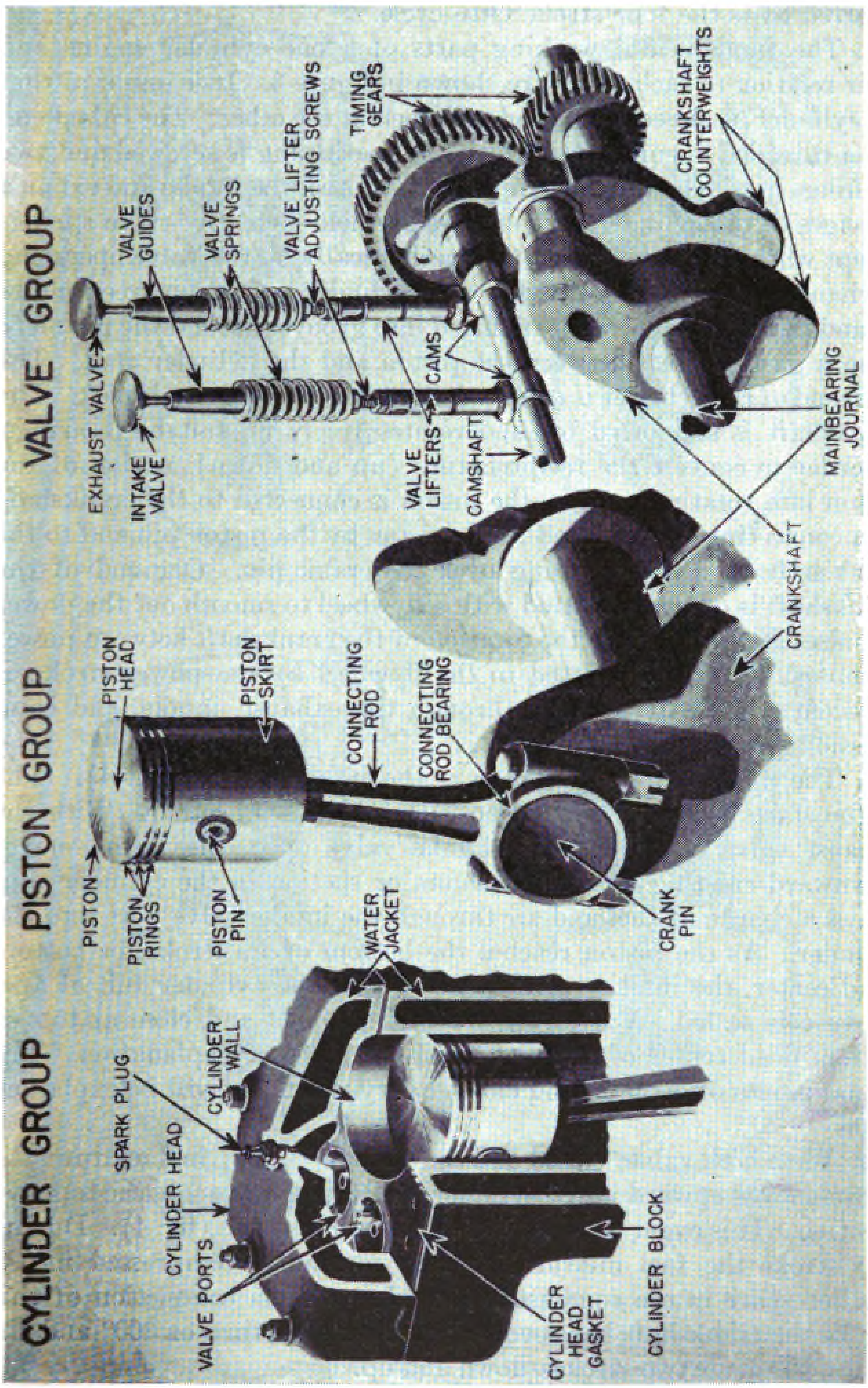


FIGURE 3.—Operating parts of four-stroke Otto cycle engine.

modynamic principle discovered by Dr. N. A. Otto in 1876, it is referred to as the four stroke Otto cycle.

b. The fundamental working parts of a one cylinder engine and their relation to each other are shown in figure 3. It is essential that the cylinder be closed at one end and open at the other. The closed end has a threaded opening into which the spark plug is screwed and two openings in which two valves operate to control the intake and exhaust passages of the cylinder. The valves are held closed by valve springs except when they are forced open mechanically by the valve operating mechanism. A piston is fitted into the cylinder so that it is free to move up and down. Piston rings are fitted into grooves around the piston to form a gastight seal between the piston and the cylinder wall. The open end of the cylinder is mounted directly above the crankshaft. The crankshaft is supported by, and rotates freely in, suitable bearings. In order to convert the reciprocating (up and down) motion of the piston into rotating motion, the piston is connected to the crankshaft by a connecting rod fastened to the piston by the piston pin and to the crankshaft by a split bearing over the crank pin. One end of the crankshaft is ordinarily fitted with a flywheel to smooth out the power impulses and to continue the rotation of the crankshaft between power impulses. Energy imparted to the flywheel by the power stroke is sufficient to keep it rotating through the exhaust, intake, and compression strokes.

c. The first event in the cycle is the intake stroke (fig. 4). The piston starts from its topmost position or top dead center. With the exhaust valve closed and the intake valve open, the piston moves downward creating a partial vacuum or suction in the cylinder that draws a charge of fuel and air through the intake valve port into the cylinder. As the piston reaches the bottom of its stroke, or bottom dead center, the intake valve closes so that the cylinder full of fuel mixture is sealed. Valves are assumed to open and close at top or bottom dead center of the piston for purposes of explanation. The actual points of opening and closing vary widely as will be explained later.

d. With both valves closed and the cylinder full of fuel mixture, the piston moves upward in the cylinder until it again reaches the topmost position. This event is called the compression stroke (fig. 4). During this stroke the fuel mixture is being constantly compressed into a smaller space in the combustion chamber. Upon completion of this stroke the crankshaft has revolved one complete turn or 360° and the piston has made two strokes, down and up.

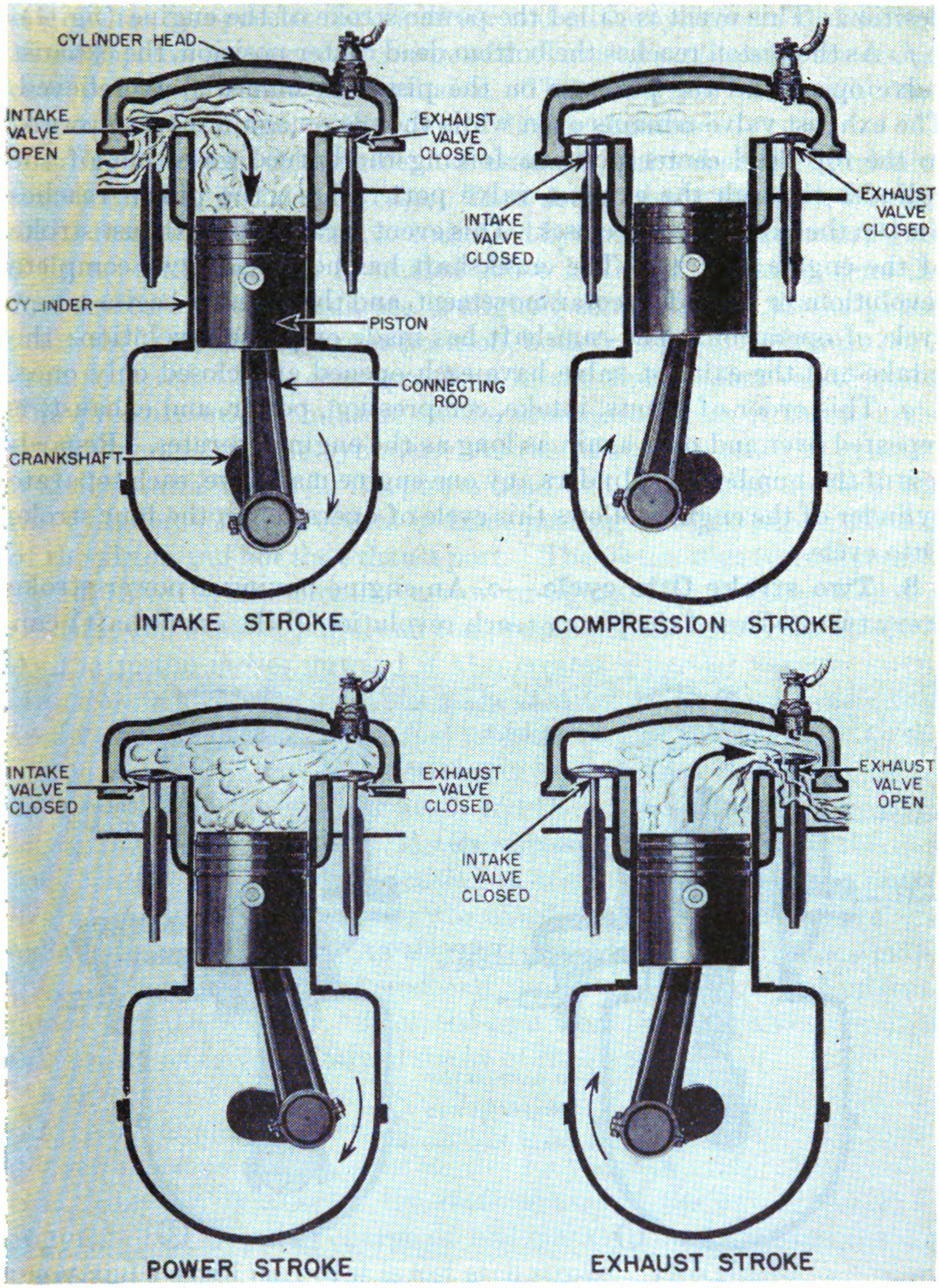


FIGURE 4.—Events of one complete cycle of four-stroke Otto cycle engine.

e. At this point in the cycle the highly compressed fuel charge is ignited by the spark plug and combustion takes place. Due to the heat of combustion, the gaseous charge builds up an extremely high pressure and the piston is forced downward to the bottom dead center position. This event is called the power stroke of the engine (fig. 4).

f. As the piston reaches the bottom dead center position, the exhaust valve opens and the pressure on the piston is immediately relieved. The exhaust valve remains open while the piston again moves upward to the top dead center position forcing the burned gases out of the cylinder through the exhaust valve port. When the piston reaches the top the exhaust valve closes. This event is called the exhaust stroke of the engine (fig. 4). The crankshaft has now made two complete revolutions or 720° of circular movement, and the cylinder begins a new cycle of operation. The camshaft has made only one revolution; the intake and the exhaust valve have each opened and closed only once.

g. This order of events, intake, compression, power, and exhaust, is repeated over and over again as long as the engine operates. Regardless of the number of cylinders any one engine may have, each separate cylinder of the engine follows this cycle of operation in the four stroke Otto cycle.

8. Two stroke Otto cycle.—*a*. An engine having a power stroke every two strokes of the piston (each revolution of the crankshaft) can

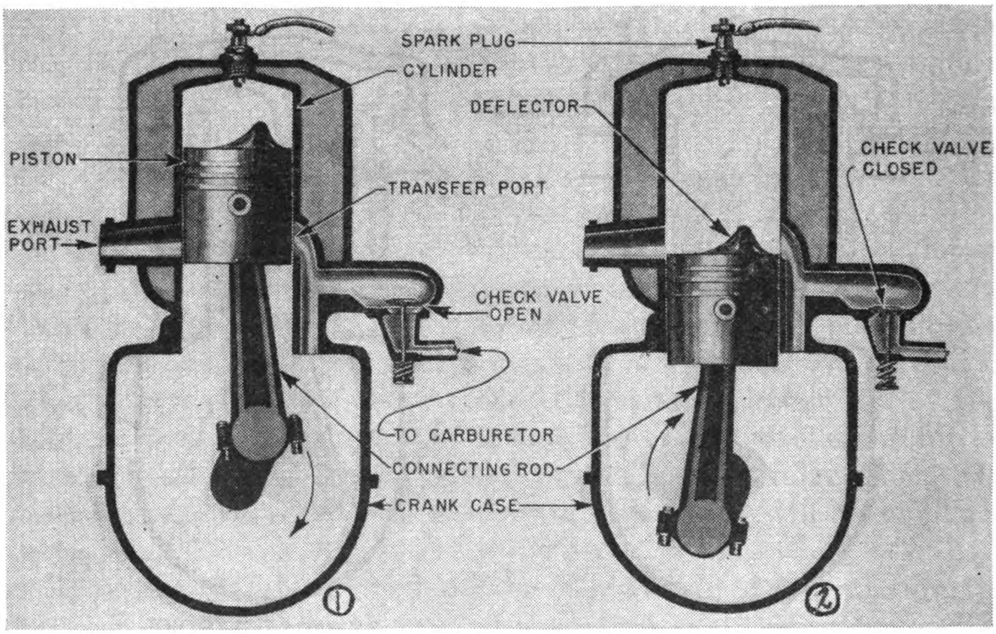


FIGURE 5.—Two-stroke Otto cycle engine of two-port type.

be made by slightly modifying the four stroke Otto cycle. This is known as a two stroke Otto cycle. In this type of engine, the four events of the Otto cycle are completed in two strokes of the piston. Figure 5 shows the general arrangement of the working parts of a simple two stroke cycle engine of the two port type. This type of engine has the space at the crankcase end of the cylinder sealed as well as the top end because each charge of fuel must pass through the crankcase before it enters the cylinder. The crankcase is airtight and becomes an extension of the lower cylinder chamber.

b. In describing this engine, it is assumed that a charge of fuel mixture is already in the crankcase. Then as the piston moves downward on its first or initial stroke, as indicated by the circular arrow in figure 5 ①, a partial vacuum is created above it and at the same time the fuel mixture in the crankcase is slightly compressed. As the piston nears the bottom dead center position, both transfer and exhaust ports are uncovered. This corresponds to intake and exhaust valve action. The pressure on the mixture in the crankcase forces it through the transfer port into the cylinder. As the mixture enters the cylinder it strikes the deflector in the piston head and is deflected upward into the cylinder. This prevents it from passing straight across the top of the piston and out the exhaust port. The piston then starts upward, as indicated by the circular arrow in figure 5 ②, closing both the transfer and exhaust ports, and compresses the charge of fuel mixture. As the piston moves upward it also creates a partial vacuum in the crankcase which lifts or opens a check valve in the intake manifold and draws a fresh charge of fuel mixture into the crankcase. As the piston reaches the top of the stroke, the compressed fuel is ignited by a spark plug in the cylinder head, and the piston is forced downward on its initial power stroke. As the piston moves downward the new fuel charge is slightly compressed in the crankcase. As the piston nears the bottom of the stroke, the exhaust port is uncovered and the exhaust gases rush out. As the piston moves a short distance more, the transfer port is uncovered and the new charge of fuel mixture moves into the cylinder. It can be seen from this that a power stroke takes place on each downward stroke of the piston.

c. From this discussion it would seem, in similar engines of the same size running at the same speed, that the two stroke cycle would deliver twice as much power as the four stroke cycle. This is not true, however, because of the inefficiencies of the two stroke cycle engine. The incoming charge of fuel quickly mixes with the exhaust gases and a small part of it is lost each stroke. This results in a waste of fuel and a loss of power. The volumetric efficiency of a two stroke cycle is less than that of a four stroke because the intake and exhaust actions overlap and because of the movement of the piston necessary to close the ports.

d. A three-port two-cycle engine is shown in figure 6. The principal difference between the two-port and the three-port engine is the manner in which the fuel charge is admitted to the cylinder. Instead of the air-fuel mixture being controlled by a check valve as it is in a two-port engine, a third port is used and the skirt of the piston acts as a valve. As shown in figure 6 ①, the intake port remains covered by the piston until the piston nears the top of its upward stroke. During the upward stroke, the piston creates a partial vacuum in the crankcase up to the point where the intake port

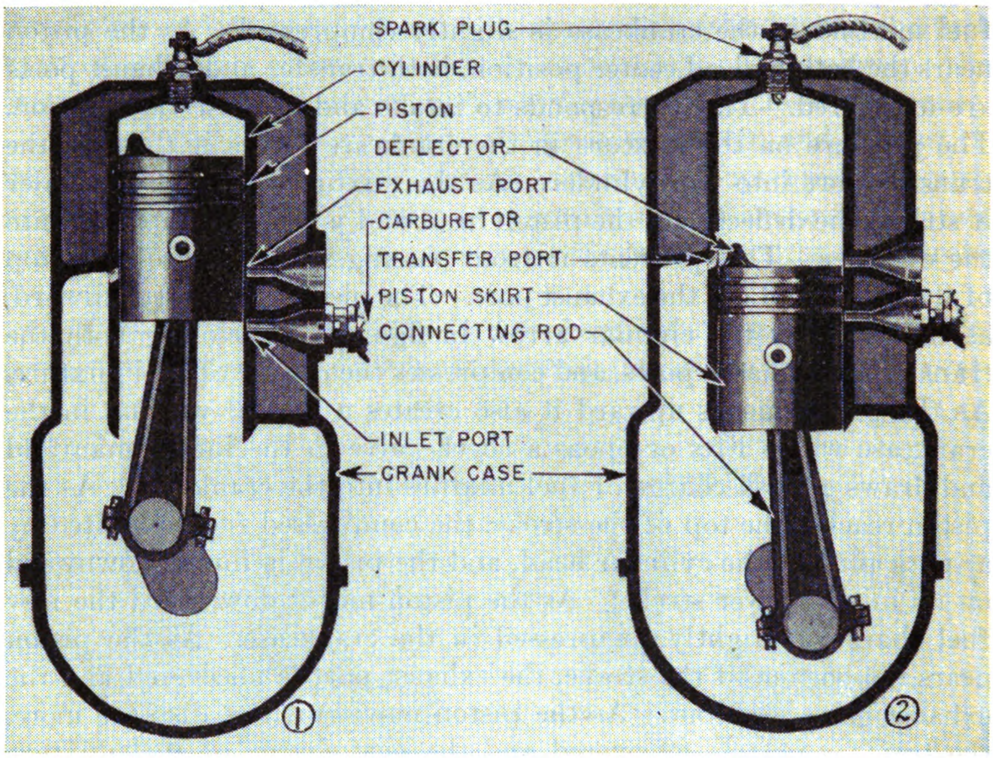


FIGURE 6.—Two-stroke Otto cycle engine of three-port type.

is uncovered. As soon as it is uncovered a charge of fuel-air mixture rushes in. As the piston moves downward on the power stroke, the intake port is closed and the remainder of the cycle continues in the same manner as a two-port engine.

9. Diesel cycle.—*a.* In general, the events of the Diesel cycle are similar to those of the four-stroke Otto cycle. The principal differences are in admitting and igniting the fuel. Air only is drawn into the cylinder on the intake stroke and compressed to much higher pressures. Compression pressures of 500 pounds per square inch or more are not uncommon in Diesel engines. These extremely high pressures raise the air temperature to about 1,000° F. Just before the piston reaches top dead center on the compression stroke, a measured quantity of fuel oil is forced into the cylinder through a fuel injection system. The high temperature of the air in the cylinder ignites the injected fuel, and the power stroke follows. This principle of ignition, by taking advantage of the higher temperatures created by the greatly increased compression, eliminates the necessity for an ignition system.

b. For the types of Diesel engines, Diesel fuels, and engine accessories common to the Diesel engine see TM 10-575.

10. Compression ratios.—*a.* The ratio of compression or compression ratio of an engine is the total volume of the cylinder divided by the clearance volume, or—

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

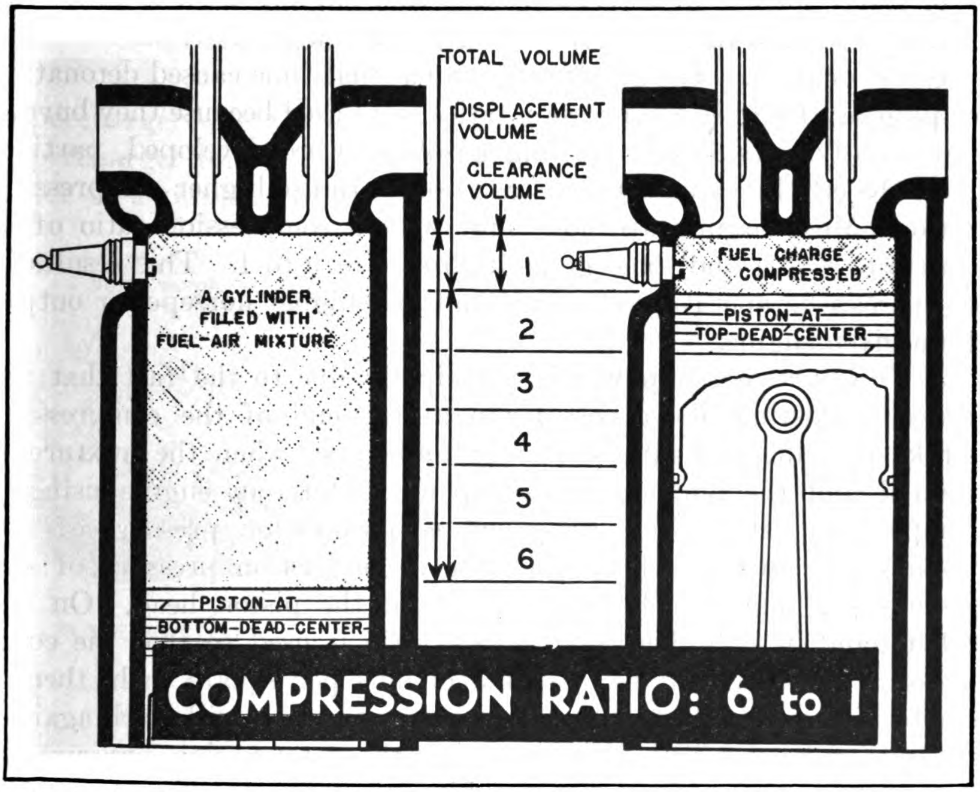


FIGURE 7.—Compression ratio in terms of total, clearance, and displacement volumes.

A study of figure 7 shows the relationship of these volumes. The volume above the piston, when it is at top dead center, is the clearance volume (minimum volume). The displacement volume is the increase in volume as the piston moves to bottom dead center. Volumes only should be considered in referring to compression ratio. Pressures are sometimes confused with this term.

Example: Assume that an engine cylinder with a 3-inch diameter bore and a 3.5-inch stroke has a clearance volume of 4.95 cubic inches above the piston when the piston is in top dead center position. The piston displacement would be—

$$\frac{4}{3.1416\times\text{diameter of bore squared}\times\text{length of stroke,}}\ \text{or}$$

$$\frac{3.1416\times3\times3\times3.5}{4}=24.74\ \text{cubic inches.}$$

The compression ratio would then be $\frac{24.74+4.95}{4.95}=6$ to 1.

b. Early models of internal combustion engines used compression ratios of from 3 to 1 to about 4 to 1. These are known as low compression engines. The gasolines in use at that time caused detonation or pinging if higher compression ratios were used because they burned too rapidly. As slower burning gasolines were developed, particularly the ethyl-treated type, it was possible to use higher compression ratios. Most engines are now built with a compression ratio of at least 5 or 6 to 1 and some go as high as 8 or 9 to 1. This results in an increase in operating efficiency and in a higher horsepower output for a given engine.

c. This increase in power is principally due to the fact that the pressure existing above the piston at the end of the compression stroke is multiplied approximately four times when the mixture is ignited and the burning gases expand. Thus, an engine using a compression ratio which results in a compression pressure of 100 pounds per square inch would have a combustion pressure of 400 pounds per square inch to work against the piston head. On the other hand, if a higher compression ratio is used so that the compression pressure will be, say, 125 pounds per square inch, then a combustion pressure of 500 pounds per square inch will work against the piston head. Thus, by increasing the compression pressure 25 pounds per square inch, the working pressure was increased 100 pounds per square inch.

11. Supercharging.—Blowers or superchargers are sometimes used to obtain a more efficient fuel charge in the cylinders. The supercharging principle is shown in figure 8. The air passing through the carburetor picks up fuel under normal atmospheric conditions. The air and fuel mixture is then drawn through the

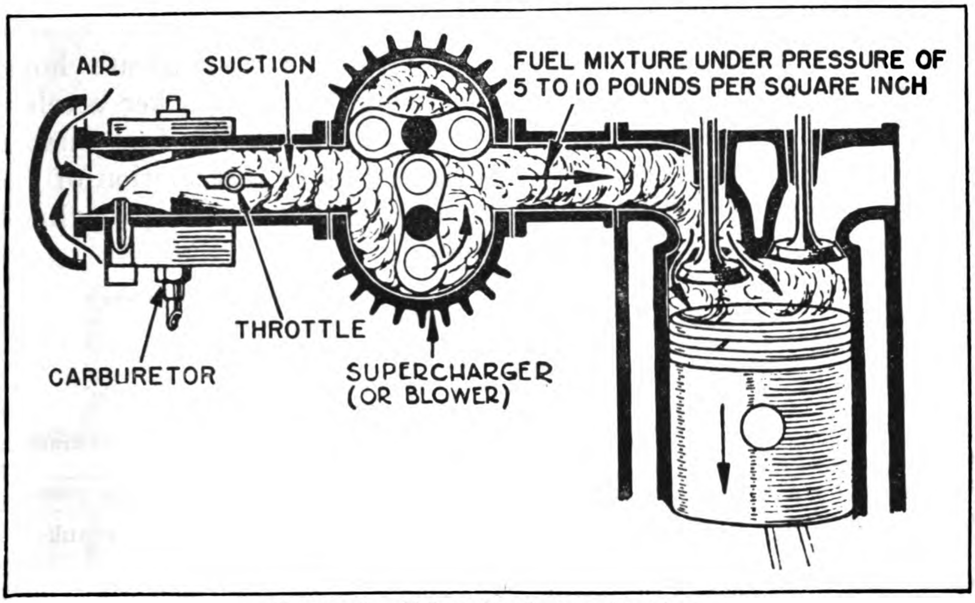


FIGURE 8.—Principle of supercharging.

supercharger where it is more thoroughly atomized and mixed. The supercharger forces this mixture into the cylinder through the intake valve at a pressure of from 3 to 10 pounds per square inch. This

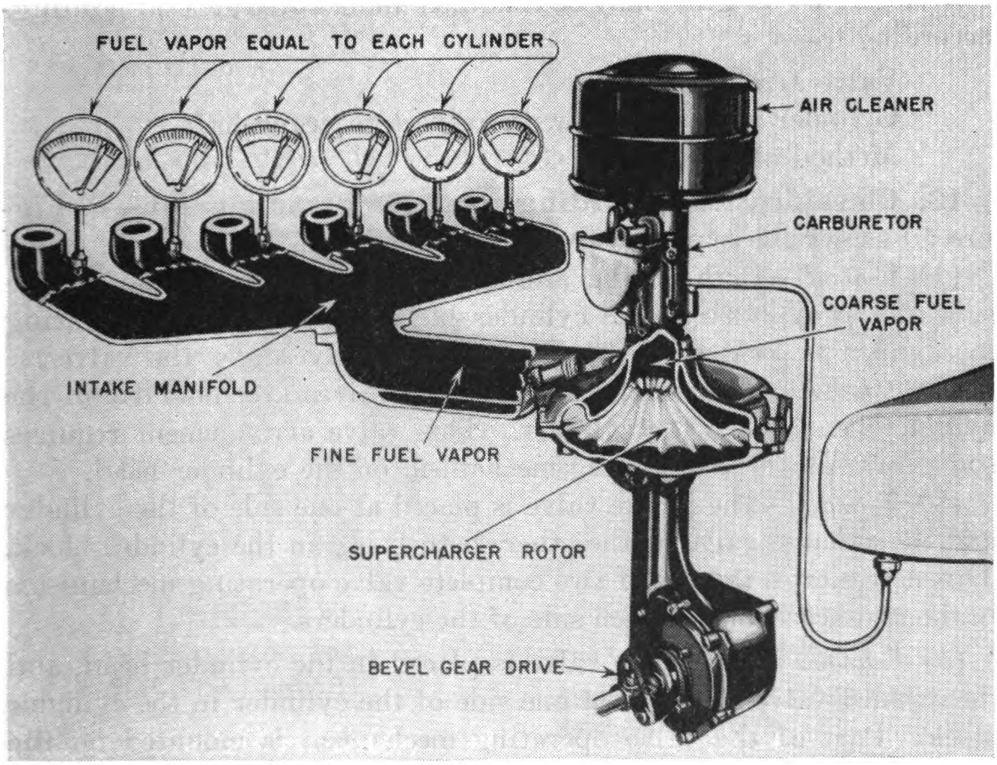


FIGURE 9.—Use of supercharger to effect more even distribution of fuel.

action causes a larger charge of a better blended air-fuel mixture to enter the cylinder for each cycle, and consequently a greater horsepower output is developed. A supercharger gives quicker acceleration and increased fuel economy by distributing the fuel mixture more evenly. Since a supercharger gives better distribution of fuel mixture, its use simplifies the intake manifolding of multiple-cylinder engines and increases engine efficiency.

Section III

TYPES OF ENGINES

12. General.—There have been many different internal combustion engine designs. However, the application by a manufacturer to a particular need or system of manufacturing has caused certain designs to be more commonly used than others and to be recognized as conventional. Engines may be classified under three general headings according to—

Valve arrangement.
Cylinder arrangement with respect to crankshaft.
Method of cooling.

13. Classification according to valve arrangement.—*a.* Figure 10 shows the typical valve arrangements in common use.

(1) L-*head.*—Both intake and exhaust valves are placed at one side of the cylinder in the cylinder block, and the valve operating mechanism is located in the crankcase directly under the valves.

(2) I-*head.*—Both intake and exhaust valves are mounted in the cylinder head above the cylinder. This valve arrangement requires some form of valve operating mechanism on the cylinder head.

(3) T-*head.*—The intake valve is placed at one side of the cylinder and the exhaust valve at the other, both being in the cylinder block. This necessitates the use of two complete valve operating mechanisms in the crankcase, one on each side of the cylinders.

(4) F-*head.*—The intake valve is placed in the cylinder head, and the exhaust valve is placed at one side of the cylinder in the cylinder block. Part of the valve operating mechanism is mounted on the cylinder head and part in the crankcase.

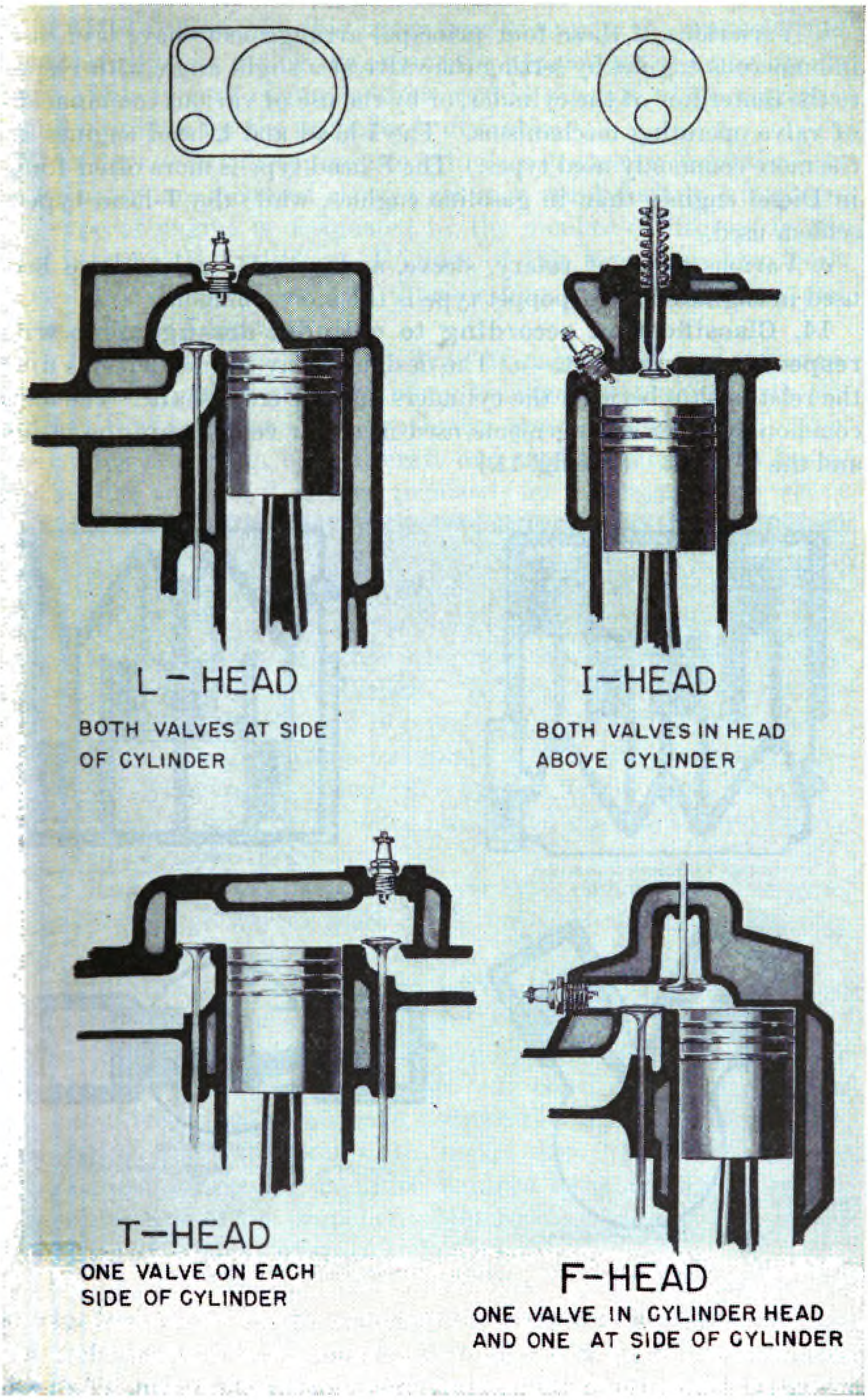


FIGURE 10.—Typical valve arrangements.

b. Variations of these four principal arrangements have been used in numerous engines by setting the valve at a slight angle with respect to the center line of the cylinder, or by the use of various combinations of valve operating mechanisms. The **I**-head and **L**-head engines are the more commonly used types. The **F**-head type is more often found in Diesel engines than in gasoline engines, while the **T**-head type is seldom used.

c. Various types of rotary, sleeve, and cylinder valves have been used in engines but the poppet type is the more common.

