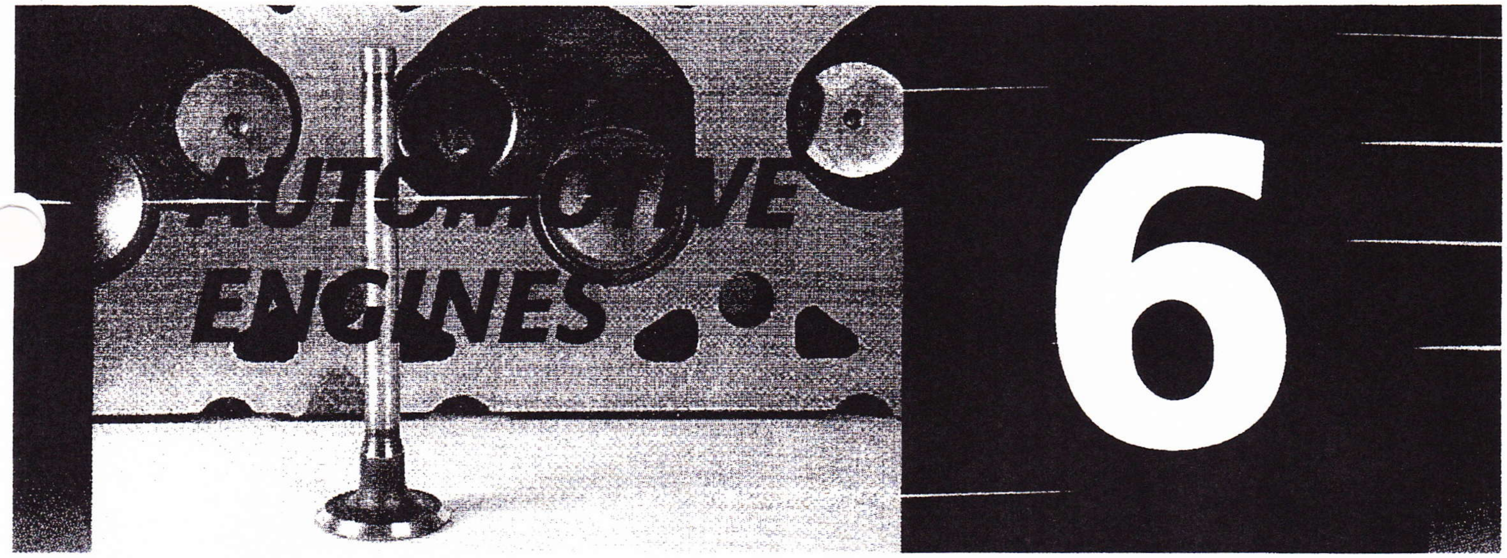
Automotive Engines



OBJECTIVES

◆ Describe the various ways in which engines can be classified. ◆ Explain what takes place during each stroke of the four-stroke cycle. ◆ Describe the differences between two-stroke and four-stroke engines. ◆ Outline the advantages and disadvantages of the in-line and V-type engine designs. ◆ Define important engine measurements and performance characteristics, including bore and stroke, displacement, compression ratio, engine efficiency, torque, and horsepower. ◆ Explain how to evaluate the condition of an engine. ◆ List and describe nine abnormal engine noises. ◆ Outline the basics of diesel, rotary, and stratified engine operation.

Modern engines are highly engineered power plants. These engines are designed to meet the performance and fuel efficiency demands of the public. The days of the heavy, cast-iron V-8 engine with its poor gas mileage are quickly drawing to a close. Today, these engines have been replaced by compact, lightweight, and fuel-efficient engines (Figure 6–1). Modern engines are made of lightweight engine castings and stampings; non-iron materials (for example, aluminum, magnesium, fiber-reinforced plastics); and fewer and smaller fasteners to hold things together. These fasteners are made possible through computerized joint designs that optimize loading patterns. Each of these newer engine designs has its own distinct personality, based on construction materials, casting configurations, and design.

These modern engine building techniques have changed how engine repair technicians make their money. Before these changes can be explained, it is important to explain the "basics" of engine design and operation (Figure 6–2).

FIGURE 6–1 Typical late-model engine. *Courtesy of General Motors Corporation*

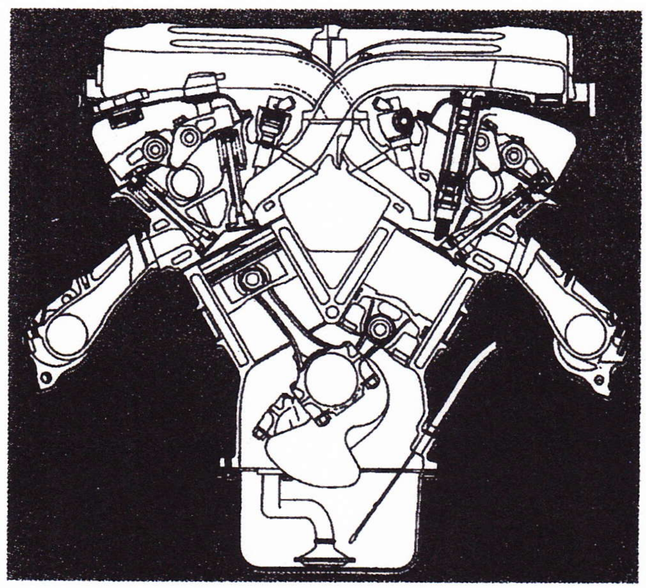


FIGURE 6–2 Modern V-6 engine. *Courtesy of Chrysler Corporation*

ENGINE CLASSIFICATIONS

Today's automotive engines can be classified in several ways depending on the following design features.

- Operational cycles. Most technicians will generally come in contact with only four-stroke cycle engines (Figure 6–3). However, a few older cars

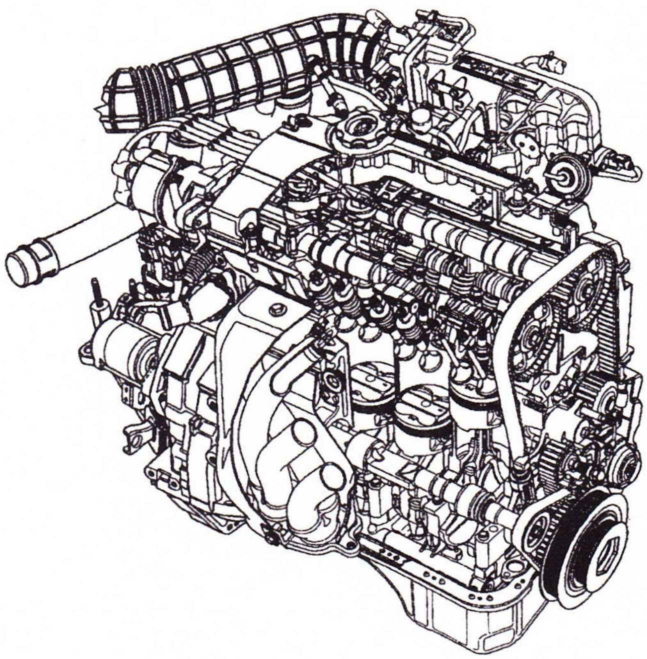


FIGURE 6–3 Major components of a four-stroke engine. *Courtesy of American Honda Motor Company, Inc.*

have used and some cars in the future will use a two-stroke engine.

- Number of cylinders. Current engine designs include 3-, 4-, 5-, 6-, 8-, and 12-cylinder engines.
- Cylinder arrangement. An engine can be flat (opposed), in-line, or V-type. Other more complicated designs have also been used.
- Valve train type. Engine valve trains can be either the overhead camshaft (**OHC**) type or the camshaft in-block overhead valve (**OHV**) type. Some engines separate camshafts for the intake and exhaust valves. These are based on the OHC design and are called dual overhead camshaft (**DOHC**) engines. V-type DOHC engines have four camshafts—two on each side.
- Ignition type. There are two types of ignition systems: spark and compression. Gasoline engines use a spark ignition system. In a spark ignition system, the air/fuel mixture is ignited by an electrical spark. Diesel engines, or compression ignition engines, have no spark plugs. An automotive diesel engine relies on the heat generated as air is compressed to ignite the air/fuel mixture for the power stroke.
- Cooling systems. There are both air-cooled and liquid-cooled engines in use. Nearly all of today's engines have liquid-cooling systems.
- Fuel type. Several types of fuel currently used in automobile engines include gasoline, natural gas, diesel, and propane. The most commonly used is gasoline.

FOUR-STROKE GASOLINE ENGINE

In a passenger car or truck, the engine provides the rotating power to drive the wheels through the transmission and driving axles. All automobile engines, both gasoline and diesel, are classified as internal combustion because the combustion or burning takes place inside the engine. These systems require an air/fuel mixture that arrives in the combustion chamber at the correct time and an engine constructed to withstand the temperatures and pressures created by the burning of thousands of fuel droplets.

The **combustion chamber** is the space between the top of the piston and cylinder head. It is an enclosed area in which the gasoline and air mixture is burned. The piston is a hollow metal tube with one end closed that moves up and down in the cylinder. This reciprocating motion is caused by an increase of pressure, due to combustion, in the cylinder.

The reciprocating motion must be converted to a rotary motion before it can drive the wheels of a vehicle. This change of motion is accomplished by connecting the piston to a crankshaft with a connecting rod (Figure 6–4). The upper end of the connecting rod moves with the piston as it moves up and down in the cylinder. The lower end of the connecting rod is attached to the crankshaft and moves in a circle. The end of the crankshaft is connected to the flywheel, which transfers the engine's power through the drivetrain to the wheels.

In order to have complete combustion in an engine, the right amount of fuel must be mixed with the right amount of air. This mixture must be compressed in a sealed container then shocked by the right amount of heat at the right time. When these condi-

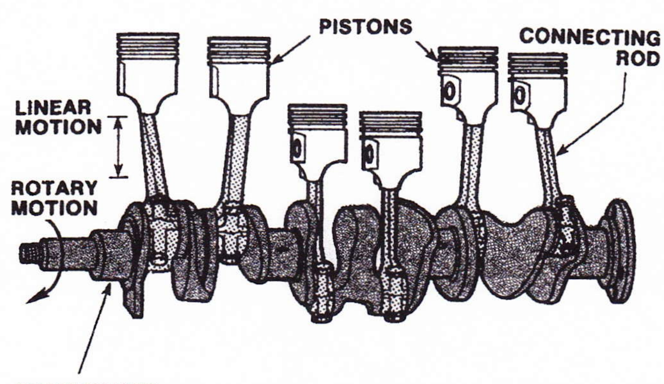


FIGURE 6–4 The reciprocating motion of the pistons is converted to rotary motion by the crankshaft.

tions exist, all the fuel that enters a cylinder is burned and converted to power. This power is used to move the vehicle. The ignition system is responsible for providing the heat, and the air and fuel system is responsible for providing the air/fuel mixture. The construction of the engine and its different parts are responsible for providing a container for the combustion process. This container is the cylinder of an engine. Automotive engines have more than one cylinder. Each cylinder should receive the same amount of air, fuel, and heat, if the engine is to run efficiently.

Although the combustion must occur in a sealed cylinder, the cylinder must also have some means of allowing heat, fuel, and air into it. There must also be a means to allow the burnt air/fuel mixture out so a fresh mixture can enter and the engine can continue to run. To accommodate these requirements, engines are fitted with valves.

There are at least two valves at the top of each cylinder. The air/fuel mixture enters the combustion chamber through an intake valve and leaves (after having been burned) through an exhaust valve. The valves are accurately machined plugs that fit into machined openings. A valve is said to be seated or closed when it rests in its opening. When the valve is pushed off its seat, it opens.

A rotating camshaft, driven by the crankshaft, opens and closes the intake and exhaust valves. **Cams** are raised sections of a shaft that have high spots called **lobes**. As the camshaft rotates, the lobes rotate and push the valve open by pushing it away from its seat. Once the cam lobe rotates out of the way, the valve, forced by a spring, closes. The camshaft can be located either in the cylinder block or in the cylinder head.

When the action of the valves and the spark plug is properly timed to the movement of the piston, the combustion cycle takes place in four strokes of the piston: the intake stroke, the compression stroke, the power stroke, and the exhaust stroke. A **stroke** is the full travel of the piston either up or down in the cylinder bore.

The up-and-down movement of the piston on all four strokes is converted to a rotary motion by the crankshaft. It takes two full revolutions of the crankshaft to complete the four-stroke cycle.

The piston moves by the pressure produced during combustion only about half a stroke or one-quarter of crankshaft revolution. This explains why a flywheel is needed. The flywheel stores some of the power produced by the engine. This power is used to keep the pistons in motion during the rest of the four-stroke cycle. This power is also used to compress the air/fuel mixture just before combustion.

