CHAPTER 16

Heat Engine Design

OBJECTIVES

After reading this chapter, you will be able to:

- Compare different types of engines, including internal, external, intermittent, continuous, reciprocating, rotary, and other classifications.
- Define the basic parts of any engine.
- State the requirements for combustion on heat engines.
- Analyze the differences between two- and four-cycle engine designs on both gasoline and diesel engines.
- State the operation of the rotary engine design.
- Identify the operation of several continuous combustion engines, including the Stirling, gas turbine, and steam turbine.

KEY TERMS

Internal Combustion	Rich Mixture	Air Box
Reciprocating	Lean Mixture	Swash Plate
Piston	Engine Displacement	Turbine
Crankshaft	BMEP	Compressor
Timing	Reed Valve	Regenerator
Air-fuel Ratio	Scavenging	Axial

Introduction

Many types of heat energy converters are used to power our transportation technologies. This chapter looks at several types of engine converters that are commonly used. They are called *heat engines* because they convert the thermal energy in fuel into mechanical energy for motion. This chapter discusses basic heat engine principles and terminology, combustion requirements, two- and four-cycle engines, diesel, rotary, and continuous combustion engines.

Types of Engines

Heat engines can be classified in several ways. These classifications are based on the location of the combustion, the type of combustion, and the type of internal motion.

Internal Combustion Engine

An *internal combustion engine* (ICE) is so named because the combustion occurs internally in the engine. For example, a gasoline engine used in a chain saw is considered an internal combustion engine. The combustion process occurs directly on the parts that must be moved inside the engine. Small lawn mower engines, snowmobile engines, and motorcycle engines are all also considered internal combustion engines. Internal combustion directly touches the parts that must be moved in order to produce mechanical energy. The burning of fuel takes place internally in the engine, Figure 16-1.

External Combustion Engine

In an *external combustion engine*, the combustion occurs indirectly on the parts that must be moved. For example, a boiler is an external combustion engine; the combustion is not touching the piston, Figure 16-2. Actually, the thermal energy in an external combustion engine heats another fluid. In this case, it is water which is converted to steam. Steam pushes against the piston to create the power.

Intermittent Combustion Engine

In an *intermittent combustion engine*, the combustion within the engine starts and stops many times

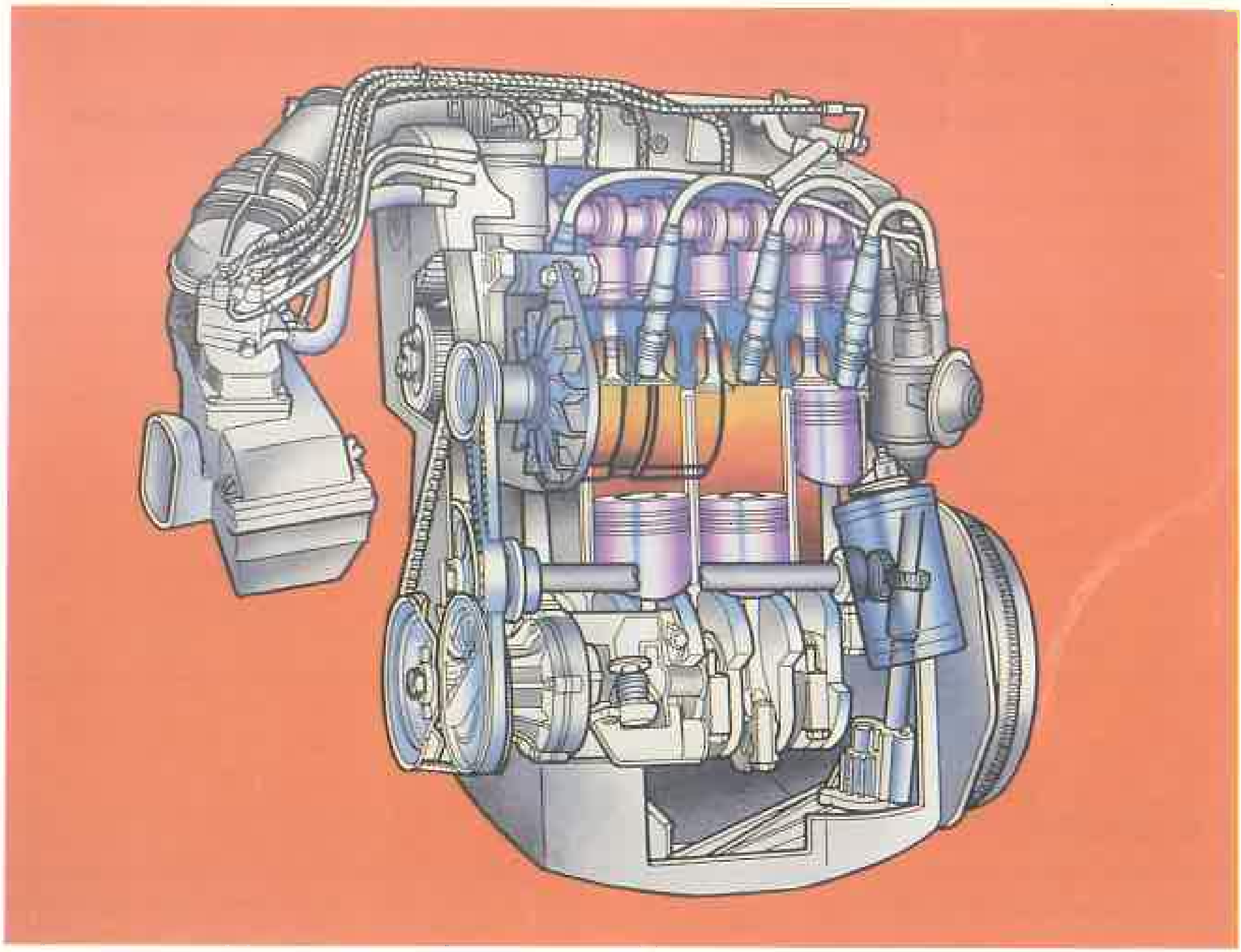


FIGURE 16-1 This engine is considered an internal combustion engine because the combustion occurs internally in the engine. *Courtesy of Volkswagen of America*