14. Classification according to cylinder arrangement with respect to crankshaft.—*a*. The design of any engine depends upon the relationship between the cylinders and the crankshaft. The more common cylinder arrangements used in motor vehicles are the in-line and the **V**-types. (See fig. 11.)

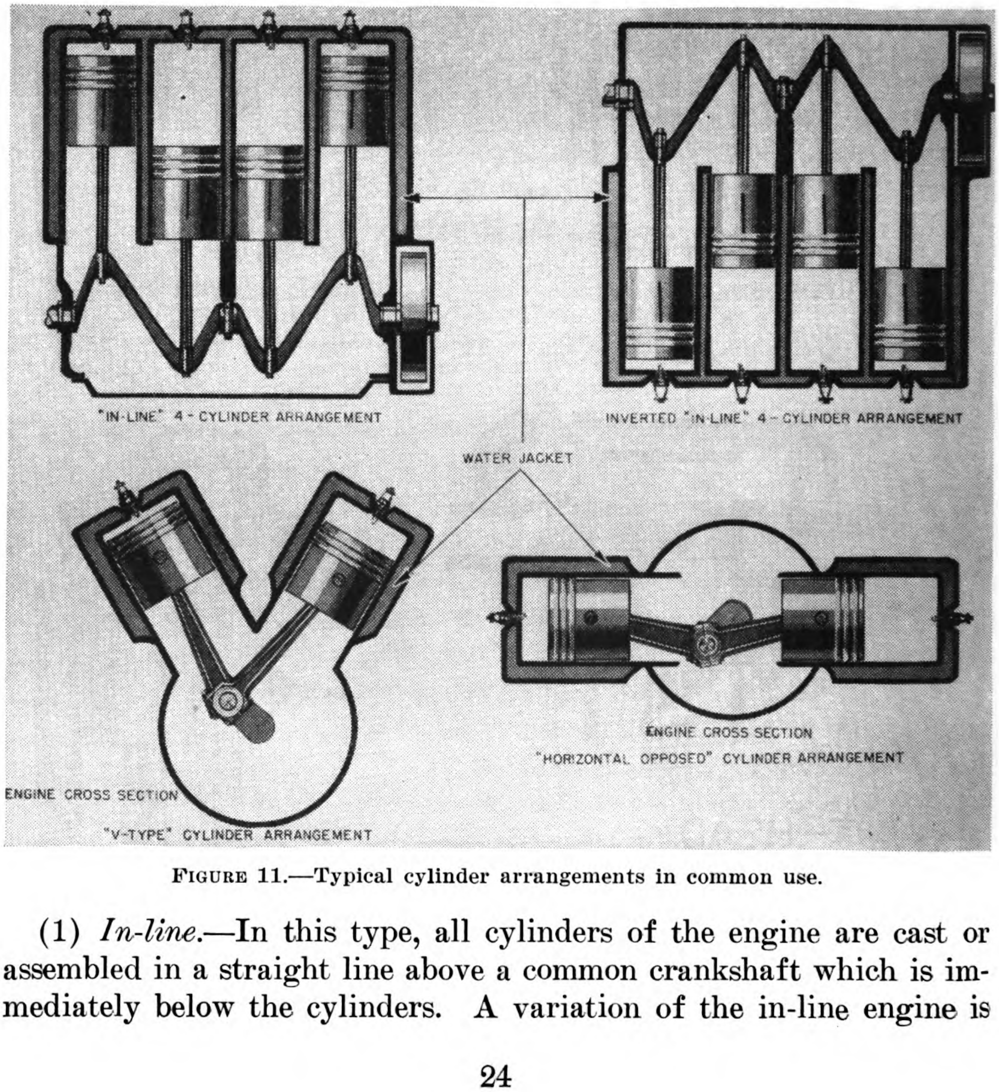


FIGURE 11.—Typical cylinder arrangements in common use.

(1) *In-line*.—In this type, all cylinders of the engine are cast or assembled in a straight line above a common crankshaft which is immediately below the cylinders. A variation of the in-line engine is

the inverted in-line. In this latter type of engine the crankshaft is above the cylinders giving the engine the appearance of being upside down. This type of engine is often used in aircraft where a greater ground clearance for the propeller is desirable.

(2) *V-type.*—In this engine two cylinders or groups (banks) of in-line cylinders are mounted above a common crankshaft in a V-shape. This type of engine is designated by the number of degrees in the angle between the cylinders. Engines of this type have been built for racing and marine use with three or four banks of cylinders and known as W- or X-types.

(3) *Horizontal-opposed.*—This type of engine has two cylinders or banks of cylinders arranged along the same crankshaft with the cylinders horizontal and the two banks opposite each other. This type engine is used in both aircraft and motor vehicles. In heavy duty vehicle engines, it is used primarily in passenger buses where it is mounted under the body of the vehicle because of its low over-all height.

b. The radial engine has its cylinders placed in a circle around the crankshaft. Large horsepower engines of the radial type may have two rows of cylinders, in which case each row operates on its own "throw" or crank on the crankshaft. Engines of the radial type are used primarily in aircraft and in certain types of military vehicles.

c. The duplex engine uses a less common type of cylinder arrangement. The cylinders are placed side by side, either with a common cylinder head or separate cylinder heads, and operate on two crankshafts that are geared together.

d. Other types of engines are the lever type, cam or crankless type, and the squash or wabble plate types, but these are not sufficiently used to be discussed here.

15. Classification by method of cooling.—Engines may also be classified by methods of cooling: air-cooled or liquid-cooled.

a. Air-cooled in-line and opposed engines have been used in motor vehicles at various times. However, air-cooled engines have been most extensively used in aircraft, because the absence of a radiator, water jacket, and water pump, etc., makes them lighter, and because of the natural air-cooling facilities obtained by mounting the engine in the air stream of the propeller. Motorcycle engines are air-cooled as a matter of economy of space and of weight.

b. Liquid-cooled engines have, for the most part, been adopted for motor vehicle use. These engines require a water jacket around the valve ports, combustion chamber, and cylinders; and a radiator for dissipating the heat from the cooling liquid into the surrounding air. As a rule, liquid-cooled engines use a pump for circulating the cooling liquid.

SECTION IV

MULTIPLE-CYLINDER ENGINES

16. Power impulses.—*a.* Practically all internal combustion engines used as motor vehicle power plants are the multiple-cylinder type. In the early motor vehicle, one cylinder, two cylinder, and some three cylinder engines were employed, but the advantages of engines with a larger number of cylinders soon led to their general adoption for automotive use. It was shown in the discussion of the four-stroke Otto cycle that power was delivered only during one event of the cycle—the expansion or power stroke—and that during the balance of the cycle, power was delivered by the flywheel for the operation of the suction, compression, and exhaust strokes.

b. In actual operation, power is produced through only about four-fifths of the expansion (power) stroke. This loss is due to the mechanics of valve timing. Thus in a single cylinder of a 5-inch-stroke engine, power is produced for only 4 inches of piston movement, despite the fact that the piston must travel a total of 20 inches in that cylinder to complete the four events of an Otto cycle: intake, compression, power, exhaust. In the cited example, power is actually produced during only 20 percent of the piston travel.

c. As additional cylinders are added to an engine, each separate cylinder must still complete the four events of the Otto cycle during two revolutions of the engine crankshaft, even though each cylinder is working on a different event of the cycle at the same time. In a two-cylinder engine, two power strokes are developed for each completed engine cycle. In a two-cylinder engine having a 5-inch stroke, the events would occur in the following order:

	Inches of piston power travel
First stroke:	
Cylinder—	
No. 1 intake	0
No. 2 power	4
Second stroke:	
Cylinder—	
No. 1 compression	0
No. 2 exhaust	0

	Inches of piston power travel
Third stroke:	
Cylinder—	
No. 1 power	4
No. 2 intake	0
Fourth stroke:	
Cylinder—	
No. 1 exhaust	0
No. 2 compression	0

This shows that during a total piston travel of 20 inches for each piston of the engine (two revolutions of the crankshaft) a total piston travel of 8 inches representing power was obtained from both pistons combined, or power was obtained during 40 percent of the cycle of the two-cylinder engine.

d. In a four-cylinder engine having a 5-inch stroke, four power strokes are obtained in two revolutions of the crankshaft; the events in each cylinder occurring in the following order:

	Inches of power developed
First stroke:	
Cylinder—	
No. 1 power	4
No. 3 compression	0
No. 4 intake	0
No. 2 exhaust	0
Second stroke:	
Cylinder—	
No. 1 exhaust	0
No. 3 power	4
No. 4 compression	0
No. 2 intake	0
Third stroke:	
Cylinder—	
No. 1 intake	0
No. 3 exhaust	0
No. 4 power	4
No. 2 compression	0
Fourth stroke:	
Cylinder—	
No. 1 compression	0
No. 3 intake	0
No. 4 exhaust	0
No. 2 power	4

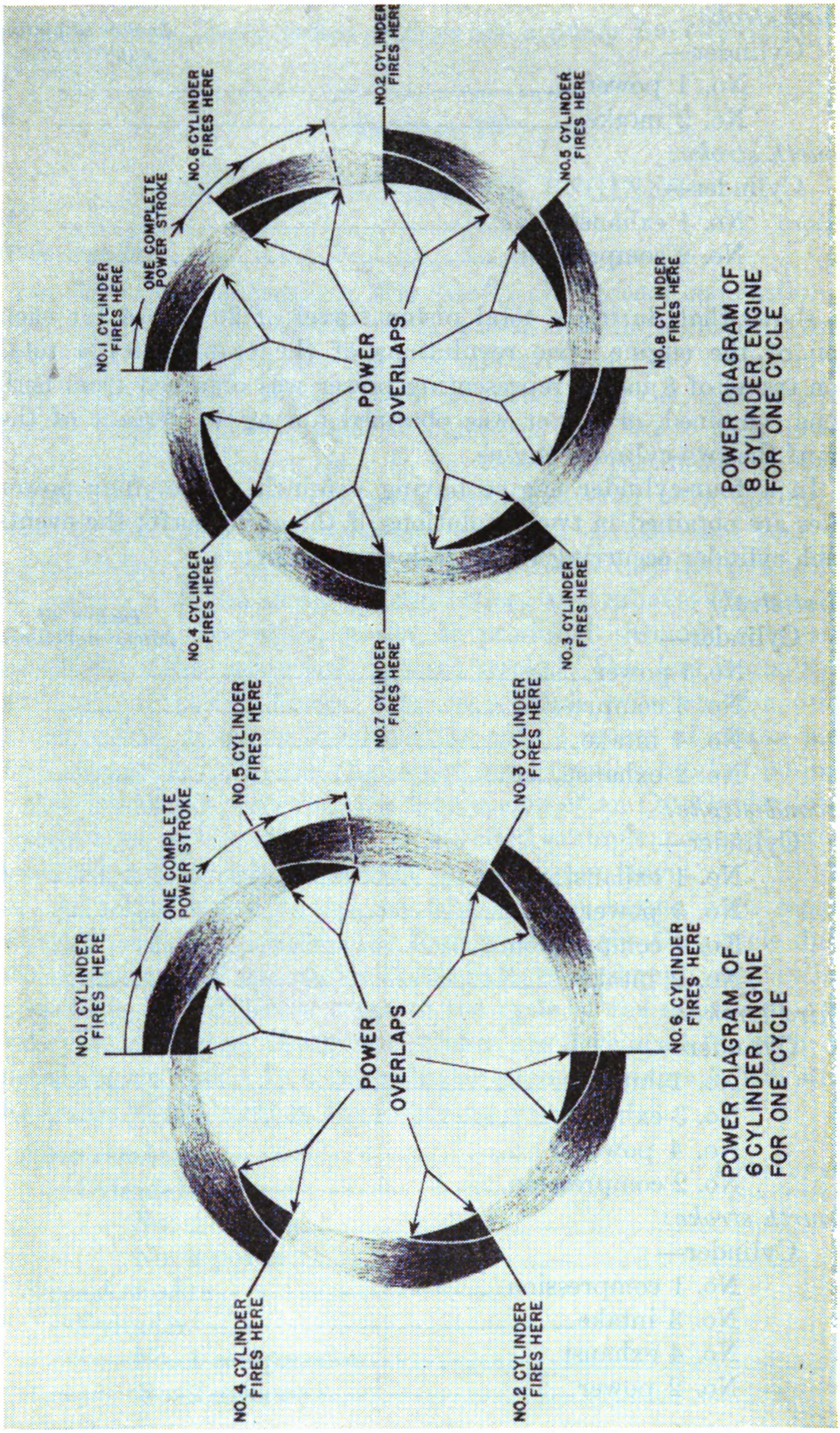
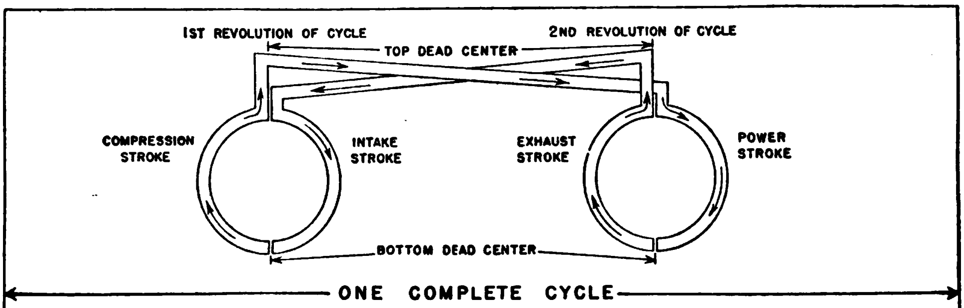


FIGURE 12.—Relation and overlap of power strokes for one complete cycle. Note increase in amount of overlap as number of cylinders and corresponding power strokes are increased.

This shows that during a total piston travel of 20 inches for each piston (two revolutions of the crankshaft) a total piston travel of 16 inches representing power was obtained from all pistons combined, or power was obtained during 80 percent of the cycle of the four-cylinder engine.

e. In a six-cylinder engine having six power strokes in two revolutions of the crankshaft each piston travels 20 inches, and a total piston travel of 24 inches representing power is obtained from all



2 REVOLUTIONS OF CRANKSHAFT — 720°			
1—REVOLUTION 360°		1—REVOLUTION 360°	
½ REV. 180°	½ REV. 180°	½ REV. 180°	½ REV. 180°
1 STROKE DOWN	2 STROKE UP	3 STROKE DOWN	4 STROKE UP
P	E	I	C
FLYWHEEL ABSORBS POWER	FLYWHEEL IS GIVING UP POWER ABSORBED DURING 1ST. OR POWER STROKE		
P—POWER; E—EXHAUST; I—INTAKE; C—COMPRESSION.			

FIGURE 13.—One-cylinder engine.

six pistons combined. The 24 inches of power travel would indicate that power was produced during 120 percent of the engine cycle. Since 100 percent represents the total possible travel during the cycle, it is apparent that the power strokes of each cylinder overlap those of another cylinder. This power overlap results in a continuous flow of power. If the power strokes of the cycle are considered as a circle, the diagrams in figure 12 show the overlapping of power in a six- and eight-cylinder engine. The overlapping of power increases as the number of cylinders increases.

f. (1) The relation of the power strokes to each other and their coordination with the events of other cylinders in multiple-cylinder engines are shown by the diagrams in figures 13 to 18, inclusive. Figure 13 shows the events in a single-cylinder engine and indicates that power is absorbed by the flywheel during the power stroke and given up during the remainder of the engine cycle. Figure 14 shows the

FIRING ORDER OF CYLINDERS	ONE COMPLETE CYCLE			
	2-REVOLUTIONS OF CRANKSHAFT — 720°			
	1-REVOLUTION 360°		1-REVOLUTION 360°	
	½ REV. 180°	½ REV. 180°	½ REV. 180°	½ REV. 180°
	1 STROKE DOWN	2 STROKE UP	3 STROKE DOWN	4 STROKE UP
1	P	E	I	C
2	I	C	P	E

P–POWER; E–EXHAUST; I–INTAKE; C–COMPRESSION.

FIGURE 14.—Two-cylinder engine.

FIRING ORDER OF CYLINDERS	ONE COMPLETE CYCLE			
	2-REVOLUTIONS OF CRANKSHAFT — 720			
	1-REVOLUTION 360		1-REVOLUTION 360	
	½ REV. 180	½ REV. 180	½ REV. 180	½ REV. 180
	1 STROKE DOWN	2 STROKE UP	3 STROKE DOWN	4 STROKE UP
1	P	E	I	C
3	C	P	E	I
4	I	C	P	E
2	E	I	C	P

P–POWER; E–EXHAUST; I–INTAKE; C–COMPRESSION.

FIGURE 15.—Four-cylinder in-line engine.

power strokes of a two-cylinder engine. Here again the flywheel absorbs power and gives it up during two strokes of the engine cycle. Figure 15 shows the power strokes of a four-cylinder engine. It will be noted that power is being developed throughout the cycle in a four-cylinder engine.

(2) As the number of cylinders is increased in an engine, the number of power strokes in each cycle increases accordingly. Figure 16 shows how power strokes overlap in a six cylinder engine. This

FIRING ORDER OF CYLINDERS	ONE COMPLETE CYCLE											
	2—REVOLUTIONS OF CRANKSHAFT —720°											
	I—REVOLUTION — 360°						I—REVOLUTION — 360°					
	½ REV. 180°			½ REV. 180°			½ REV. 180°			½ REV. 180°		
	1 STROKE DOWN			2 STROKE UP			3 STROKE DOWN			4 STROKE UP		
	60	60	60	60	60	60	60	60	60	60	60	60
1	P	P	P	E	E	E	I	I	I	C	C	C
5	C	C	P	P	P	E	E	E	I	I	I	C
3	I	C	C	C	P	P	P	E	E	E	I	I
6	I	I	I	C	C	C	P	P	P	E	E	E
2	E	E	I	I	I	C	C	C	P	P	P	E
4	P	E	E	E	I	I	I	C	C	C	P	P

P-POWER; E-EXHAUST; I-INTAKE; C-COMPRESSION.

FIGURE 16.—Six-cylinder in-line engine.

diagram shows a new power stroke starting each 120° of crankshaft rotation and lasting for one stroke or 180°. This gives a 60° overlap of power. Figure 17 shows the same effect in an eight cylinder engine. In the eight cylinder engine a new power stroke begins each 90° of crankshaft rotation and lasts for 180° or one stroke. This gives a 90° overlap of power. Since the cylinders fire at regular intervals, the power overlap will be the same regardless of firing order. This is true in either in-line or V-type engines.

(3) The relationship of the events of a cycle in a radial engine is the same as that in other engines. Figure 18 shows the overlap of power strokes in a five cylinder radial engine. A power stroke occurs each 144° of crankshaft rotation and lasts for 180° or one stroke. This gives a power overlap of 36° between each two power strokes.

FIRING ORDER OF CYLINDER "V-TYPE" ENGINE	FIRING ORDER OF CYLINDER "IN-LINE" ENGINE	ONE COMPLETE CYCLE — 2 REVOLUTIONS OF CRANKSHAFT — 720°															
		1-REVOLUTION OF CRANKSHAFT 360°								1-REVOLUTION OF CRANKSHAFT 360°							
		½ REV. 180°				½ REV. 180°				½ REV. 180°				½ REV. 180°			
		1 STROKE DOWN				2 STROKE UP				3 STROKE DOWN				4 STROKE UP			
		45	45°	45°	45°	45°	45°	45°	45°	45°	45°	45°	45°	45°	45°	45°	45°
1L	1	P	P	P	P	E	E	E	E	I	I	I	I	C	C	C	C
4R	6	C	C	P	P	P	P	E	E	E	E	I	I	I	I	C	C
4L	2	C	C	C	C	P	P	P	P	E	E	E	E	I	I	I	I
2L	5	I	I	C	C	C	C	P	P	P	P	E	E	E	E	I	I
3R	8	I	I	I	I	C	C	C	C	P	P	P	P	E	E	E	E
2L	3	E	E	I	I	I	I	C	C	C	C	P	P	P	P	E	E
2R	7	E	E	E	E	I	I	I	I	C	C	C	C	P	P	P	P
1R	4	P	P	E	E	E	E	I	I	I	I	C	C	C	C	P	P

P—POWER; E—EXHAUST; I—INTAKE; C—COMPRESSION
R OR L INDICATES RIGHT OR LEFT BANK OF CYLINDERS

FIGURE 17.—Eight-cylinder engine.

(4) The interval of power strokes in a multiple cylinder engine can be found by dividing 720° by the number of cylinders. In engines of more than eight cylinders, the power strokes become still closer, and three cylinders deliver power at the same time during parts of the complete engine cycle.

FIRING ORDER OF CYLINDERS	ONE COMPLETE CYCLE — 2-REVOLUTIONS OF CRANKSHAFT — 720°																			
	1-REVOLUTION OF CRANKSHAFT 360°										1-REVOLUTION OF CRANKSHAFT 360°									
	½ REV. 180°					½ REV. 180°					½ REV. 180°					½ REV. 180°				
	1 STROKE DOWN					2 STROKE UP					3 STROKE DOWN					4 STROKE UP				
	36°	36°	36°	36°	36°	36°	36°	36°	36°	36°	36°	36°	36°	36°	36°	36°	36°	36°	36°	36°
1	P	P	P	P	P	E	E	E	E	E	I	I	I	I	I	C	C	C	C	C
3	C	C	C	C	P	P	P	P	P	E	E	E	E	E	I	I	I	I	I	C
5	I	I	I	C	C	C	C	C	P	P	P	P	P	E	E	E	E	E	I	I
2	E	E	I	I	I	I	I	C	C	C	C	C	P	P	P	P	P	E	E	E
4	P	E	E	E	E	E	I	I	I	I	I	C	C	C	C	C	P	P	P	P

P-POWER; E-EXHAUST; I-INTAKE; C-COMPRESSION.

FIGURE 18.—Five-cylinder radial engine.

SECTION V

ENGINE PARTS AND THEIR COORDINATED FUNCTIONS

Paragraph

17. General.—*a.* All the parts that make up the internal combustion engine, except the fuel system and electrical units, are discussed in this section. For the fuel system and electrical units see TM 10–550 and TM 10–580.

b. For the service procedure and methods used in adjusting and repairing automotive gasoline engines see TM 10–520 and TM 10–530.

18. Crankshaft.—*a.* The crankshaft might well be called the backbone of the engine because it is subjected to all the forces of the power developed by the engine. It has to transform the reciprocating power it receives from the piston and connecting rod into rotary power and transmit it to the flywheel or clutch. The crankshaft, as its name implies, is a shaft which has one or more cranks along its length. The cranks or throws are formed by forging offsets into the shaft before it is machined. The arrangement of the cranks along the crankshaft influences the firing order of the engine for which it is designed. The relationship of the camshaft to the crankshaft establishes the firing order for any given engine. (See par. 28.)

b. Crankshafts are generally forged from an alloy of steel and nickel. This material is very strong and durable yet soft enough to be machined by a lathe or a hand tool. Some crankshafts are case-hardened after rough grinding in order to provide a harder bearing surface for main and connecting rod bearings. These cannot be reconditioned by ordinary methods. The case-hardening should never be penetrated when reconditioning or finishing grinding.

c. Most crankshafts are similar in design. Figure 19 shows several common crankshaft arrangements. Crankshafts for four cylinder engines have either three or five main or support bearings and four throws in one plane, with the throws for Nos. 1 and 4 cylinders 180° from those for Nos. 2 and 3. A crankshaft for an eight-cylinder V-type engine would be of the same basic design. One design for V-type eight cylinder crankshafts has one set (two) of throws advanced 90° over the other for better balance and smoother operation.

d. The eight cylinder in-line crankshafts follow two general designs. The first is to have two identical four cylinder crank arrangements set end to end with one advanced 90° over the other. This is known as a 4-4 shaft. In the other design, the 2-4-2 shaft, one four cylinder crankshaft is used in the center and another, cut in half, is placed at each end of the first shaft. Each two cylinders are advanced 90° or one-quarter turn with relation to the center four.

e. Crankshafts for six cylinder engines have either 3, 4, or 7 main bearings. The throws for the connecting rod bearings are forged in three planes 120° apart with two bearings per plane. Cylinders Nos. 1 and 6 are in the first plane, Nos. 2 and 5 in the second, and Nos. 3 and 4 in the third. Shafts for twelve-cylinder V-type engines have these same general characteristics.

f. Every piece of revolving machinery has a certain definite speed at which a vibration is set up in the revolving mass. In designing a crankshaft, it is sometimes possible to place this critical speed outside the speed range of the engine. If not, the crankshaft must be heavy enough to withstand the vibration. In severe cases of vibration the crankshaft may break. In order to run smoothly, a crankshaft must be balanced for static balance while at rest and

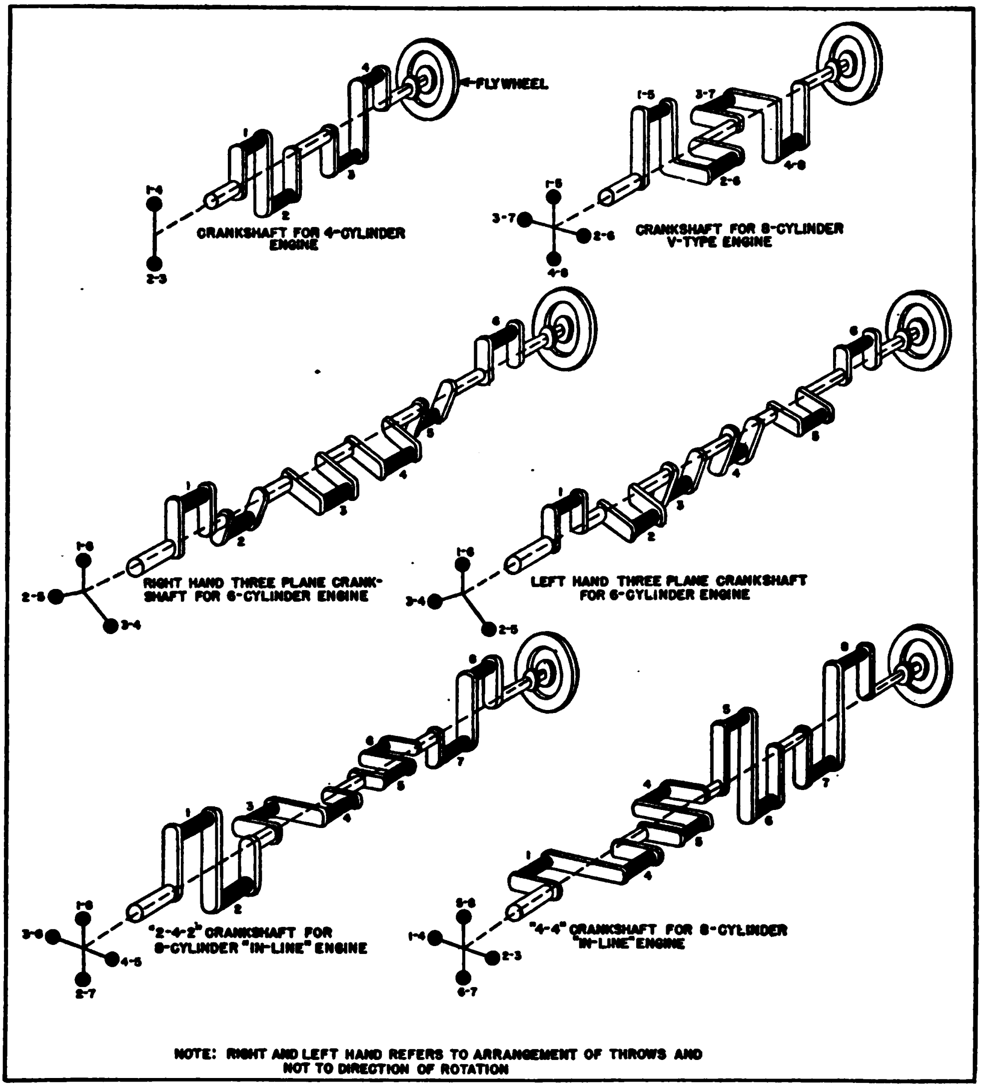


FIGURE 19.—Crank throw arrangements most commonly used.

for dynamic balance while running at low and high speeds. Deflection in the crankshaft caused by load stresses will quite often throw a shaft out of balance, especially at high speed. Crankshafts are balanced by use of weights to overcome vibration, load deflection, and uneven balance. These may be forged as part of the shaft or they may be bolted on. If balance weights are removed and replaced in the servicing of an engine, they should be marked before removing and replaced in the same position.

g. Torsional vibrations set up in crankshafts, due to twists in the shaft as loads are applied, are "balanced out" or dampened by a small unit at the front end of the crank, known as a vibration

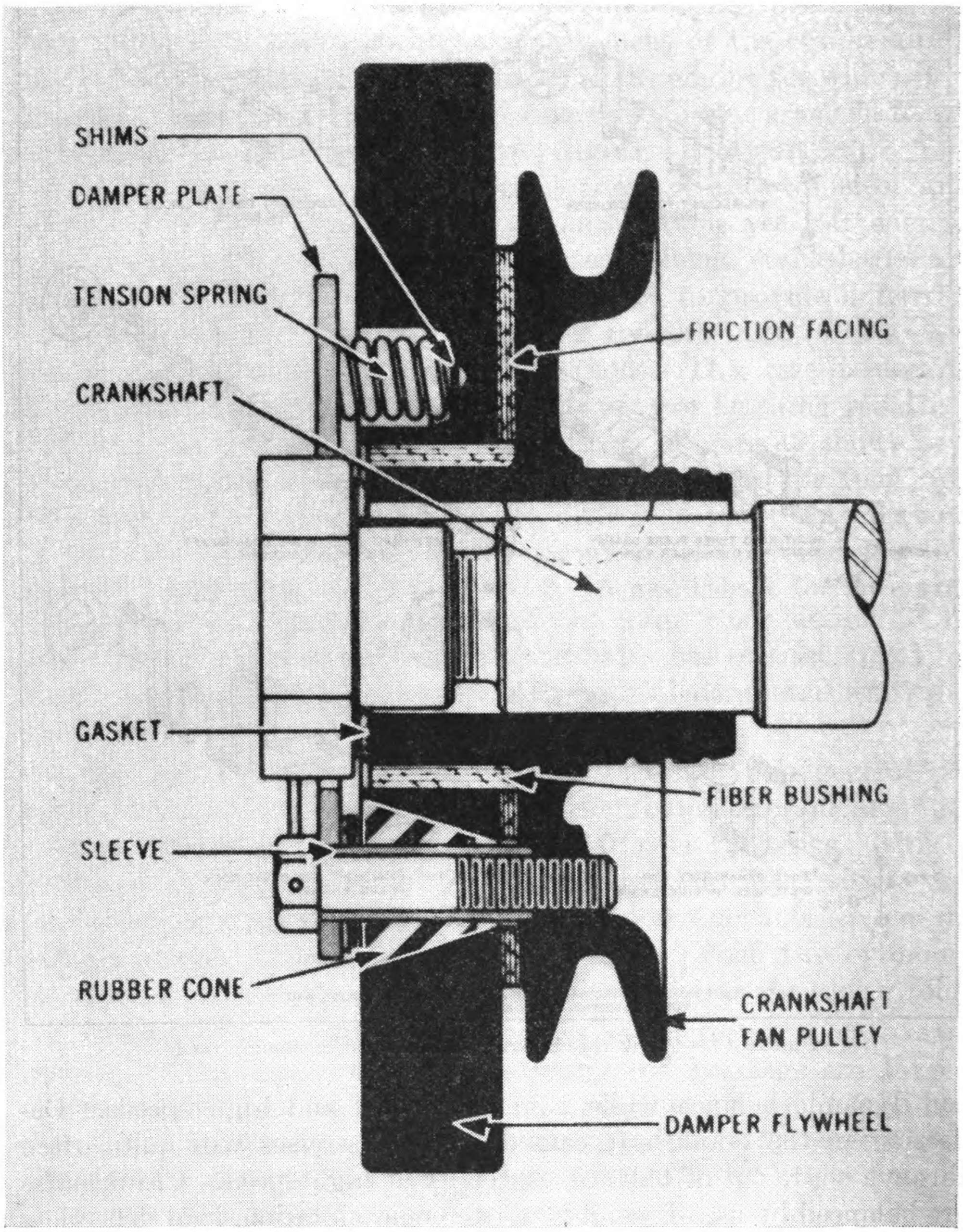


FIGURE 20.—Torsional vibration damper of friction type mounted at fan pulley drive end of crankshaft.

damper. The application of the inertia weight of this unit is controlled by rubber mountings or friction faces so that the rotating mass of the unit is released to counteract the twisting actions of the crankshaft. This unit usually carries a V-type pulley for driving cooling fans and other units. Figure 20 shows a vibration damper of the friction type.

h. The front end of the crankshaft also carries a keyed gear or chain sprocket for driving the camshaft and perhaps other units, such as ignition distributors, generators, and water and oil pumps. A notched nut for engaging a starting crank is often screwed into

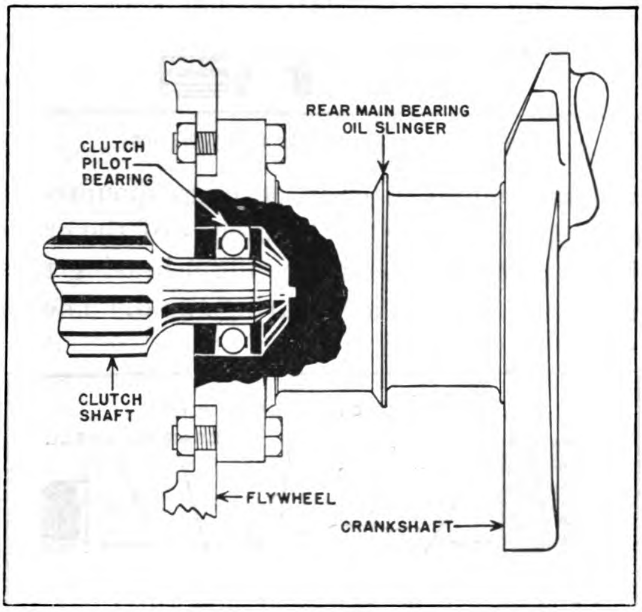


FIGURE 21.—Rear end of crankshaft, showing flywheel mounting and recess for clutch shaft pilot bearing.

the front end of the crankshaft and usually acts as a retainer for the vibration damper assembly and the crankshaft timing gear.

i. The rear end of the crankshaft is provided with a flange to which the flywheel is bolted and a recessed center which receives the small ball or roller pilot bearing that carries the forward end of the clutch shaft. (See fig. 21.) The flywheel rim carries a ring gear, either integrally machined with the flywheel or shrunk on, which is engaged with the starter drive for cranking the engine. The rear face of the flywheel is usually machined and ground and acts as one of the pressure surfaces for the clutch, becoming part of the clutch assembly. Most engine manufacturers place dead center and timing marks on or near the edge of the rim of the flywheel.