INTAKE STROKE The first stroke of the cycle is the intake stroke. As the piston moves away from top dead center (TDC), the intake valve opens (Figure 6–5A). The downward movement of the piston increases the volume of the cylinder above it. This reduces the pressure in the cylinder. This reduced pressure, commonly referred to as engine vacuum, causes the atmospheric pressure to push a mixture of air and fuel through the open intake valve. (Some engines are equipped with a super- or turbocharger that pushes more air past the valve.) As the piston reaches the bottom of its stroke, the reduction in pressure stops. This causes the intake of air/fuel mixture to slow down. It does not stop because of the weight and movement of the air/fuel mixture. It continues to enter the cylinder until the intake valve closes. The intake valve closes after the piston has reached bottom dead center (BDC). This delayed closing of the valve increases the volumetric efficiency of the cylinder by packing as much air and fuel into it as possible.

COMPRESSION STROKE The compression stroke begins as the piston starts to move from BDC. The intake valve closes, trapping the air/fuel mixture in the cylinder (Figure 6–5B). The upward movement of the piston compresses the air/fuel mixture, thus heating it up. At TDC, the piston and cylinder walls form a combustion chamber in which the fuel will be burned. The volume of the cylinder with the piston at BDC compared to the volume of the cylinder with the piston at TDC determines the compression ratio of the engine.

POWER STROKE The power stroke begins as the compressed fuel mixture is ignited (Figure 6–5C). An electrical spark across the electrodes of a spark plug ignites the air/fuel mixture. The burning fuel rapidly expands, creating a very high pressure against the top of the piston. This drives the piston down toward BDC. The downward movement of the piston is transmitted through the connecting rod to the crankshaft.

EXHAUST STROKE The exhaust valve opens just before the piston reaches BDC on the power stroke (Figure 6–5D). Pressure within the cylinder causes the exhaust gas to rush past the open valve and into the exhaust system. Movement of the piston from BDC pushes most of the remaining exhaust gas from the cylinder. As the piston nears TDC, the exhaust valve begins to close as the intake valve starts to open. The exhaust stroke completes the four-stroke cycle. The opening of the intake valve begins the cycle again. This cycle occurs in each cylinder and is repeated over and over, as long as the engine is running.

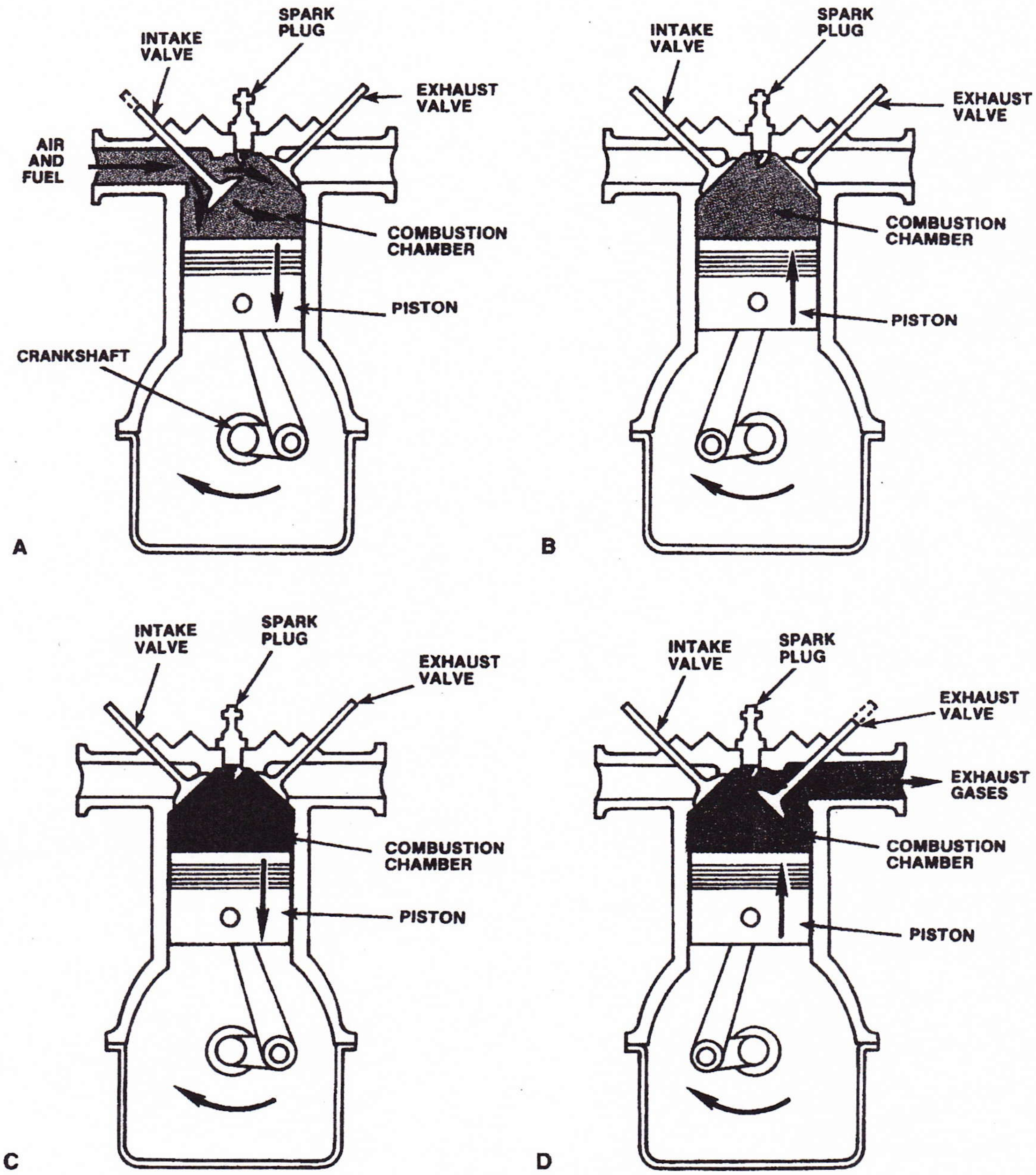


FIGURE 6–5 (A) Intake stroke, (B) compression stroke, (C) power stroke, and (D) exhaust stroke.

TWO-STROKE GASOLINE ENGINE

In the past, several imported vehicles have used two-stroke engines. As the name implies, this engine requires only two strokes of the piston to complete all four operations: intake, compression, power, and exhaust. As shown in Figure 6–6, this is accomplished as follows.

1. Movement of the piston from BDC to TDC completes both intake and compression (Figure 6–6A).
2. When the piston nears TDC, the compressed air/fuel mixture is ignited, causing an expansion of the gases. Note that the reed valve is closed and the piston is blocking the intake port (Figure 6–6B).
3. Expanding gases in the cylinder force the piston down, rotating the crankshaft (Figure 6–6C).
4. With the piston at BDC, the intake and exhaust ports are both open, allowing exhaust gases to leave the cylinder and air/fuel mixture to enter (Figure 6–6D).

Although the two-stroke-cycle engine is simple in design and lightweight because it lacks a valve train, it has not been widely used in automobiles. They tend to be less fuel efficient and have dirtier exhaust than four-stroke engines. Oil is often in the exhaust

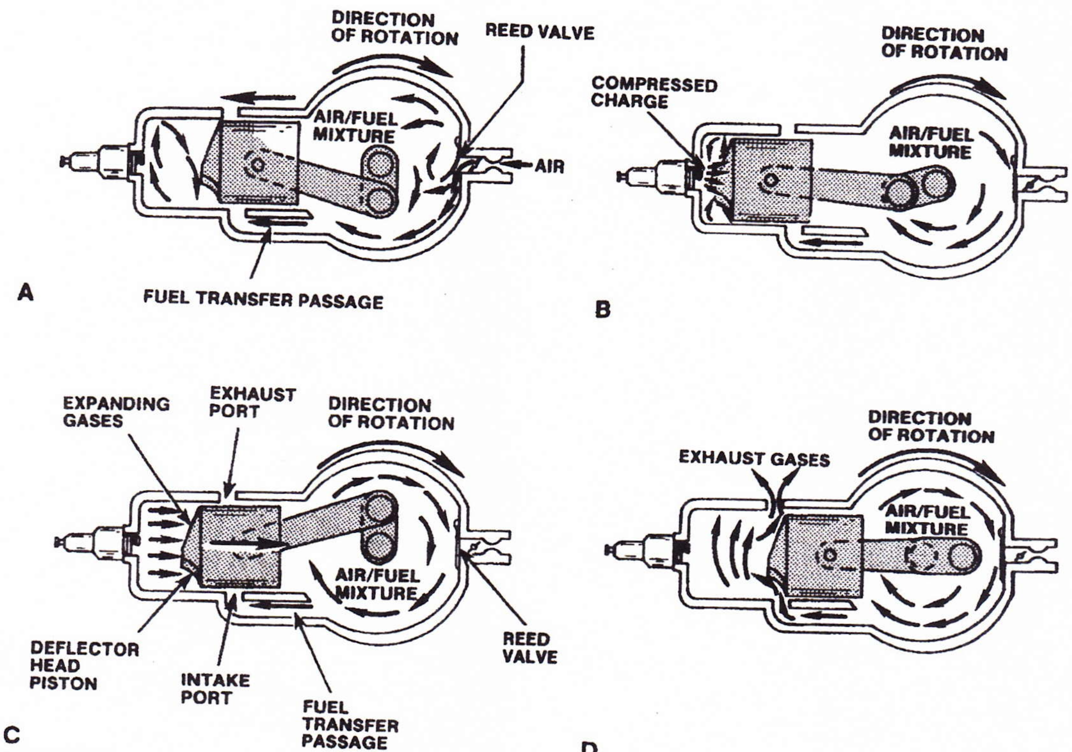


FIGURE 6–6 Steps of a two-stroke engine cycle.

stream because these engines require constant oil delivery to the cylinders to keep the piston lubricated. Some of these engines require a certain amount of oil to be mixed with the fuel.

In recent years, however, thanks to a revolutionary pneumatic fuel injection system, there has been increased interest in the two-stroke engine. The injection system, which works something like a spray paint gun, uses compressed air to flow highly atomized fuel directly into the top of the combustion chamber. The system becomes the long sought-after answer to the fuel economy and emissions problems of the conventional two-stroke engine. This fuel injection system is the basis for orbital two-stroke direct injection piston engine, which may be used in cars in the future.

A small two-stroke engine can deliver as much horsepower, with less fuel, as a larger displacement four-stroke engine because in a two-stroke engine, combustion occurs every crankshaft revolution rather than every other revolution (Figure 6–7). This fact explains why the orbital engine has gained promise for the future. The improvement in fuel economy the orbital engine has achieved is due in part to a number of mechanical design features in addition to its pneumatic direct injection fuel system.

One of these features is the use of a three-cylinder engine block (Figure 6–8). Although the same direct injection technology can be used with a four-cylinder or a V-6, a three-cylinder block saves the weight, bulk, and manufacturing expenses. The reduction in internal engine friction achieved by eliminating additional pistons and the absence of a valve train is in itself worth a significant improvement in fuel economy.

Additional performance improvements are obtained in the orbital two-stroke design by using a high-turbulence combustion chamber. The engine also has an exhaust port scavenge flow control valve, which is controlled by the engine computer to increase low-speed torque and assist in emissions control. The valve can be partially closed to restrict the

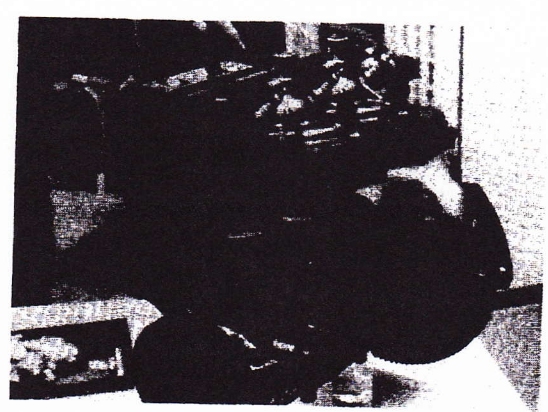


FIGURE 6–7 Cutaway of a two-stroke engine.

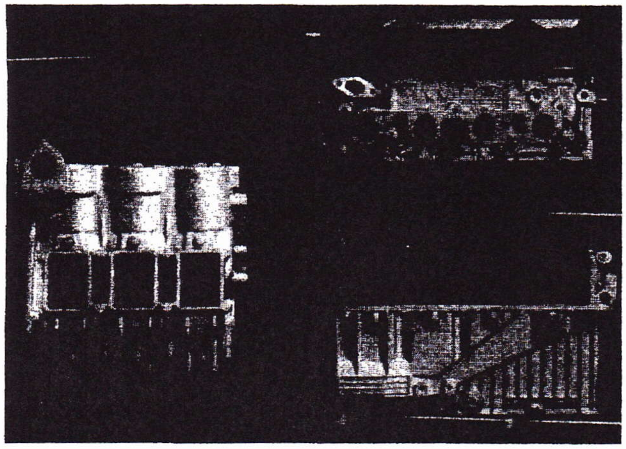


FIGURE 6–8 Main castings of the 3-cylinder orbital engine.

flow of exhaust out of the cylinder. This accomplishes the same results as an EGR, a reduction in NO_X.