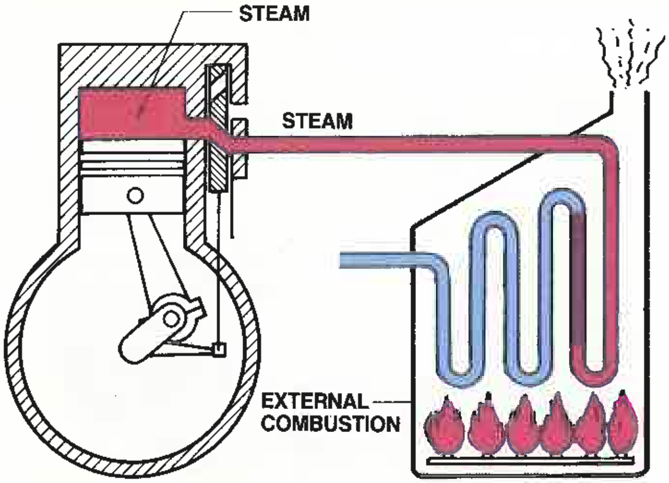


FIGURE 16-2 The combustion chamber of an external combustion engine is located separately from the internal parts of the engine.

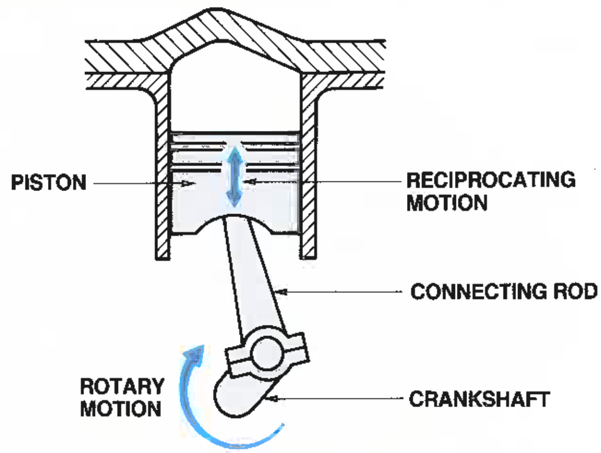


FIGURE 16-3 In a reciprocating engine, a piston moves up and down, causing rotary motion at the crankshaft.

during operation. A standard gasoline engine has an intermittent combustion design. Diesel engines are also intermittent combustion engines. Diesel engines are used primarily by large trucks and heavy equipment. They have also been used in automobiles by several automobile manufacturers.

Continuous Combustion Engine

A *continuous combustion engine* has a combustion process that continues constantly without stopping; it keeps burning continuously. A propane torch is one example of continuous combustion. Engines that use continuous combustion include turbine engines, rocket engines, stirling engines, and jet engines. Turbines, for example, are used in many industrial applications for pumping processes, and for aircraft applications.

Reciprocating Engine

A *reciprocating engine* is one in which the motion produced from the energy within the fuel moves parts up and down. The motion reciprocates or moves back and forth. Gasoline and diesel engines are considered reciprocating engines. In these operations, the power from the air and fuel starts the internal parts (piston) moving. The piston starts, then stops, then starts, then stops, over and over again. In this type of engine, the reciprocating motion must then be changed into rotary motion. A crankshaft is designed to change this motion. Figure 16-3 shows the basic parts of a reciprocating heat engine.

Reciprocating engines can also be related to the systems model of technology. For example:

1. The "input" in this system is the command to change chemical energy to mechanical energy.
2. The "process" is the engine and its parts. The engine processes chemical energy into mechanical energy. It requires parts, materials, tools, knowledge, energy, and other factors.
3. The "output" is the mechanical energy produced at the crankshaft.
4. The "feedback" is the carburetor, throttle, on/off switch, governor, and other controls required to control the engine.
5. The "impact" is the pollution produced from burning fossil fuels, the depletion of natural resources, and the social impacts of using cars that have engines, among others.

Rotary Engine

A *rotary engine* has continuous rotation of the parts that are moving. For example, a turbine engine and a Wankel engine are considered rotary engines. The mechanical motion of the parts is in the shape of a circle. The crankshaft operation in Figure 16-3 is also an example of rotary motion.

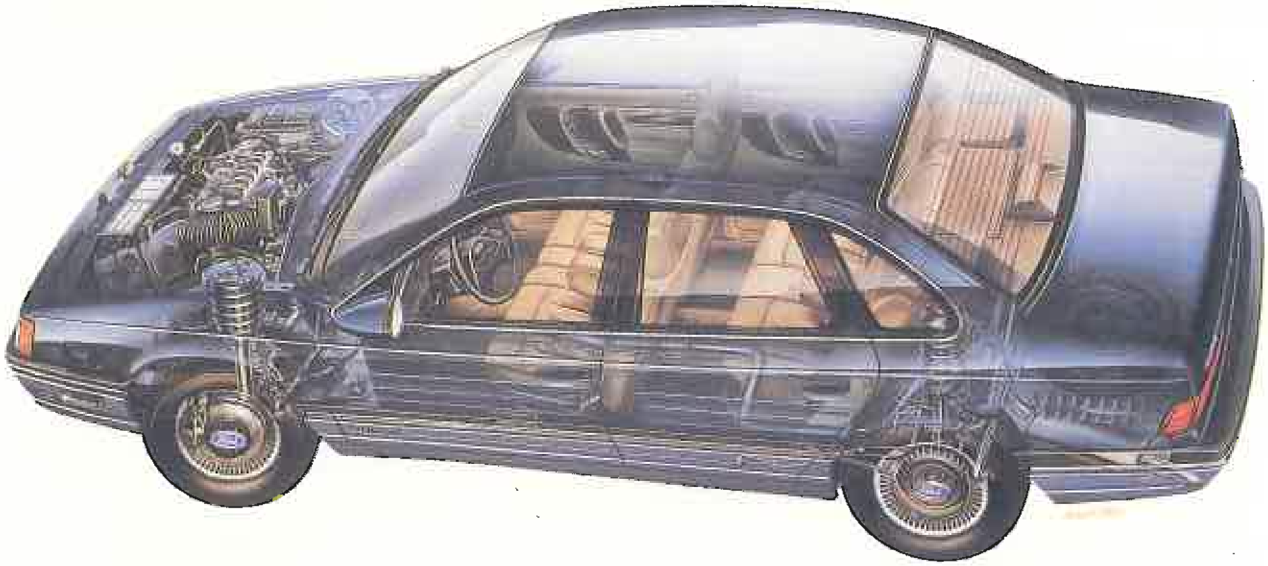


FIGURE 16-4 This car uses an internal combustion, intermittent combustion, reciprocating-type engine.
Courtesy of Ford Motor Company