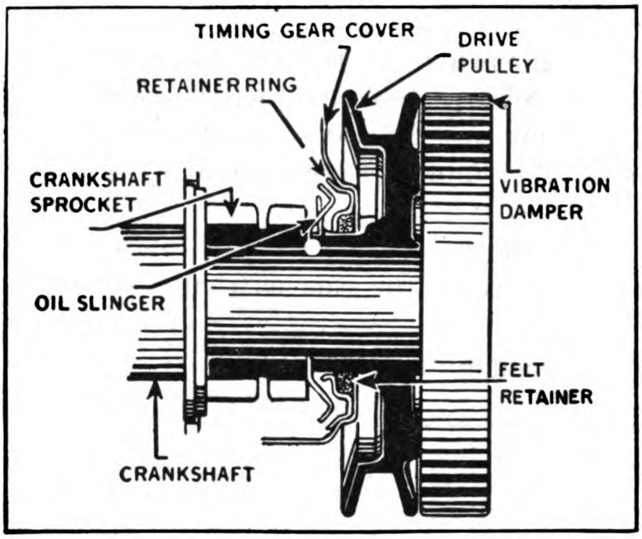


FIGURE 22.—Crankshaft front oil seal.

j. The crankshaft rotates in main bearings mounted in the crankcase. Main bearings are placed at both ends of the crankcase and at one or more intermediate points in the main bearing trusses or webs, depending on the number of main bearings used. The main bearings

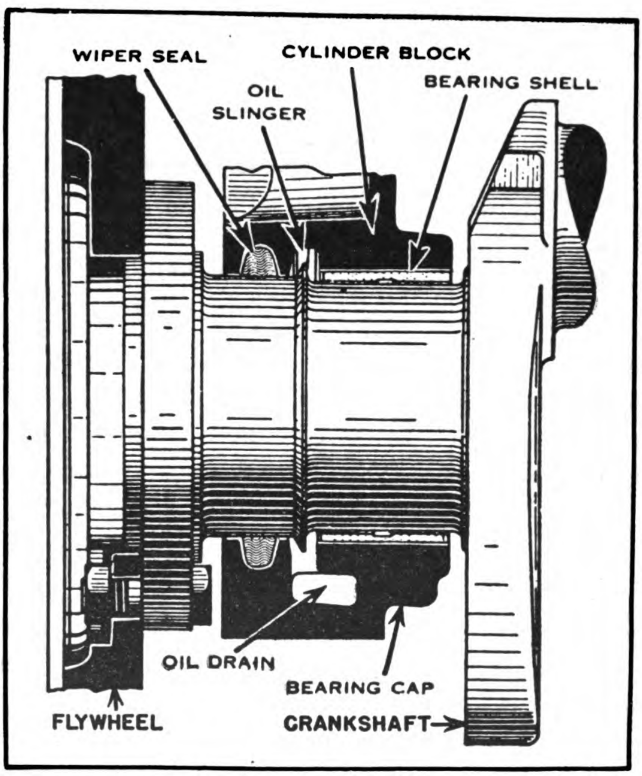


FIGURE 23.—Rear main-bearing oil seal and drain.

of most high speed automotive engines are usually of the thin shell bronze or steel backed type, in which one-half of the bearing shell is secured to the crankcase and the other half is fastened in the cap part of the bearing. This latter half is sometimes "poured" into the cap without the harder metal backing shell. The principal load on the main bearings of an engine is radial. The small end thrust load on the crankshaft is usually taken by the rear main bearing which is provided with a rather broad thrust face, and acts as a combination radial and thrust bearing. The main bearings are often channeled for oil distribution and may be lubricated by pressure or by splash from the crankcase.

k. Oil seals are as a rule placed at both ends of the crankshaft where it extends through the crankcase to prevent loss of the engine lubricating oil. (See figs. 22 and 23.)

19. Cylinders.—*a.* The cylinders of an automotive internal combustion engine, together with the crankcase, form the framework or main body of the engine about which the other parts of the engine are assembled. In addition to this structural function, the cylinders provide the combustion spaces in which the burning and expansion of the gases take place, and in which the heat energy of the fuel is transformed into mechanical energy. The design and construction of the cylinders depend upon a number of factors of which the following are the most important:

(1) Piston displacement (bore and stroke).

(2) Compression ratio desired.

(3) Arrangement for cooling the cylinder walls.

(4) Materials used.

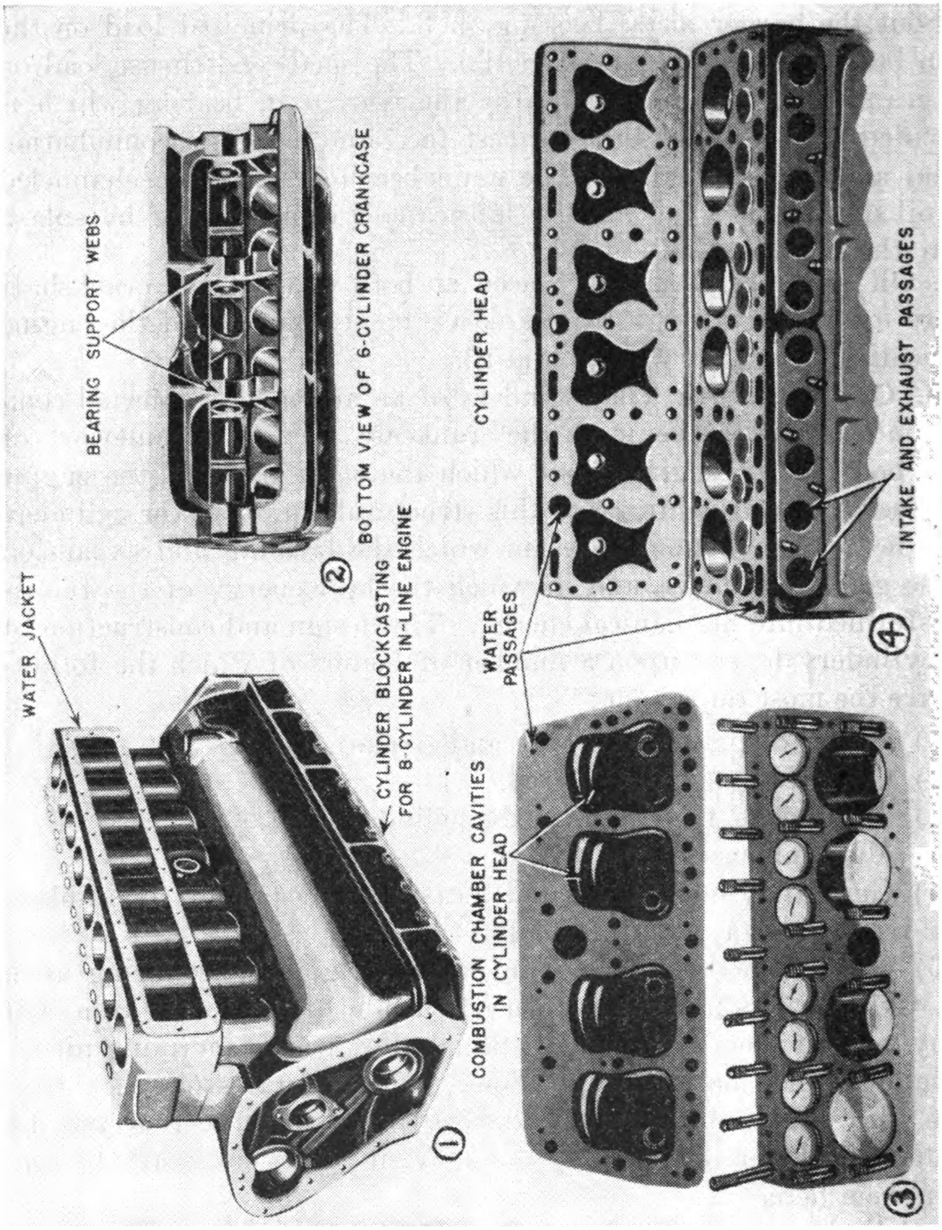
(5) General form of the cylinder castings (cast singly or in-block with removable or integral heads).

(6) General methods of casting, machining, and producing used.

b. Cylinder castings were formerly made of gray cast iron, but today most of them are made of special alloy irons containing nickel, chromium, and molybdenum. Some experimental work has been done with aluminum alloy cylinder castings, but since they are not produced commercially in any quantity, it is not necessary to consider them here.

c. Cylinders are cast by a number of methods. As a general rule, the size of the engine and the system of cooling determine the method of casting. Figure 24 shows views of cylinder and cylinder head castings for automobile engines.

d. The cylinders and crankcase of nearly all in-line and V-type passenger car engines are cast in-block, that is, in one piece. The cylinder head usually is cast separately. All except the largest commercial car and truck engines use this method. As a rule, all air-cooled automobile engines have the cylinders cast singly. Some few



① Cylinders and crankcase for straight-eight engine.
② Bottom view of cylinder and crankcase casting for six-cylinder engine.
③ Four-cylinder engine with cylinder head removed.
④ Six-cylinder casting with cylinder head removed (top view of casting shown in ②).

engines in which the cylinders are cast singly, in pairs, or in-block have the cylinder head or heads cast integrally with the cylinders. Others in which the cylinders are cast in-block have two or more heads cast separately.

e. The problem of molding intricate cylinder castings, such as are common in the present day engine, delayed the development of in-block castings for many years, but factors favoring the in-block method are so great that it has become almost universal. It produces a shorter, more compact and a decidedly more rigid construction at less cost than cylinders cast singly or in pairs. It simplifies the assembly of the engine and makes it easy to inclose the valve operating mechanism. Cylinders for air-cooled engines must be cast singly in order to insure that the maximum outside cylinder wall area is exposed to the cooling air.

f. Removable cylinder heads are almost universal on modern engines. This is true regardless of whether the cylinders are cast in-block, in pairs, or singly. Heads are usualy cast in one piece based on the number of cylinders in the block casting. If cylinders are cast in pairs, the heads for these two cylinders are usually cast in one piece. A few large engines in which the cylinders are cast in-block have the cylinder heads cast in two, three, or more pieces. This is true also of V-type blocks, as the cylinder heads for each bank of cylinders are separate castings.

g. All cylinder heads were formerly made of cast iron, but many engines are now being built with cylinder heads of cast aluminum alloy because it is a better conductor of heat. Hence, it is possible to keep the walls of the combustion chamber cool enough to avoid hot spots and to permit the use of higher compression pressures.

h. The combustion chamber is largely contained in the cylinder head. The shape of this chamber is very important from the standpoint of flame propagation, combustion, and cooling, and, as a result of these factors, smoothness of operation. The ideal combustion chamber would be semispherical, but it is not possible even to approach this shape except perhaps on engines with sleeve or I-head valves. The technical details of combustion chamber design are beyond the scope of this manual.

i. The cylinder block and the cylinder head contain the water jackets or outside cooling fins necessary to maintain proper operating temperatures within the engine. Water jackets are cast integrally with the block and head as shown in figure 25. Cylinders cast in-block with removable heads have communicating passageways between the block and head to permit the circulation of water between them. The gasket between the block and head has openings corresponding to the openings in the block and the head to allow circulation of the water. Gaskets must maintain watertight and gastight joints. Outside cooling fins usually are cast only on air-cooled cylinders.

j. Cylinder liners or sleeves are coming into common use in large truck and bus engines. Figure 25 illustrates the use of these liners. Liners are made of alloys specially treated to give them better wearing qualities than it is possible to obtain from cast iron alloys. They

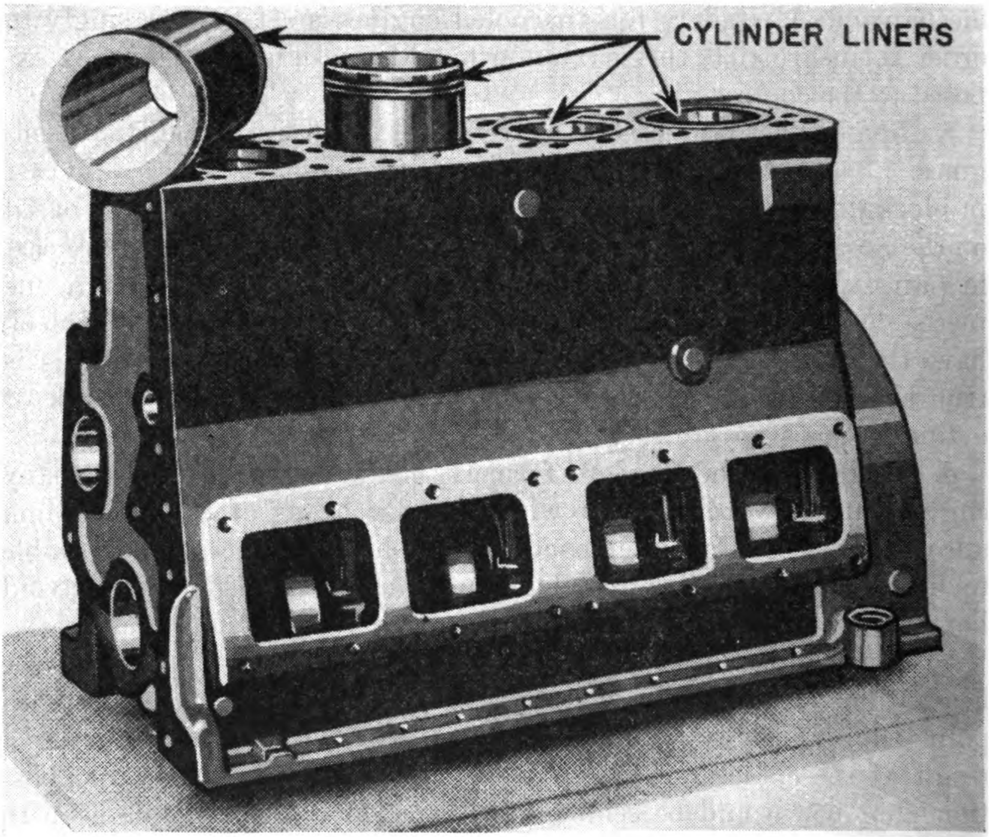


FIGURE 25.—Cylinder liners in a four-cylinder engine block.

are made with outside diameters as large as the opening into which they fit. They are then forced into the cylinder block, giving a watertight fit to prevent water from the cooling system leaking into the combustion chamber. Liners have two great advantages over conventional cylinder blocks. They usually wear longer, and after they have worn and been rebored and worn beyond the maximum oversize, they can be replaced with new liners, saving replacement with the more expensive complete block casting.

k. The camshaft bearings, oil pump, accessory mountings, oil passages, valve lifter brackets, intake and exhaust ports, and suitable bosses for necessary mountings all form an integral part of the complicated block casting.

l. The shape and finish of the cylinder wall are of extreme importance to engine performance. It must be absolutely round and true and have a highly finished surface. These surfaces are obtained in manufacturing by boring, reaming, grinding, and honing (done in the order given), and the final surface has a mirrorlike finish that offers little resistance and makes a uniform seal between the cylinder surface and the piston. Extreme care must be exercised in machining cylinder blocks to see that top and bottom surfaces are parallel and that cylinders are perpendicular to these surfaces.

20. Crankcase.—*a*. The crankcase is that portion of the engine which supports the crankshaft, provides a tight inclosure for the crank pins, provides a reservoir for the supply of lubricating oil, and acts as a support for a number of auxiliaries. It is common prac-

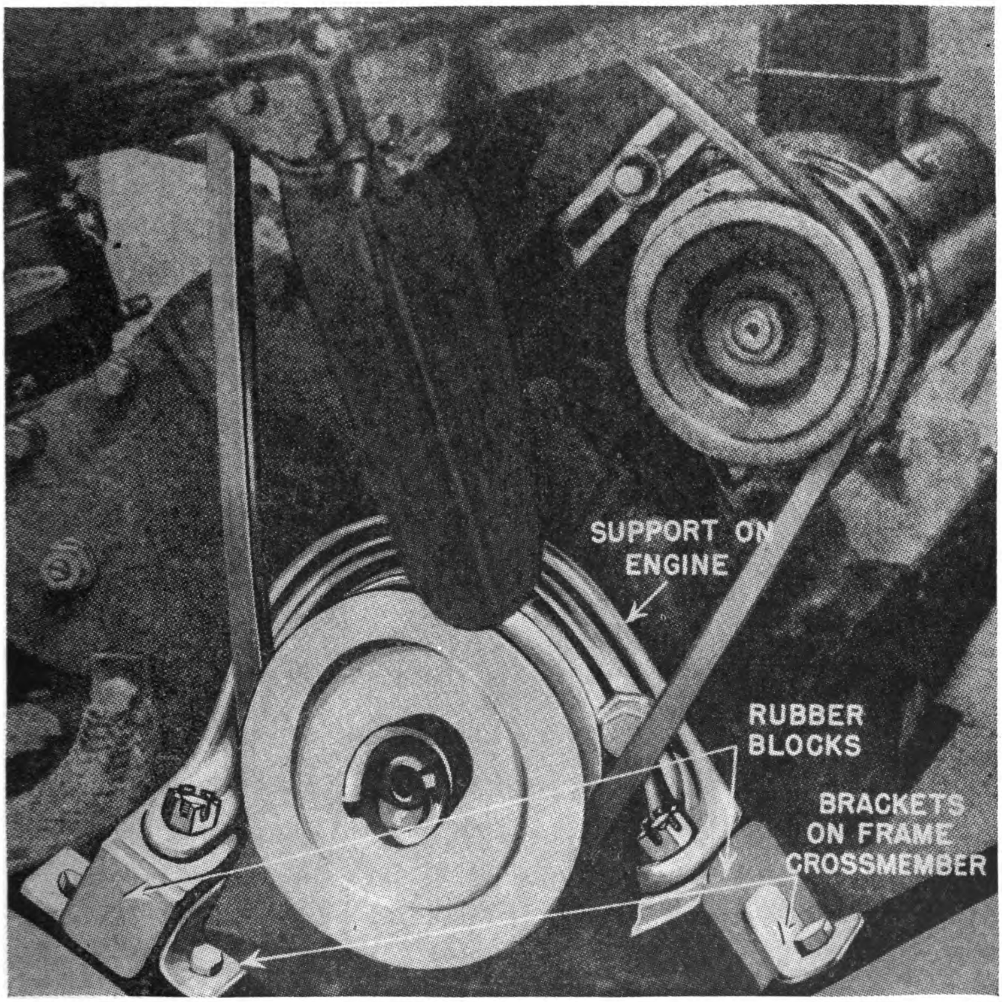


FIGURE 26.—Front supports of commercial vehicle, showing use of rubber blocks for insulation against vibration.

tice at the present time to cast the upper part of the crankcase as part of the cylinder block. As a rule, the lower half (oil pan) is made of pressed or cast metal attached by screws to the upper part. It only contains the lubricating oil and incloses the crank pins. Some oil pans are fitted with exterior ribs or fins to provide additional cooling area. The crankshaft, carried by the upper half of the crankcase, is held in place by bearing caps.

b. In addition to the above functions, the crankcase supports the engine on the vehicle frame or on a subframe specifically constructed for the purpose. The supporting arms (engine supports) are built as an integral part of the crankcase or are bolted to it in such a way that they support the power plant at three or four points. At one time the three point suspension was considered the best, but a large number of the modern engines use four point suspension. The points of contact with the frame are usually made of rubber. This insulates the frame and body from the engine vibration and noise and prevents damage to the engine supports and transmission re-

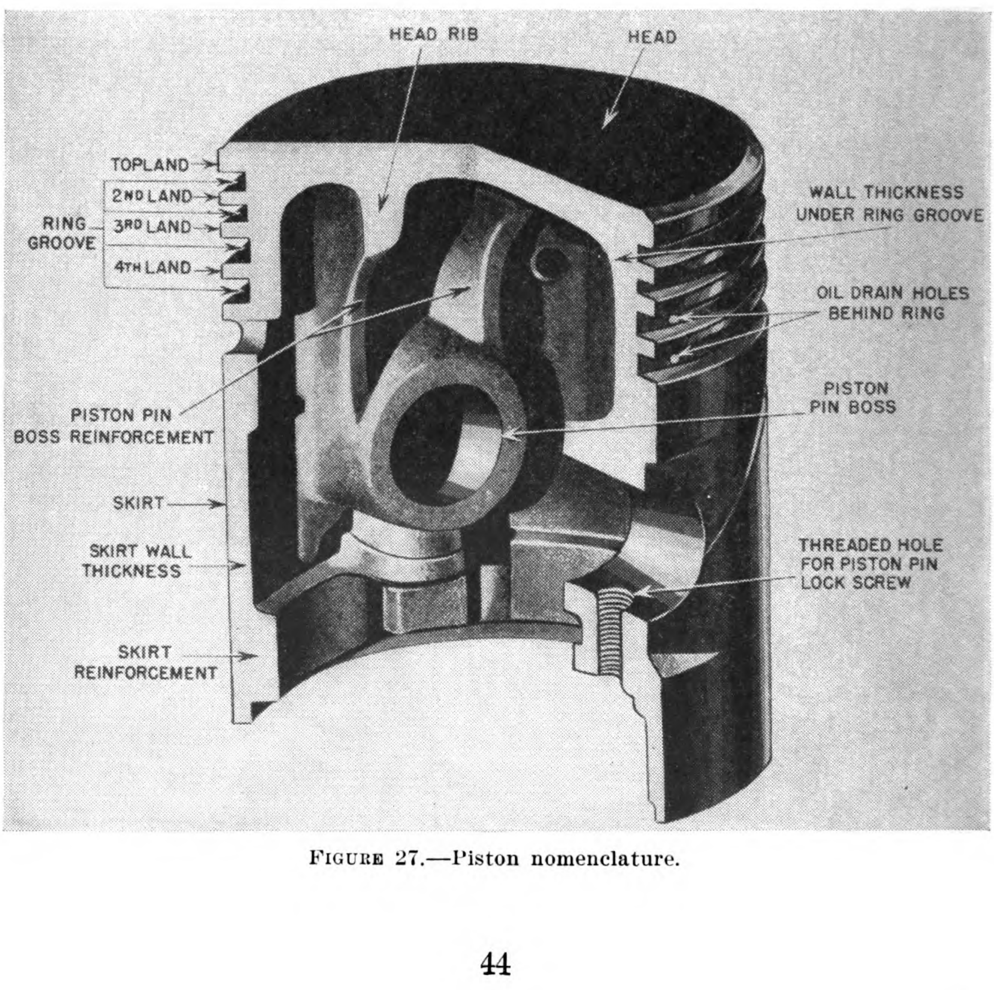


FIGURE 27.—Piston nomenclature.

sulting from engine twisting and frame distortion. Figure 26 illustrates one type of rubber insulated engine mounting.

21. Pistons.—*a.* The pistons of an engine receive the energy or force resulting from the combustion of the fuel within the cylinders and transmit it to the crankshaft through the connecting rod. Automotive pistons are commonly made of light gray cast iron, semisteel,

FIGURE 28.—Typical automotive-engine pistons.

or aluminum alloy, which are light, wear well, and have high tensile strength. At each end of the strokes of the cycle, a piston must come to a complete stop and start again in a reverse direction. Considerable energy is required to overcome the inertia and momentum of the piston when it stops and starts. With the trend toward high speed engines, the subject of piston weight has become more and more important. Later developments in design and material provide compensation for the high expansion of aluminum alloy pistons by the use of low expansion steel inserts in the piston skirt, by slots cut in the piston skirt, and by cam grinding.

b. The head and skirt of a piston are made as thin as possible, consistent with the strength required, in order to reduce weight. See figure 27 for piston nomenclature. Reinforcing ribs are used on the under side of the piston head. These also assist in conducting heat from the head of the piston to the rings and out through the cylinder

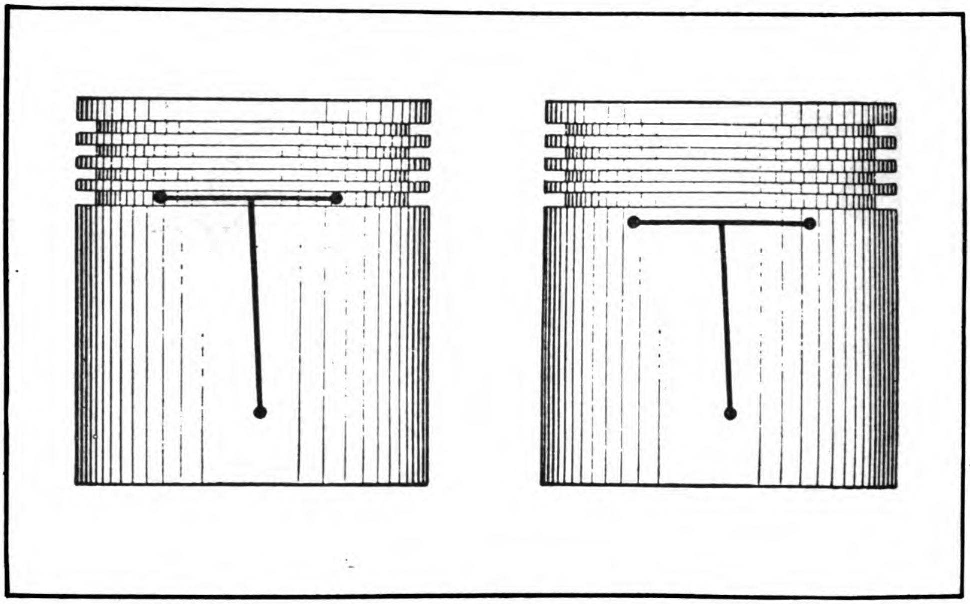


FIGURE 29.—Types of T-slot pistons. Left-hand piston has horizontal slot behind lower oil ring, while right-hand piston has slot in piston skirt.

walls. Special ribs are also used to reinforce the piston pin bosses. On practically all pistons, the piston wall surrounding the piston pin bosses is either relieved or cut away entirely to reduce the weight of the piston and to prevent it from bulging as the piston pin bosses expand. These features of piston design are shown in figure 28. Many aluminum pistons are made with split skirts in order to allow the piston to expand without increasing the skirt diameter. Two types of slotted pistons are shown in figure 29.

c. The major problem in using aluminum alloy pistons is that of controlling clearances. Since aluminum has a greater coefficient of expansion than cast iron, early types of aluminum alloy pistons were fitted with considerable clearance when cold in order to prevent them from sticking and scoring when they expanded under high operating temperatures. The amount of clearance between the cylinder wall

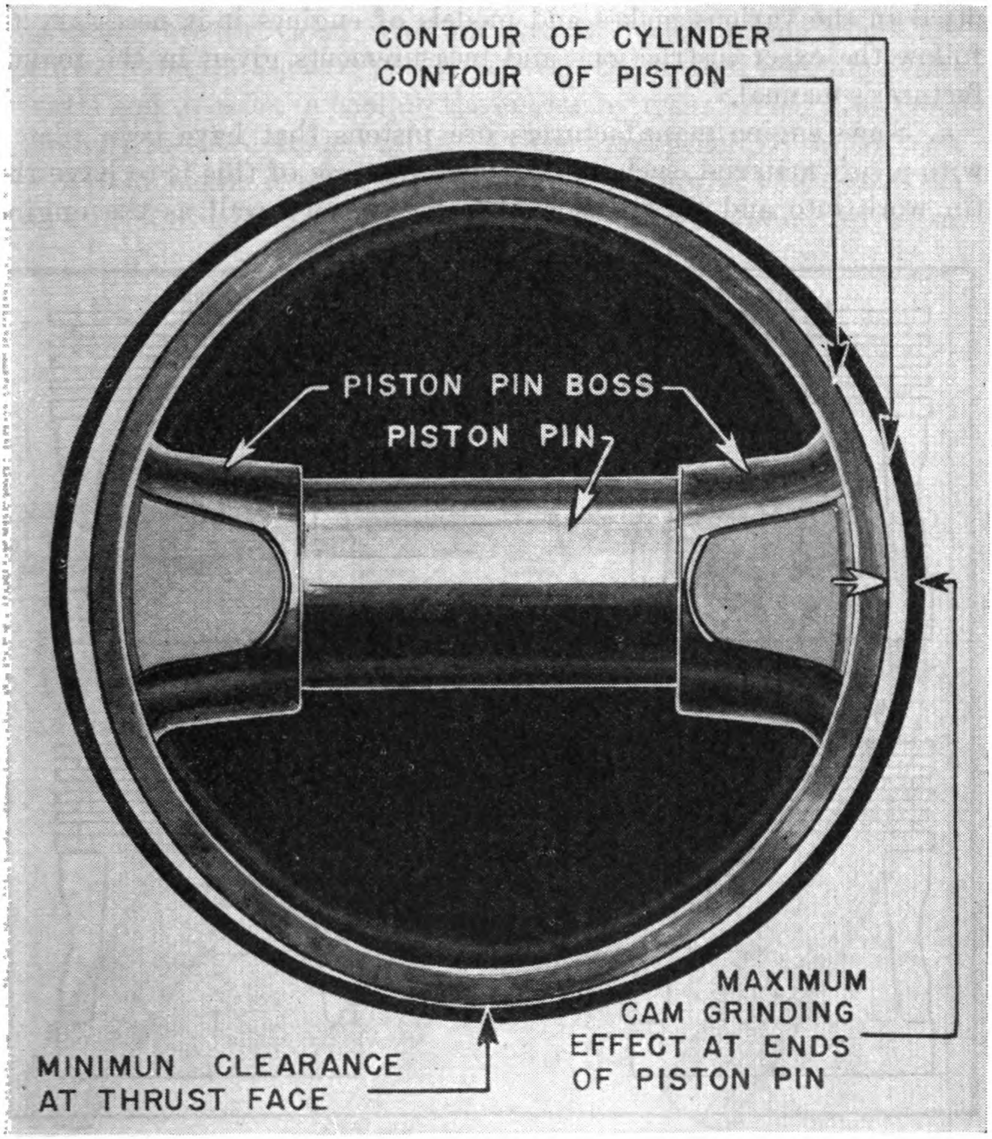


FIGURE 30.—Exaggerated contour of a cam-ground piston skirt.

and piston depends upon the diameter of the piston, its design, and the material from which it is made. Cast iron pistons and aluminum alloy pistons which have low coefficients of expansion can be fitted much closer than alloy pistons having higher coefficients of expansion. Since the skirt of a piston runs much cooler than the head, which is in direct contact with the flame of burning gases, it does not require as much clearance. The development of low expansion aluminum alloys, together with improved piston design and improved methods of cylinder and piston finishing, has made the matter of piston clearances specific rather than general. When pistons are fitted in the various makes and models of engines it is necessary to follow the exact instructions and measurements given in the manufacturer's manual.

d. Some engine manufacturers use pistons that have been plated with a soft material, such as tin. The purpose of this is to have the tin work into and fill the pores of the cylinder wall as the engine