CHARACTERISTICS OF FOUR-STROKE ENGINE DESIGN

Depending on the vehicle, either an in-line, V-type, slant, or opposed cylinder design can be used. The most popular designs are in-line and V-type engines.

IN-LINE ENGINE In the in-line engine design (Figure 6–9), the cylinders are all placed in a single row. There is one crankshaft and one cylinder head for all of the cylinders. The block is cast so all cylinders are located in an upright position.

In-line engine designs have certain advantages and disadvantages. They are easy to manufacture and service. However, because the cylinders are positioned vertically, the front of the vehicle must be higher. This affects the aerodynamic design of the car. Aerodynamic design refers to the ease at which the car can move through the air. When equipped with an in-line engine, the front of a vehicle cannot be made as low as it can with other engine designs.

V-TYPE ENGINE The V-type engine design has two rows of cylinders (Figure 6–10) located 60 to 90 degrees away from each other. A V-type engine uses one crankshaft, which is connected to the pistons on both sides of the V. This type of engine has two cylinder heads, one over each row of cylinders.

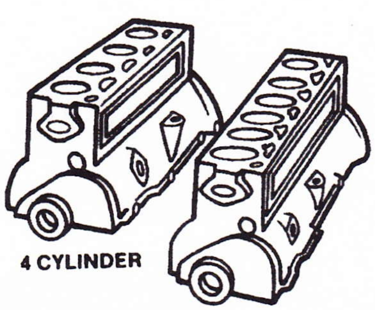


FIGURE 6–9 In-line engine designs.

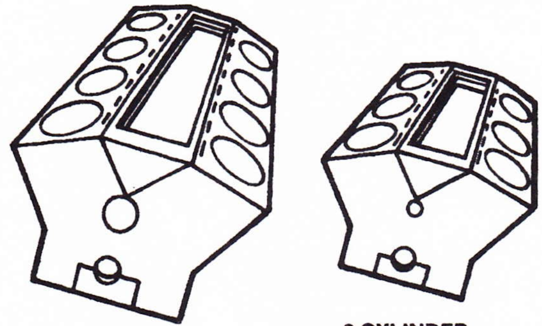


FIGURE 6–10 V-type engine designs.

One advantage of using a V-configuration is that the engine is not as high or long as an in-line configuration. The front of a vehicle can now be made lower. This design improves the outside aerodynamics of the vehicle. If eight cylinders are needed for power, a V configuration makes the engine much shorter, lighter, and more compact. Many years ago, some vehicles had an in-line eight-cylinder engine. The engine was very long and its long crankshaft also caused increased torsional vibrations in the engine.

SLANT CYLINDER ENGINE Another way of arranging the cylinders is in a slant configuration (Figure 6–11A). This is much like an in-line engine, except the entire block has been placed at a slant. The slant engine was designed to reduce the distance from the top to the bottom of the engine. Vehicles using the slant engine can be designed more aerodynamically.

OPPOSED CYLINDER ENGINE In this design, two rows of cylinders are located opposite the crankshaft (Figure 6–11B). Opposed cylinder engines are used in applications in which there is very little vertical room for the engine. For this reason, opposed cylinder designs are commonly used on vehicles that have the engine in the rear. The angle between the two cylinders is typically 180 degrees. One crankshaft is used with two cylinder heads.

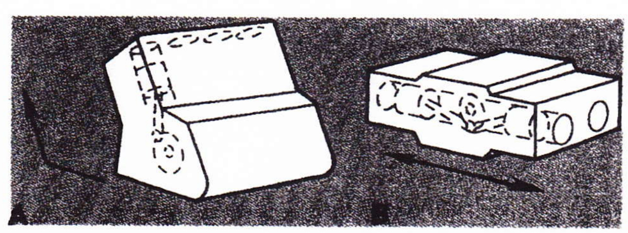


FIGURE 6–11 (A) Slant cylinder and (B) opposed cylinder engine designs.

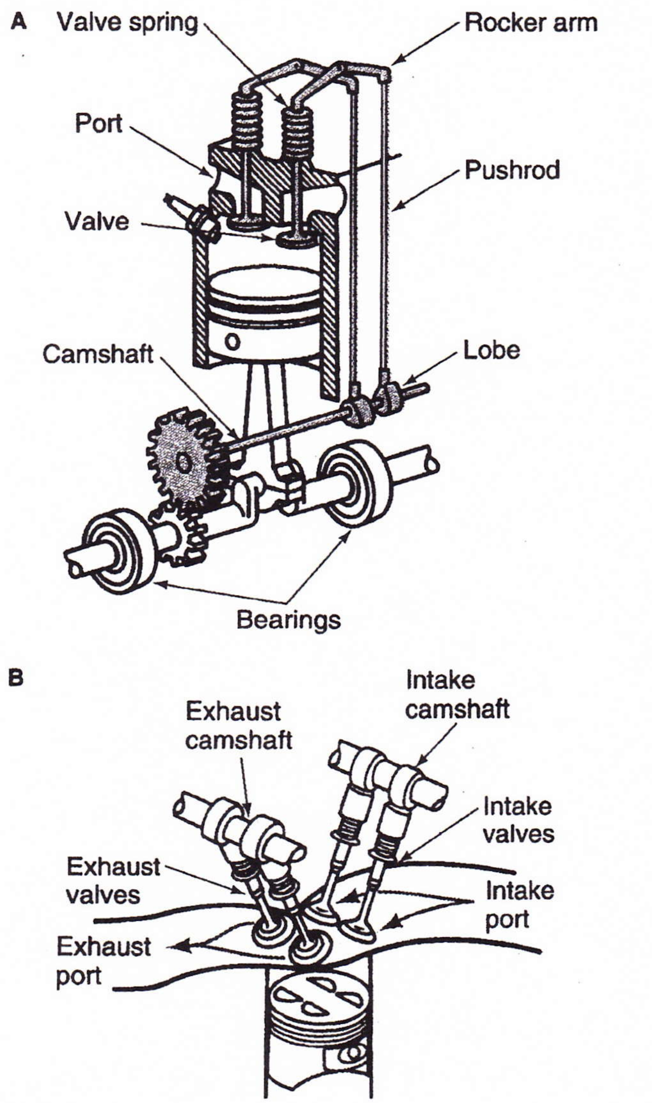


FIGURE 6–12 Basic valve and camshaft placement configurations: (A) overhead valve and (B) overhead cam.

Valve and Camshaft Placement Configurations

Two basic valve and camshaft placement configurations of the four-stroke gasoline engines are used in automobiles (Figure 6–12).

OVERHEAD VALVE (OHV) As the name implies, the intake and exhaust valves on an overhead valve engine are mounted in the cylinder head and are operated by a camshaft located in the cylinder block. This arrangement requires the use of valve lifters, pushrods, and rocker arms to transfer camshaft rotation to valve movement. The intake and exhaust manifolds are attached to the cylinder head.

OVERHEAD CAM (OHC) An overhead cam engine also has the intake and exhaust valves located in the cylinder head. But as the name implies, the cam is located in the cylinder head. In an overhead cam engine, the valves are operated directly by the camshaft or through cam followers or tappets.

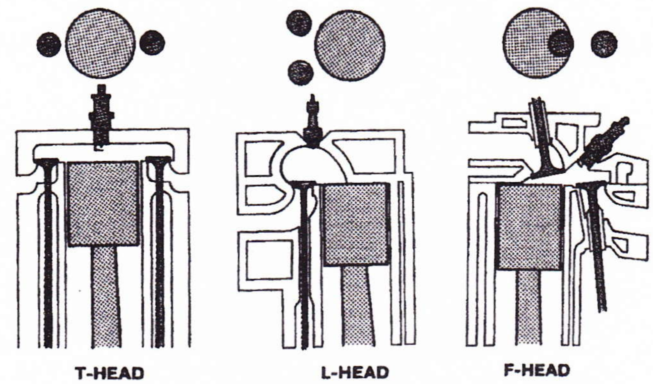


FIGURE 6–13 Other valve arrangements.

Valve Arrangement

As shown in Figure 6–13, there are several valve arrangements. Most of these designs are not used in current automotive engines.

L-HEAD ENGINE DESIGN Engines that use the L-head engine design also are called flathead or side valve engines. This was a popular valve arrangement. This engine type is characterized by having no moving parts contained in the cylinder head. The head serves only as the combustion chamber. The valves are located in the cylinder block beside each cylinder. The intake and exhaust manifolds mount to the cylinder block. The valves were opened and closed directly by the camshaft. A major drawback of this design was the air/fuel mixture had to change direction to reach the combustion chamber. This limited the overall performance of the engine.

I-HEAD ENGINE DESIGN I-head means the valves are directly above the piston (overhead valves). The valves are located in the cylinder head. The design allows air and fuel to move easily into and out of the cylinder with little restriction. Variations of this design are used in today's engines.

T-HEAD ENGINE DESIGN In the T-head design, the valves are located within the block. The difference between this design and the L-head design is that two camshafts are needed. Because of this extra expense, T-head designs have not been used in the automotive industry for many years.

F-HEAD ENGINE DESIGN The F-head engine design is a combination of the I-head and the L-head designs. There are valves located in the head as well as in the block. It has some of the advantages of the L-head and I-head designs. However, the increased cost of parts is a disadvantage.

Valve and Camshaft Operation

In OHV engines with the camshaft in the block (Figure 6–14), the valves are operated by valve lifters and pushrods that are actuated by the camshaft. On overhead cam engines, the cam lobes operate the valves directly and there is no need for pushrods or lifters.

Cam lobes are oval shaped. The placement of the lobe on the shaft determines when the valve will open. Design of the lobe determines how far the valve will open and how long it will remain open in relation to piston movement.

The camshaft is driven by the crankshaft through gears, or sprockets, and a cogged belt, or timing chain. The camshaft turns at half the crankshaft speed and rotates one complete turn during each complete four-stroke cycle.

Engine Location

The engine is typically placed in one of three locations. In the vast majority of vehicles, it is located at the front of the vehicle, in front of the passenger compartment. Front-mounted engines can be positioned either longitudinally or transversely with respect to the vehicle.

The second engine location is a mid-mount position between the passenger compartment and rear suspension. Mid-mount engines are normally transversely mounted. The third, and least common, engine location is the rear of the vehicle. The engines are typically opposed-type engines.

Each of these engine locations offers advantages and disadvantages. Typical engine locations and drivetrain configurations are illustrated in the color insert of the text.

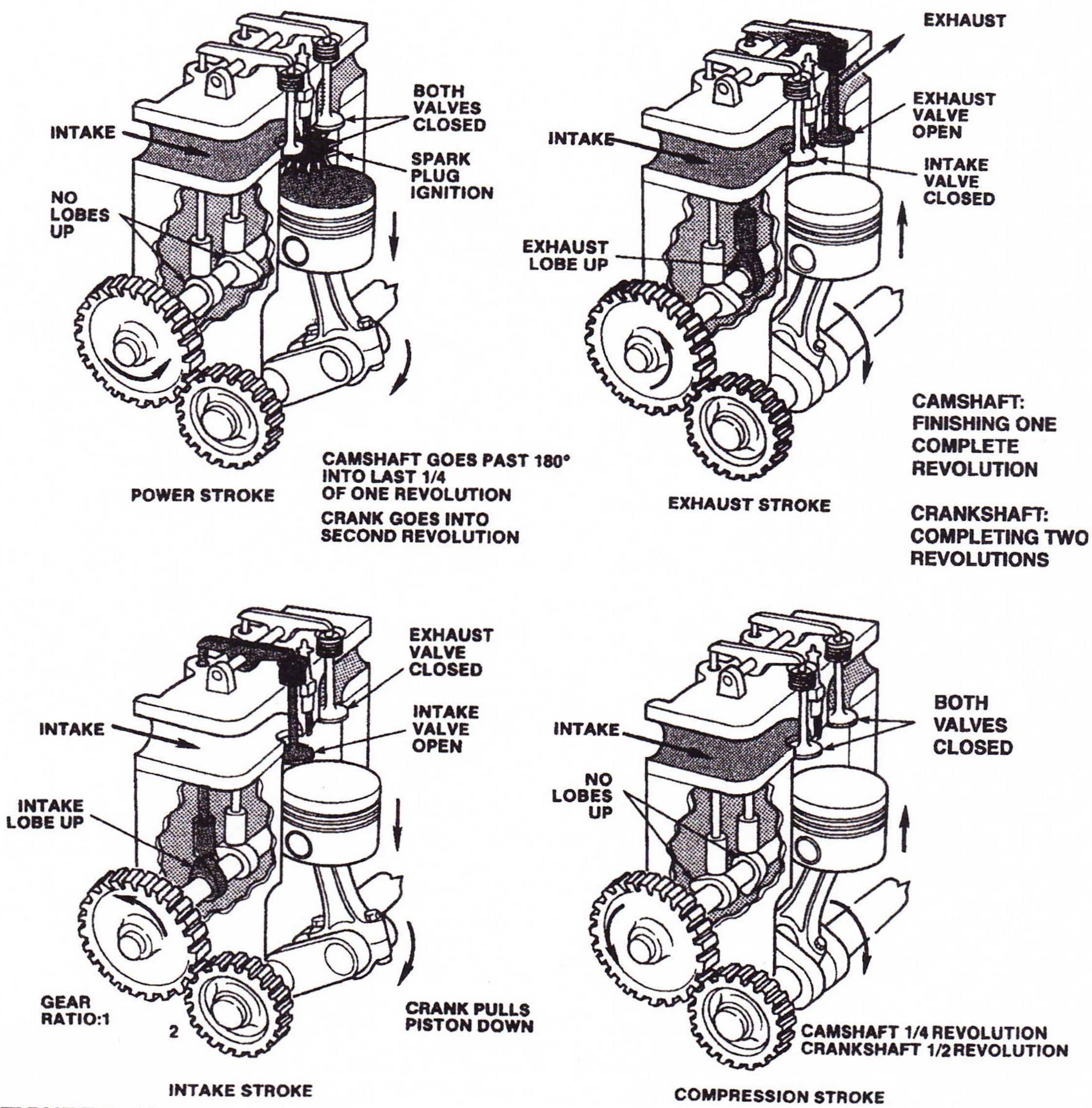


FIGURE 6–14 Valve operation in an overhead engine.