Other Heat Engine Classifications

Heat engines can also be classified additionally by:

1. Cycles — There are two- and four-cycle engines.
2. Cooling systems — There are liquid-cooled and air-cooled engines.
3. Fuel system — There are gasoline-fueled and diesel-fueled engines.
4. Ignition systems — There are spark-ignition and compression-ignition engines.

All of these methods of classifying engines can be combined with those previously mentioned.

Most Common Engine Classifications

The most common engines used today are the gasoline or diesel engines. The gasoline and diesel engines used in cars, trucks, buses, lawn mowers, and so forth, are considered internal combustion, intermittent combustion, reciprocating-type engine designs. Figure 16-4 shows a phantom view of a car with such an engine. If the rotary (Wankel) engine is used, it is considered an internal combustion, intermittent combustion, rotary design. These engines are also considered four cycle, either liquid or air cooled.

Heat Engine Parts and Systems

In order to understand the principles of heat engines, certain parts must be defined. These parts are considered the major components of any reciprocating heat engine. They include the cylinder block, cylinders, pistons, connecting rod and crankshaft, cylinder head, combustion chamber, valves, flywheel, and carburetor/fuel injection.

Cylinder Block

The *cylinder block* is defined as the foundation of any heat engine, Figure 16-5. The cylinder block is made of cast iron or aluminum. All other components of the engine are attached to the cylinder block. The cylinder block has several internal passageways to allow cooling fluid to circulate around the cylinders. It also has several large holes machined into the block where the combustion occurs.

Cylinders

The *cylinders* are defined as internal holes in the cylinder block, Figure 16-5. These holes (cylinders) are used as combustion chambers. The number of holes indicate the number of cylinders used on an engine. For example, on small gasoline engines, such as lawn mowers, there is one cylinder. Automobiles usually use four, six or eight cylinders. Some engines used on heavy equipment have as many as 24 cylinders.

Pistons

Pistons are defined as the round piece that slides up and down in a cylinder, Figure 16-5. There is one piston for each cylinder. Pistons are made of lightweight material, such as high-quality aluminum, that can withstand high temperatures. When combustion of fuel occurs above the piston, the expansion of heated gases forces the piston downward. This downward motion of the piston converts the energy in the fuel into mechanical energy. Pistons are equipped with seals or rings, which are used to stop any combustion from passing by the side of the piston.

Connecting Rod and Crankshaft

The connecting rod is attached to the bottom of the piston, as is shown in Figure 16-5. The main purpose of the *connecting rod* is to attach the piston to the crankshaft. The crankshaft changes the reciprocating motion of the piston and connecting rod to rotary motion. Rotary motion is used as the output power of a heat engine.

Cylinder Head

The *cylinder head* is the part that fits over the top of the cylinder block, Figure 16-5. All reciprocating engines have some form of cylinder head. It usually houses the valves and ports that allow fuel and air to enter into the cylinder. The spark plug is also attached to the cylinder head. The cylinder head is made of cast iron or aluminum. When it is bolted to the cylinder block, it seals the cylinders so that the air and fuel flow can be controlled in and out of the cylinder.

Combustion Chamber

The combustion chamber is where the combustion takes place inside the cylinder. When the cylinder head has been attached to the cylinder block, the area inside of the cylinder head and block is called the *combustion chamber*. On some engines, the combustion chamber is located inside the head. Other engines have the combustion chamber located inside the top of the piston; this is especially true on diesel engines. On certain types of turbine engines, the combustion chamber is a separate unit.

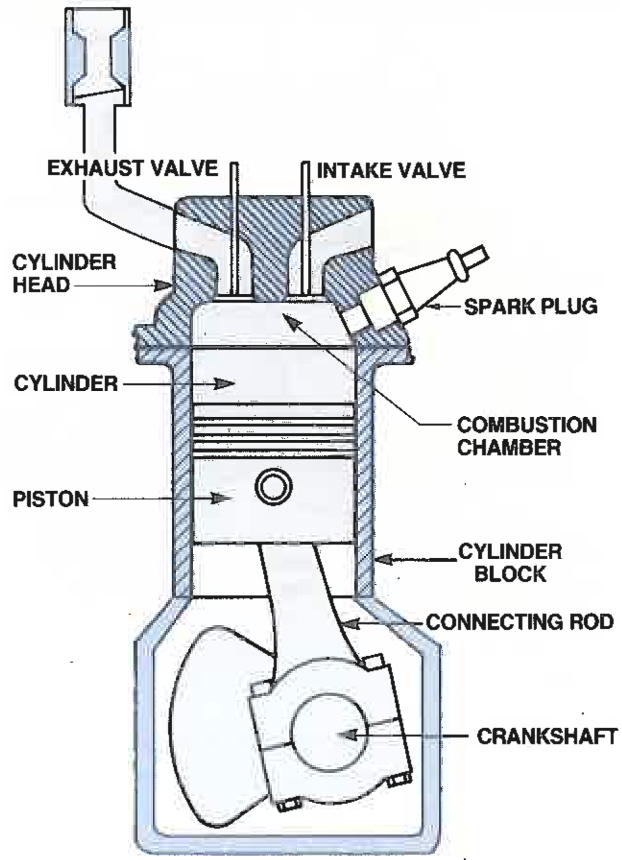


FIGURE 16-5 The cylinder block is the foundation for all of the basic parts of a reciprocating engine.