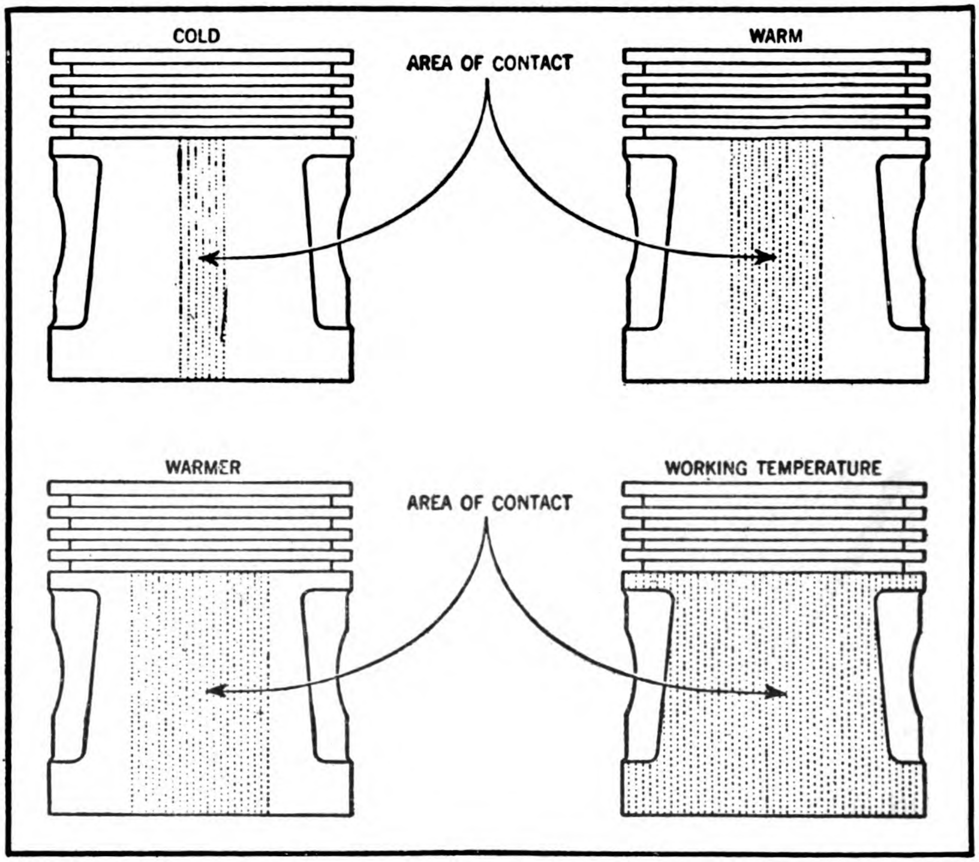


FIGURE 31.—Variable contact of a cam-ground piston skirt thrust face with a cylinder wall due to changes in operating temperatures.

runs in, providing a more perfect fit between the piston and the cylinder wall and allowing for a shorter breaking-in period.

e. In the cam ground piston, the skirt is ground to an irregular shape, generally elliptical. (See fig. 30.) Figure 31 shows the action of a cam ground piston skirt as it warms up to operating temperature by showing how area of contact with the cylinder wall changes. As the elliptical-shaped piston skirt expands, the flatter sides are forced outward and the skirt assumes the shape of the cylinder.

f. Pistons are provided with grooves in which piston rings are placed to maintain a gastight seal between the pistons and the cylinder walls and to assist in cooling the engine by transferring heat from the pistons to the cylinder walls. Pistons are generally fitted with three or four piston rings. (See fig. 29.) The lowest ring above the piston pin is usually an oil ring. In some cases a special oil wiper

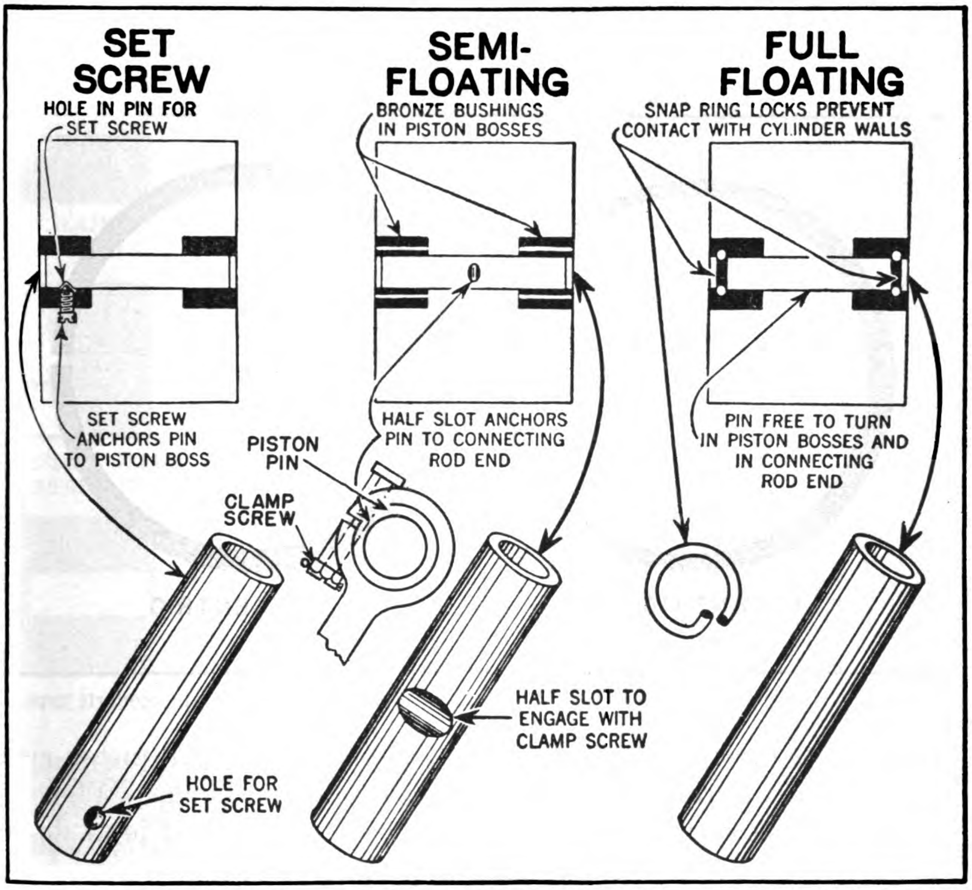


FIGURE 32.—Methods of securing piston pins within piston or connecting rod.

ring is placed in the skirt below the piston pin to scrape surplus oil from the cylinder. The ring groove under an oil ring is provided with openings through which the oil flows back into the crankcase.

g. A piston is connected to the upper end of the connecting rod by a piston or wrist pin. This pin passes through the piston at the piston pin bosses and through the upper end of the connecting rod which rides on the central part of the pin. The piston pin may be clamped to the connecting rod, in which case the pin works in bearings carried in the piston pin bosses; it may be fastened in the piston with set screws, in which case the bearing is in the connecting rod; or it may be secured within the piston by snap rings in the outer ends of the piston pin bosses. (See fig. 32.) Piston pins are made of alloy steel with a glass-smooth finish, case-hardened to increase the wearing qualities. Piston pins are tubular to give them strength with minimum weight. They are lubricated by splash from the connecting rods or by pressure through rifle-bore connecting rods.

22. Piston rings.—*a.* Piston rings are used on pistons to maintain gastight joints between the piston and cylinder walls and to assist in cooling the pistons. About one-third of the heat absorbed by the

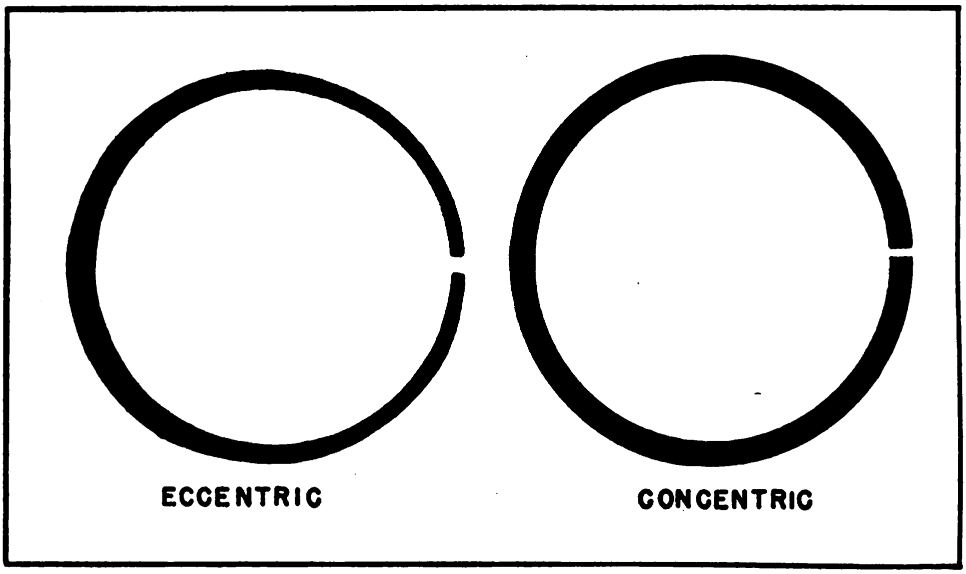


FIGURE 33.—Types of piston rings, showing variations in thickness of eccentric type.

piston passes through the rings to the cylinder wall. All piston rings must be split in order to slip them over the piston lands. When the ring is in place within the cylinder, the ends of the split joint do not form a perfect seal, so it is common practice to use more than one ring and stagger the joints around the piston. Although piston rings have been made from many materials, cast iron has proven the most satisfactory as it withstands the heat, forms a good wearing surface, and retains a greater amount of its original elasticity after considerable use. Steel side pieces are sometimes used on two and three section oil control rings. All rings are either eccentric or concentric as shown in figure 33.

b. Two types of piston rings are used: The compression ring and the oil control ring. The principal function of the compression ring is to prevent gases leaking past the piston during its compression and power strokes. The principal function of the oil control ring is to assist in lubricating the cylinder walls and to prevent oil from passing into the combustion chamber. Cross sections of typical one piece piston rings are shown in figure 34. Various types of piston ring joints are shown in figure 35. Other piston rings are shown in figure 36.

c. Piston rings are made to be of the proper diameter when closed to the specified gap that allows for expansion. The gap is about

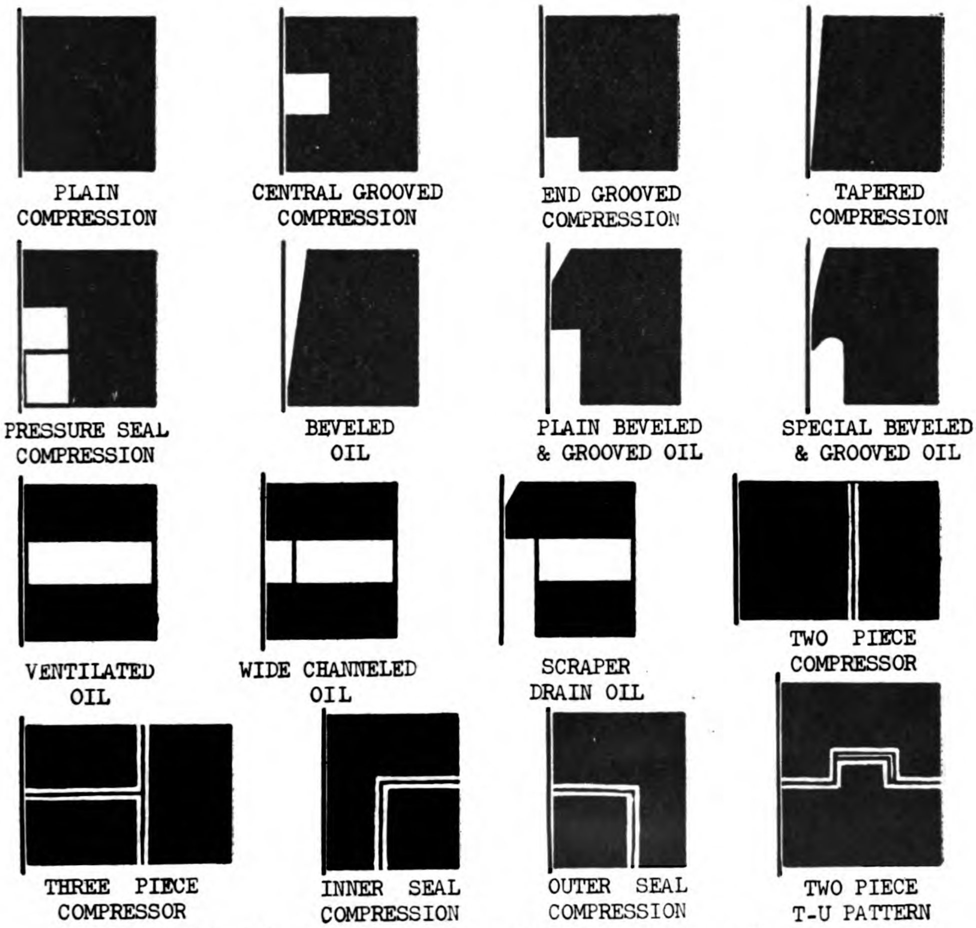


FIGURE 34.—Typical one-piece piston rings (cross sections).

0.003 inch for each inch of cylinder diameter. When a ring is fitted within a cylinder of the size for which it is intended, it should have the specified gap or joint clearance, should exert equal pressure at all points against the cylinder, and should fit the cylinder so that no light can be seen between the ring and cylinder wall. In addition to making a gastight fit against the cylinder wall, the ring must also make a gastight fit against the piston land.

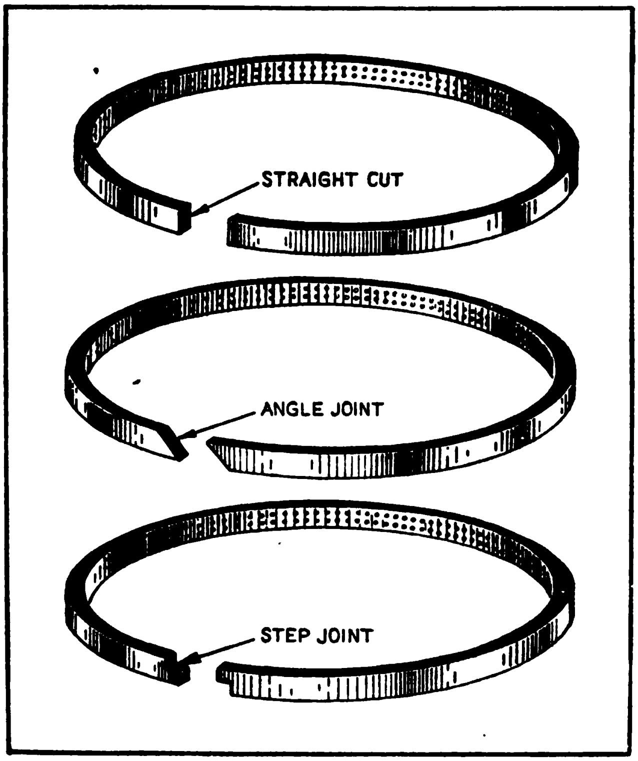


FIGURE 35.—Common types of piston-ring joints.

23. Connecting rods.—*a.* The connecting rod connects the reciprocating piston with the revolving crankshaft. It must be strong enough to transmit the thrust of the piston to the crankshaft. Since it must be as light as possible, it is generally made with an I-beam section and forged from a steel alloy capable of withstanding heavy loads without deflection (bending or twisting). Connecting rods are roughly drop forged to the desired shape and then machined for the accurate fitting of bearings and bushings. The two end holes of a connecting rod should always be parallel. Figure 37 shows a connecting rod assembly with bearing cap removed.

b. The upper or piston pin end of the connecting rod is connected to the piston by the piston pin. If the piston pin is locked in the piston bosses or floats in both piston and connecting rod, the upper end of the connecting rod is equipped with a bushing of bronze or similar material. As the lower end of the connecting rod revolves with the crankshaft, the upper is forced to oscillate back and forth on the piston pin bushings. Although the movement of the piston pin bearing is not great, the unit pressures exerted are extremely high and the temperatures are quite high. For these reasons correct

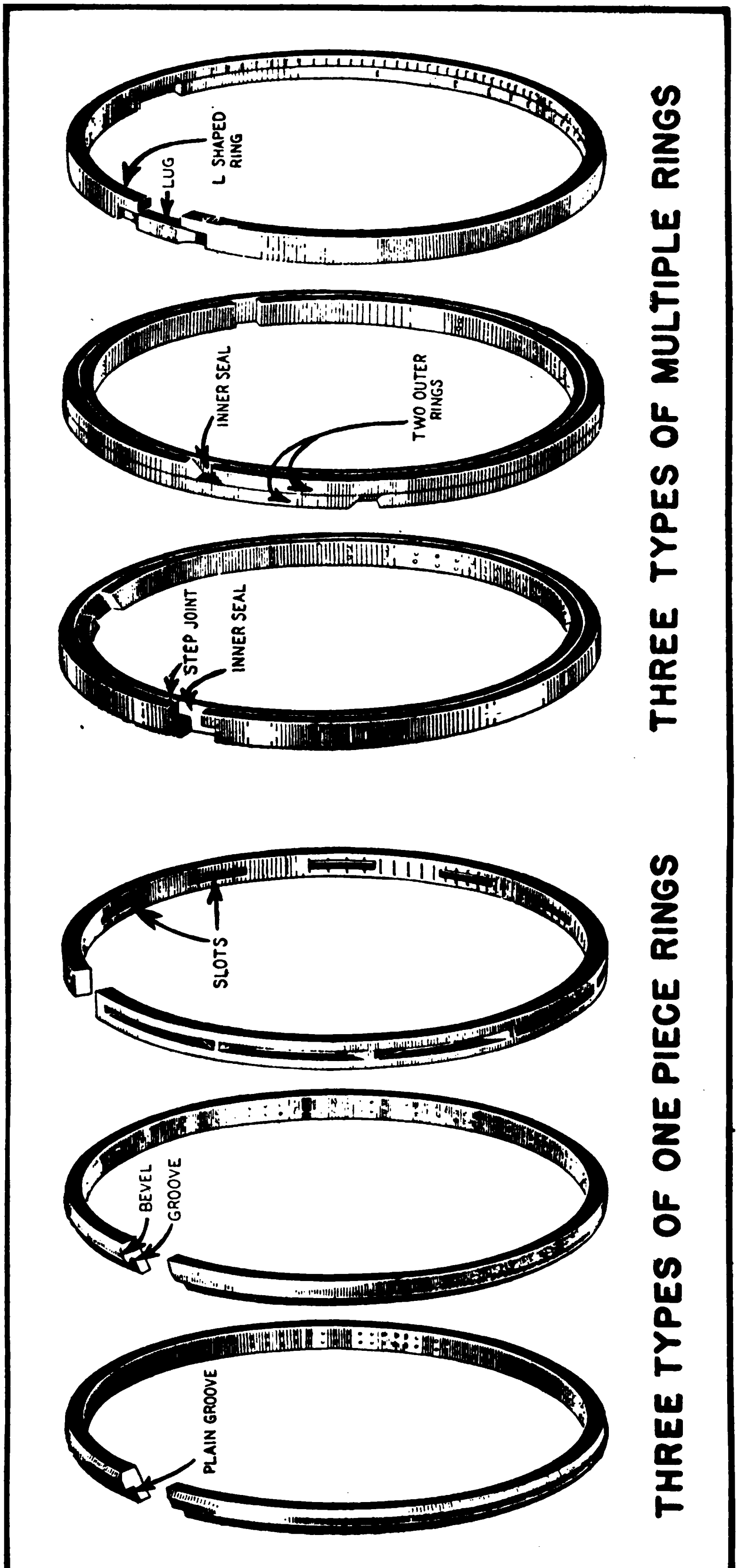


FIGURE 36.—Single- and multiple-piece piston rings.

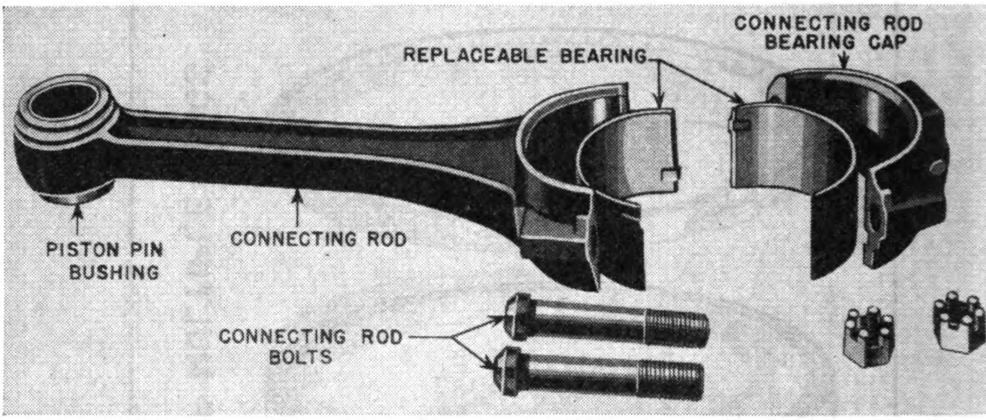


FIGURE 37.—Connecting-rod assembly, showing interchangeable crank-pin bearing.

lubrication of the piston pin is extremely difficult. Piston pins are lubricated in many engines by feeding a lubricant under pressure through an oil hole drilled the entire length of the connecting rod or through a tube attached to its side. A drilled connecting rod is shown in figure 38.

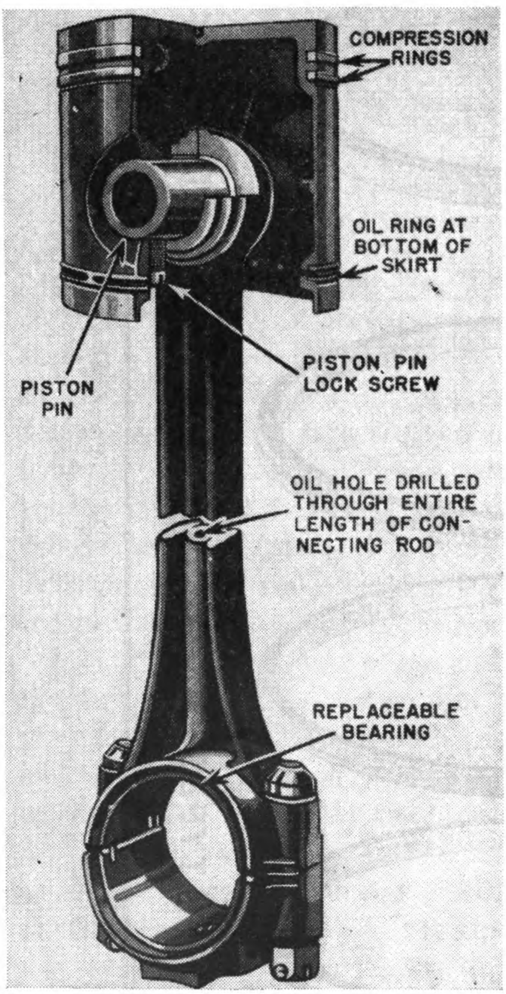


FIGURE 38.—Piston and connecting-rod assembly, showing oil hole through rod.

c. The lower end of the connecting rod bears on the crank pin through a suitable bearing. As a general practice the bottom portion or cap of the rod is made of the same material as the rod and machined at the same time. The cap is attached to the rod by two or more connecting rod bolts. The actual bearing surface may be in the form of a special two part bronze shell, the upper half being assembled in the rod and the lower half in the cap. The shells are held in place and prevented from turning by the use of dowel pins, projections, or short brass screws. The connecting rod bearing is sometimes formed by spinning babbitt metal onto the rod and cap assembled as a unit and then machining the babbitt down to the required dimensions and finish. The advantage of this type of construction is that bonding the bearing metal to the metal of the rod assists in conducting heat away from the bearing.

d. Aluminum alloy rods because of their light weight have been used in special engines, particularly in high speed racing engines.

e. Connecting rod assemblies are weighted and matched in sets for each engine in order to assure a better balance of the reciprocating parts.

f. In V-type and opposed engines a number of methods have been used to permit the connecting rods of opposite cylinders to act on the

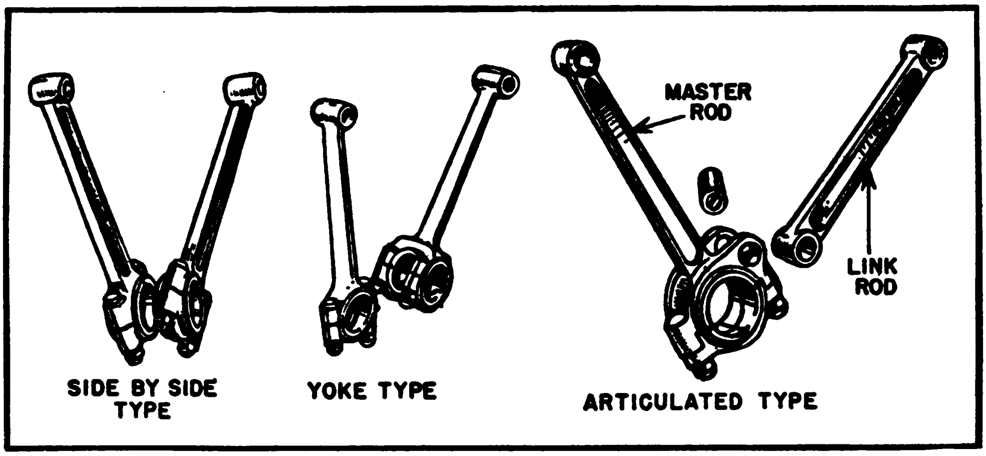


FIGURE 39.—Connecting rods used in V-type engines.

same crank pin. Some of these are shown in figure 39. The simplest of the arrangements is the side by side type. With the straight rods operating side by side, one bank of cylinders is offset a small distance from the other to allow the two rods to clear each other.

24. Bearings.—*a.* The word "bearing" in its general meaning indicates a support. In connection with the automotive vehicle, a bearing is usually considered as that part which supports and guides the motion of a rotating part. The automotive vehicle today is composed of a great number of moving parts which must be supported and guided. These parts must be held in position within very close tolerances to provide efficient and quiet operation and yet allow freedom of motion. To accomplish this and at the same time reduce the friction of these moving parts to a point where the power loss is not excessive, lubricated bearings of different kinds and types are used throughout a vehicle.

b. The rotating parts of automotive engines are generally supported on plain bearings with the journals turning within a bearing of antifriction metal, such as babbitt, bronze, or special alloy. Babbitt has a very low coefficient of friction but is too soft to withstand high pressures. Bronze has a high compressive strength and a higher coefficient of friction than babbitt. In order to combine the advantages of these two metals, the bronze-backed babbitt bearing was developed, having a thin layer of babbitt on the inside surface of a bronze body. This bearing is made by undercutting the bronze body or by drilling holes through the shell and die-casting the babbitt into the shell. Another method of securing the babbitt to

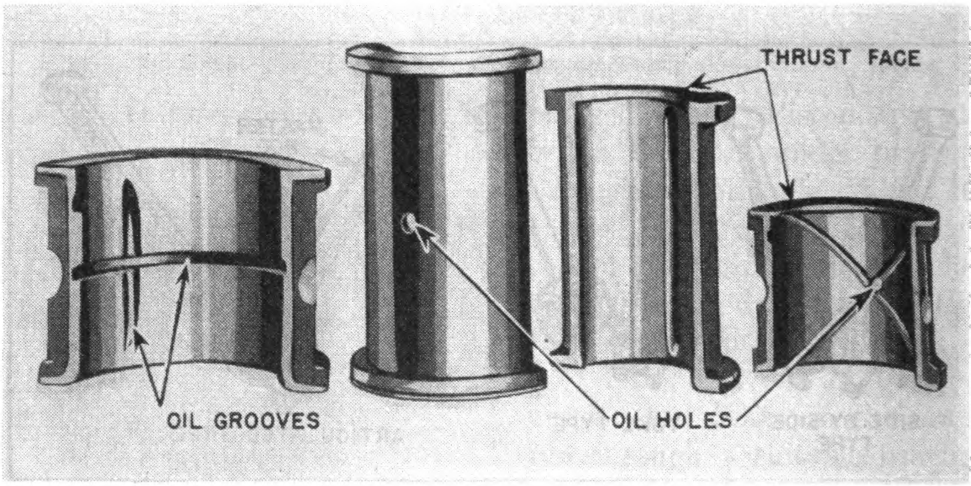


FIGURE 40.—Types of grooving in connecting-rod bearings used with splash lubricating systems.

the shell is to coat the shell with a thin layer of solder before the babbitt is cast in place.

c. Difficulties have been experienced with babbitt bearings in high speed engines with increased horsepower output. Under heavy loads and high temperatures the babbitt fails, due to fatigue, and the bond with the backing metal loosens allowing the babbitt to break and the pieces to drop out.

d. Other quite satisfactory lining materials have been developed. A lining of bronze with a high lead content produces a bearing with fairly low coefficient of friction, high load capacity, and long wearing life. An alloy of cadmium, silver, and copper has proven extremely satisfactory as a bearing-lining material. It melts at a higher temperature than babbitt, can be fitted with the same clearance, and holds readily to the shell material.

e. Most modern bearings for the connecting rods and main journals of the crankshaft consist of precision steel shells lined with a suitable lining material to withstand the high unit loads, high speeds, and high temperatures encountered in this type of service. This type of bearing is highly desirable because it can be replaced without scraping the fitting.

f. Split bearings used in automotive engines with splash lubricating systems require diagonal or lateral oil grooves so the oil can find its way over the entire friction surface. The oil is introduced at the point of lease pressure and the grooves act as reservoirs, carrying the oil to points of high bearing pressure. Bearing shells for splash lubricating systems are shown in figure 40. Joints between

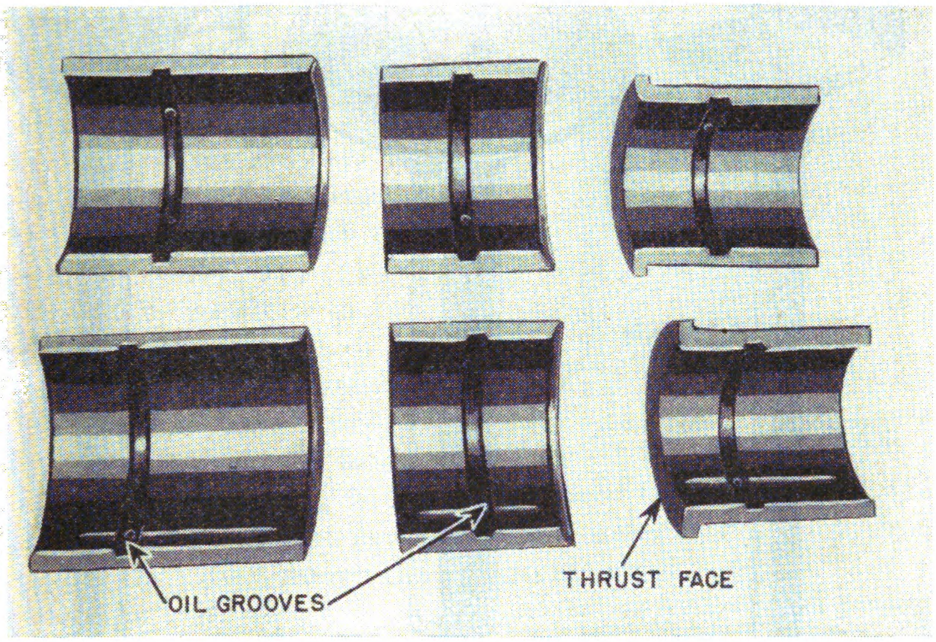


FIGURE 41.—Types of grooving in connecting-rod bearings for use with force-feed lubricating systems.

the bearing halves should be chamfered (beveled) to prevent the oil from being wiped away from the journal.

g. Bearings for force feed lubricating systems have grooves cut into them to carry the oil around the bearing. The oil is then forced out on the surfaces in contact by pressure from an oil pump. Usually when a spun or bonded babbitt bearing is used with a pressure lubricating system no grooves are used. Bearing shells for pressure lubricating systems are shown in figure 41.