FRONT ENGINE LONGITUDINAL In this type of vehicle, the engine, transmission, front suspension, and steering equipment are installed in the front of the body, and the differential and rear suspension are installed in the rear of the body. Most front engine longitudinal vehicles are rear-wheel drive. Some front-wheel-drive cars with a transaxle have this configuration, and most four-wheel-drive vehicles are equipped with a transfer case and have the engine mounted longitudinally in the front of the vehicle.

Total vehicle weight can be evenly distributed between the front and rear wheels with this configuration. This lightens the steering force and equalizes the braking load. With this design, it is possible to independently remove and install the engine, propeller shaft, differential, and suspension. Longitudinally mounted engines require large engine compartments. The need for a rear-drive propeller shaft and differential also cuts down passenger compartment space.

FRONT ENGINE TRANSVERSE Front engines that are mounted transversely sit sideways in the engine compartment. They are used with transaxles that combine transmission and differential gearing into a single compact housing, fastened directly to the engine. Transversely mounted engines reduce the size of the engine compartment and overall vehicle weight.

Transversely mounted front engines allow for down-sized, lighter vehicles with increased interior space. However, most of the vehicle weight is toward the front of the vehicle. This provides for increased traction by the drive wheels. The weight also places a greater load on the front suspension and brakes.

MID-ENGINE TRANSVERSE In this design, the engine and drivetrain are positioned between the passenger compartment and rear axle. Mid-engine location is used in smaller, rear-wheel-drive, high-performance sports cars for several reasons. The central location of heavy components results in a center of gravity very near the center of the vehicle. This vastly improves steering and handling. Since the engine is not under the hood, the hood can be sloped downward, improving aerodynamics and increasing the driver's field of vision. However, engine access and cooling efficiency are reduced. A barrier is also needed to reduce the transfer of noise, heat, and vibration to the passenger compartment.

GASOLINE ENGINE SYSTEMS

The operation of an engine relies on several other systems. The efficiency of these systems affects the overall operation of the engine.

AIR/FUEL SYSTEM This system makes sure the engine gets the right amount of both air and fuel needed for efficient operation. For many years air and fuel were mixed in a carburetor, which supplied the resulting mixture to the cylinder. Today, most late-model automobiles have a fuel injection system, which replaces the carburetor but performs the same basic function.

IGNITION SYSTEM This system delivers a spark to ignite the compressed air/fuel mixture in the cylinder at the end of the compression stroke. The **firing order** of the cylinders is determined by the engine's manufacturer and can be found in the vehicle's service manual. Typical firing orders are illustrated in Figure 6–15.

LUBRICATION SYSTEM This system supplies oil to the various moving parts in the engine. The oil lubricates all parts that slide in or on other parts, such as the piston, bearings, crankshaft, and valve stems. The oil enables the parts to move easily so little power is lost and wear is kept to a minimum. The lubrication system also helps transfer heat from one part to another for cooling.

COOLING SYSTEM This system is also extremely important. Coolant circulates in jackets around the cylinder and in the cylinder head. This removes part of the heat produced by combustion and prevents the engine from being damaged by overheating.

EXHAUST SYSTEM This system removes the burned gases from the combustion chamber and limits the noise produced by the engine.

① ② ③ ④ ⑤ ⑥
FIRING ORDER 1-5-3-6-2-4
6 CYLINDER

② ④ ⑥ ⑧ RIGHT BANK
① ③ ⑤ ⑦ LEFT BANK
FIRING ORDER 1-8-4-3-6-5-7-2
V-8

⑤ ③ ① RIGHT BANK
⑥ ④ ② LEFT BANK
FIRING ORDER 1-4-5-2-3-6
V-6

② ④ ⑥ ⑧ RIGHT BANK
① ③ ⑤ ⑦ LEFT BANK
FIRING ORDER 1-8-7-2-6-5-4-3
V-8

① ② ③ ④ RIGHT BANK
⑤ ⑥ ⑦ ⑧ LEFT BANK
FIRING ORDER 1-5-4-8-6-3-7-2
V-8

① ② ③ ④
FIRING ORDER 1-3-4-2
1-2-4-3
4 CYLINDER

② ④ ⑥ RIGHT BANK
① ③ ⑤ LEFT BANK
FIRING ORDER 1-6-5-4-3-2
V-6

① ② ③ ④ RIGHT BANK
⑤ ⑥ ⑦ ⑧ LEFT BANK
FIRING ORDER 1-5-4-2-6-3-7-8
V-8

FIGURE 6–15 Common cylinder firing orders.

EMISSION CONTROL SYSTEM Several control devices, which are designed to reduce the amount of pollutants released by the engine, have been added to the engine. Engine design changes, such as reshaped combustion chambers and altered valve timing, have also been part of the manufacturers' attempt to reduce emission levels.

ENGINE MEASUREMENT AND PERFORMANCE

Some of the engine measurements and performance characteristics a technician should be familiar with follow.

BORE AND STROKE The **bore** of a cylinder is simply its diameter measured in inches (in.) or millimeters (mm). The stroke is the length of the piston travel between TDC and BDC. Between them, bore and stroke determine the displacement of the cylinders (Figure 6–16). When the bore of the engine is larger than its stroke, it is said to be oversquare. When the stroke is larger than the bore, the engine is said to be undersquare. Generally, an oversquare engine will provide for high engine speeds, such as for automobile use. An undersquare or long-stroke engine will deliver good low-speed power, such as an engine for a truck or tractor.

The **crank throw** is the distance from the crankshaft's main bearing centerline to the crankshaft throw centerline. The stroke of any engine is twice the crank throw (Figure 6–17).

DISPLACEMENT **Displacement** is the volume of a cylinder between the TDC and BDC positions of the piston. It is usually measured in cubic inches, cubic centimeters, or liters (Figure 6–18). The total displacement of an engine (including all cylinders) is a rough indicator of its power output. Displacement can be increased by opening the bore to a larger diameter or by increasing the length of the stroke. Total displacement is the sum of displacements for all cylinders in an engine. Cubic inch displacement (CID) may be calculated as follows.

$$CID = \pi \times R^2 \times L \times N$$

in which $\pi = 3.1416$
R = bore radius or bore diameter/2
L = length of stroke
N = number of cylinders

Example: Calculate the cubic inch displacement (CID) of a six-cylinder engine with a 3.7-in. bore and 3.4-in. stroke.

$$CID = 3.1416 \times 1.85^2 \times 3.4 \times 6$$
$$CID = 219.66$$

Most of today's engines are described by their metric displacement. Cubic centimeters and liters are determined by using metric measurements in the displacement formula.

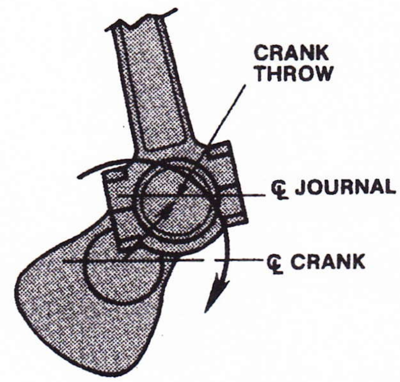


FIGURE 6–17 The stroke of an engine is equal to twice the crank throw.

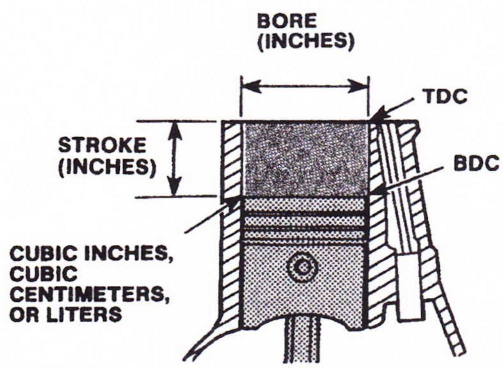
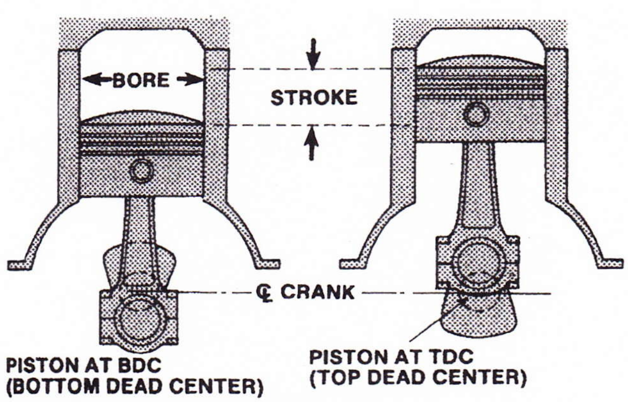


FIGURE 6–18 Displacement is the volume the cylinder holds between TDC and BDC.



$\frac{\text{BORE}}{\text{STROKE}}$ = BORE STROKE RATIO

FIGURE 6–16 The bore and stroke of a cylinder.

Example: Calculate the metric displacement of a four-cylinder engine with a 78.9-mm stroke and a 100-mm bore.

$$\text{Displacement} = 3.1415 \times 100^2 \times 78.9 \times 4$$
$$\text{Displacement} = 2479 \text{ cubic centimeters (cc)}$$
$$= 2.5 \text{ liters (L)}$$

Larger, heavier vehicles are provided with large displacement engines. Large displacement engines produce more torque than smaller displacement engines. They also consume more fuel. Smaller, lighter vehicles can be adequately powered by lower displacement engines that use less fuel.

COMPRESSION RATIO The **compression ratio** of an engine expresses how much the air/fuel mixture will be compressed during the compression stroke. The compression ratio is defined as the ratio of the volume in the cylinder above the piston when the piston is at BDC to the volume in the cylinder above the piston when the piston is at TDC (Figure 6–19). The formula for calculating the compression ratio is as follows.

$$\frac{\text{volume above the piston at BDC}}{\text{volume above the piston at TDC}}$$

or

$$\frac{\text{total cylinder volume}}{\text{total combustion chamber volume}}$$

In many engines, the top of the piston is even or level with the top of the cylinder block at TDC. The combustion chamber is in the cavity in the cylinder head above the piston. This is modified slightly by the shape of the top of the piston. The volume of the combustion chamber must be added to each volume in the formula in order to get an accurate calculation of compression ratio.

Example: Calculate the compression ratio if the total piston displacement is 45 cubic inches and the combustion chamber volume is 5.5 cubic inches.

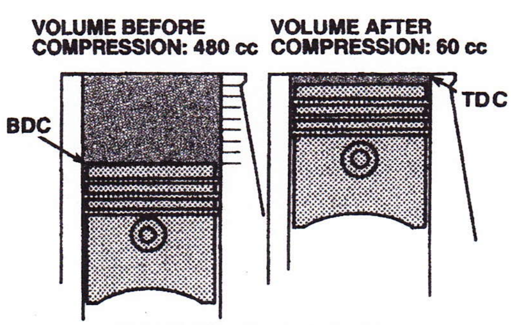


FIGURE 6–19 Compression ratio measures the amount the air and fuel have been compressed.

$$\frac{45 + 5.5}{5.5} = \text{compression ratio}$$
$$9.1{:}1 = \text{compression ratio}$$

(Be sure to add the combustion chamber volume to the piston displacement to get the total cylinder volume.)