Valves and Ports

Valves and *ports* are located inside of the cylinder head and block. Their purpose is to allow air and fuel to enter and leave the combustion area. The valves are shown in Figure 16-5. Valves are designed so that when they are closed the port is sealed perfectly. They must also be designed so that they can be opened exactly at the right time. The valves are opened by using a camshaft, and closed by using springs. An intake valve allows fuel and air to enter the cylinder, and an exhaust valve allows the burned gases to exit the cylinder.

Camshaft

The *camshaft* is used to open the valves at the correct time. Cam lobes, or slightly raised areas, are machined on the camshaft to open the valves so that air and fuel can enter the cylinder. The valves are then closed by springs on each valve. The

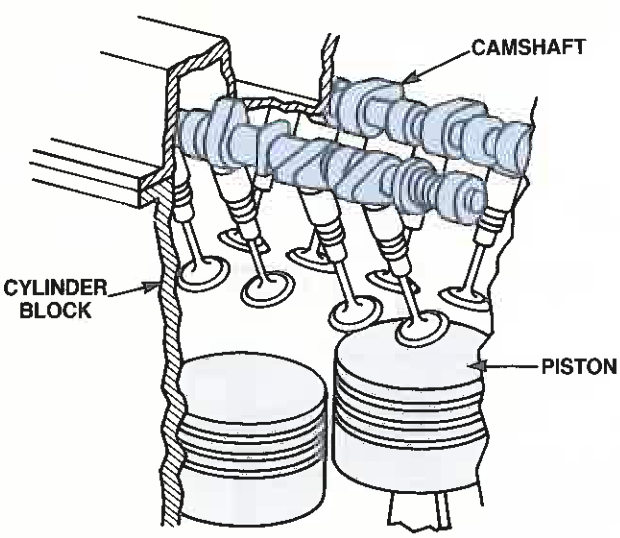


FIGURE 16-6 A dual overhead camshaft is used on some engines to operate the intake and exhaust valves.

camshaft is driven by the crankshaft. This means that the camshaft must be timed to the crankshaft, so that the valves will open and close in correct time with the position of the piston. One lobe is placed on the camshaft for each valve that must be opened and closed.

The camshaft may be mounted in the block or mounted directly on top of the cylinder head. When mounted on top of the cylinder head, it is called an overhead camshaft (OHC). A dual overhead camshaft is shown in Figure 16-6.

Flywheel

The *flywheel*, which is located on the end of the crankshaft, is designed to act as a weight to keep the crankshaft rotating once power has started. The flywheel is usually heavy. It smooths out any intermittent motion from the power pulses. The flywheel is a good example of Newton's law of motion. This law says that an object in motion tends to remain in motion, whereas an object at rest tends to remain at rest. Once the flywheel is in motion, it tends to remain in motion.

Carburetor/Fuel Injection

The carburetor is placed on the engine to mix the air and fuel in the correct proportion. This is called the *fuel induction* system. On heat engines today, fuel induction can also be done by *fuel injection*. Air and fuel must be mixed correctly for the engine to operate efficiently. The carburetor's or fuel injector's job is to mix the air and fuel during cold weather, warm weather, high altitudes, high humidity, low- and high-speed conditions, and acceleration.

Engine Systems

All engines require several mechanical, fluid, and electrical systems to operate. These systems are usually considered part of the engine. Without the following systems, the engine would not run correctly or efficiently.

Cooling System. The cooling system is designed to keep the engine temperature at a constant and most efficient temperature. Both liquid-cooled and air-cooled designs are used. Figure 16-7 shows a typical cooling system in a multiple-cylinder reciprocating engine.

Fuel System. The fuel system is used to monitor and precisely control the amount of fuel being fed into the engine. Carburetors and fuel injectors are now generally controlled by computers.

Lubrication System. The lubrication system is used to keep all internal moving parts well lubricated.

Ignition System. The ignition system is used to provide the necessary spark for combustion of the air and fuel mixture. The ignition system must also provide the spark at the correct time during engine operation.

Starting System. The starting system is used to crank the engine during starting conditions only. Usually, a battery and a direct-current starter motor are used in conjunction with switches and a solenoid.

Charging System. The charging system is used to provide electricity to charge the battery and operate the required accessory systems.

Air/Exhaust System. The air and exhaust systems are used to feed air into and out of an engine. Common components include air filters, turbochargers, mufflers, and catalytic converters. Figure 16-8 shows the exhaust system of a typical vehicle.

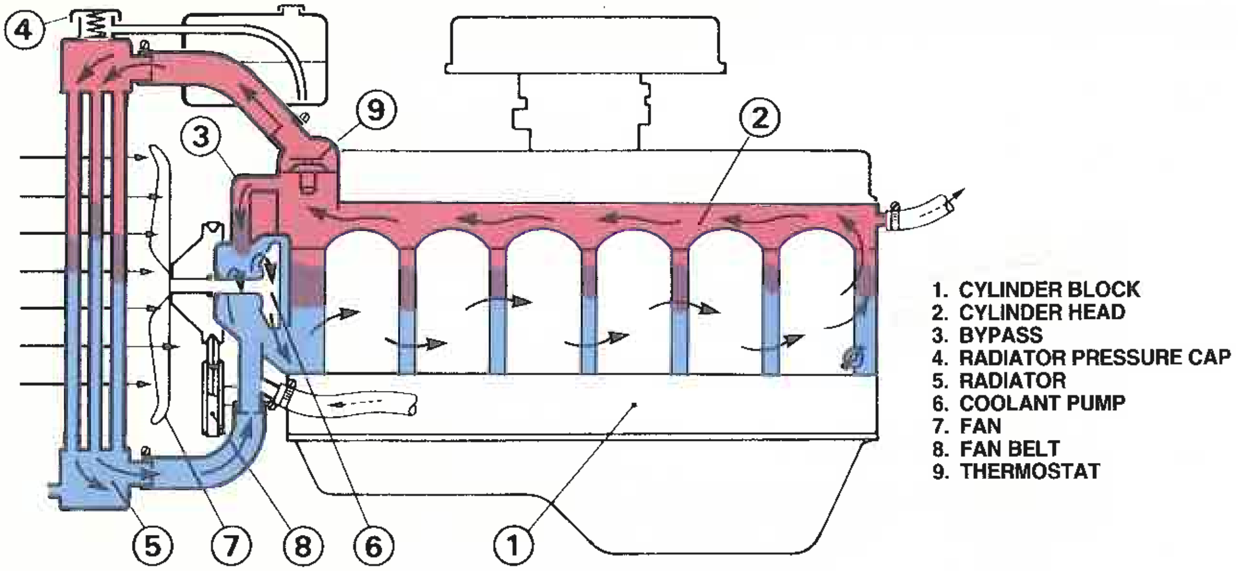


FIGURE 16-7 This cooling system is an example of one of the major systems used in a heat engine. *Courtesy of First Brands Corporation*