25. Valve operating mechanisms.—*a.* The internal combustion engine operating on the four-stroke cycle requires a passageway and opening into the cylinder from the carburetor to draw in fuel-air mixture on the intake stroke, and a passageway and opening for the burnt gases to escape from the cylinder out into the exhaust system on the exhaust stroke. These openings are controlled by valves. Each cylinder must have at least one intake valve and one exhaust valve if the engine is to operate properly.

b. The type commonly used in automobile engines is called a poppet or mushroom valve. The word "poppet" is derived from the popping action of the valve and the word "mushroom" from

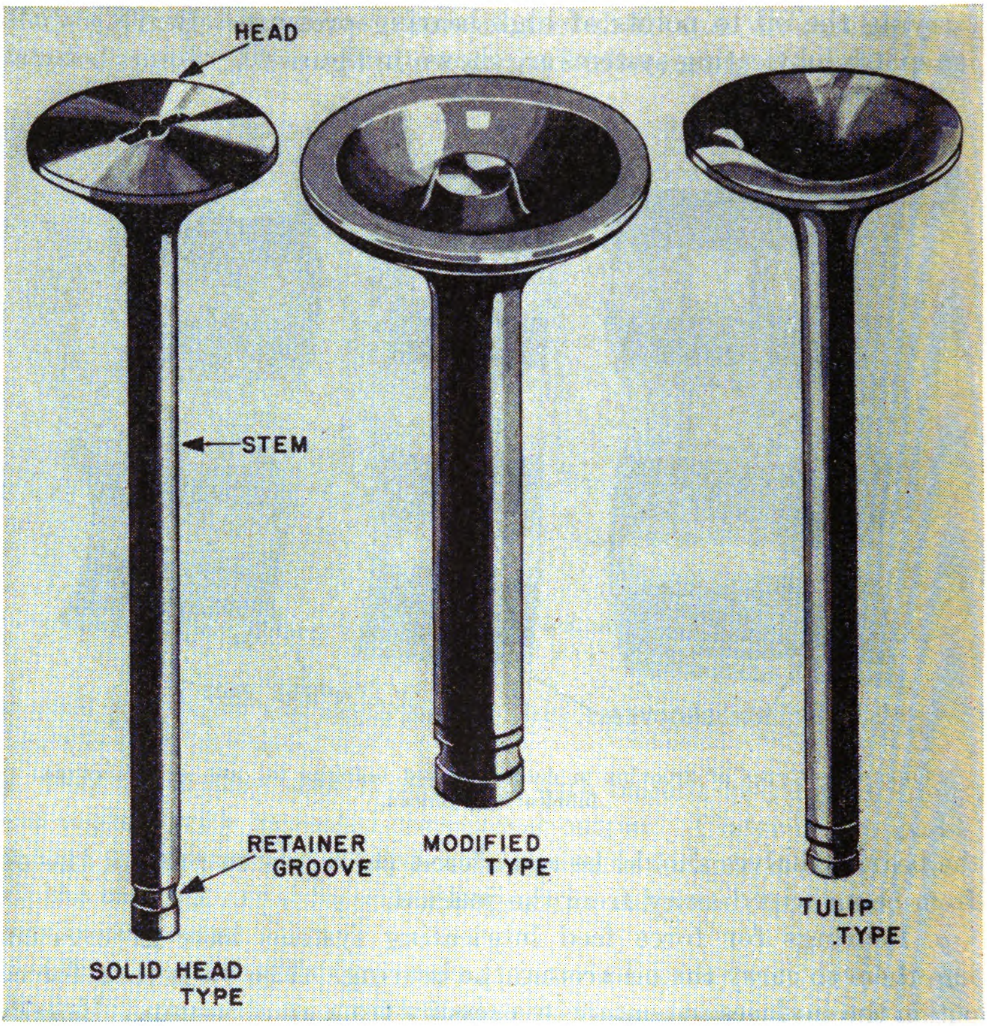


FIGURE 42.—Common types of poppet valves.

its general shape. Figure 42 shows some common shapes of poppet valves. Poppet valves are usually made in one piece from special alloy steels. A chromium-nickel alloy is ordinarily used for intake valves, but silcrome alloys are usually used for exhaust valves because of the extremely high temperatures these valves must withstand. Rotary and sleeve type valves have been successfully but not extensively used in automotive engines so their mechanisms will not be discussed here.

c. As shown in figure 43, the valve seat is the face of a circular opening leading into the combustion chamber of the cylinder. There are two such openings or valve ports in each cylinder to which are connected the intake and exhaust manifolds. It is the function of the valves to open and close their respective ports in certain exact relation to the position of the piston in each separate cylinder during the cycle of engine operation. The valves are opened by positive mechanical action working against the tension of the valve springs which close the valves. The valves are held in proper position and alinement by the valve guides in which the valve stems pass. The guide may be cast integrally with the cylinder or cylinder head or it may be a removable part pressed into place. The valve must be fairly light in weight to lessen the inertia forces resulting from its high speed reciprocating motion, but it must have sufficient metal to allow excess heat to flow from the head of the valve through the stem to the guide.

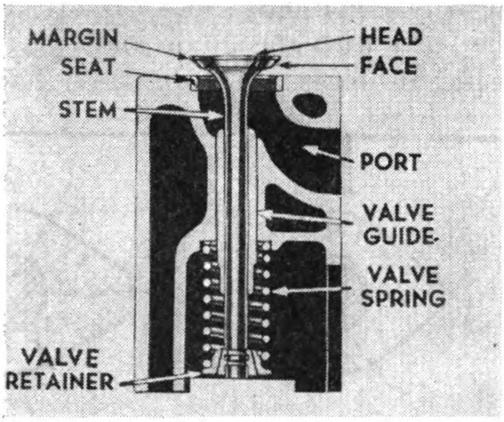


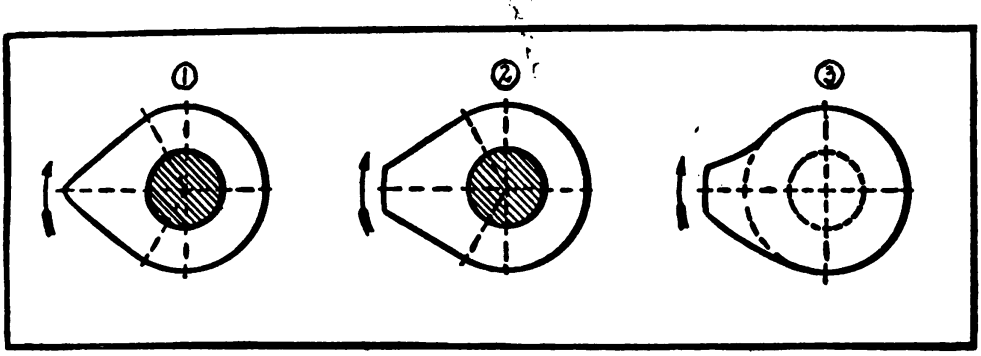
FIGURE 43.—Poppet type valve assembled in its guide with valve spring in position.

d. (1) The valve seat must be of a material that can be ground to make a tight-fitting leak-proof joint with the valve. It must resist corrosion and pitting over long operating periods in order to insure a gastight joint, to withstand wear, the high stresses imposed by the burning fuel, and the constant opening and closing action of the valve spring.

(2) Ordinary valve seats, especially for exhaust valves, are subjected to intense heat, pitting, burning, and pounding, with resulting wear and leakage. This necessitates valve grindings and reseatings to renew the seating surfaces. Some manufacturers minimize wear by using a nickel-chrome hard cast iron in the cylinder castings, while others employ valve seat inserts. These inserts are rings of special alloy steel machined and pressed into place in the cylinder block or cylinder head to serve as valve seats. The inserts may be replaced if necessary. (See fig. 43.) The use of valve inserts lessens the frequency of valve grinding. Some designers recom-

mend the use of valve inserts for both intake and exhaust valves and others for exhaust valves only.

e. Valve stems are ground to fit the guides in which they operate. The reamed hole in the guide must be concentric with the valve seat to insure proper alinement of the valve face. The guides may be integral parts of the cylinder block or head, or they may be removed and replaced when worn. Removable valve guides are for the most part made of cast iron. Bronze guides may be used in some instances, particularly where corrosion is present, as it is in marine engines. Valve heads are cooled solely by the contact of the stem with the guide and by contact of the valve face with its seat. In order to obtain better heat conductivity, valves have been



① To give accelerated lift to valve as it starts to open.
② To give quick opening and closing to valve with long period of maximum opening.
③ To give maximum possible valve opening for high-speed racing engine.
FIGURE 44.—Typical cam profiles.

made with hollow stems and filled with salt or sodium, either of which conducts heat much faster than steel. This type of valve is especially suitable for air-cooled aircraft engines in which operating temperatures are much higher than in water-cooled automotive engines. Valve seats are cooled by the transfer of heat to adjacent metals which are cooled by the water surrounding them.

f. Instead of two large valves per cylinder, some engines have two intake and two exhaust valves of smaller size allowing passageways of larger total area into and out of the cylinder. This arrangement increases the volumetric efficiency and assists in scavenging the exhaust gases. It permits the use of lighter valves, valve springs, and valve operating mechanisms.

g. All mechanisms or mechanical linkages for operating valves begin with the camshaft. The simplest form of cam is a wheel that revolves off-center. In actual practice the outside of the cam or its "profile" is shaped to give the valve a calculated speed or action. Figure 44 shows some cam profiles used in automobile engines. The camshaft has a cam for each intake and each exhaust valve. The cams are either made integrally with the shaft or are made separately and pinned or keyed to it. The integral type is the more commonly used because it is impossible for the cams to become loose on the

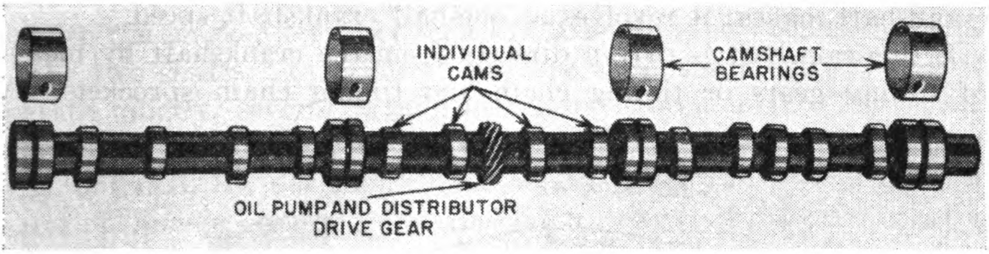


FIGURE 45.—One-piece camshaft with camshaft bearings. Distributor and oil-pump drive gear in center of shaft are integral with it.

shaft or shift out of their correct positions and thereby throw the valve action of the engine out of line. Camshafts with integral cams must have bearings of larger diameter than the highest point on the cams so the shaft can be assembled in the engine by sliding it through

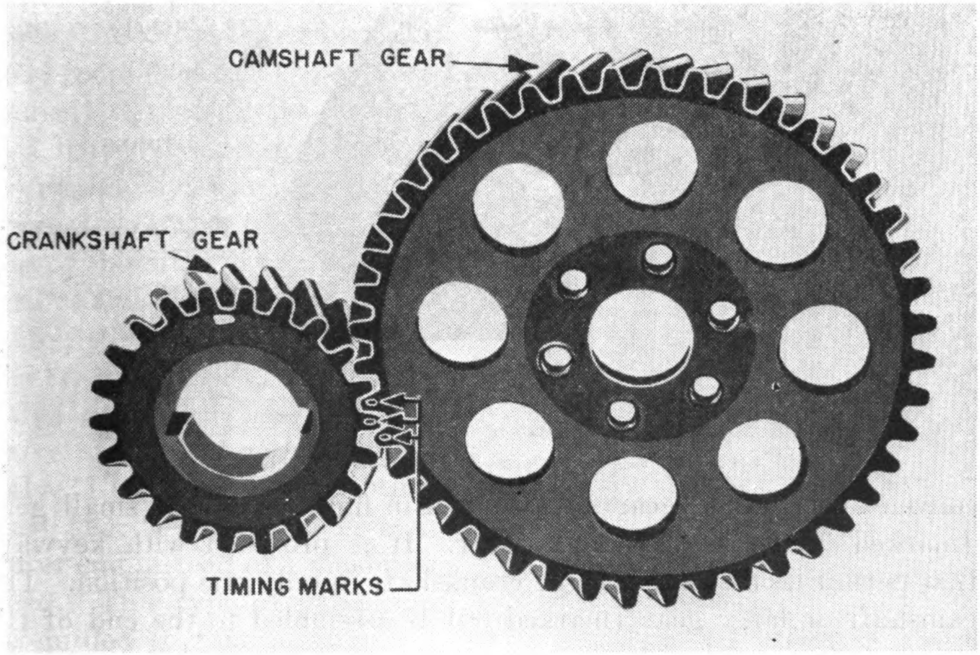


FIGURE 46.—Timing gears and method of marking for proper assembly.

the bearing shells in the cylinder block. A one-piece camshaft with its bearing shells is shown in figure 45. This illustration also shows a gear near the center of the shaft for driving the ignition distributor and oil pump. Although the drop forged steel camshaft has been the prevailing type for a number of years, several manufacturers are now using chilled cast-iron camshafts.

h. Since the valves open and close only once for each complete cycle or for each two revolutions of the crankshaft, the camshaft is required to make only one-half the number of revolutions that the crankshaft makes; it revolves at one-half crankshaft speed.

i. The camshaft is driven directly from the crankshaft by means of timing gears or timing chain and timing chain sprockets. A

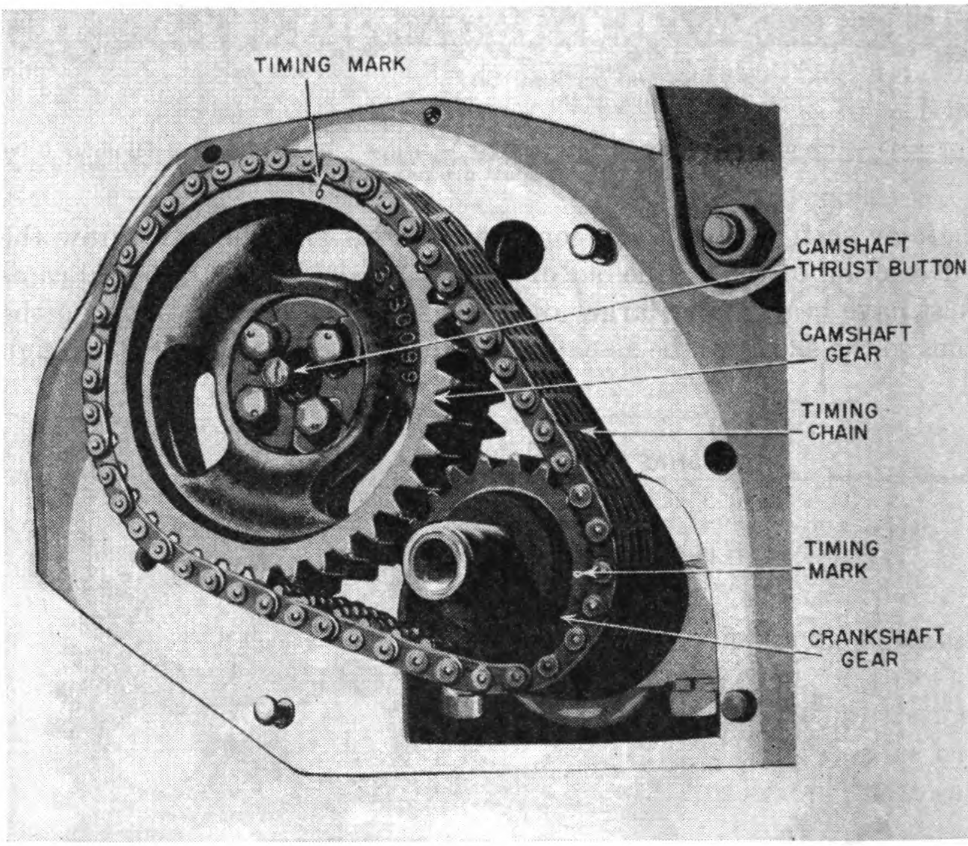


FIGURE 47.—Camshaft driven by timing chain.

conventional timing gear set is shown in figure 46. The small gear (marked 0) is the crankshaft gear. It is provided with keyways that permit its assembly on the crankshaft in only one position. The camshaft or large gear (marked 00) is assembled to the end of the camshaft by means of studs or capscrews also arranged to permit its assembly in only one position. Thus, if the gears are always assembled with the tooth marked 0 between the two teeth marked 00, the camshaft will always be in a 1 to 2 relation with the crankshaft, and all events controlled by the camshaft will occur at the proper time with respect to the position of the crankshaft or pistons. When a timing chain is used for camshaft drive (fig. 47) the action is substantially the same as that when timing gears are used. The sprockets by means of a linked chain act as gears in maintaining the 1 to 2 relation between the two shafts. Here again certain teeth are marked and set with a certain number of chain links between them or with the marked teeth set on a line extending between the centers of the two shafts. In order to produce a camshaft drive that will operate quietly, several arrangements have been used. The silent chain or link belt type of drive has long been considered the quieter type, but with the development of helical gears and special molded material for camshaft gears, the gear drive has become equally quiet.

j. In a T-head engine two camshafts are required—one on either side of the engine—giving the same valve action as a double L-head type.

k. The complete valve operating mechanism for the valve of an L-head engine is shown in figure 48. This is the simplest of all valve mechanisms inasmuch as it requires a minimum number of parts. A valve lifter having a mushroom type head is mounted immediately above the camshaft in a lifter bushing or guide. It is raised by the cam action against its lower face. The top end of the lifter has an adjusting screw and lock nut assembly which pushes against the end of the valve stem in lifting the valve against the reaction of the valve spring. Another type of valve lifter that is sometimes used (fig. 50) has a roller at its lower end instead of a mushroom head. This type of lifter must be guided so that it cannot revolve in order that the roller will always operate in the same plane as the cam. The roller type lifter has less friction against the cam than the mushroom type. Some engines are equipped with automatic hydraulic valve lifters which have no clearance between the valve lifter and the valve stem, making clearance adjustments unnecessary. This type of lifter is shown in figure 49.

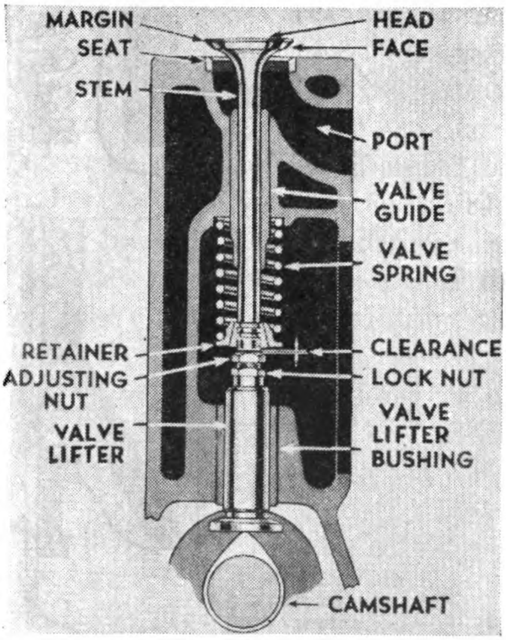


FIGURE 48.—Poppet-type valve and related parts used in L-head engine.

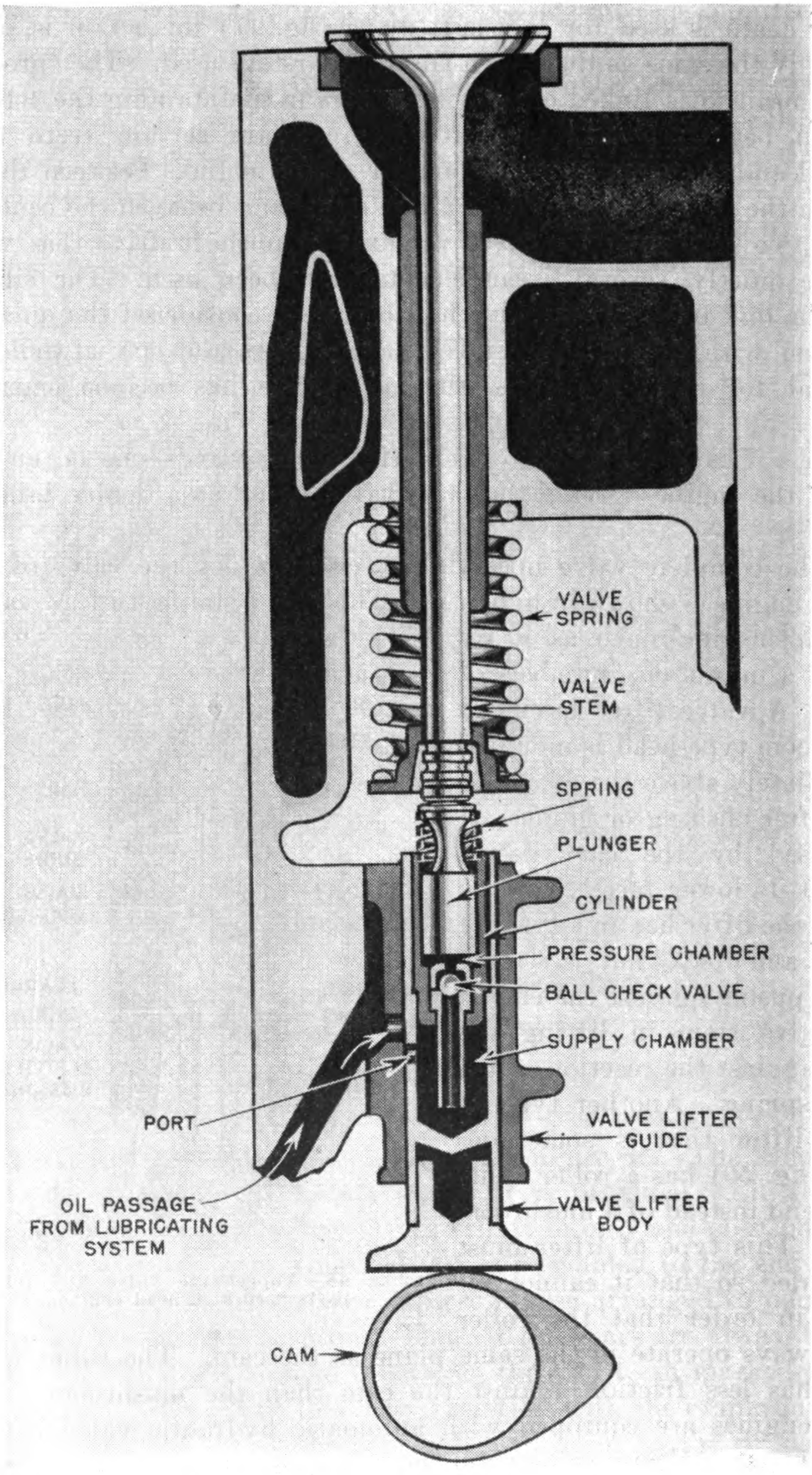


FIGURE 49.—Automatic hydraulic valve lifter.

(1) The outer portion or body of the lifter is similar to manually adjusted lifters except for having a straight machined barrel to receive the hydraulic unit instead of a threaded hole for an adjusting screw. The hydraulic unit consists of a cylinder, a plunger, a ball check valve, and a spring. The supply chamber under the hydraulic unit receives oil under pressure from the lubricating system of the engine through a port in the lifter body each time it moves past a hole in the valve lifter guide.

(2) With the face of the lifter on the base circle of the cam, and the engine valve seated as shown in figure 49, the light spring lifts the plunger so that its upper end touches the valve stem, giving zero valve lifter clearance. As the plunger moves upward, increasing the volume of the pressure chamber under the plunger, the ball check valve moves off its seat and the pressure chamber is filled with oil from the supply chamber.

(3) As the camshaft rotates, it raises the lifter body, increasing the pressure in the pressure chamber which forces the ball check valve to its seat. Further rotation of the camshaft moves the valve lifter upward, and the confined body of oil in the pressure chamber acts as a rigid unit of the valve-operating mechanism. The valve is lifted and cushioned by this column of oil, which carries the load as long as the engine valve is off its seat. During this period a predetermined quantity of oil leaks from the pressure chamber between the plunger and the cylinder bore. This is necessary in order to provide space so that enough oil to fill the pressure chamber can enter it as soon as the lifter body leaves the receding flank of the cam and comes in contact with the base circle. This maintains the lifter clearance at zero during the next cycle.

(4) In other words, the hydraulic lifter provides a column of oil between the cam and the valve stem which carries the load while the engine valve is off its seat. The length of the column is automatically adjusted with each revolution of the camshaft.

(5) This lifter is self-adjusting when either a warm or a cold engine is being started, because the supply chamber in the body of the lifter remains filled with oil from the previous operation of the engine.

(6) It is impossible for the lifter to hold the valve open when it should be closed during normal engine operation. When the valve is closed, the principal force tending to open it is the spring acting on the plunger, which is much lighter than the valve spring which closes the valve. An additional force which tends to push the

plunger upward and open the valve is the pressure of the oil in the supply chamber. The effect from this source, however, is negligible.

(7) This type of lifter works equally well in a vertical or horizontal position.

l. Figure 50 shows the addition of a push rod and rocker arm arrangement for operating the valves in a cylinder head. The **I**-head

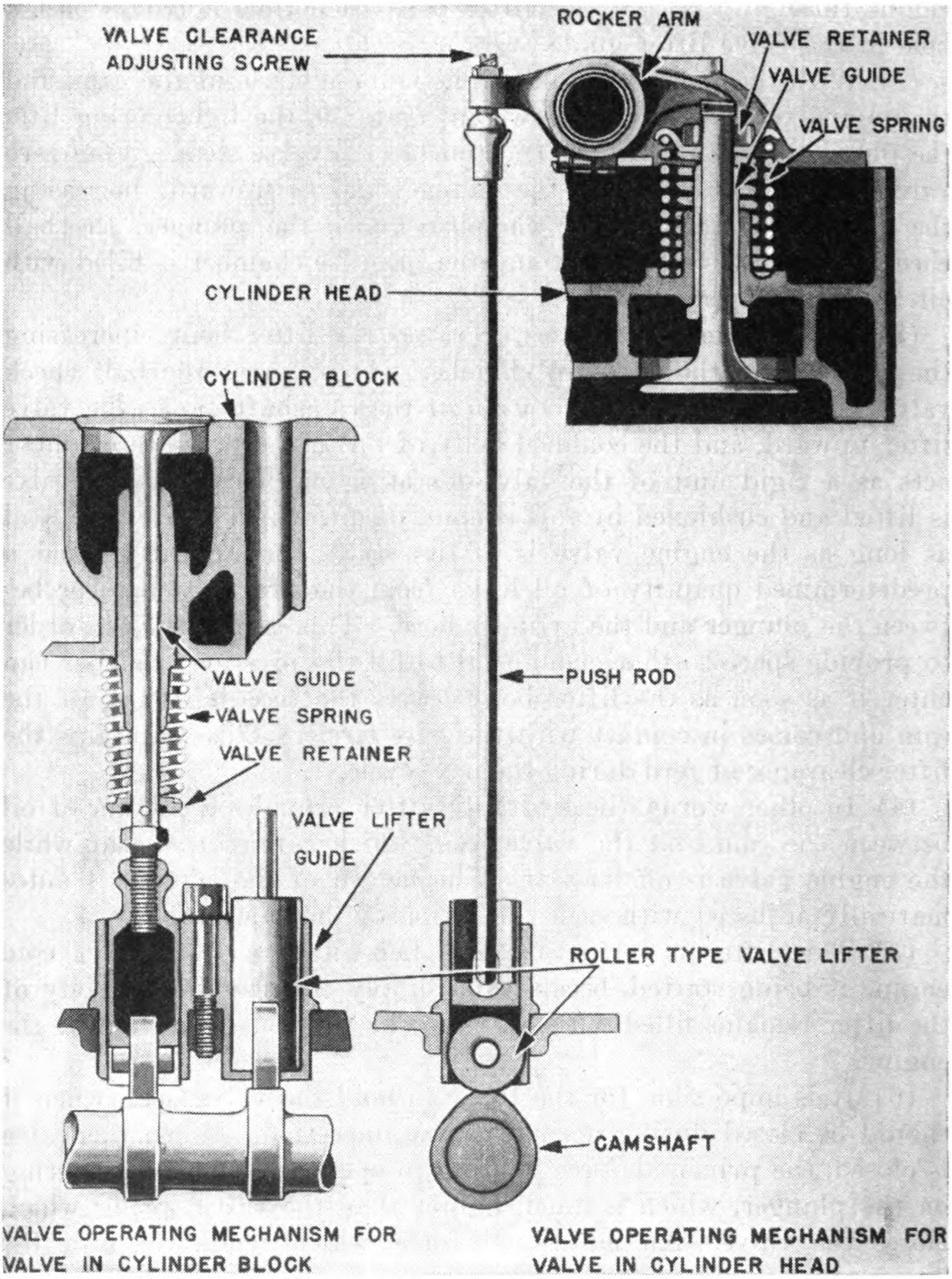


FIGURE 50.—Valve-operating mechanisms used in **L**-head, **I**-head, and **F**-head engines.

engine, which has intake and exhaust valves in the head, requires two push rods and rocker arms per cylinder. In the F-head engine, one valve is operated as in the L-head and one as in the I-head engine; that is, one valve, usually the exhaust, operates directly from the valve lifter over the camshaft, while the intake valve is located in the cylinder head and operates from a push rod and rocker arm. Overhead valves are sometimes set at an angle as shown in figure 51.

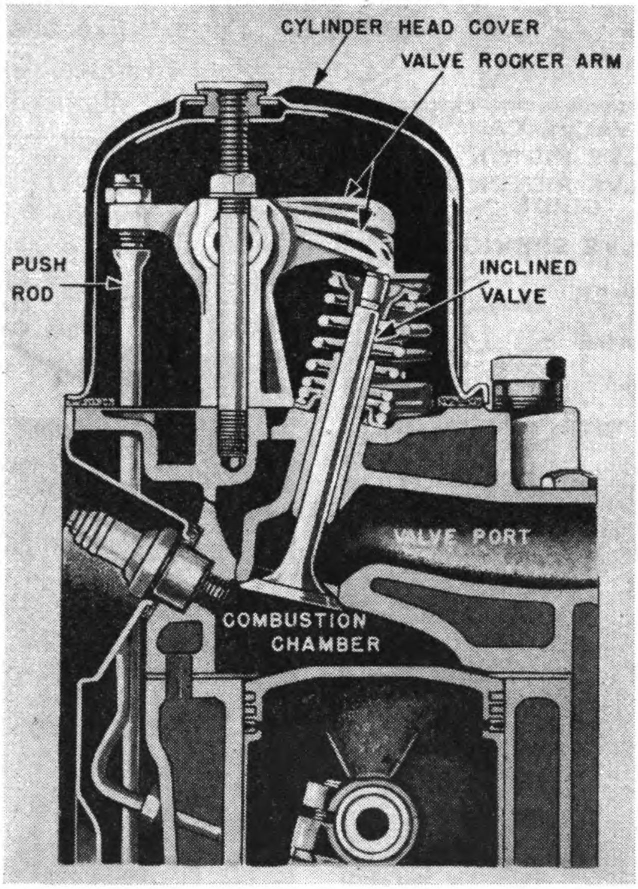


FIGURE 51.—Overhead-valve design with inclined valves.

m. In engines with overhead cams the valves are actuated directly from the cams. A special guide arrangement is necessary to take the side thrust from the cam that is ordinarily taken by the valve lifter. The parts of this type of valve action are shown in section by figure 52. Another adaptation of the overhead camshaft has the valves inclined outward at the top with the rocker arms acting between the camshaft and the valve stems.

n. The spring that closes the valve must be sufficiently strong to give good acceleration to the moving valve parts and to seat the valve firmly enough to insure tightness. Valve springs are made of a special grade of spring steel wire that is not subject to change under the rather high temperatures to which valve springs are sub-

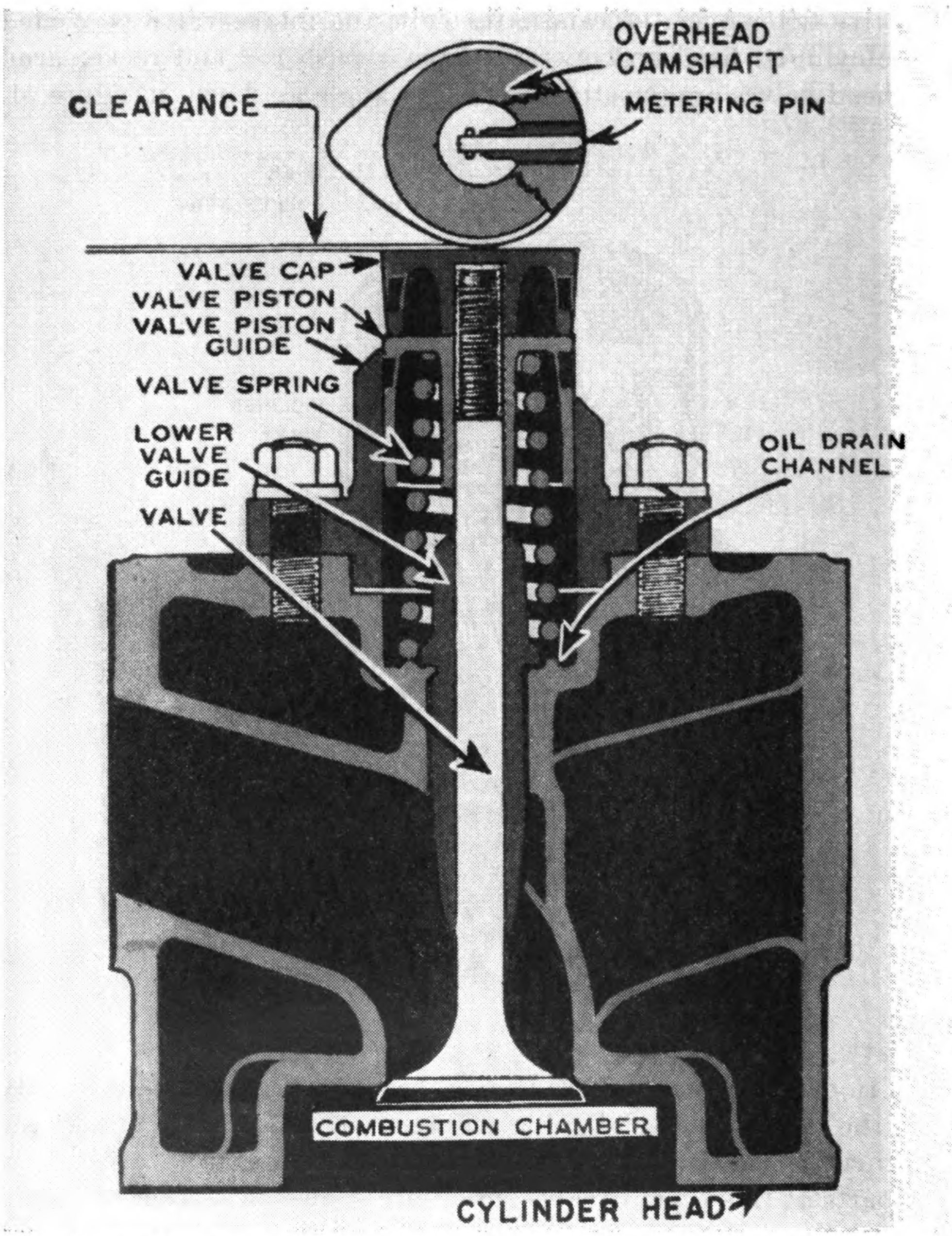


FIGURE 52.—Section through valve mechanism of overhead-camshaft engine.

jected. Some designers employ two springs, one within the other, for each valve in order to lessen valve spring inertia and spring vibration. Valve spring dampers are also used to lessen spring vibration. These are small metal stampings which fit over one end of the spring in cup fashion with two fingers extending down along the sides of the spring to press against the center coils.