The higher the compression ratio, the more power an engine theoretically can produce. Also, as the compression ratio increases, the heat produced by the compression stroke also increases. Gasoline with a low octane rating burns fast and may explode rather than burn when introduced to a high compression ratio. This can cause preignition. The higher a gasoline's octane rating, the less likely it is to explode.

As the compression ratio increases, the octane rating of the gasoline also should be increased to prevent abnormal combustion.

ENGINE EFFICIENCY Engine **efficiency** is a measure of the relationship between the amount of energy put into the engine and the amount of available energy from the engine. Engine efficiency is expressed in a percentage. The formula for determining efficiency is:

$$\text{efficiency} = \frac{\text{output energy}}{\text{input energy}} \times 100$$

There are other aspects of the engine that are expressed in efficiencies. These include mechanical efficiency, volumetric efficiency, and thermal efficiency. They are expressed as a ratio of input (actual) to output (maximum or theoretical). Efficiencies are expressed as percentages. They are always less than 100 percent. The difference between the efficiency and 100 percent is the percentage lost during the process. For example, if there were 100 units of energy put into the engine and 28 units came back, the efficiency would be equal to 28 percent. This would mean that 72 percent of the energy received was wasted or lost.

TORQUE AND HORSEPOWER **Torque** is a turning or twisting force. The engine's crankshaft rotates with a torque that is transmitted through the drivetrain to turn the drive wheels of the vehicle. **Horsepower** is the rate at which torque is produced.

Engines produce power by turning a crankshaft in a circular motion. To convert terms of force applied in a straight line to a force applied in a circular motion, the formula is:

$$\text{torque} = \text{force} \times \text{radius}$$

Example: A 10-pound force applied to a wrench 1 foot long will produce 10 pound-feet (lb-ft) of torque.

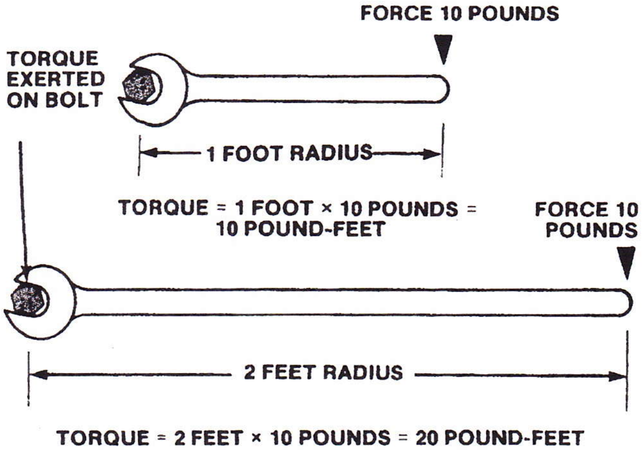


FIGURE 6–20 Force applied to a wrench produces torque.

Imagine that the 1-foot-long wrench is connected to a shaft. If 1 pound of force is applied to the end of the wrench, 1 pound-foot of torque is produced. Ten pounds of force applied to a wrench 2 feet long will produce 20 pound-feet of torque (Figure 6–20).

The technically correct torque measurement is stated in pound-feet (lb-ft). However, it is rather common to state torque in terms of foot-pounds (ft-lb). In the metric or SI system, torque is stated in Newton-meters (N-m) or kilogram-meters (kg-m).

If the torque output of an engine at a given speed (rpm) is known, horsepower (HP) can be calculated by the following formula.

$$HP = (\text{torque} \times \text{rpm}) \div 5{,}252$$

An engine produces different amounts of torque based on the rotational speed of the crankshaft and other factors. A mathematical representation, or graph, of the relationship between the horsepower and torque of an engine is shown in Figure 6–21.

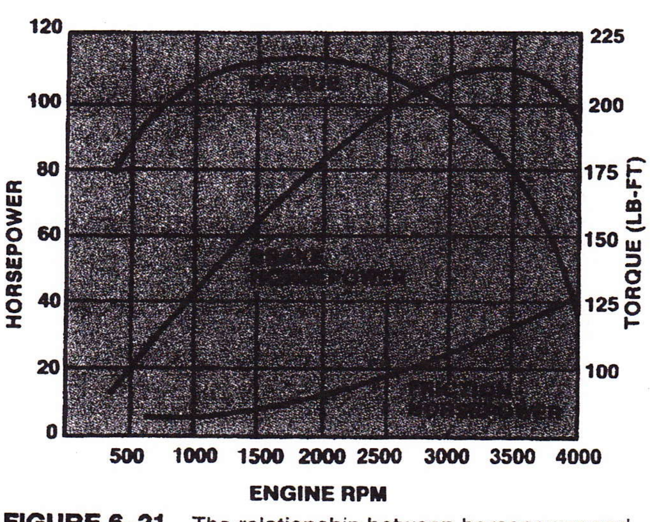


FIGURE 6–21 The relationship between horsepower and torque.

GENERAL SPECIFICATIONS	
DISPLACEMENT	1.9L
NUMBER OF CYLINDERS	1-4
BORE AND STROKE	
1.9L	82 x 88 (3.23 x 3.46)
FIRING ORDER	1-3-4-2
OIL PRESSURE (HOT 2000 RPM)	240-450 kPa (35-65 PSI)
DRIVE BELT TENSION	178-311 (40-70 Lb-Ft)
CYLINDER HEAD AND VALVE TRAIN① ②	
COMBUSTION CHAMBER VOLUME (cc)	EFI-HO 55 ± 1.6
VALVE GUIDE BORE DIAMETER	EFI 39.9 ± 0.8
Intake	13.481-13.519mm (0.531-0.5324 in.)
Exhaust	13.481-13.519mm (0.531-0.532 in.)
VALVE GUIDE I.D.	
Intake and Exhaust	8.063-8.094 N-m (.3174-.3187 in.)
VALVE SEATS	
Width — Intake & Exhaust	1.75-2.32mm (0.069-0.091 in.)
Angle	45°
Runout (T.I.R.)	0.076mm (0.003 in.) MAX.
Bore Diameter (Insert Counterbore Diameter)	
Intake	(EFI-HO) 43.763mm (1.723 in.) MIN.
	43.788mm (1.724 in.) MAX.
	(EFI) 39.940 mm (1.572 in.) MIN.
	39.965 mm (1.573 in.) MAX.
Exhaust	(EFI-HO) 38.263mm (1.506 in.) MIN.
	38.288mm (1.507 in.) MAX.
	(EFI) 34.940 mm (1.375 in.) MIN.
	39.965 mm (1.573 in.) MAX.
GASKETS SURFACE FLATNESS	0.04mm (0.0016 in.)/26mm (1 in.)
	0.08mm (0.003 in.)/156mm (6 in.)
	0.15mm (0.006 in.) Total
HEAD FACE SURFACE FINISH	0.7/2.5 0.8 (28/100 .030)
VALVE STEM TO GUIDE CLEARANCE	
Intake	0.020-0.069mm (0.0008-0.0027 in.)
Exhaust	0.046-0.095mm (0.0018-0.0037 in.)
VALVE HEAD DIAMETER	
Intake	42.1-41.9mm (1.66-1.65 in.)
Exhaust	37.1-36.9mm (1.50-1.42 in.)
VALVE FACE RUNOUT	
LIMIT	Intake & Exhaust 05mm (0.002 in.)
VALVE FACE ANGLE	45.6°
VALVE STEM DIAMETER (Std.)	
Intake	8.043-8.025mm (0.3167-0.3159 in.)

FIGURE 6–22 Service manuals contain engine specifications. *Courtesy of Ford Motor Company*

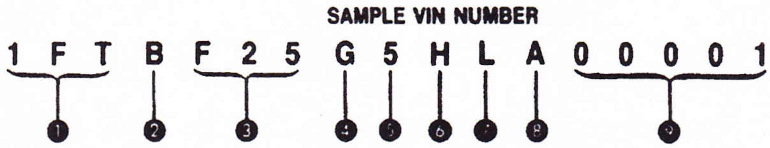
This graph shows that torque begins to decrease when the engine's speed reaches about 1,700 rpm. Brake horsepower increases steadily until about 3,500 rpm. Then it drops. The third line on the graph indicates the horsepower needed to overcome the friction or resistance created by the internal parts of the engine rubbing against each other.

Complete engine specifications can usually be found in service manuals as shown in Figure 6–22.

ENGINE IDENTIFICATION

To find the correct specifications for an engine, a technician must know how to use the vehicle identification number **(VIN)**. The VIN is a code of seventeen numbers and letters stamped on a metal tab that is riveted to the instrument panel close to the windshield (Figure 6–23). From this number much information about the vehicle can be found.

FIGURE 6–23 The VIN is visible through the driver's side of the windshield.



① POSITION 1, 2, AND 3—MANUFACTURER, MAKE, AND TYPE (WORLD MANUFACTURER IDENTIFIER)
② POSITION 4—BRAKE SYSTEM
③ POSITION 5, 6, AND 7—MODEL OR LINE, SERIES, CHASSIS, CAB OR BODY TYPE
④ POSITION 8—ENGINE TYPE
⑤ POSITION 9—CHECK DIGIT
⑥ POSITION 10—MODEL YEAR
⑦ POSITION 11—ASSEMBLY PLANT
⑧ POSITION 12—CONSTANT A UNTIL SEQUENCE NUMBER 99,999 IS REACHED, THEN CHANGES TO A CONSTANT B AND SO ON.
⑨ POSITION 13 THROUGH 17—SEQUENCE NUMBER—BEGINS AT 00001

FIGURE 6–24 The VIN provides a great deal of information.

USING SERVICE MANUALS

Normally, information used to identify the size of an engine is given in service manuals at the beginning of the section covering that particular manufacturer. ■

The adoption of the seventeen-number-and-letter code became mandatory beginning with 1981 vehicles. The standard VIN of the United States National Highway Transportation and Safety Administration Department of Transportation is being used by all manufacturers of vehicles, both domestic and foreign.

By referring to the VIN, much information about the vehicle can be determined (Figure 6–24). An engine serial number is also stamped on many blocks (Figure 6–25). Its location is different for the different manufacturers. The service manual will tell you where to look for it. The engine code is generally found beside the serial number. A typical engine code might be DZ or MO. These letters indicate the horsepower rating of the engine, whether it was built for an automatic or manual transmission, and other important details. The engine code will help you determine the correct specifications for that particular engine.

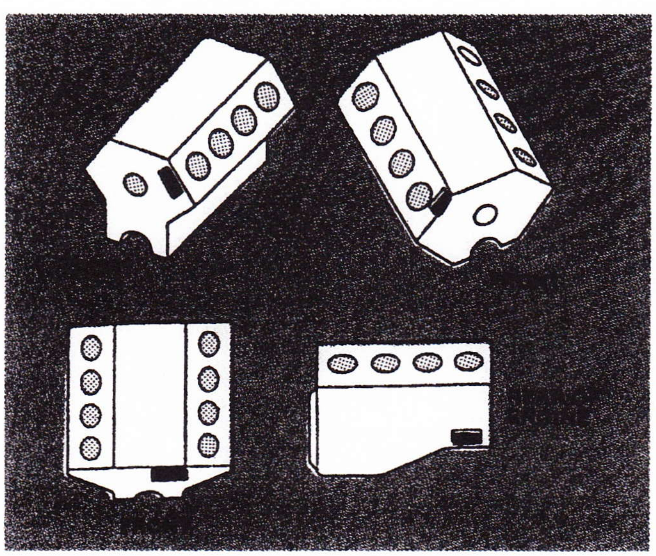


FIGURE 6–25 Common engine serial number locations.

Casting numbers are often mistaken for serial numbers and engine codes. Manufacturers use a casting number to identify major engine parts on the assembly line. They seldom can be used to identify the type of engine.

ENGINE DIAGNOSTICS

In the previous chapter, different types of test equipment were discussed. Many of these tested the mechanical condition of an engine, such as the wet and dry compression, cylinder leakage, and engine vacuum. In addition to these, two other common tests can be performed to evaluate the condition of an engine and to identify any problem areas. The cylinder power balance test checks the efficiency of individual cylinders. The results of this test are often used in conjunction with the results of compression and cylinder leakage tests.

Unlike other engine tests, an oil pressure test does not test a cylinder's ability to seal. It is used to determine wear on the engine's parts. Excessive clearances, often the result of wear, between a shaft and its bearings will have an affect on oil pressure. The oil pressure test is performed with an oil pressure gauge and measures the pressure of the oil while it is circulating through the engine. The pressure of the oil depends upon the efficiency of the oil pump and the clearances through which it travels.