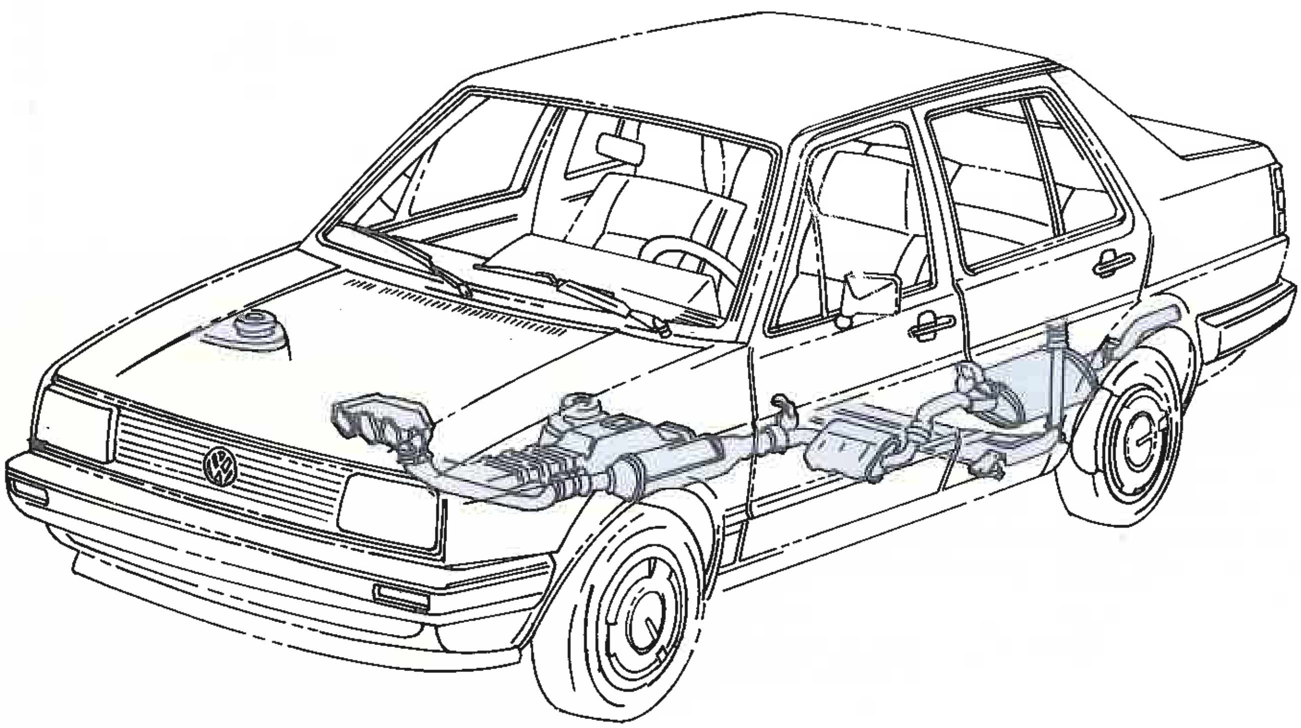


FIGURE 16-8 The exhaust system on a heat engine such as in this vehicle, is used to reduce noise and eliminate pollution. *Courtesy of Volkswagen of America*

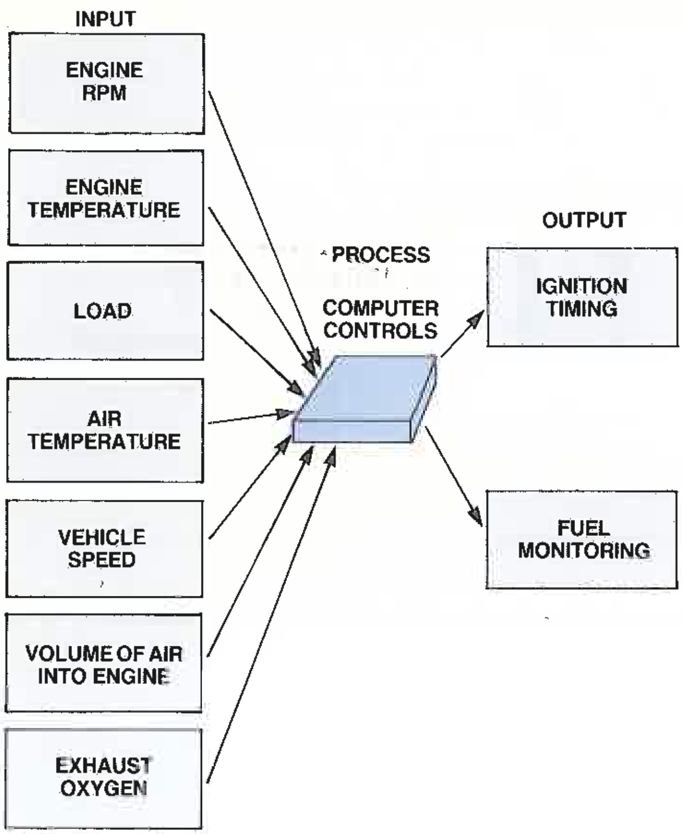


FIGURE 16-9 Computer controls (processor) are used on a heat engine to monitor ignition timing and the fuel.

Computer-controlled Systems. Many heat engines have computer controls (processor) to aid in precise operation. For example, ignition timing and fuel monitoring (outputs) are controlled by inputs from several sources as shown in Figure 16-9.