26. Intake and exhaust ports.—*a.* Intake and exhaust ports are usually considered part of the engine cylinder block or cylinder head, depending on the valve arrangement. Although a port is fundamentally an opening, such as an intake or exhaust opening into the engine cylinder, it is often considered to include that section of the intake and exhaust passage which is cast as a part of the engine cylinder block or cylinder head.

b. Since each intake or exhaust port must be connected to the intake or exhaust manifold, the design of the manifold is influenced by the design of the cylinder block. It is the customary practice in multiple-cylinder engines to have an exhaust port from each cylinder entering directly into the exhaust manifold. This design affords the least possible resistance to the exhaust gases and quickly dissipates excessive heat. Intake ports are usually arranged so that the ports from two consecutive cylinders come together within the block and have a common opening into the intake manifold. This arrangement allows each branch of the intake manifold to furnish the fuel mixture to two cylinders.

27. Valve timing.—*a.* Smooth and efficient operation of the engine depends basically on the coordinated movement of the parts involved in the events of the cycle, that is, through the intake, compression, power, and exhaust strokes or events. Having the correct charge of fuel mixture in the cylinder depends on the intake valve opening and closing at the proper time. Expelling all the exhaust gases depends primarily on the exhaust valve opening and closing at the proper time. Should either valve be slightly open during any part of the compression or the power stroke, fuel or power losses will develop. Valves must open and close so that they are constantly in step with the piston movement of the cylinder which they control. In theory, an event or stroke of the cycle begins at the top or bottom center of the piston movement and continues for 180° rotation of the crankshaft. This would indicate, then, that the valves should open or close when this piston is at the top or bottom of its stroke, depending on the event that is taking place. Actually, however, this does not happen because of other conditions that must be considered.

b. The burned gases will exert considerable pressure at the end of the power stroke. In order to keep power losses at a minimum, this pressure on the piston is relieved before the momentum of the flywheel starts to move it upward by opening the exhaust valve before the piston reaches bottom center on the power stroke. The exhaust gases immediately start out the exhaust port, relieving the pressure on the piston, making it easier for the flywheel to move the piston up to top center. Some of the power is lost at the end of the power stroke, but the gain is greater than the loss, and a net gain in power results.

c. As the crankshaft moves through top or bottom center positions, it is moving horizontally and the piston does not move perceptibly. This is called the "rock" position of the piston. During the exhaust stroke, the piston has imparted considerable momentum to the exhaust gases and they pass outward through the exhaust port. If the exhaust valve is timed to close before top dead center, a small portion of the exhaust gases will be trapped in the combustion chamber and dilute the incoming fresh fuel charge.

d. Since the piston has little downward motion while in the rock position, the exhaust valve can remain open during this period to allow a more complete scavenging of exhaust gases by taking advantage of their momentum. Based on the above discussion, an example of the opening and closing points of the exhaust valve is shown diagramatically in figure 53 ①. As the piston passes through the rock position at top dead center it creates very little vacuum or suction effect in the combustion chamber because it has moved downward only a very short distance on the intake stroke. The exhaust gases, however, because of their momentum in passing through the exhaust valve port have created an air current or turbulence in the combustion chamber. This effect is sufficient to cause the air-fuel mixture to move into the combustion chamber if the intake valve is open. For this reason, the intake valves open slightly before top dead center. The vacuum or suction effect in the cylinder becomes greater as the piston moves downward on the intake stroke, and considerable momentum is created in the incoming fuel charge. By closing the intake valve after the piston has passed through its period of rock at bottom dead center, full advantage can be taken of the momentum of the incoming charge. This "packs" the fuel-air mixture and a maximum fuel charge is obtained in the cylinder. The opening and closing points of the intake valve are shown diagrammatically in figure 53 ②. Diagrams in figure 53 ③ and ④ show the approximate relation of the compression and power strokes.

e. Figure 54 shows a typical valve timing diagram as it would probably be found in a manufacturer's service manual. This dia-

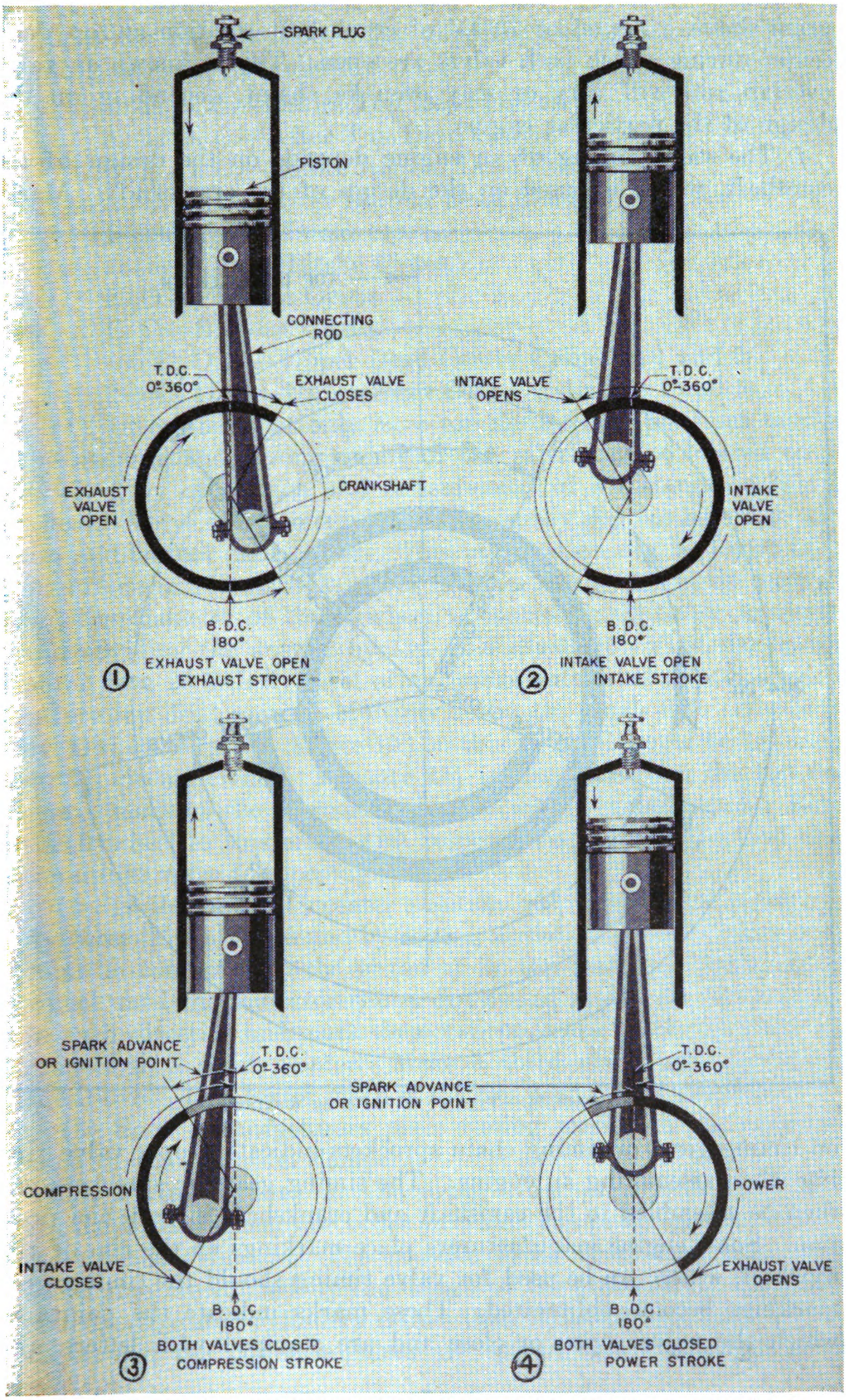


FIGURE 53.—Opening and closing points of valves during entire four events of cycle.

gram shows a period of 73°45′ of crankshaft rotation at top dead center during which both valves are open. This is known as valve overlap and will vary or may even be absent, depending on the design of the particular engine.

f. The valve timing of an engine depends on the design of the camshaft, which is based on the design of the crankshaft. Marks

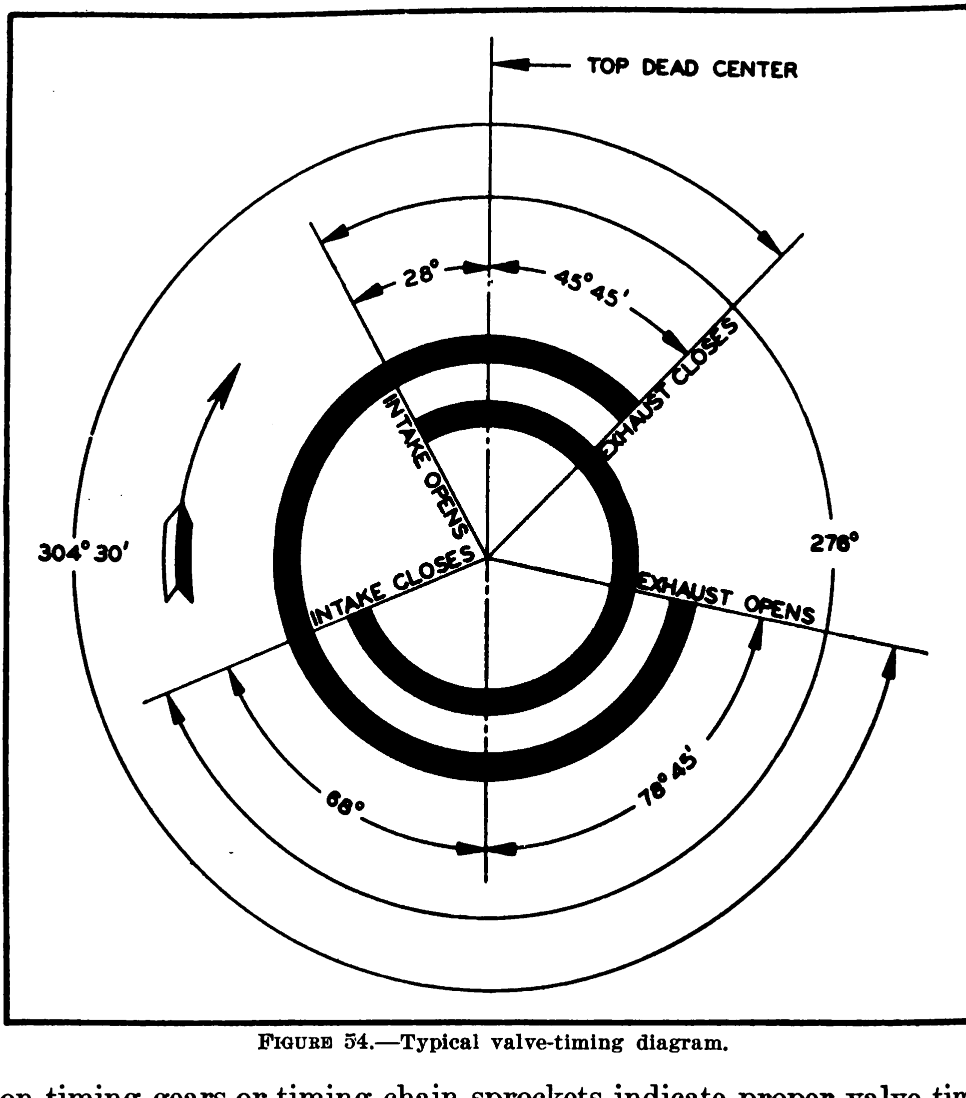


FIGURE 54.—Typical valve-timing diagram.

on timing gears or timing chain sprockets indicate proper valve timing when assembling an engine. The timing gears or sprockets can then be assembled to the camshaft and crankshaft in only one position. Some engine manufacturers place markings on the rim of the flywheel, which can be used for valve timing should the timing gear markings become obliterated. These marks indicate the points at which the valves open or close and are stamped with letters and figures for identification. The abbreviations usually used for the timing marks are as follows:

B. T. D. C.—Before Top Dead Center.
A. T. D. C.—After Top Dead Center.
B. B. D. C.—Before Bottom Dead Center.
A. B. D. C.—After Bottom Dead Center.
I. (or A.) O.—Intake Opens.
I. (or A.) C.—Intake Closes.
E. O.—Exhaust Opens.
E. C.—Exhaust Closes.
1–6 U. D. C.—Upper Dead Center Cylinders 1 and 6.
1–8 U. D. C.—Upper Dead Center Cylinders 1 and 8.

(1) In engines that only have top dead center positions marked, the opening and closing points of the valves can be located on the flywheel by calculation and measurement of a distance on the flywheel. Valve operations take place so many degrees before or after top and bottom dead center. This information can be found in the manufacturers' handbook. This distance can be found by multiplying the diameter of the flywheel in inches by the angle in degrees and dividing the answer by 114. To illustrate: Find the opening point on a 20-inch flywheel of an intake valve that should open 10° before top dead center. Multiply 20 by 10; equals 200. Divide 200 by 114; equals 1.75. Hence 10° on this flywheel would be 1¾ inches on its circumference. Measure 1¾ inches back from the top dead center mark on the flywheel and mark with a center punch. Rotate the flywheel to this mark with respect to a fixed pointer and check the intake valve for opening.

(2) If the top dead center position of piston is not marked on flywheel this can be found by setting a dial indicator so that it will come in contact with the piston at its top position. Rock the flywheel until the indicator shows downward movement of the piston in each direction and mark these two positions on the flywheel with respect to a fixed pointer. Make a third mark halfway between these two. This center mark is the top dead center position.

(3) Some manufacturers place timing marks on the circumference of the vibration damper.

28. Firing order.—*a.* The firing order of a multiple cylinder engine is the sequence or order in which the power strokes occur in its various cylinders. The possible firing order combinations for an engine are limited by the design of the crankshaft. By having widely separated cylinders rather than adjacent cylinders fire consecutively, the power impulses are spread over the length of the crankshaft. This reduces the tendency of the crankshaft to "wind-up," thus lessening engine vibration. The designer chooses a firing order best suited to his engine and designs the camshaft accordingly. This definitely fixes the firing order for that particular engine.

b. The cylinders of in-line engines are numbered consecutively from front to rear, 1–2–3, etc. Some V-type engines are numbered 1R–2R–3R, etc., indicating the right hand cylinders, and 1L–2L–3L, etc., indicating the left hand cylinders. Other V-type engines are numbered 1–2–3, etc., for the right-hand cylinders and continue with 7–8–9, etc., for the left-hand cylinders. In both cases the cylinders are numbered consecutively from front to rear. In automotive radial engines the cylinders are numbered clockwise (looking at the engine from the rear end; that is, opposite the drive end) beginning with No. 1 as the top cylinder.

c. The cylinder numbers are used to designate firing order. To illustrate: 1–5–3–6–2–4 would be the firing order of a six-cylinder engine. The firing order of most engines is stamped or cast in a prominent place on the engine. It is also given in repair manuals and instruction books by the manufacturer. If this information is not at hand, the firing order can be easily determined. First, expose the valve operating mechanism by removing the valve lifter cover plates or valve covers and mark all intake valves with the number of the cylinder which it serves. Starting with No. 1 intake valve as it begins to open, slowly rotate the crankshaft and note the sequence in which the intake valves open. This sequence is the firing order of the engine. Another method of determining firing order is to fit a tightly wadded piece of paper into each spark plug hole. As the crankshaft is rotated each piston will come upward on its compression stroke with both valves closed. This increased pressure will blow the pieces of paper out, and the sequence or firing order can be noted and recorded.

d. Radial engines usually consist of an odd number of cylinders so that a constant interval between firing of the cylinders is maintained. Some radial engines having a large number of cylinders are arranged as two banks of radial cylinders having a common crankcase and crankshaft. In this type of engine each bank contains an odd number of cylinders. The odd numbered cylinders fire in succession during the first revolution of the crankshaft, and the even numbered cylinders fire in succession during the second revolution of the crankshaft. Thus cylinders always fire alternately to give smooth performance.

SECTION VI

ENGINE LUBRICATION

29. General.—*a.* The need for lubricating the moving parts of an engine can best be shown by a simple demonstration. Place a book on a table and slide it along the table top. The book tends to resist movement. The greater part of this resistance is friction. Now place two round lead pencils under the book to act as rollers and again move it along the table top. The resistance will be only a very small part of what it was during the first part of the demonstration. Lubricating an engine is equivalent to putting the pencils (rollers) under the book.

b. Most of the bearings in an engine are plain, that is, the surface of one moving part slides over the surface of the part against which it moves. The friction between the parts is lessened by placing a thin film of oil between the parts so that they actually ride on the oil film instead of against each other. Bearings usually have a clearance varying from 0.0005 inch for a 1-inch shaft to 0.001 or 0.0015 inch for a 3-inch shaft.

c. The lubricating oil in an engine also provides a certain amount of cooling. This is accomplished by the continual splash of the oil against the cylinder walls below the piston and against the under side of the piston. The oil then returns to the oil pan where it is cooled by the radiation of the heat into the surrounding air.

30. Engine lubricants.—*a.* Mineral oil is used in all internal combustion engines except racing engines or other engines operating under unusual conditions which use castor or other special oils. Although lubricating oils are designated by various characteristics and tests given in TM 10-540, the characteristic commonly used by the mechanic or vehicle operator is the viscosity of an oil.

b. The viscosity of an oil refers to its internal resistance to flow. It is the opposite of fluidity. A high viscosity oil is thick and flows with difficulty; a low viscosity oil is thin and flows readily. Refiners designate their various grades of oil by a series of SAE (Society of Automotive Engineers) numbers such as SAE 20W; SAE 30; SAE 40, etc.; the higher the number, the heavier the oil.

31. Selection of oil.—*a*. An oil should be secured in accordance with the current annual U. S. Navy Department contract and should be of the grade recommended by the manufacturer of the engine. This information can be found in the manufacturer's operation manual or in W. D., Q. M. C. Form No. 248 (Motor Vehicle Service Record Book). Different oils are usually recommended to meet different operating conditions. These include air temperatures, operating temperatures of the engine, and age of the engine. Thus an engine requiring an SAE 30 or 40 oil in summer or in southern climates would require an SAE 20 or 20W oil in winter or in northern climates. A liquid-cooled engine might require an SAE 30 or 40 oil whereas an air-cooled engine operating under the same conditions would require an SAE 40 or 50 oil because of its higher operating temperature. It is generally considered good practice to break-in a new engine with the lightest oil possible without causing excessive oil consumption. The heavier oils are then used as the engine becomes older and oil consumption becomes excessive.

b. For purposes of comparison and selection, the following SAE and corresponding Navy symbol numbers are given:

General classification	*Navy symbol*	*SAE number*
	3050	20 (20W)
	3065	30
Force feed oils (automotive and general)	3080	40
	3100	50
	3120	60
Aviation oils	1080	40
	1100	50
	1120	60
	1150	70

The SAE 10 (10W) grade (Navy symbol 2110) is a light engine oil that is sometimes used in extremely low temperatures. It is also suitable for the lubrication of starting motors, generators, and other engine accessories requiring a light grade of engine oil.

32. Operating characteristics of oil.—*a*. As oil is used in an engine for a considerable length of time, it undergoes certain physical changes which render it unsuitable. The more important of these changes are dilution, engine carbon, oxidation, and sludge.

b. Dilution of the oil in a crankcase is caused by unburned gasoline washing past the pistons into the crankcase. This causes a decided thinning effect on the viscosity of the oil. A dilution of as little as 5 percent will reduce the body of an SAE 30 oil about one-third while 15 percent will reduce it about two-thirds. Such dilutions as this are common in cold weather operation, especially when frequent starts and stops are made without allowing the engine to warm up enough to evaporate the gasoline in the oil.

c. Engine carbon, formed from burned particles of oil, packs in and around the piston rings and restricts their motion. This results in oil pumping and poor compression. Carbon forming on the piston, both on top and under the head, interferes with heat transfer and causes overheating. Carbon on the valve heads and stems makes the valves overheat, burn, and pit.

(1) Combustion chamber carbon results in foul spark plugs and carbon deposits which increase knocking and preignition. These deposits usually combine with road dust and gum to form a very hard and tenacious lining in the combustion chamber.

(2) Engine carbon is not confined to the piston and combustion chamber. Small particles become dislodged and fall into the crankcase. These floating carbon particles are liable to block oil lines and grooves and clog oil screens.

d. Oxidation of oil is the breaking down and combining of oil particles with air to form a dark, sticky substance of a tarry nature. This change in oil structure is the result of severe service under extreme temperatures in the presence of highly agitated air in the interior of the engine. As oxidation becomes complete, these particles separate to a great extent. In the early stages of oxidation they form a lustrous, varnishlike coating in the upper parts of the engine, which causes sticky piston rings, valve stems, and valve lifters. Oxidation is increased by high operating temperatures, low oil consumption, and infrequent oil drains.

e. Water sludge, formed in the crankcase, is an emulsion of water and oil. Water condenses in the crankcase in cold weather. As the oil and water are churned in the crankcase in the presence of dust, dirt, and carbon particles, they form sludge—a black, creamy substance. Sludge which forms in the very best oils can only be minimized by controlling operating conditions to prevent as far as possible the formation of water in the crankcase, and by making frequent crankcase drains during the cold weather operations.

33. Crankcase oil changes.—If oil in the crankcase could be kept clean and free from impurities, there would be no need for changing it. However, since oil does become contaminated by water, dust,

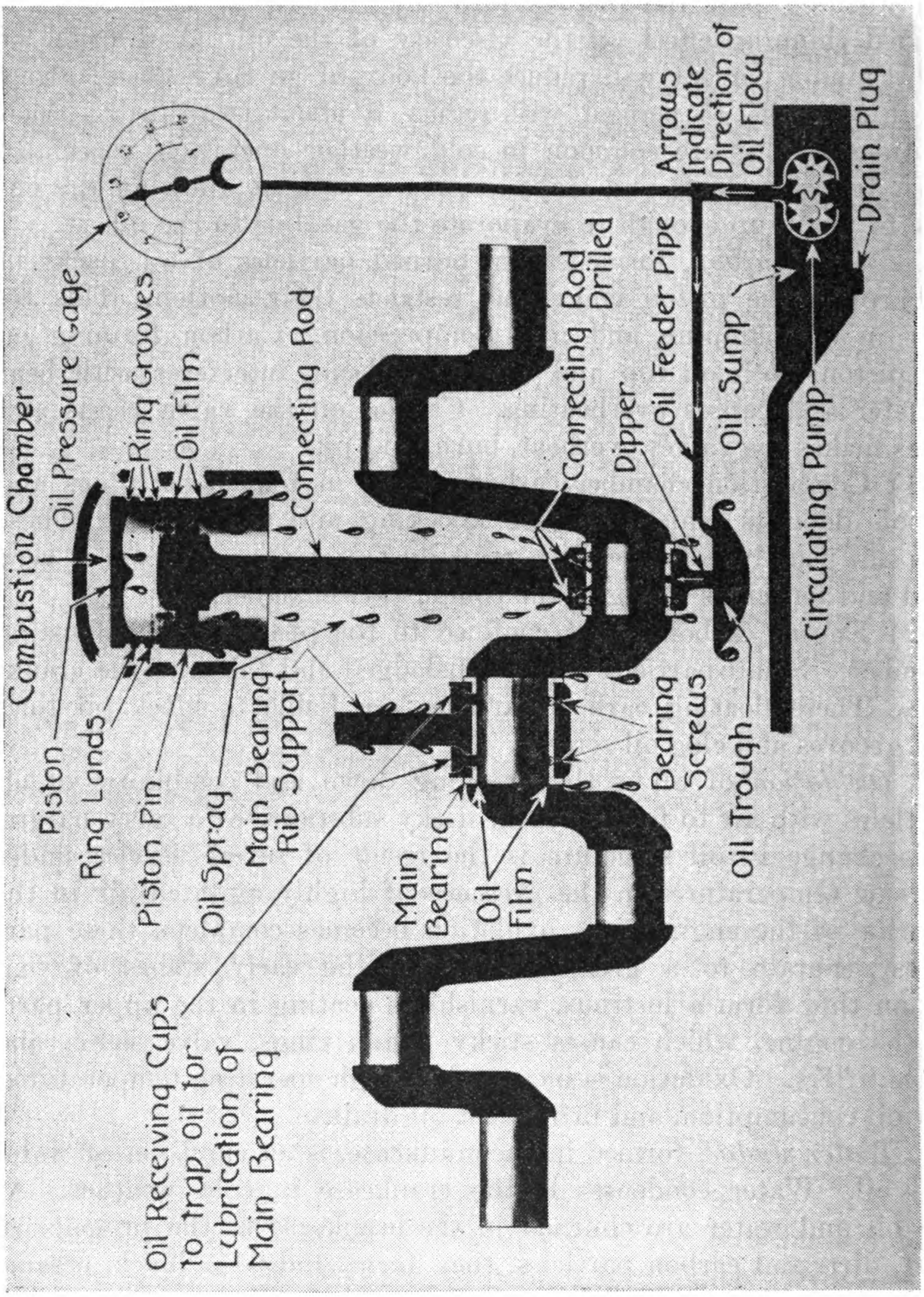


FIGURE 55.—Splash lubricating system with circulating pump.

dilution, and oxidation it must be changed. Contamination is caused by such dissimilar conditions as wide temperature ranges, varying load conditions, and dusty atmosphere, so no fixed rule can govern the

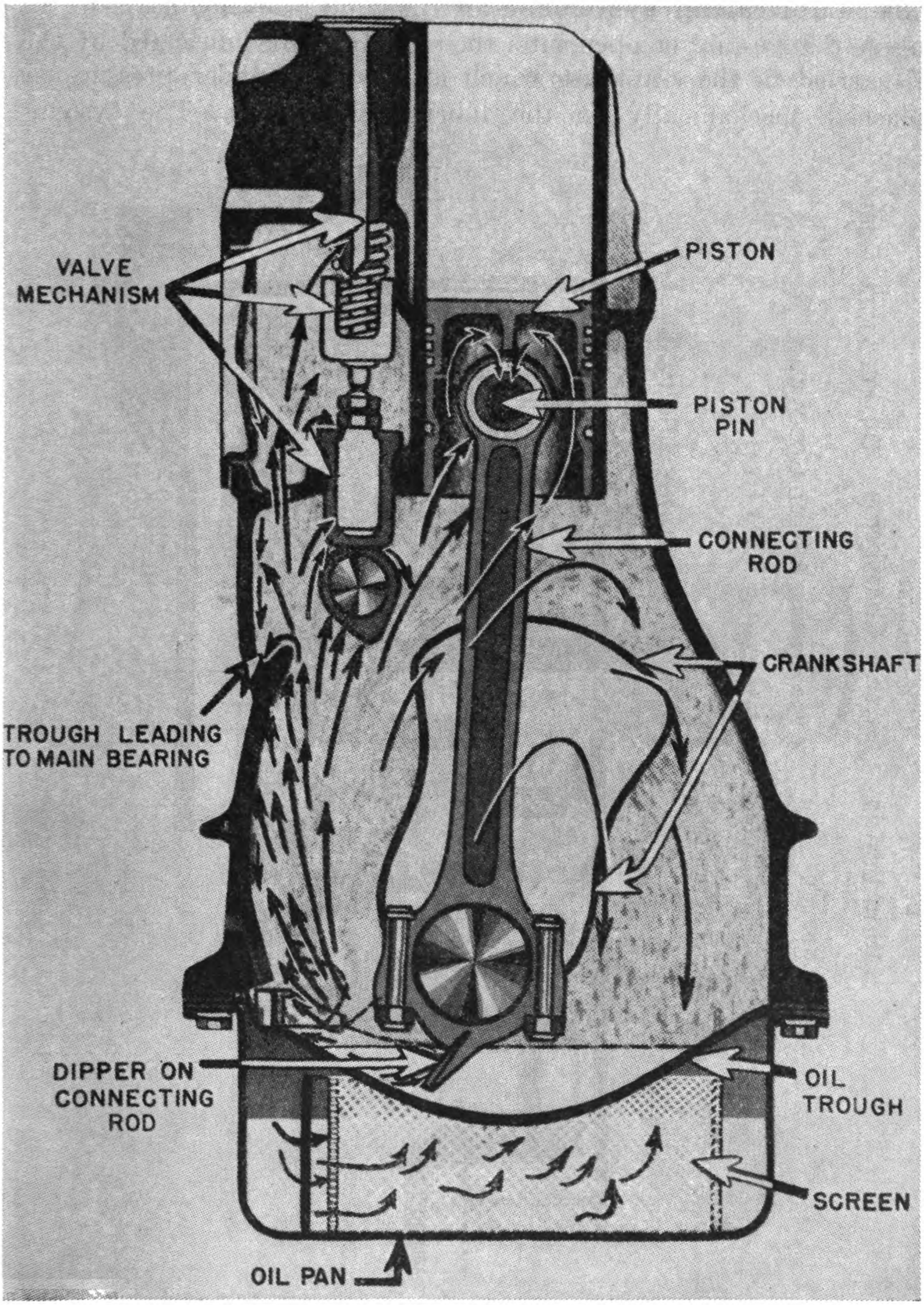


FIGURE 56.—Splashing action of connecting rod.

frequency of oil changes. The recommendations of the vehicle manufacturer provide sufficient safety for all except the most extreme operating conditions.