USING SERVICE MANUALS

Whenever you test oil pressure, be sure to refer to the service manual to find out the required conditions for the test and the desired pressure readings. ■

OIL PRESSURE TESTING

Loss of performance, excessive engine noise, and poor starting can be caused by abnormal oil pressures. An insufficient amount of pressure may also cause premature wear on rotating parts. An oil pressure tester is a gauge with a high-pressure hose attached to it. The scale of the gauge typically reads from 0 to 100 psi. The hose is connected to the engine block in a place where oil pressure can be measured (usually where the oil pressure indicator light sensor is screwed into the block).

To conduct the test, simply follow the guidelines given in the service manual and observe the gauge. The pressure is read when the engine is at normal operating temperatures and at a fast idle speed. Low oil pressures can be caused by a worn oil pump, excessive wear on the crankshaft or camshaft and their bearings, a plugged oil pickup screen, or a weak or broken oil pressure relief valve. High oil pressure is normally caused by restrictions in the oil passages or a faulty pressure regulator.

CYLINDER POWER BALANCE TESTING

The **cylinder power balance** test is used to see if all the engine's cylinders are producing the same amount of power. Ideally, all cylinders produce the same amount. This minimizes the amount of power that is lost by keeping the engine running and allows the engine to run smoothly. To check the balance of the cylinders, the cylinders are shorted out one at a time and the change in engine speed is recorded. Ideally, the changes in engine rpm should be about equal as each cylinder is shorted out. Unequal cylinder power can mean a problem in the cylinders themselves, as well as the rings, valves, intake manifold, head gasket, fuel system, or ignition system.

The power balance test is performed quickly and easily using an engine analyzer, because the spark plugs can be controlled with push buttons. Changes are measured in rpm drop. Keep in mind that the push-button numbers refer to the cylinder firing order, not the cylinder number designation. For example, when testing an engine with a firing order of 1-3-4-2, pushing the first button shorts out the number of 1 cylinder, pushing the second button shorts out the number 3 cylinder, and so on.

SHOP TALK

A cylinder power balance test can be conducted with just a tachometer. To do this, simply remove a spark plug wire and ground it. Do this to each spark plug, one at a time, and observe the change in engine rpm. If the engine is equipped with electronic ignition, do not ground the spark plug wire directly to ground. Insert a test spark into the end of the wire and ground the test plug before running the engine. ■

Test Precautions

On some computer-controlled or fuel-injected engines, certain components must be disconnected before attempting the power balance test. Because of the wide variations from manufacturer to manufacturer, consult the vehicle's service manual for specific instructions.

If the engine being tested has an exhaust gas recirculation (EGR) system, added precautions must be taken. If the system is valve controlled, disconnect the vacuum or electrical connection to the EGR valve. This will prevent the valve from cycling due to vacuum changes when the cylinders are shorted out. For engines with a floor jet EGR system, the power balance test cannot be performed accurately because of the possibility of the unburned fuel mixture being sent back into the cylinders. The compression test is the recommended alternative in such cases.

Care must be taken when performing the power balance test on vehicles with catalytic converters. To prevent unburned fuel from building up in the converter, short each spark plug for less than 15 seconds, then allow the engine to run for another 30 seconds before shorting another one.

Performing the Test

The standard power balance test is fairly simple. If the engine has an air/fuel mixture feedback control or O_2 sensor (Figure 6–26A), disconnect the plug, either the air pump hose going to the catalytic converter or the downstream hose between the air switching valve and the check valve. On some Ford models, the air switching valve can routinely have up to 10 percent leakage, in which case both hoses must be disconnected and plugged. If the engine does not have an air/fuel mixture feedback control or O_2 sensor (Figure 6–26B), disconnect and block the air pump on the valve side.

Override the controls of the electric cooling fan by jumper wiring the controls so the fan runs constantly. If the fan cannot be bypassed, disconnect it. Be careful that the engine does not overheat during the test.

Connect the engine analyzer's leads, referring to the equipment's instruction manual for specific instructions.

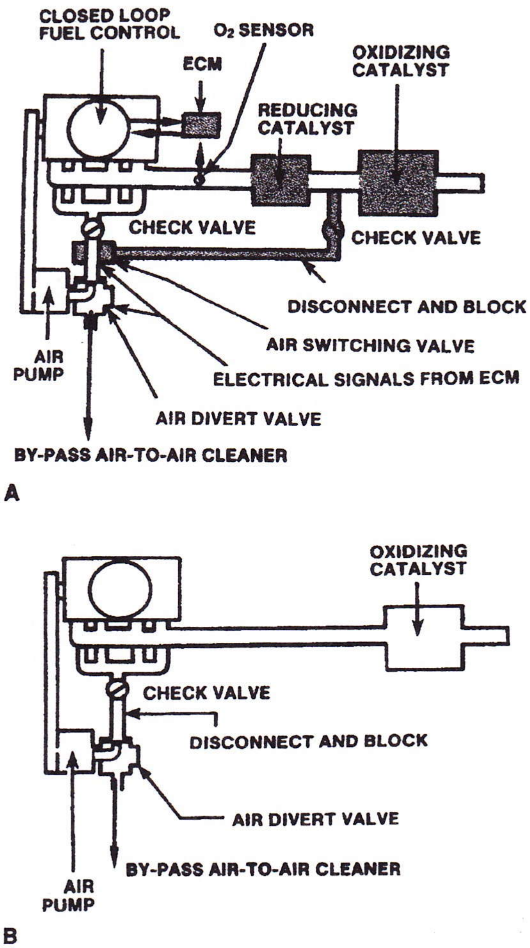


FIGURE 6–26 The procedure for conducting a cylinder power balance test differs, depending on whether the engine (A) has an air/fuel mixture feedback control or (B) does not have an air/fuel mixture feedback control.

Turn on the engine and let it reach its normal operating temperature before beginning the test. Engine speed should be stabilized at approximately 1,000 rpm. When a cylinder is shorted, note any drop in rpm or manifold vacuum.

As each cylinder is shorted out, a noticeable drop in engine speed should occur. Little or no decrease in rpm indicates a weak cylinder. If all the readings are fairly close to each other, the engine is in sound mechanical condition. If a reading in one or more cylinders differs greatly from the rest, there is a problem. Further testing should be done to determine the exact cause of the problem.

EVALUATING THE ENGINE'S CONDITION

Once the compression, cylinder leakage, vacuum, and power balance tests are performed, a technician is ready to evaluate the engine's condition. For example, an engine with good relative compression but high cylinder leakage past the rings is typical of a high-mileage worn engine. This engine would have these symptoms: excessive blowby, lack of power, poor performance, and reduced fuel economy.

If these same compression and leakage test results are found on an engine with comparatively low mileage, the problem is probably stuck piston rings that are not expanding properly. If this is the case, try treating the engine with a combustion chamber cleaner, oil treatment, or engine flush. If this fails to correct the problem, an engine overhaul is required.

A cylinder that has poor compression but minimal leakage indicates a valve train problem. Under these circumstances, a valve might not be opening at the right time, might not be opening enough, or might not be opening at all. This condition can be confirmed on engines with a pushrod-type valve train by pulling the rocker covers and watching the valves operate while the engine is cycled. If one or more valves fail to move, either the lifters are collapsed or the cam lobes are worn. If all of the cylinders have low compression with minimal leakage, the most likely cause is incorrect valve timing.

If compression and leakage are both good, but the power balance test reveals weak cylinders, the cause of the problem is outside the combustion chamber. Assuming there are no ignition or fuel problems, check for broken, bent, or worn valve train components, collapsed lifters, leaking intake manifold, or excessively leaking valve guides. If the latter is suspected, squirt some oil on the guides. If they are leaking, blue smoke will be seen in the exhaust.

NOISE DIAGNOSIS

More often than not, malfunction in the engine will reveal itself first as an unusual noise. This can happen before the problem affects the driveability of the vehicle. Problems such as loose pistons, badly worn rings or ring lands, loose piston pins, worn main bearings and connecting rod bearings, loose vibration damper or flywheel, and worn or loose valve train components all produce telltale sounds. Unless the technician has experience in listening to and interpreting engine noises, it can be very hard to distinguish one from the other.

CUSTOMER CARE

When attempting to diagnose the cause of abnormal engine noise, it may be necessary to temper the enthusiasm of a customer who thinks they have pinpointed the exact cause of the noise using nothing more than their own two ears. While the owner's description may be helpful (and should always be asked for), it must be stressed that one person's "rattle" can be another person's "thump." You are the professional. The final diagnosis is up to you. If customers have been proven correct in their diagnosis, make it a point to tell them so. Everyone feels better about dealing with an automotive technician who listens to them. ■

When correctly interpreted, engine noise can be a very valuable diagnostic aid. For one thing, a costly and time-consuming engine teardown might be avoided. Always make a noise analysis before doing any repair work. This way, there is a much greater likelihood that only the necessary repair procedures will be done. Careful noise diagnosis also reduces the chances of ruining the engine by continuing to use the vehicle despite the problem.

WARNING!

Be very careful when listening for noises around moving belts and pulleys at the front of the engine. Keep the end of the hose or stethoscope probe away from the moving parts. Physical injury can result if the hose or stethoscope is pulled inward or flung outward by moving parts. ■

Using a Stethoscope

Some engine sounds can be easily heard without using a listening device, but others are impossible to hear unless amplified. A stethoscope or rubber hose (as mentioned earlier) is very helpful in locating engine noise by amplifying the sound waves. It can also distinguish between normal and abnormal noise. The procedure for using a stethoscope is simple. Use the metal prod to trace the sound until it reaches its maximum intensity. Once the precise location has been discovered, the sound can be better evaluated. A sounding stick, which is nothing more than a long, hollow tube, works on the same principle, though a stethoscope gives much clearer results.

The best results, however, are obtained with an electronic listening device. With this tool you can tune into the noise. Doing this allows you to eliminate all other noises that might distract or mislead you.

Common Noises

Following are examples of abnormal engine noises, including a description of the sound, its likely cause, and ways of eliminating it. An important point to keep in mind is that insufficient lubrication is the most common cause of engine noise. For this reason, always check the oil level first before moving on to other areas of the vehicle. Some noises are more pronounced on a cold engine because clearances are greater when parts are not expanded by heat. Remember that aluminum and iron expand at different rates as temperatures rise. For example, a knock that disappears as the engine warms up is probably piston slap or knock. An aluminum piston expands more than the iron block, allowing the piston to fit more closely as engine temperature rises.

RING NOISE This sound can be heard during acceleration as a high-pitched rattling or clicking in the upper part of the cylinder. It can be caused by worn rings or cylinders, broken piston ring lands, or insufficient ring tension against the cylinder walls. Ring noise is corrected by replacing the rings, pistons, or sleeves or reboring the cylinders.

PISTON SLAP This is commonly heard when the engine is cold. It often gets louder when the vehicle accelerates. When a piston slaps against the cylinder wall, the result is a hollow, bell-like sound. Piston slap is caused by worn pistons or cylinders, collapsed piston skirts, misaligned connecting rods, excessive piston-to-cylinder wall clearance, or lack of lubrication, resulting in worn bearings. Correction requires either replacing the pistons, reboring the cylinder, replacing or realigning the rods, or replacing the bearings. Shorting out the spark plug of the affected cylinder might quiet the noise.

PISTON PIN KNOCK Piston pin knock is a sharp, metallic rap that can sound more like a rattle if all the pins are loose. It originates in the upper portion of the engine and is most noticeable when the engine is idling and the engine is hot. Piston pin knock sounds like a double knock at idle speeds. It is caused by a worn piston pin, piston pin boss, piston pin bushing, or lack of lubrication, resulting in worn bearings. To correct it, either install oversized pins, replace the boss or bushings, or replace the piston.

RIDGE NOISE This noise is less common but very distinct. As a piston ring strikes the ridge at the top of the cylinder, the result is a high-pitched rapping or clicking noise that becomes louder during deceleration (Figure 6–27).

There can be more than one reason for the ridge interfering with the ring's travel. For one thing, if new rings are installed without removing the old ridge, the new rings will contact the ridge and make a noise. Also, if the piston pin is very loose or the

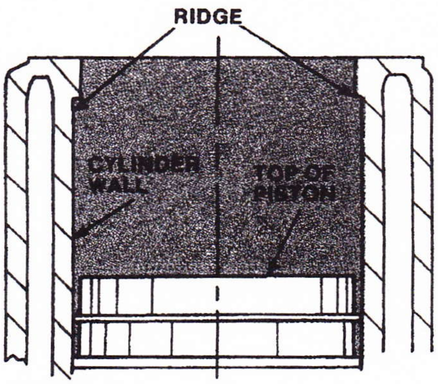


FIGURE 6–27 When the piston strikes the ridge at the top of the cylinder, a high-pitched rapping or clicking sound is made.

connecting rod has a loose or burned-out bearing, the piston will go high enough in the cylinder for the top ring to contact the ridge. Thus, in order to eliminate ridge noise, remove the old ring ridge and replace the piston pin or piston.