Pollution Control Systems. Many pollution control systems are used on heat engines today. Most engines produce carbon monoxide, nitrogen oxides, and hydrocarbon emissions. Pollution control systems include positive crankcase ventilation (PCV), controlled combustion systems (CCS), air injection reactors (AIR), exhaust gas recirculators (EGR), and others.

Combustion Requirements

To produce heat, some form of combustion is required. The quality of combustion has a direct effect on the efficiency of the heat engine. Several terms that relate directly to reciprocating-type engines help to describe combustion requirements. In addition, several of these concepts are directly related to other types of heat engines as well.

Air, Fuel, and Ignition

All internal combustion-type engines have certain requirements for efficient operation. Every engine has three requirements for effective operation: 1) there must be sufficient air for combustion, 2) the correct amounts of fuel must be mixed with the air, and 3) some type of ignition is needed to start combustion. When these three requirements are met, combustion will take place, Figure 16-10. This combustion changes the chemical energy in the fuel to thermal energy. The thermal energy will then cause a rapid expansion of burning gases. This expansion pushes on the pistons or turbine blades. For example, these forces cause crankshafts to rotate or generators to turn. The rotary motion can then be used for moving transportation technology. If any one of these three requirements is missing, the engine will not run.

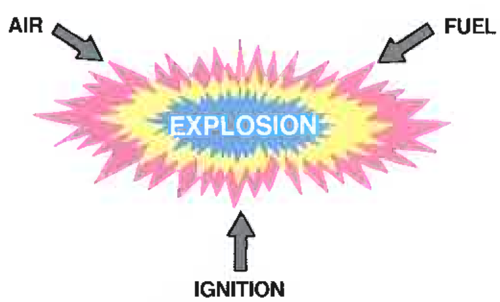


FIGURE 16-10 Air, fuel, and ignition are the three requirements for efficient combustion in a heat engine.

Timing

Timing is defined as the process of identifying the exact time when the air, fuel and ignition for combustion occurs. Most internal combustion engines require exact timing of certain events. This is done in relationship to the position of the piston and crankshaft. In order for the engine to operate efficiently, the air and fuel mixture must enter the cylinder at the correct time. This means that the intake valve must be opened and closed at the correct time. The exhaust valve must also be opened and closed at the correct time.

The ignition must also be timed. Ignition of the air and fuel must occur at a precise time. The timing of the ignition also changes with the speed and load of the engine. When the intake and exhaust valves are correctly timed, and the ignition occurs at the correct time, maximum power will be obtained in converting chemical energy into mechanical energy.

Air to Fuel Ratio

Air to fuel ratio is defined as the ratio of air to fuel mixed in any heat engine.. The air and fuel must be thoroughly mixed. Each molecule of fuel must have enough air surrounding it to be completely burned. If the two are not mixed in the correct ratio, engine efficiency will drop. Exhaust emission levels will also increase.

The standard air to fuel ratio should be about 15 parts of air to 1 part of fuel. This measurement is calculated by weight. Actually, the most efficient ratio is stated as 14.7:1. For every pound of fuel used, 15 pounds of air are needed, Figure 16-11A. In terms of size, this is equal to burning 1 gallon of fuel to 9,000 gallons of air.

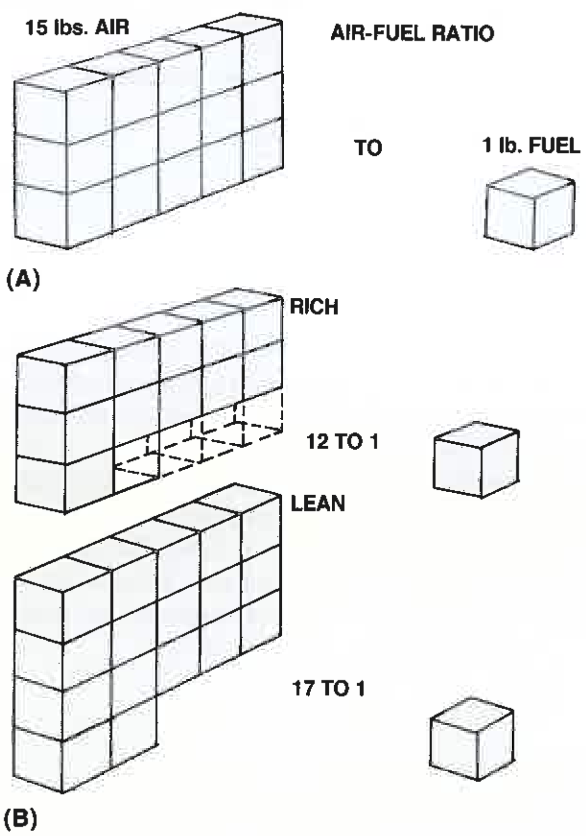


FIGURE 16-11 (A) Any combustion process works most efficiently when there is an exact air to fuel mixture. This mixture is usually 15 to 1 (exactly 14.7:1). (B) A rich air to fuel ratio has less air. A lean air to fuel ratio has more air.

Rich and Lean Mixtures. A low ratio of around 12:1 suggests a *rich mixture* of fuel. A mixture of 18:1 suggests a *lean mixture*. The rich and lean mixtures are shown in Figure 16-11B. Generally, rich mixtures are less efficient during combustion. The rich mixture is used during cold weather starting conditions. The lean mixture burns hotter than a rich mixture. Normally, the fuel acts as a coolant in the combustion process. With less fuel to cool, the combustion process gets hotter. A lean mixture can cause severe damage to the pistons and valves and other internal parts if not corrected.

Much has been done in the past few years to control the air to fuel ratio to exact requirements. Fuel systems are better able to keep the mixture under control with the use of computers and special types of fuel injection. By controlling air-fuel mixtures accurately, efficiency of the engine increases. For example, fuel mileage on cars can be increased well into the 40 to 50 miles per gallon range for smaller engine sizes.