34. Lubricating systems.—All the vital working parts of an engine that are in, or open into, the crankcase are lubricated by the oil carried in the crankcase which is circulated under pressure or splashed mechanically on the lubricated surfaces. The systems

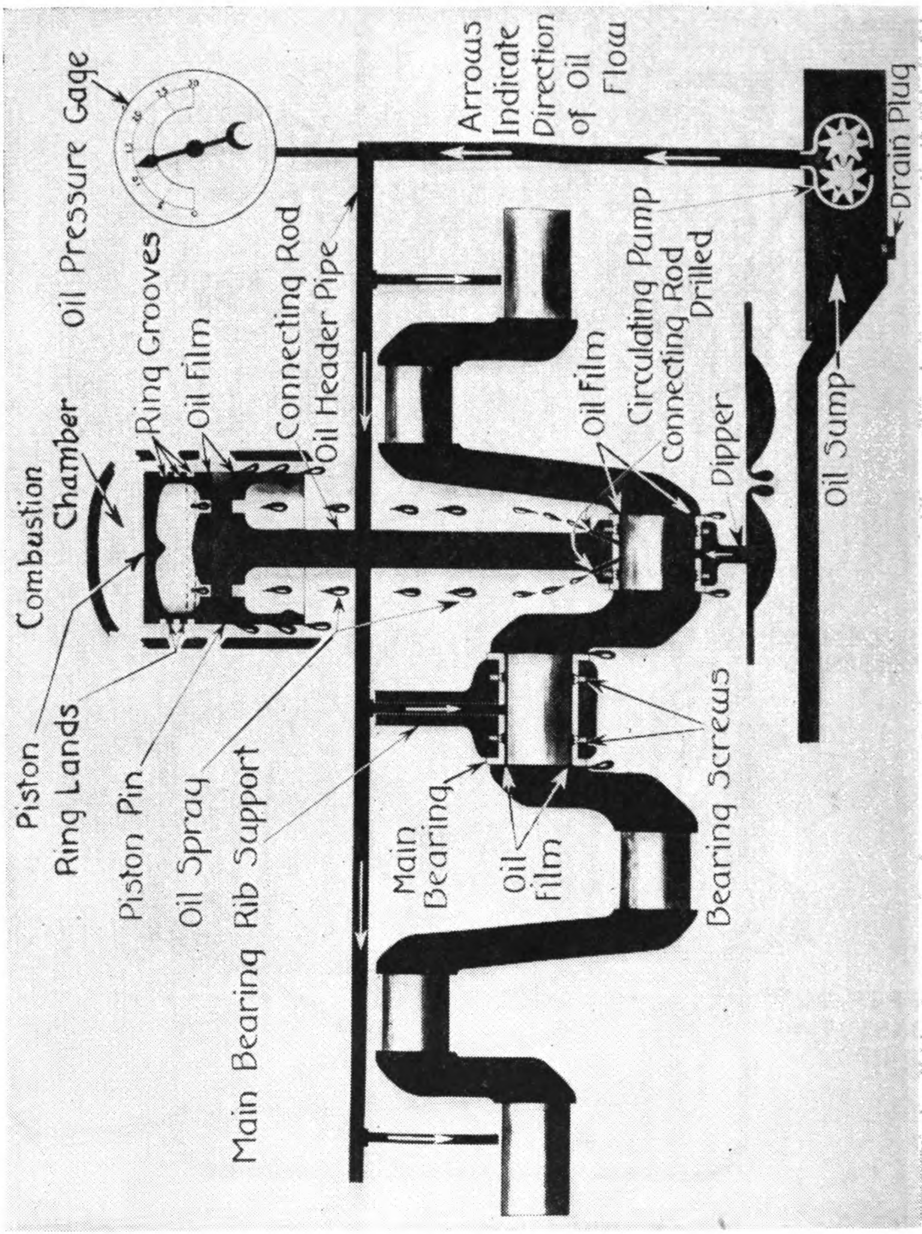


FIGURE 57.—Combination splash- and force-feed lubricating system.

commonly used are referred to as splash, force (pressure) feed and splash, force (pressure) feed, and full force (pressure) feed.

a. Splash system.—In modern splash lubrication, an oil-circulating pump normally carries the oil from the oil pan to troughs (or trays) under the connecting rod throws. Projections (dippers) on the lower part of the connecting rods pick up the oil in the troughs. As the crankshaft rotates, the dippers swing through the oil in the troughs during the lower portion of each stroke, forcing the oil into

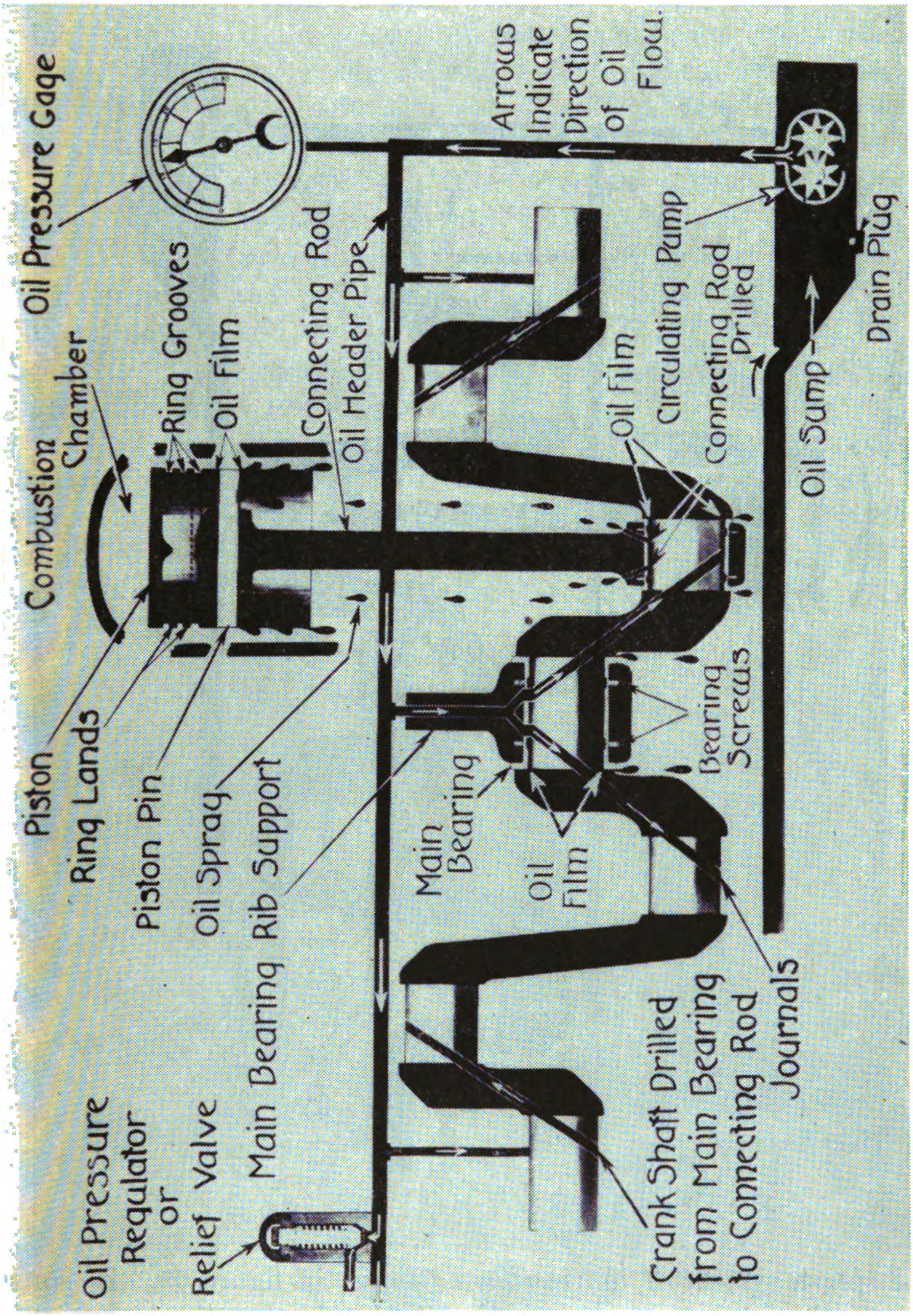


FIGURE 58.—Force-feed lubrication system.

the connecting rod bearing. The force of the dipper entering the oil also splashes oil in the form of spray up into the cylinder and other parts opening into the crankcase. Troughs are sometimes used in the upper part of the crankcase to catch a portion of the splashed oil and conduct it to the main bearings. These troughs are usually cast integrally with the upper half of the crankcase. The principle

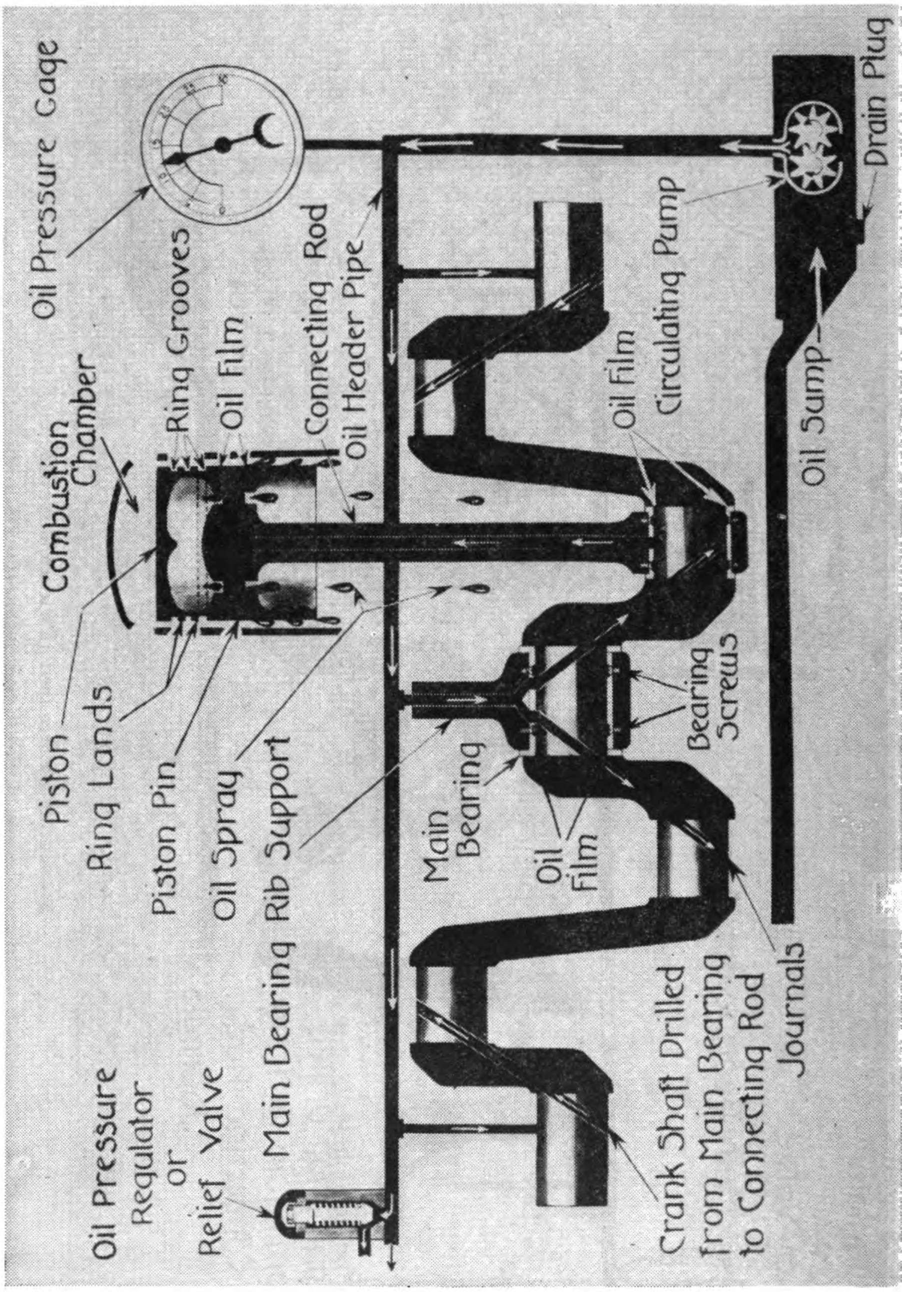


FIGURE 59.—Full force-feed lubricating system.

of the splash system of lubrication is shown in figure 55. In some instances, the oil may be dipped directly out of the oil pan but this method is now seldom used. The section view of an engine, figure 56, illustrates the splashing action of the connecting rod.

b. Combination splash and force-feed systems.—This system is used in some engines. Oil is pumped under pressure to the main bearings. Oil pipes in each separate oil trough direct a stream of oil against the dipper on the lower end of the connecting rod. Piston pins, cylinders, timing chains or gears, camshafts, and valve mechanisms depend upon the splashed oil for their lubrication. The principle of the combination splash and pressure feed system of lubrication is shown in figure 57.

c. Force-feed systems.—In the force-feed system of lubrication, figure 58, oil is forced by a pump to all main connecting rods, camshafts, and rocker-arm (in overhead valve engines) bearings. The cylinder walls and piston pins are lubricated by oil thrown off by the crankshaft and connecting rods. Oil is carried from the main bearings to the connecting rod bearings through passages drilled in the crankshaft as shown in figure 58.

d. Full force feed system.—In the full force feed system of lubrication, figure 59, all principal bearings and wearing surfaces of the engine are lubricated by oil forced through a passage which runs the length of the connecting rod. The oil spray from around the piston pin lubricates the piston and cylinder walls.

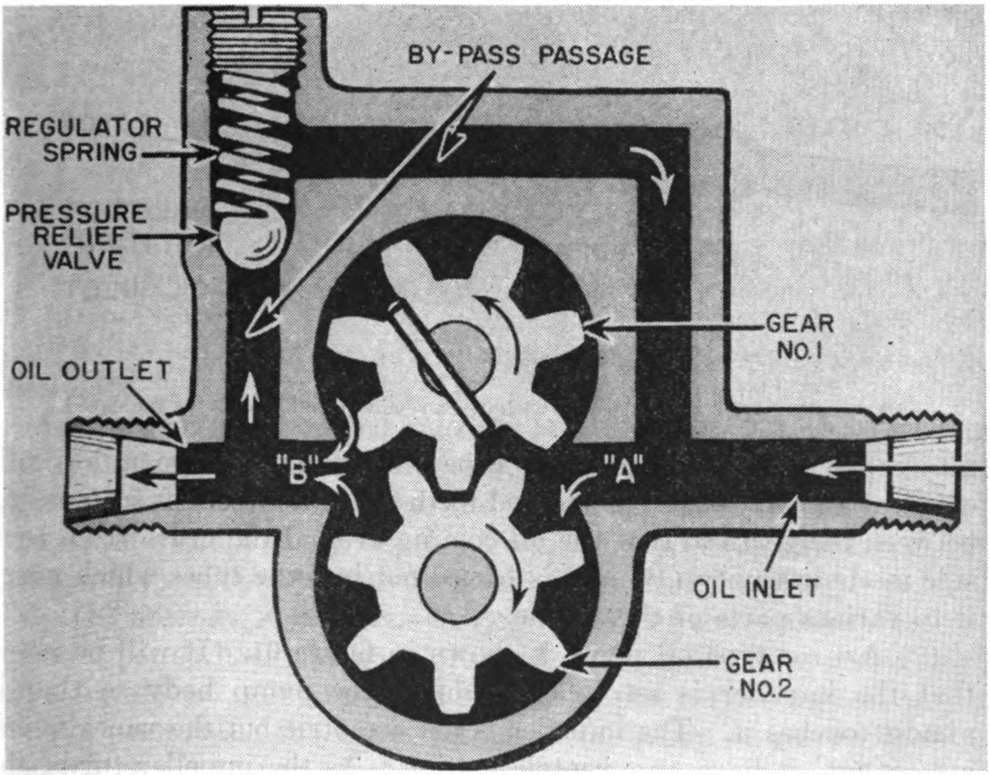


FIGURE 60.—Gear type oil pump with cover removed, showing oil passage and pressure relief valve.

35. Oil pumps.—*a. Types.*—Oil pumps are mounted both inside (submerged) and outside (elevated) the crankcase depending on engine design. They are generally arranged so that they can be driven from a worm or spiral gear directly from the camshaft. Oil pumps are of three general types: gear, vane, and plunger.

(1) A *gear* type oil pump is shown in figure 60. Gear No. 1 rotates with the pump drive shaft and drives gear No. 2. Oil is drawn

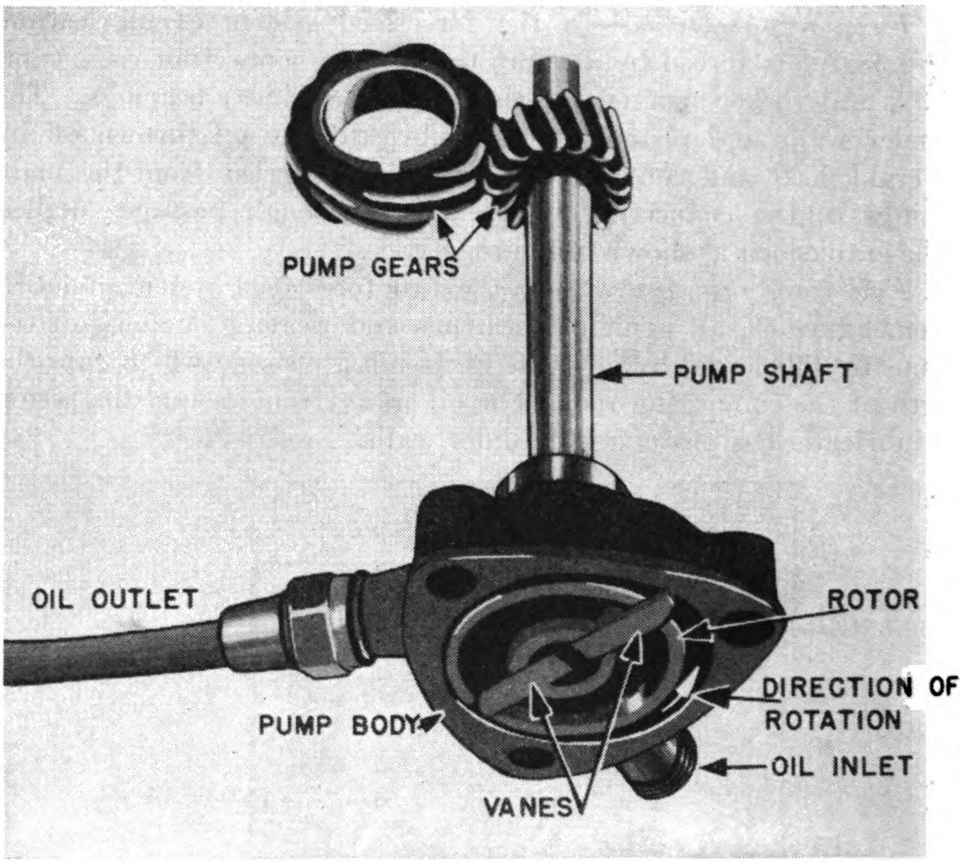


FIGURE 61.—Vane type oil pump with cover removed and gear drive indicated.

into cavity (A) through an oil pipe and follows the gears as indicated by the arrows. The meshed teeth prevent the oil from passing between the gears so that the oil coming around the gears from each side meets in cavity (B) and is forced out into the tubes which carry it to various parts of the engine.

(2) A *vane* type oil pump is shown in figure 61. It will be noted that the impeller is set to one side of the pump body so that it almost touches it. The impeller is not eccentric but the vanes which are set into it have an eccentric motion. As the impeller turns, the vanes are forced outward by springs which hold them in contact with

the pump body at all times. Oil, drawn in after one of the vanes through the entrance, is trapped by the vane ahead. As a vane is rotated to the opposite side of the pump, the space between the impeller and the pump body becomes smaller. This pushes the vane into the rotor against spring pressure and forces the trapped oil out through the outlet into the oil lines.

(3) The *plunger* type pump, figure 62, is used mostly in splash systems where it acts as an oil circulator by pumping oil from the oil

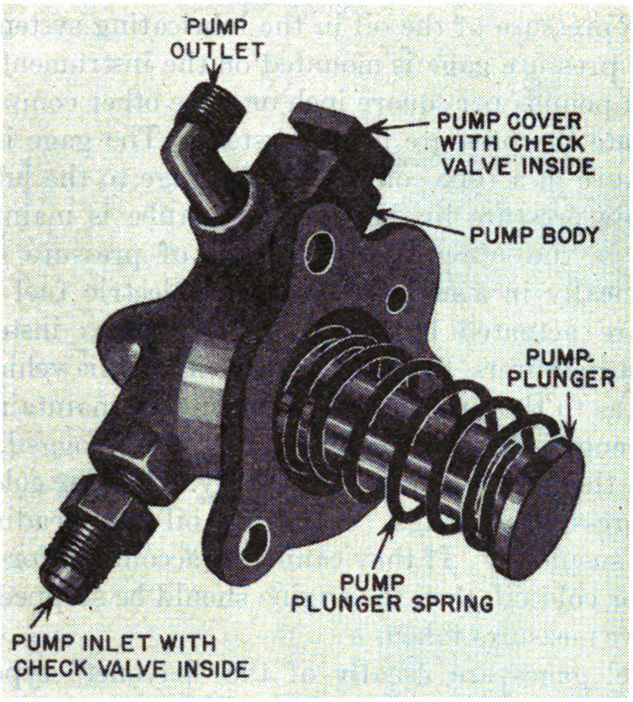


FIGURE 62.—Plunger type oil pump.

pan to the oil troughs. It is usually operated from a cam on the camshaft.

As the plunger is forced outward by the spring, oil is drawn into the cylinder and a ball check valve closes after it. As the plunger is forced back into the body of the pump, the charge of oil is pumped out of the cylinder past a spring loaded check valve, which stops the return of the oil on the outward suction stroke of the plunger.

b. Oil pressure regulators.—Any oil pump of the positive displacement type, such as the gear or vane types, must be provided with some means of relieving the pressure to prevent damage from excessive pressures. Since the output of the pump is many times the normal requirements of the engine lubricating system, all the oil cannot escape through bearing clearances and restricted oil holes, and high oil pressures result if some relieving device is not used. Oil pressure regulators are used to relieve these high pressures and to regulate the pressure drops below a predetermined amount. Figure 60 shows the connections to a regulator. The overflow usually returns to the oil pan or to the suction side of the pump, as in the figure. Some manufacturers build the regulator into the oil pump while others place it elsewhere in the oil distributing system.

36. Oil gages.—*a*. There are two classes of oil gages in general use: one class indicates the oil level in the oil pan, and the other indicates the pressure of the oil in the lubricating system.

b. The oil pressure gage is mounted on the instrument panel. It is calibrated in pounds per square inch or some other comparative marking to indicate the pressure in the system. The gage is operated by the air pressure in a tube connecting the gage to the lubricating system. The air pressure in the connecting tube is maintained by the oil pressure in the system. Other types of pressure gages are operated electrically in a manner similar to electric fuel gages, except that they are actuated by pressure diaphragms instead of floats. Vehicle manufacturers fit proper gages to their vehicles and give instructions as to the pressure which should be maintained. If some part of the engine lubricating system becomes clogged, the pressure indicated on the gage will rise abnormally. New or cold oil will also show high pressure readings. Abnormal oil gage readings should be viewed with suspicion. If they cannot be accounted for reasonably as due to new or cold oil, then the engine should be stopped immediately and corrective measures taken.

c. Oil level gages are usually of the "bayonet" type. This consists of a small, flat, or rounded rod which extends into the oil pan through a small hole in the side of the crankcase near the oil filler opening. It is usually marked for empty, low, and full oil levels. Readings are taken by removing the gage from its normal position and noting the height of the oil on its lower end by the gage markings.

d. Oil temperature gages are sometimes used on heavy-duty motor vehicles to indicate the operating temperature of the oil pan of the engine. These gages are usually of the "long distant" thermometer type, consisting of an instrument panel unit connected by a small diameter tube to a bulb located in the oil pan. The two units and their connecting tube are factory assembled since they must be sealed and calibrated. They contain a fluid (usually ether) which vaporizes at low temperatures. This vapor, the greater amount of which is located in the bulb, is expanded as it is heated, and the resulting pressure actuates the pointer on the instrument panel unit. This unit is calibrated in ° F.

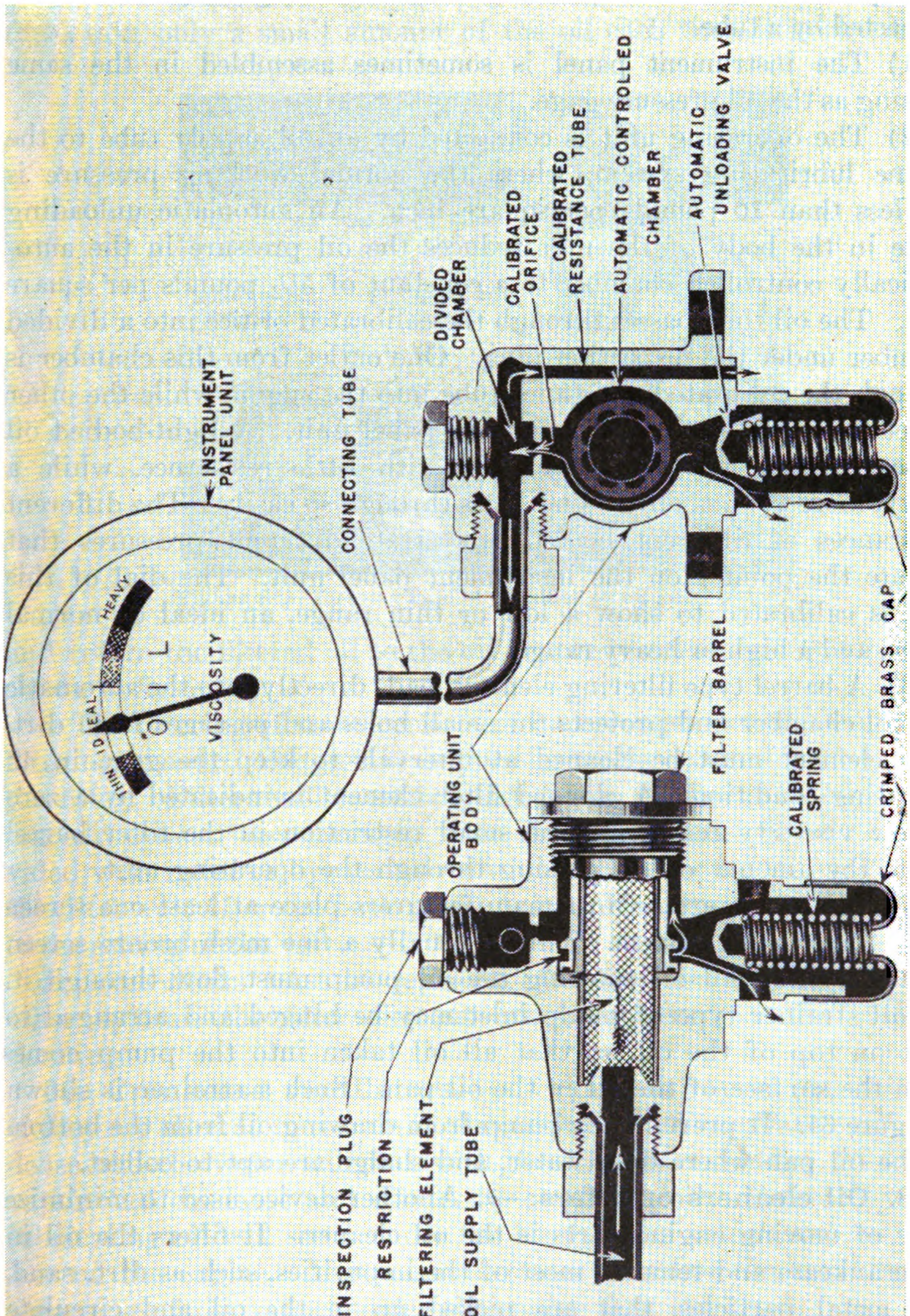


FIGURE 63.—Gage indicating relative viscosity of engine.

e. Another gage that is sometimes used on heavy duty vehicles is the viscometer (fig. 63). It indicates the viscosity of the oil in the engine under actual operating conditions after the oil has reached the normal operating temperature. The gage consists of an instrument panel unit and an operating unit on the engine. The two are connected by a tube.

(1) The instrument panel is sometimes assembled in the same housing as the oil pressure gage.

(2) The operating unit is connected by an oil supply tube to the engine lubricating system, where the normal working pressure is not less than 10 pounds per square inch. An automatic unloading valve in the body of the unit reduces the oil pressure in the automatically controlled chamber to a constant of 5½ pounds per square inch. The oil then passes through the calibrated orifice into a divided chamber under the inspection plug. One outlet from this chamber is through the calibrated resistance tube into the engine while the other outlet is connected to the instrument panel unit. A light-bodied oil passes through the resistance tube with little resistance, while a heavy, more viscous oil does not pass through so easily. The different resistances of different bodied oils create different pressures that actuate the pointer on the instrument panel unit. The dial of this unit is calibrated to show a low or thin range, an ideal or normal range, and a high or heavy range.

(3) A barrel type filtering element leads directly into the automatic control chamber and protects the small holes and passages from dirt. This element must be cleaned at intervals to keep the gage in an operating condition. A clogged filter element is indicated by a zero or low viscosity reading. The small restriction in the filter barrel limits the amount of oil passing through the operating unit.

37. Oil strainers.—Most manufacturers place at least one screen in the lubrication system. This is usually a fine mesh bronze screen located so that all oil entering the oil pump must flow through it. An oil strainer type of pump inlet may be hinged and arranged to float on top of the oil, so that all oil taken into the pump comes from the surface of the oil in the oil pan. Such a strainer is shown in figure 64. It prevents the pump from drawing oil from the bottom of the oil pan where dirt, water, and sludge are apt to collect.

38. Oil cleaners or filters.—*a.* Another device used to minimize wear of moving engine parts is the oil cleaner. It filters the oil in the crankcase and removes most of the impurities, such as dirt, sand, and metal particles, that are picked up in the oil and circulate through the engine. The cleaner is mounted on the fire wall or engine and connected so that part or all of the oil passes through it each time the oil is circulated through the engine.

b. Some filters are designed to handle the full output of the oil-circulating pump, and all the oil passes through them before being distributed to the bearings. This is called the full flow type. Other types take only a small amount of the oil each time it is circulated

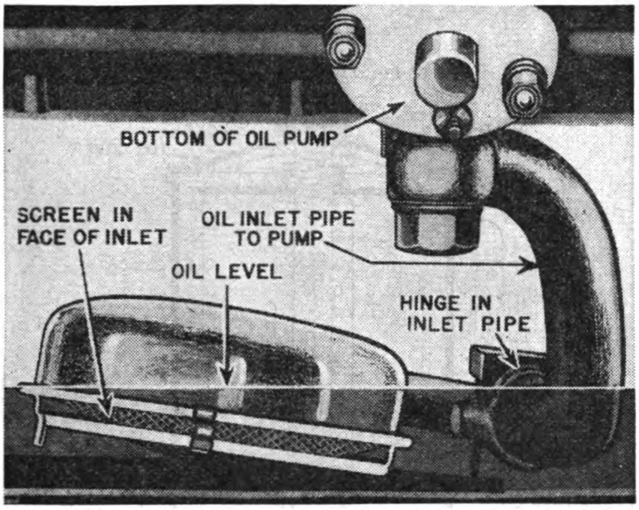


FIGURE 64.—Floating type oil strainer on oil pump intake.

and return the filtered oil to the oil pan or reservoir. A filter unit is shown in figure 65.

c. The filtering element consists of an arrangement of screens and filtering material that retain impurities as the oil is forced through the filter. Filters will eventually become so blocked with impurities that oil cannot pass through. For this reason most filters are provided with relief or bypass valves which allow the oil to flow around the filter unit after the back pressure is increased to an amount equal to the setting of the valve.

d. Some filters must be replaced after they become clogged. In other systems the filter element can be renewed or removed for cleaning.

39. Crankcase ventilators.—*a.* Crankcase vapors are harmful if they are allowed to remain in the crankcase. Water vapor will condense and the water will mix with the oil to form sludge. Gasoline vapor will condense and dilute the crankcase oil. Vapor from the lubricating oil will settle under the hood of the vehicle and accumulate on the engine. Most manufacturers ventilate the crankcase by disposing of the vapors under the engine dust shields.

b. Some types of ventilators have breather tubes connected to the crankcase high above the oil level. The breather tubes extend downward under the vehicle where there is sufficient air stream to draw the vapors out of the crankcase. This type is sometimes incorporated with the crankcase filler opening. Other types are placed so that the air from the cooling fan will flow through the breather pipe and increase the suction on the crankcase.

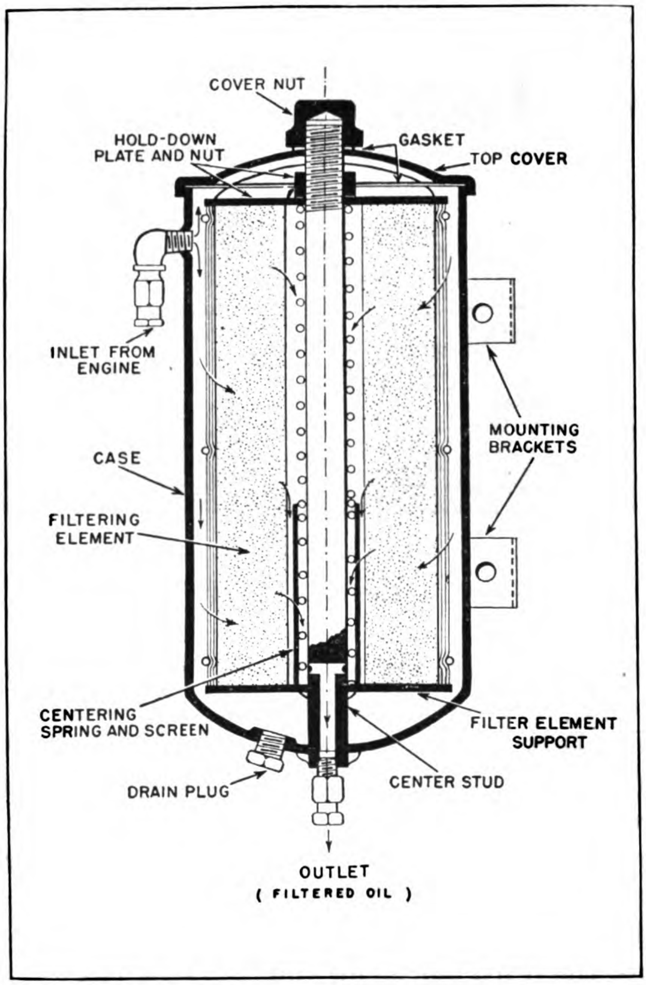


FIGURE 65.—Oil-filter unit using depth (absorption) type filter element.