ROD-BEARING NOISE The result of worn or loose connecting rod bearings, this noise is heard at idle as well as at speeds over 35 mph. Depending on how badly the bearings are worn, the noise can range from a light tap to a heavy knock or pound. Shorting out the spark plug of the affected cylinder can lessen the noise, unless the bearing is extremely worn. In this case, shorting out the plug will have no effect. Rod-bearing noise is caused by a worn bearing or crankpin, a misaligned rod, or lack of lubrication, resulting in worn bearings. To correct it, service or replace the crankshaft, realign or replace the connecting rods, and replace the bearings.

MAIN OR THRUST BEARING NOISE A loose crankshaft main bearing produces a dull, steady knock, while a loose crankshaft thrust bearing produces a heavy thump at irregular intervals. The thrust bearing noise might only be audible on very hard acceleration. Both of these bearing noises are usually caused by worn bearings or crankshaft journals. To correct the problem, replace the bearings or crankshaft.

TAPPET NOISE Tappet noise is characterized by a light, regular clicking sound that is more noticeable when the engine is idling. It is the result of excessive clearance in the valve train. The clearance problem area is located by inserting a feeler gauge between each lifter and valve, or between each rocker arm and valve tip, until the noise subsides. Tappet noise can be caused by improper valve adjustment, worn or damaged parts, dirty hydraulic lifters, or lack of lubrication. To correct the noise, adjust the valves, replace any worn or damaged parts, or clean or replace the lifters.

ABNORMAL COMBUSTION NOISES Preignition and detonation noises are caused by abnormal engine combustion. For instance, **detonation** knock or **ping** is a noise most noticeable during acceleration with the engine under load and running at normal temperature. Excessive detonation can be very harmful to the engine. It is often caused by advanced ignition timing or substantial carbon buildup in the combustion chambers that increases combustion pressure. Carbon deposits that get so hot they glow will also preignite the air/fuel mixture, causing detonation. Another possible cause is fuel with octane that is too low. Detonation knock can usually be cured by removing carbon deposits from the combustion chambers with a rotary wire brush as well as recommending the use of a higher octane gasoline. A malfunctioning EGR valve can also cause detonation and even rod knock.

Sometimes abnormal combustion combines with other engine parts to cause noise. For example, rumble is a term that is used to describe the knock or noise resulting from another form of abnormal ignition. Rumble is a vibration of the crankshaft and connecting rods that is caused by multi-surface ignition. Rumble is a form or preignition in which several flame fronts occur simultaneously from overheated deposit particles. Multi-surface ignition causes a tremendous sudden pressure rise near top dead center. It has been reported that the rate of pressure rise during rumble is five times the rate of normal combustion.

A loose vibration damper causes a heavy rumble or thump in the front of the engine that is more apparent when the vehicle is accelerating from idle under load or is idling unevenly. A loose flywheel causes a heavy thump or light knock at the back of the engine, depending on the amount of play and the type of engine. Both of these problems are corrected either by tightening or replacing the damper or flywheel.

OTHER ENGINE DESIGNS

The gasoline-powered, internal combustion piston engine has been the primary automotive power plant for many years and probably will remain so for years to come. Present-day social requirements and new technological developments, however, have necessitated searches for ways to modify or replace this time-proven workhorse. This portion of the chapter takes a brief look at the most likely contenders, and how they work. The orbital two-stroke cycle engine was discussed earlier and is not explained in the following. This certainly does not mean that this engine design is not a viable one.

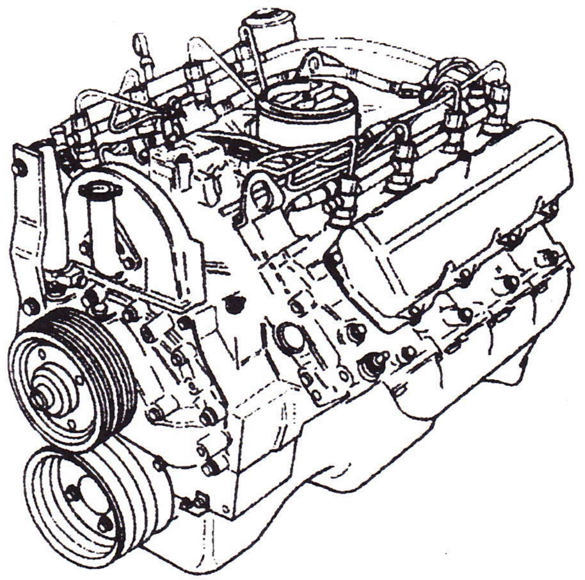


FIGURE 6–28 Typical four-stroke diesel engine. *Courtesy of Ford Motor Company*

Diesel Engine

Diesel engines represent tested, proven technology with a long history of success. Invented by Dr. Rudolph Diesel, a German engineer, and first marketed in 1897, the diesel engine is now the dominate power plant in heavy-duty trucks, construction equipment, farm equipment, buses, and marine applications.

During the late 1970s and early 1980s, many predicted small diesel engines would replace gasoline engines in passenger vehicles. However, stabilized gas prices and other factors dampened the enthusiasm for diesels in these markets. The use of diesel engines in cars and light trucks is now limited to a few manufacturers.

Diesel engines (Figure 6–28) and gasoline-powered engines share several similarities. They have a number of components in common, such as the crankshaft, pistons, valves, camshaft, and water and oil pumps. They both are available in four-stroke combustion cycle models. However, the diesel engine and four-stroke compression-ignition engine are easily recognized by the absence of a ignition system. Instead of relying on a spark for ignition, a diesel engine uses the heat produced by compressing air in the combustion chamber to ignite the fuel. The systems used in diesel-powered vehicles are essentially the same as those used in gasoline vehicles.

Figure 6–29 shows the four-strokes of a diesel engine. Fuel injection is used on all diesel engines. Injectors spray pressurized fuel into the cylinders just as the piston is completing its compression stroke. The heat of the compressed air ignites the fuel and begins the power stroke.

Glow plugs are used only to warm the combustion chamber when the engine is cold. Cold starting is impossible without these plugs because even the high-compression ratios cannot heat cold air enough to cause combustion.

Diesel combustion chambers are different from gasoline combustion chambers because diesel fuel burns differently. Three types of combustion chambers are used in diesel engines: open combustion chamber, precombustion chamber, and turbulence combustion chamber. The open combustion chamber has the combustion chamber located directly inside the piston. Diesel fuel is injected directly into the center of the chamber. The shape of the chamber and the quench area produces turbulence. The precombustion chamber is a smaller, second chamber connection to the main combustion chamber. On the power stroke, fuel is injected into the small chamber. Combustion is started there and then spreads to the main chamber. This design allows lower fuel injection pressures and simpler injection systems on diesel engines.

The turbulence combustion chamber is designated to create an increase in air velocity or turbulence in the combustion chamber. The fuel is injected into the turbulent air and burns more completely. The prechambers on a diesel engine head must be proper-

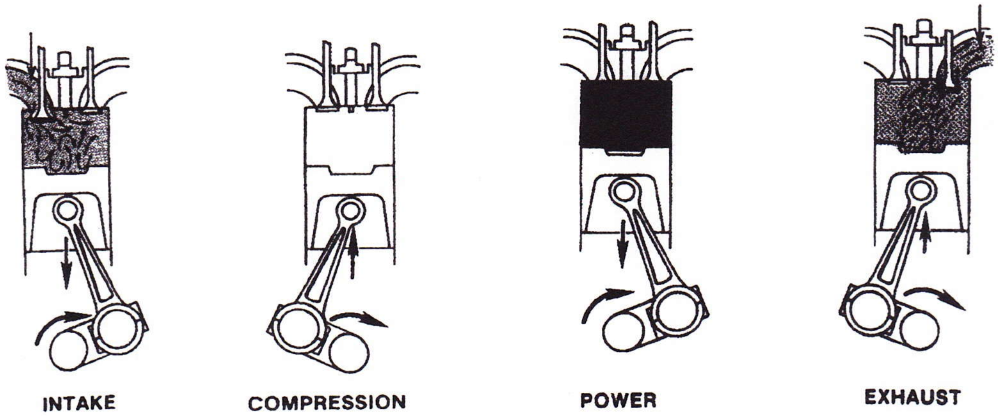


FIGURE 6–29 Four-stroke diesel engine cycle.

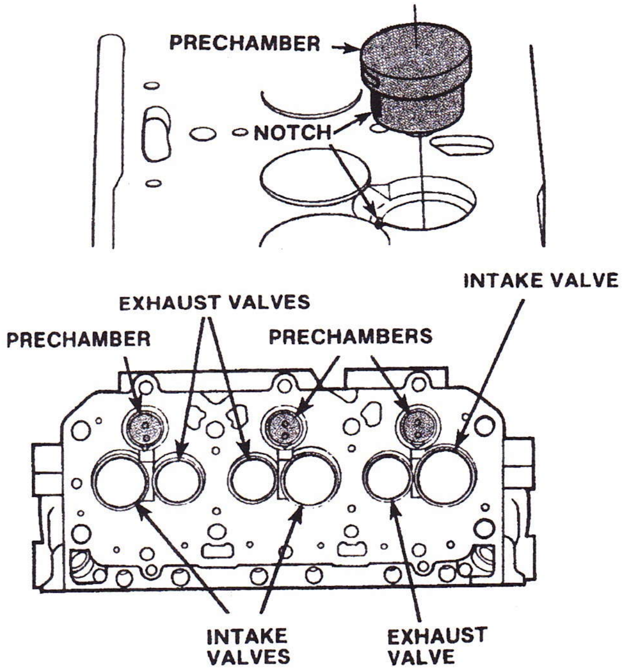


FIGURE 6–30 Correctly installed diesel prechambers.

ly indexed with the head and correctly installed (Figure 6–30). They must be perfectly flush (not above or below) with the cylinder head. Failure to follow this will cause the head gasket to fail.

Table 6–1 compares the gasoline and diesel four-stroke-cycle engines. Diesel engines are also available in two-stroke-cycle models (Figure 6–31).

Rotary Engine

The **rotary** engine, or **Wankel** engine, is somewhat similar to the standard piston engine in that it is a four-cycle, spark ignition, internal combustion engine. Its mechanical design, however, is quite different. For one thing, the rotary engine uses a rotating motion rather than a reciprocating motion. In addition, it uses ports rather than valves for controlling the intake of the air/fuel mixture and the exhaust of the combusted charge.

As shown in Figure 6–32 the heart of a rotary engine is a roughly triangular rotor that "walks" around a smaller, rigidly mounted gear. The rotor is connected to the crankshaft through additional gears in such a manner that for every rotation of the rotor the crankshaft revolves three times. The tips of the triangular rotor move within the housing and are in constant contact with the housing walls. As the rotor moves, the volume between each side of the rotor and the housing walls continually changes.

Referring to Figure 6–33, when side A of the rotor is in position 1, the intake port is uncovered and the air/fuel mixture is entering the upper chamber. As the rotor moves to position B, the intake port

TABLE 6–1 COMPARISON BETWEEN GASOLINE AND DIESEL ENGINES

	Gasoline	Diesel
Intake	Air/fuel	Air
Compression	8–10 to 1 130 psi 545°F	13–25 to 1 400–600 psi 1,000°F
Air/fuel mixing point	In intake manifold near the intake valve.	In cylinder near TDC by injection
Combustion	Spark ignition	Compression ignition
Power	464 psi	1,200 psi
Exhaust	1,300°–1,800°F CO = 1%	700°–900°F CO = 0.5%
Efficiency	22–28%	32–38%

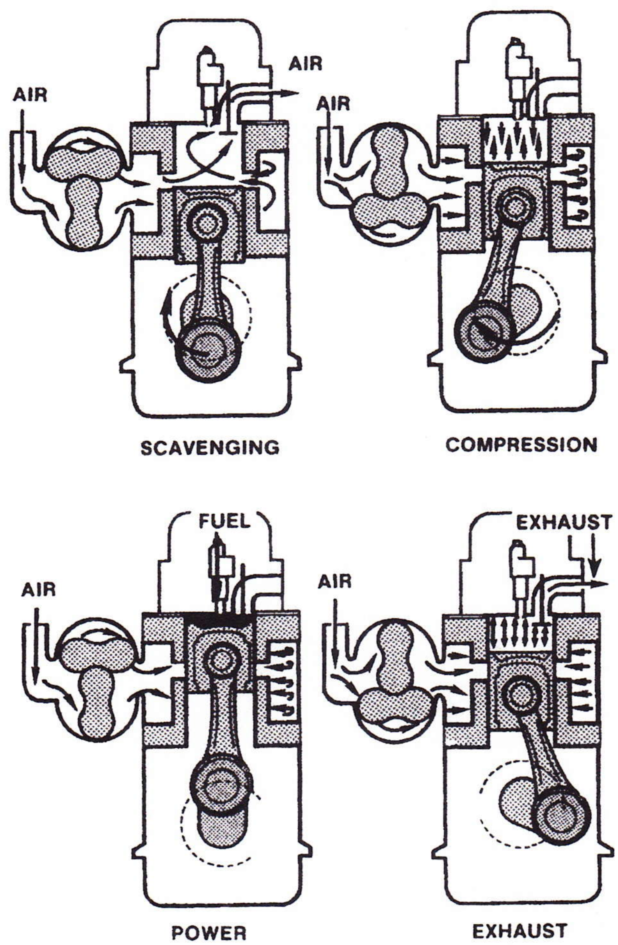


FIGURE 6–31 Two-stroke diesel engine cycle.