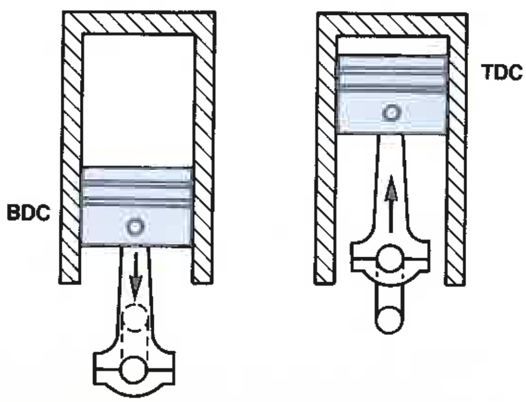


FIGURE 16-12 The position of the piston is shown at bottom dead center (BDC) and top dead center (TDC).

TDC and BDC

TDC stands for top dead center. BDC stands for bottom dead center. These terms are related to reciprocating piston engines. TDC indicates the position of the piston when it reaches the top of its upward motion. When the piston is at the bottom of its travel, it is at bottom dead center (BDC), Figure 16-12. These two terms are used to help identify the position of the piston during some of the timing processes.

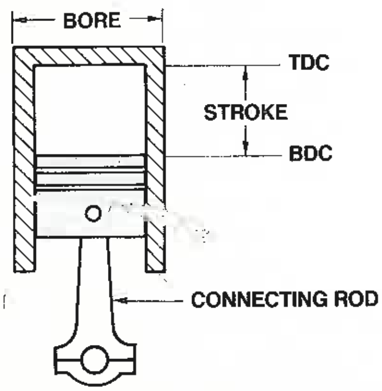


FIGURE 16-13 The bore and stroke of an engine.

Bore and Stroke

The bore and stroke of an engine help to identify its size, Figure 16-13. The *bore* of the engine is defined as the diameter of the cylinder. The *stroke* of the engine is a measurement of the distance the piston travels from the top to the bottom of its movement or the length from TDC to BDC.

The stroke is determined by the design of the crankshaft. The distance from the center of the crankshaft to the center of the crankpin is called the *throw*, Figure 16-14. This dimension, when multiplied by 2, is the same distance traveled by the stroke. If the stroke is changed on any heat engine, the crankshaft will have a different length throw.

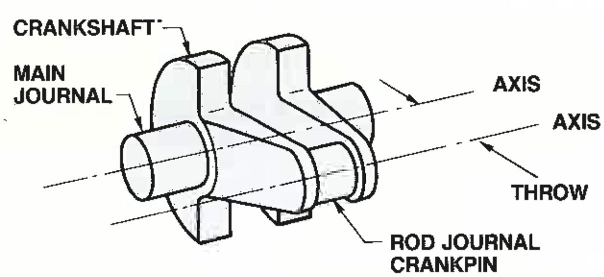


FIGURE 16-14 The throw is the distance from the center of the crankshaft to the center of the crankpin.

Engine Displacement

Engine displacement is defined as the volume of air in all of the cylinders of an engine. Each cylinder has a certain displacement.

TECH LINK

Displacement of a cylinder can be determined by using the following formula:

$$\text{Displacement} = 0.785 \times \text{bore}^2 \times \text{Stroke in cubic inches}$$

This formula gives the exact displacement in cubic inches of one piston from top dead center to bottom dead center. In order to calculate the displacement in metric units the formula is the same, only the bore and stroke are measured in centimeters.

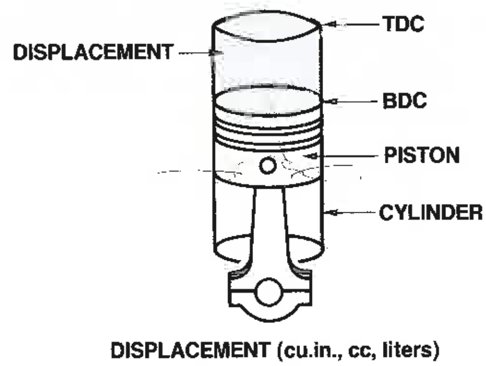


FIGURE 16-15 Displacement is the volume above the piston at bottom dead center.

Figure 16-15 shows a graphical example of the displacement of a cylinder. When there is more than one cylinder, the total displacement is multiplied by the number of cylinders.

Displacement is often calculated in cubic inches. However, today, many engines are sized by cubic centimeters (cc or cm^3) and by liters. For example, today's engines are identified as 2.5 liters, 850 cc, and so on. The conversion from cubic inches to cc is:

$$1 \text{ in}^3 = 16.387 \text{ cc}$$

and

$$1{,}000 \text{ cc} = 1 \text{ liter}$$

Compression Ratio

During any heat engine operation, the air and fuel mixture must be compressed. This compression helps squeeze and mix the air and fuel molecules for better combustion. All heat engines require some form of compression for improved efficiency. Actually, the more compression of the air and fuel, the better the efficiency of the engine.

Compression ratio is a measure of how much the air and fuel has been compressed. *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. Compression ratio is shown in Figure 16-16. Common compression ratios range anywhere from 6:1 on small gas engines and 8:1 on low-compression car engines, to 25:1 on diesel engines.

TECH LINK

The formula for calculating compression ratio in any piston-type engine is:

$$\text{Compression Ratio} = \frac{\text{Volume above the piston at BDC}}{\text{Volume above the piston at TDC}}$$

In many engines at TDC, the top of the piston is even or level with the top of the cylinder block. The combustion chamber volume 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 combustion chamber volume must be added to each volume stated in the formula to give accurate results.

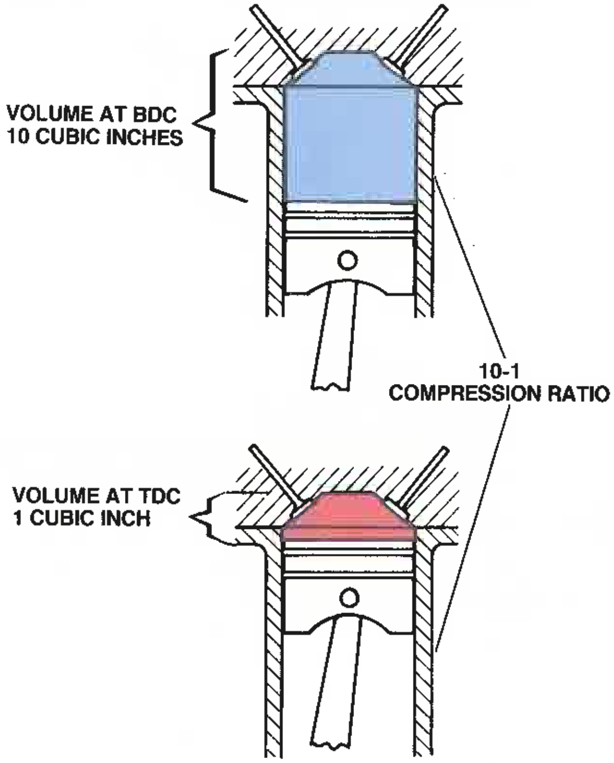


FIGURE 16-16 The compression ratio is the ratio of the volume at BDC compared to the volume at TDC.