40. Oil temperature regulators.—*a.* Oil temperature regulators, frequently referred to as coolers, are sometimes used to lower the oil temperature during summer months and to assist in increasing it during cold starts in the winter months.

b. The regulator shown in figure 66 makes use of the water temperature of the cooling system to control the oil temperature. It helps to confine the operating temperatures of the oil within closer and more desirable limits. In operation, oil is pumped through the oil lines coming from the pump in the crankcase through the small

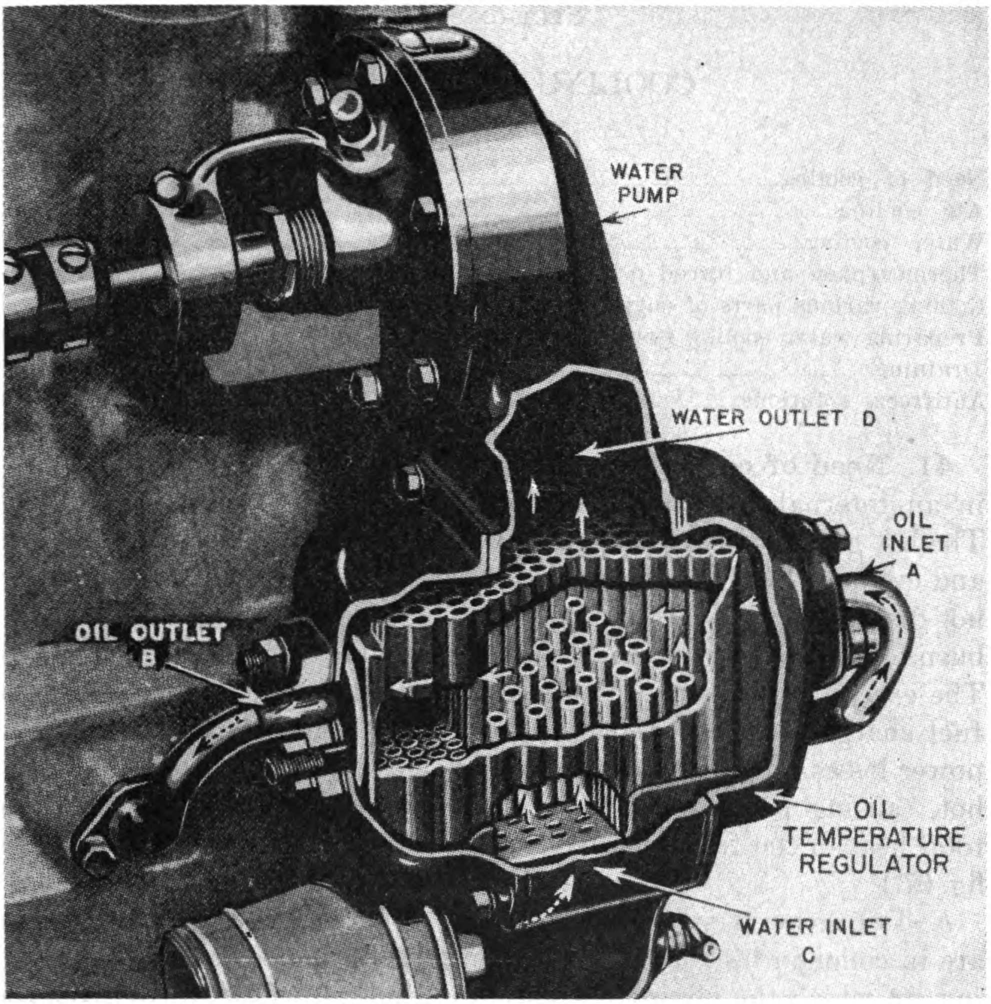


FIGURE 66.—Oil-temperature regulator (sectional view).

radiator core. The path of the oil is shown entering the unit at (A) and leaving at (B). Water enters the unit at (C), flows up through the radiator section, and leaves the unit at (D). The water picks up heat from the oil or transfers heat to it, depending on which has the higher temperature.

SECTION VII

COOLING THE ENGINE

41. Need of cooling.—*a.* The heat produced by the burning fuel in an internal combustion engine often reaches 2,000° F. or more. The hot gases come in contact with the pistons, cylinder walls, valves, and cylinder head, all of which absorb heat. If this absorbed heat is not dissipated, the valves will burn and warp, and the lubricant will burn, causing seized pistons and bearings and scored cylinder walls. The excessive temperatures would also cause undue expansion of the fuel charge, thereby creating a lean mixture which would result in power losses. Surfaces of the combustion chamber would become red hot, causing preignition. In most engines about 35 percent of the total heat in the fuel must be dissipated by the cooling system. (See fig. 67.)

b. Two general systems of cooling an internal combustion engine are in common use: *air cooling*, sometimes referred to as direct cooling, in which the engine is cooled by the direct flow of air over the cylinder surface, and *water cooling*, in which the engine is cooled by circulating water through jackets surrounding the cylinders. The water is subsequently cooled by circulating it through a radiator where is passes its heat to a current of air before being recirculated through the cylinder jacket. The later system, sometimes referred to as liquid cooling or indirect cooling, is shown in figure 68.

c. Modifications of the water-cooling system include steam cooling and sealed cooling. In the steam-cooling system, hot water is passed from the engine to the lower radiator tank, from where it returns to the engine. Steam forming in the lower tank is condensed in the radiator. This system is little used. The sealed system or "Prestone" system, as it is sometimes called, is used in some liquid-cooled aircraft engines. In this system ethylene glycol is sealed in the cooling system. Since this liquid boils at 330° F., engines using this system can run

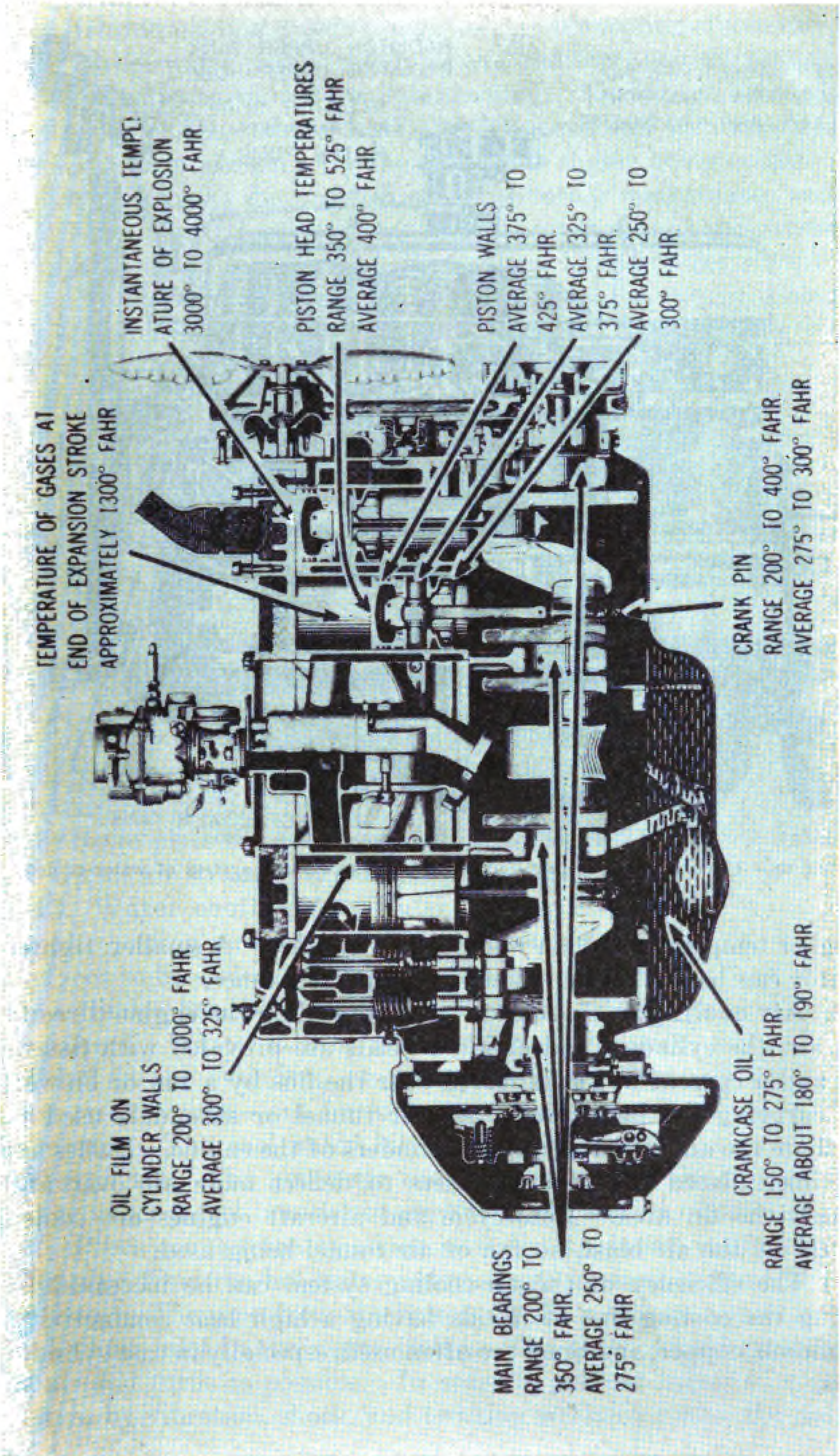


FIGURE 67.—Average operating temperatures of typical passenger-car engine at speed of about 55 miles per hour.

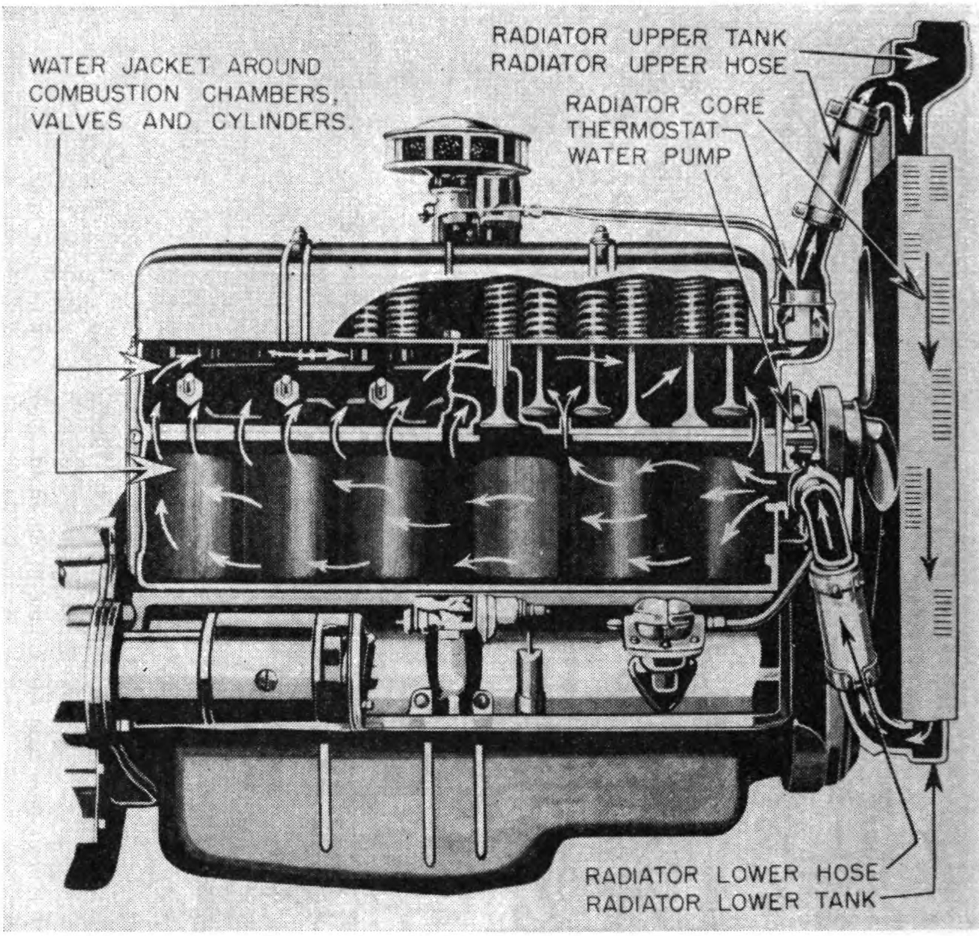


FIGURE 68.—Circulation of cooling liquid and parts of cooling system of water-cooled engine.

at higher temperatures than water-cooled engines. A smaller, lighter radiator can be used which offers less wind resistance.

42. Air cooling.—*a. Method.*—(1) In cooling the engine directly with air, the cylinders and cylinder heads are provided with fins or ribs, and a current of air is forced over the fins by a fan or blower, thus carrying the heat away. An air tunnel or shroud is used to distribute the air uniformly to all cylinders of the engine. Baffles are sometimes placed near the cylinders to deflect more air over and through the fin area. Motorcycle and aircraft engines are cooled directly by the air blast, no fan or air tunnel being used.

(2) The efficiency of the air-cooling system can be increased by making the cooling fins of metals having a high heat conductivity. Aluminum, copper, and brass are often used, especially in cast cylinder heads.

b. Advantages and disadvantages.—(1) Air cooling eliminates such parts as the water pump, water jackets, radiator, and all piping and hose connections required for water cooling. These parts are replaced by the fins on the cylinder head and cylinders, and such fans and air tunnels as are necessary for the particular engine being cooled. Air cooling eliminates the problem of cold weather maintenance and the need for an antifreeze solution. With proper design and control of temperatures, it permits higher operating temperatures with better thermal efficiency. From the military standpoint, the air-cooled engine eliminates the problem of water supply and renders the vehicle engine less vulnerable to gunfire.

(2) Since the cylinders of an air-cooled engine must be cast separately in order to provide ample cooling area, the construction of this type of engine is much more expensive than that of the water-cooled type. The air-cooled engine can only be cooled by circulating large volumes of air past the cooling fins on the cylinders. This requirement introduces the problem of providing a large fan or blower to circulate the air. A fan large enough to cool the engine at idling speeds requires too much of the engine horsepower output to drive it and reduces the net amount of power available for driving the vehicle.

(3) With few exceptions, air-cooled engines have bene confined to the motorcycle and airplane industry, where compactness and light weight are essential. When air-cooled engines are used in automotive vehicles, the trend is to use the flat, horizontal-opposed type engines in order to place the cylinders low in the vehicle where they will be in the direct air stream created by the moving vehicle. (See fig. 69.)

43. Water cooling.—*a.* Water cooling is accomplished by keeping the cooling medium, water, in circulating contact with the metal surfaces to be cooled. This is performed by placing a jacket around the cylinder head and valve seats, through which the water can be circulated. Water jackets are cast integrally with the cylinders, welded to the cylinders, or mechanically attached. Water jackets have two openings—one for cool water to enter, and one for hot water to escape. The cool-water inlet is usually near the bottom of the water jacket. The hot-water opening must be at the highest point in the water jacket in order to prevent the formation of steam pockets.

b. Pipes connect the openings in the water jacket to the radiator. The pipe from the hot-water outlet slopes upward to the top of the radiator. The pipe from the bottom of the radiator slopes up to the cool-water inlet in the water jacket. The pipes should have as few bends and turns as possible. In order to prevent injury to a cooling system by vibration, shock, and twisting strains between the radiator and the engine, the rigidity of the pipes is relieved by the use of short lengths of rubber hose (radiator hose).

c. Radiators cool the hot water leaving the water jackets so that the same water may be reused for cooling the engine. When the water has been cooled it is circulated through the jackets, thence through

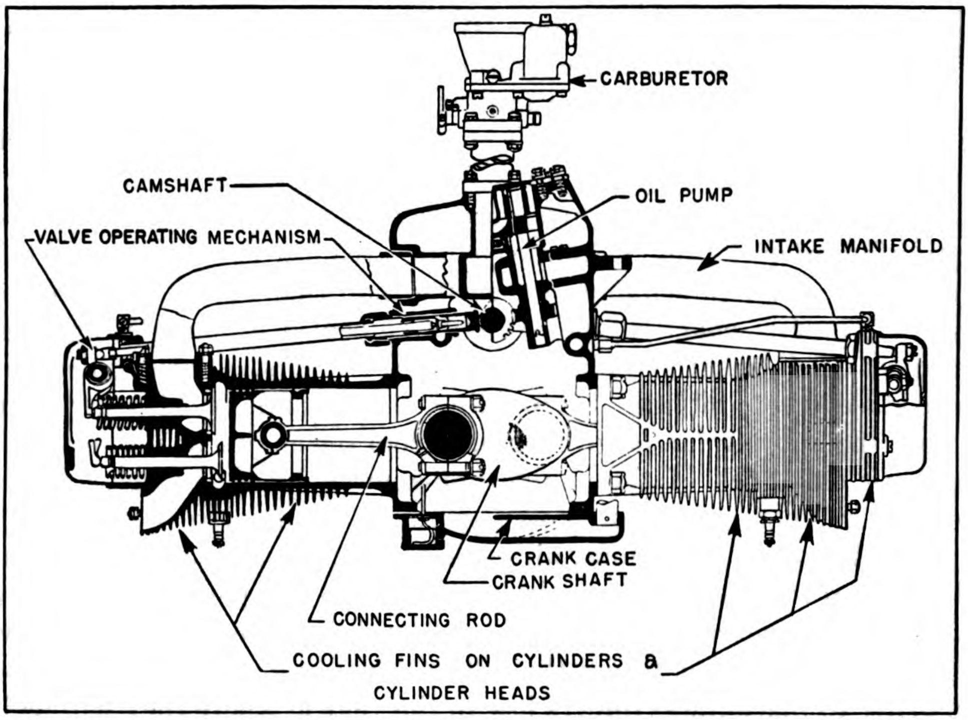


FIGURE 69.—Small air-cooled automotive engine of four-cycle horizontal-opposed type. Left-hand front cylinder is cut away to show cylinder-wall construction.

the radiator, repeating the cycle. All radiators for motor vehicles consist of two tanks, between which is a core forming the radiating element. The core, of either tubular or cellular construction, is usually made of copper or brass. The core divides the water into very thin columns or ribbons, thus exposing a large radiating surface area to the air for the volume of water to be cooled. While going through the core, the water gives up heat, transferring it through the metal conductors of the radiator core to the cool air. The air flow through the core is maintained by a fan which is usually driven by a V-belt from the front end of the engine crankshaft.

d. An overflow pipe is placed in the top of the radiator to maintain atmospheric pressure in the radiator. If the overflow pipe becomes clogged, the pressure of any steam generated is liable to rupture the thin metal walls of the radiator core.

44. Thermosyphon and forced cooling.—*a*. The flow of water through the cooling system is maintained either by a pump, usually of centrifugal type, or by thermosyphon.

b. The thermosyphon system works by gravity. Cold water is heavier than hot water. As water in the jackets becomes heated it expands and therefore becomes lighter. This heated water rises and

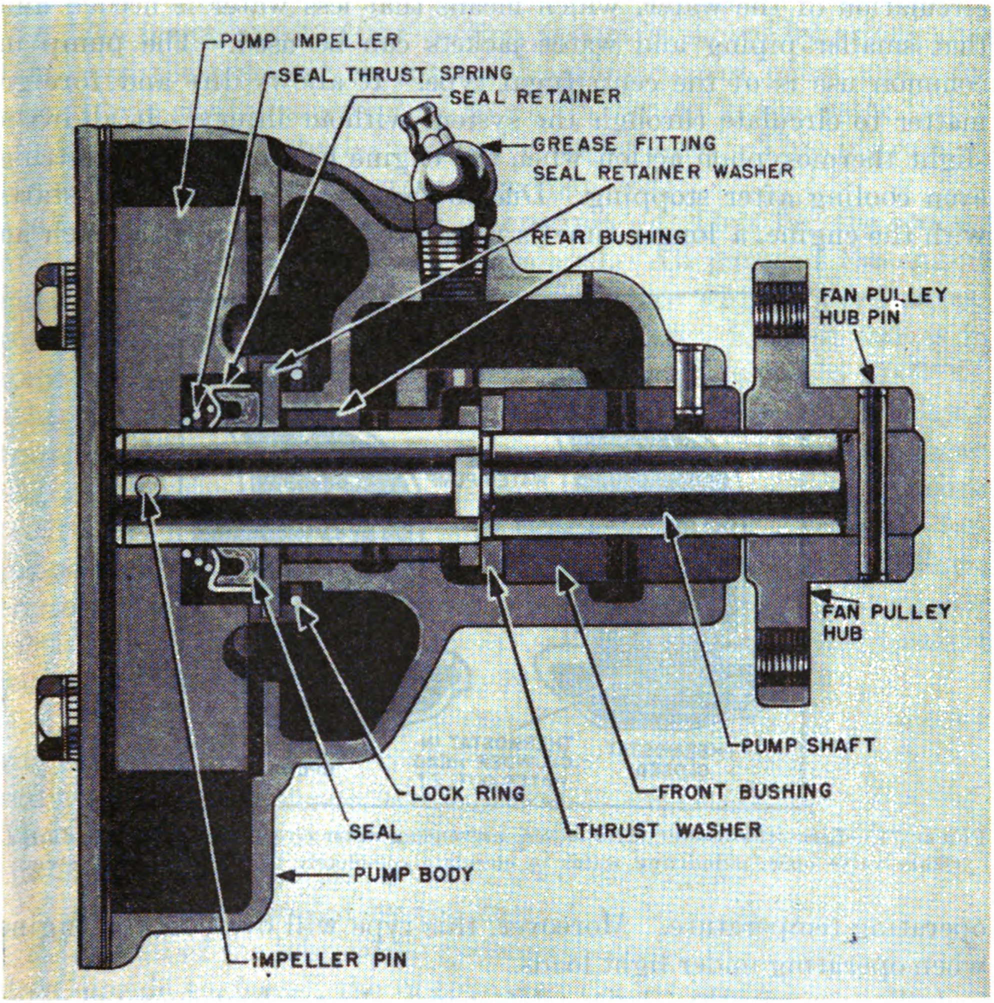


FIGURE 70.—Packless water pump (sectional view).

is displaced by the heavier cold water. The flow of water in this type of cooling system is comparatively slow. The pipe openings, and water jackets must be large to facilitate the flow of a larger volume of water than is needed in a pump circulation system. Furthermore, the water level in the radiator must always be above the hot water pipe in the top tank. This system has the advantage, however, of being simple, cheaper to construct, and allowing the cylinders to attain a running temperature rapidly without overcooling under part load operation. The rate of circulation is independent of engine speed, governed only by the heat supply to the water in the jacket.

c. The pump or force circulation system resembles the thermosyphon system except that it makes use of a pump to circulate the water. (See fig. 70.) The pump is driven by the engine and insures a rapid circulation of the water, which means that less water is needed and that smaller piping and water jackets can be used. The pump in common use is of the centrifugal type. It allows dirt and foreign matter to circulate through the system without injury. It allows a slight thermosyphon action when the engine has stopped, permitting even cooling after stopping. Due to the fact that the pump starts with the engine, a longer time is required for the engine to reach an

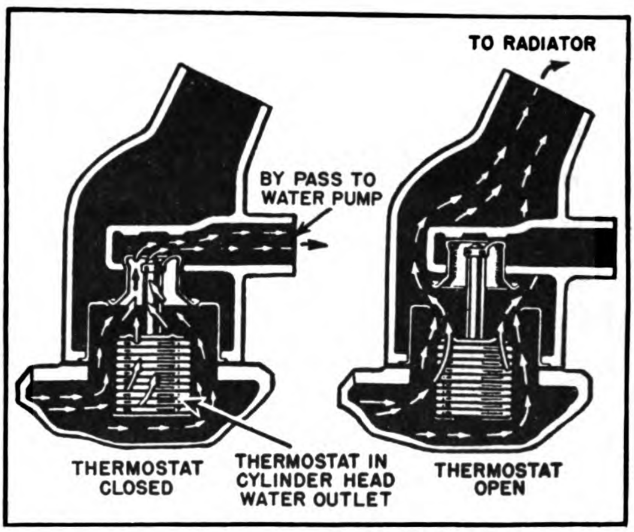


FIGURE 71.—Left—thermostat valve closed, preventing water circulation through radiator; right—valve open, permitting water to circulate completely through cooling system.

operating temperature. Moreover, this type will overcool the engine when operating under light loads.

d. To overcome this obvious defect in cooling, a heat operated valve (thermostat) is placed in the return line to the radiator to block the circulation of water partially or completely until the engine has reached an efficient operating temperature, when the valve opens and permits circulation. (See fig. 71.) When cool or cold water again reaches this valve, it closes and restricts or stops circulation until the water is sufficiently heated to open it. Other devices to insure efficient operating temperatures are the manual and automatic (operated by thermostat) shutters to restrict or block the flow of air through the core of the radiator.

e. The ideal temperature of operation for the water-cooled engine would be just under the boiling point of water (212° F.), but a safety factor must be allowed so operating temperatures of 170° to 185° F. are used. Engines are not considered warmed up until an operating temperature of 140° F. is reached. To assist in warming up during cold weather, a blanket or piece of paper may be placed over the front of the radiator.

f. The temperature of the cooling system is shown by a long distant type thermometer consisting of an instrument panel unit connected by a small diameter tube to a bulb located in the water jacket at the top of the cylinder block or cylinder head. This instrument is similar to the oil temperature gage (par. 36*d*).

45. Cooling various parts of engine.—*a.* Thus far, the cooling of the cylinders only has been considered. All parts of the engine must be kept below temperatures that interfere with proper lubrication, operation, or that cause undue expansion. Exhaust valves in some high speed engines run at temperatures of 1,800° to 2,000° F. (this is above a red heat). The exhaust valve is partly cooled by a transfer of heat from the valve head to the valve seat, and to a lesser degree from the valve stem to its guide. The exhaust valve remains on its seat for three strokes (approximately) out of the four. Improper seating of the valve will mean inadequate cooling. Some engines have a water distributing tube inserted through the cylinder casting which directs a stream of cool water against the exhaust passages. This is shown in figure 72.

b. Pistons are cooled by the transfer of heat through the piston rings and oil film to the cooled cylinder walls. Some heat is also radiated from the inside of the piston to the air in the crankcase. The oil that collects on the underside of the piston head and falls into the crankcase carries heat with it from the piston.

c. Bearings are cooled by the flow of oil through them.

d. The oil of the lubrication system also assists in cooling the cylinders (inside surfaces), the pistons, and the air inside the crankcase. The oil is cooled by radiation from the oil pan, which is sometimes provided with fins or ribs to facilitate the radiation of heat to the surrounding air. Oil coolers using either air or water as the cooling medium are being used on some engines to insure adequate cooling of the oil. To reduce the temperature of the oil during operation, from 300° F. to 210° F. of heat must be dissipated from the oil at a rate in excess of 250 B. t. u. per minute, or a heat equivalent of approximately six horsepower per minute. This summary indicates the extent to which lubricating assists in cooling an engine.

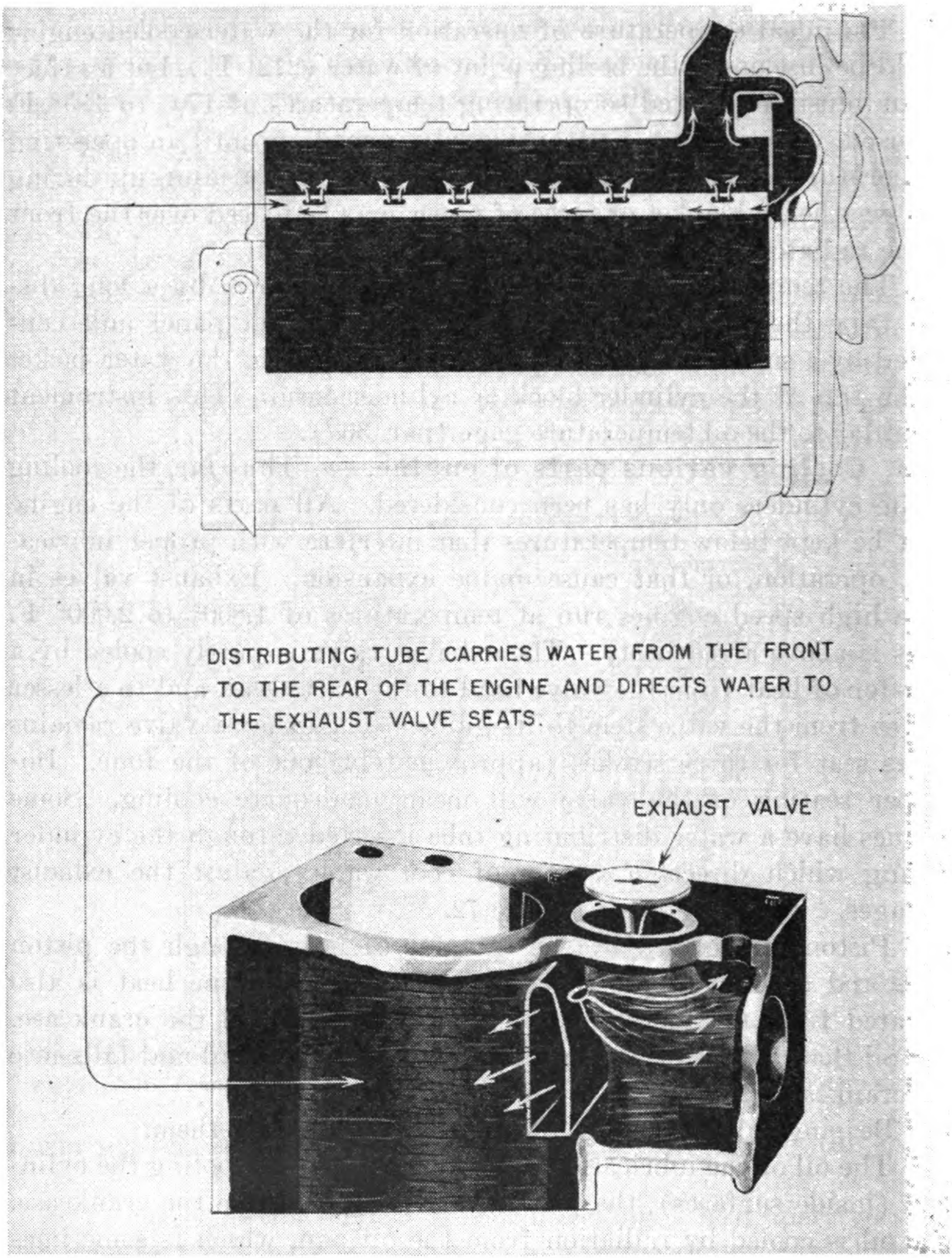


FIGURE 72.—Controlled stream of cool water against exhaust-valve ports (sectional view).

46. Preparing a water cooling system for cold weather.—
a. When water freezes it expands about one-ninth. This means that the ice, in addition to stopping the flow of water, is likely to rupture some part of the system.

b. Should a system freeze solid it must be thawed by placing the vehicle in a warm place. *Under no circumstances should the engine be run when the system is completely frozen.*

c. Sometimes mush ice will form in the radiator. While it is safer, in this case, to place the vehicle in a heated garage, the ice may be melted by placing a blanket over the radiator and running the engine very slowly.

47. Draining.—*a.* The simplest method of preventing freezing is to drain the cooling system when the vehicle is not in use. Drain cocks are usually provided at the lowest points of water jackets, at the bottom of the radiator, at the low point of the pump, and sometimes at the low point of the piping. It is advisable to run the engine for ½ minute after draining is apparently complete to make certain that all water has been drained. As an assurance that the cooling system has been drained and as an indication that it must be filled before operating the vehicle, a card with the word "drained" painted on it should be suspended from the filler cap and a similar card attached to the steering wheel.

b. When an engine has been left drained in very cold weather, hot water should be used in refilling the cooling system. This will not only prevent part of the cooling system from freezing at once but will facilitate starting. A cold engine should be warmed slowly; it is very detrimental to race or accelerate it rapidly while cold.

48. Antifreeze solutions.—*a.* A more satisfactory method of preventing water from freezing in a cooling system is to use some substance in solution with the water to reduce its freezing point. A number of such compounds are known to exist but only four of these are in common use today.

Antifreeze solution	Boiling point (°F.)	Percent (by volume) to protect at °F.				
		+20°	+10°	0°	−10°	−20°
Methyl (wood alcohol)	148	12	20	30	35	40
Ethyl (denatured) alcohol	172	20	30	40	45	50
Glycerine	227	20	30	40	45	50
Ethyleneglycol (Prestone)	330	15	25	35	40	45

b. Both methyl and denatured alcohol boil at temperatures below or in the operating temperature range of the engine. As a result these antifreezes must be renewed from time to time throughout the cold weather period. Daily readings on a "freezometer" should be taken of all vehicles operated during the day. They are both safe when used in adequate quantities. They have a disagreeable odor and if spilled on the hood will damage the lacquer finish. The initial cost of both these alcohols is low, and they offer less resistance to flow than glycerine or ethylene glycol.

c. Glycerine is obtained from certain animal fats and vegetable oils. It is a byproduct of the soap industry. It is so hydroscopic that it will absorb half its weight in water from the moisture in the air. The outstanding characteristics of glycerine as an antifreeze are: it does not evaporate in use as it has a higher boiling point than water; it offers the same degree of protection as denatured alcohol; it does not damage lacquer finishes if spilled on them; it is more expensive initially but does not require renewal unless lost through leakage; due to its tendency to creep, the cooling system must be thoroughly tightened to prevent leakage during use; it is noncorrosive if properly distilled; it can be used for more than one winter if the solution is drained and stored; it has no odor; it becomes slightly viscous at very low temperature. Due to the hydroscopic nature of glycerine and the number of firms which manufacture it (some products are of doubtful reliability), glycerine may be considerably diluted when it reaches the hands of the consumer. If diluted, more antifreeze will have to be used than is indicated by the table in *a* above, which is for 95 percent glycerine by weight.

d. Sometimes a mixture of glycerine and alcohol is used as an antifreeze. The main objection to such a practice is the impossibility of telling by hydrometer (freezometer) whether the system has adequate protection.

e. Ethylene glycol belongs to the alcohol family. It is a byproduct in the manufacture of artificial gas. Its boiling point is 330° F. The chief characteristics of ethylene glycol are: it furnishes complete protection against freezing when used in sufficient quantity; it does not evaporate in use; it is not hydroscopic in action; it is noncorrosive; it will not injure lacquer finish of car; it has no odor; it is nonviscous at low temperatures; and it can be used for more than one winter. The cooling system should be carefully serviced to prevent leakage before filling with ethylene glycol.

f. It should be remembered that although antifreeze solutions prevent the formation of ice in the cooling system, they have no effect upon keeping the engine from operating at too low a temperature. This can be achieved only by reducing the cooling area of the radiator by means of a cover or shutter device or by a thermostat to control the flow of water through the engine.

g. When using an antifreeze the cooling system should not be completely filled. An allowance should be made for expansion, otherwise a part of the solution will be lost through the overflow pipe.

Appendix

BIBLIOGRAPHY

The following sources have been consulted in the preparation of this manual for illustrations and text material. They contain more detailed information on internal combustion engines than is contained herein, and it is suggested that it would be advantageous for the student to consult them as collateral reading.

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