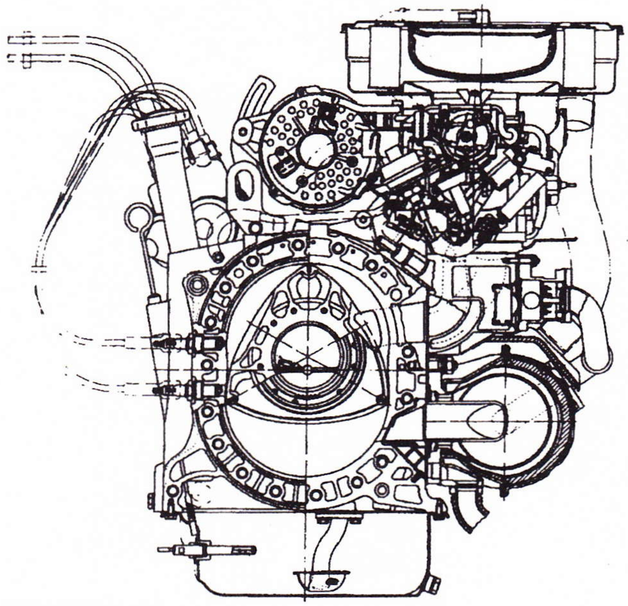


FIGURE 6–32 Typical rotary engine. *Courtesy of Mazda*

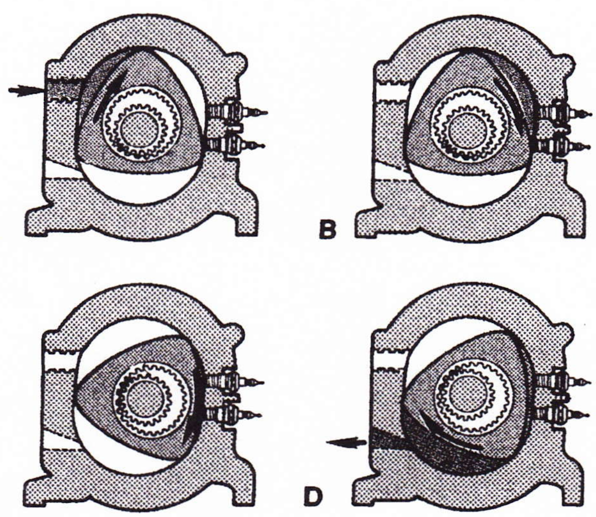


FIGURE 6–33 Rotary engine cycle.

closes and the upper chamber reaches its maximum volume. When full compression has reached position C, the two spark plugs fire, one after the other, to start the power stroke. At position D, rotor side A uncovers the exhaust port and exhaust begins. This cycle continues until position 1 is reached where the chamber volume is at minimum and the intake cycle starts once again.

The fact that the rotating combustion chamber engine is small and light for the amount of power it produces makes it attractive for use in automobiles. Using this small, lightweight engine can provide the same performance as a larger engine. But, the rotary engine, at present, cannot compete with the piston gasoline on durability, exhaust emission control, and economy.

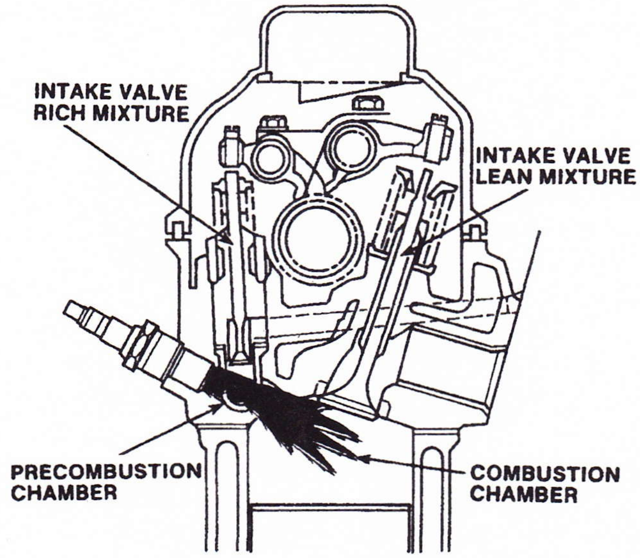


FIGURE 6–34 Typical stratified charge engine.

Stratified Charge Engine

The stratified charge engine (Figure 6–34) combines the features of both the gasoline and diesel engines. It differs from the conventional gasoline engine in that the air/fuel mixture is deliberately stratified to produce a small rich mixture at the spark plug while providing a leaner, more efficient and cleaner burning main mixture. In addition, the air/fuel mixture is swirled for more complete combustion.

Referring to position A in Figure 6–35, a large amount of very lean mixture is drawn through the main intake valve on the intake stroke to the main combustion chamber. At the same time, a small amount of rich mixture is drawn through the auxiliary intake valve into the precombustion chamber. At the end of the compression stroke in position B, the

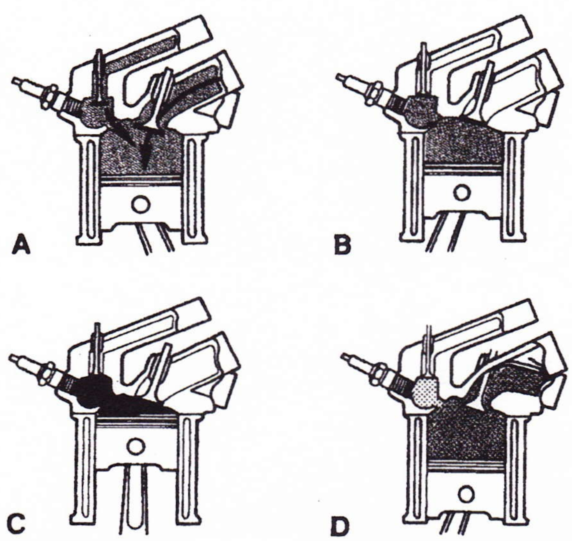


FIGURE 6–35 Four-stroke cycle of a stratified charge engine.

spark plug fires the rich mixture in the precombustion chamber. As the rich mixture ignites, it in turn ignites the lean mixture in the main chamber. The lean mixture minimizes the formation of carbon monoxide during the power stroke (position C). In addition, the peak temperature stays low enough to minimize the formation of oxides of nitrogen, and the mean temperature is maintained high enough and long enough to reduce hydrocarbon emissions. During the exhaust stroke (position D) the hot gases exit through the exhaust valve.

A great deal of automobile engineering research, especially by Japanese and European manufacturers, is being done on these engines. In fact, the Honda CVCC engine uses a stratified charge design. This engine uses a third valve to release the initial charge. The stratified charge combustion chamber has three important advantages. It produces good part-load fuel economy. It can run efficiently on low-octane fuel and has low exhaust emissions.

Electric Motors

In the early days of the automobile, electric cars outnumbered gasoline cars. An electric motor is quiet, has little or no emissions, and has few moving parts. It starts well in the cold, is simple to maintain, and does not burn petroleum products to operate. Its disadvantages are limited speed, power, and range as well as the need for heavy, costly batteries. Experimental vehicles employing solar-charged batteries are being considered as sources of automotive power.

CASE STUDY

A customer complains that the engine has a rough idle and does not have as much power as it used to. Also, the customer says that the engine is difficult to start when it is cold and runs better while cruising at highway speeds. Upon examining the car, it is found that it has a four-cylinder engine with nearly 65,000 miles on it. Driving the car verifies the customer's complaint.

Diagnosis begins with a visual inspection that reveals only that the car has been well-maintained. Because there is an endless list of possible causes for these problems, the first test is for engine vacuum. With the vacuum gauge connected to the manifold and the engine at idle speed, the gauge's needle constantly drops from a normal reading to 10 in. Hg. The rhythm of the drop matches the rhythm of the idle. The behavior of the gauge indicates a probable problem in one cylinder.

To verify this, a cylinder power balance test is conducted. The results show an engine speed drop of 100 to 125 rpm when cylinders 1, 2, and 4 are shorted, and a drop of only 10 rpm when cylinder 3 is shorted. Based on this test, cylinder 3 is identified as having the problem.

To identify the exact fault, further testing is required. The spark plugs are removed and inspected. All look normal, including cylinder 3. Next, a compression test is taken. All cylinders have normal readings. A cylinder leakage test is then conducted and it too shows normal conditions. The results of the power balance, compression, and cylinder leakage tests lead to the conclusion that the cause has to be in the valve train. Something is preventing a valve from opening.

Removing the cam cover for a visual inspection leads to the discovery of the fault: the intake lobe for cylinder 3 on the camshaft is severely worn. A replacement of the camshaft and matching lifter will correct the problem. The worn lobe only affects the opening of the valve and does not prevent it from sealing, which is why the compression and cylinder leakage test results were normal. Cylinder power and vacuum are affected by the valve not opening fully.

KEY TERMS

Bore	Glow plug
Cam	Horsepower
Combustion chamber	Lobe
Compression ratio	OHC
Crank throw	OHV
Cylinder power balance	Ping
Detonation	Rotary
Diesel	Stroke
Displacement	Torque
DOHC	VIN
Efficiency	Wankel
Firing order	

SUMMARY

- Automotive engines are classified by several different design features such as operational cycles, number of cylinders, cylinder arrangement, valve train type, valve arrangement, ignition type, cooling system, and fuel system.
- The basis of automotive gasoline engine operation is the four-stroke cycle. This includes the intake stroke, compression stroke, power stroke, and

exhaust stroke. The four strokes require two full crankshaft revolutions.

- The most popular engine designs are the in-line (in which all the cylinders are placed in a single row) and V-type (which features two rows of cylinders). The slant design is much like the in-line, but the entire block is placed at a slant. Opposed cylinder engines use two rows of cylinders located opposite the crankshaft.
- The two basic valve and camshaft placement configurations currently in use on four-stroke engines are the overhead valve and overhead cam. A third type, the flathead or side valve, once was popular but is no longer in use.
- Bore is the diameter of a cylinder, and stroke is the length of piston travel between top dead center (TDC) and bottom dead center (BDC). Together these two measurements determine the displacement of the cylinder, which is the volume the cylinder holds between the TDC and BDC positions of the piston.
- Compression ratio is a measure of how much the air and fuel have been compressed. The higher the compression ratio is, the more power an engine can produce. The compression ratio of an engine must be suited to the fuel available. As compression ratio increases, the octane rating of the fuel must increase to prevent abnormal engine combustion.
- Horsepower is the rate at which torque is produced by an engine. The torque is then transmitted through the drivetrain to turn the driving wheels of the vehicle.
- The vehicle identification number, or VIN, is used to identify correct engine specifications. It is stamped on a metal tab, which is riveted to the instrument panel.
- An oil pressure test measures the pressure of the engine oil as it circulates throughout the engine. This test is very important because abnormal oil pressures can cause a host of problems, including poor performance and premature wear.
- The cylinder power balance test reveals if all the cylinders are doing an equal amount of work; if not, there is either a mechanical problem or trouble in the fuel or ignition system. This test is performed easiest on an engine analyzer. As each cylinder is shorted out, a noticeable drop in engine speed should occur.
- An engine malfunction often reveals itself as an unusual noise. When correctly interpreted, engine noise can be a very helpful diagnostic aid.
- Abnormal engine combustion can cause preignition and detonation noises. Detonation knock or ping is most noticeable during acceleration with the engine under load. Though this can be very harmful to the engine, it can usually be cured by removing carbon deposits from the combustion chambers and using a higher octane gasoline.
- Instead of relying on a spark for ignition, diesel engines use the heat produced by compressing air in the combustion chamber to ignite the fuel. Three types of combustion chambers are used in diesel engines: open, precombustion, and turbulence.
- Features of both the gasoline and diesel engine are found in the stratified charge engine. Its major advantages are good part-load fuel economy, low exhaust emissions, and an ability to operate on low-octane fuel.
- In addition to the diesel and stratified charge, other automotive engines that may figure prominently in the future include the rotary or Wankel, and the electric.

TECH MANUAL

The following procedures are included in Chapter 6 of the Tech Manual that accompanies this book:

1. Perform a cylinder compression test.
2. Perform cylinder leakage test.
3. Measure engine oil pressure.