BMEP

BMEP stands for the phrase brake mean effective pressure. This is an engineering term used to indicate how much pressure is applied to the top of any piston from TDC to BDC. It is measured in pounds per square inch. This term becomes very useful when analyzing the results of different fuels used in heat engines. For example, if diesel fuel is used in an engine, more BMEP is produced. This then produces more output power than if gasoline as a fuel were used. Also, as different injection systems, combustion designs, and new ignition systems are developed, they all affect the BMEP of the engine.

Four-Stroke Engine Design

The four-stroke engine is one of the most popular types of reciprocating-type heat engines. A four-stroke engine can also be called a four-cycle engine. The terms stroke or cycle can be used interchangeably. A four-stroke engine has a very distinct operation. The four strokes are titled intake, compression, power, and exhaust.

When the piston moves downward with the intake valve open, intake occurs. When the piston moves upward with both valves closed, compression occurs. When the spark ignites the mixture after combustion, the power stroke occurs. After the power stroke, the exhaust valve opens. As the piston moves upward, the spent gases are exhausted.

The next sections describe the four-stroke gasoline engine in detail. However, remember that there are also four-cycle diesel engines as well.

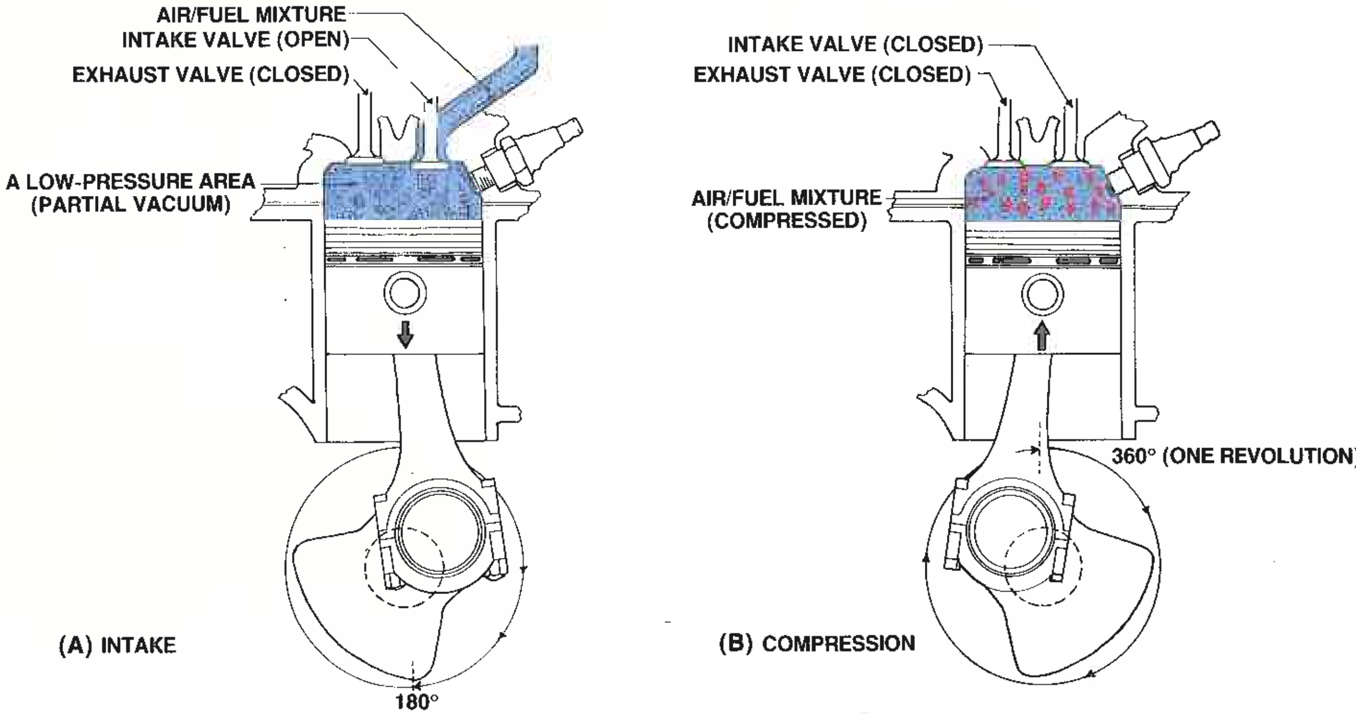


FIGURE 16-17 The four events of a four-stroke gasoline engine are: intake, compression, power, and exhaust. *Reprinted by permission of PWS-KENT Publishing Company, by Glen F. Ireland, Automotive Fuel, Ignition, and Emission Control Systems © 1981*

Intake Stroke

Refer to Figure 16-17A. To start, the location of the piston is near TDC. Note that the intake valve is opened. As the piston is cranked downward, called the *intake stroke,* air and fuel are brought into the cylinder. This occurs because, as the piston moves down, a vacuum is created. When any object is removed from an area, a vacuum is created. This vacuum (lower than atmospheric pressure) brings fresh air and fuel into the cylinder. It can also be said that higher air pressure outside of the engine pushes the air and fuel into the engine.

The air is first drawn through the carburetor. Here, the air is mixed with the fuel at the correct air to fuel ratio (14.7:1). When the piston gets to BDC, the intake valve starts to close. With the valve closed, the air and fuel mixture is trapped inside the cylinder area.

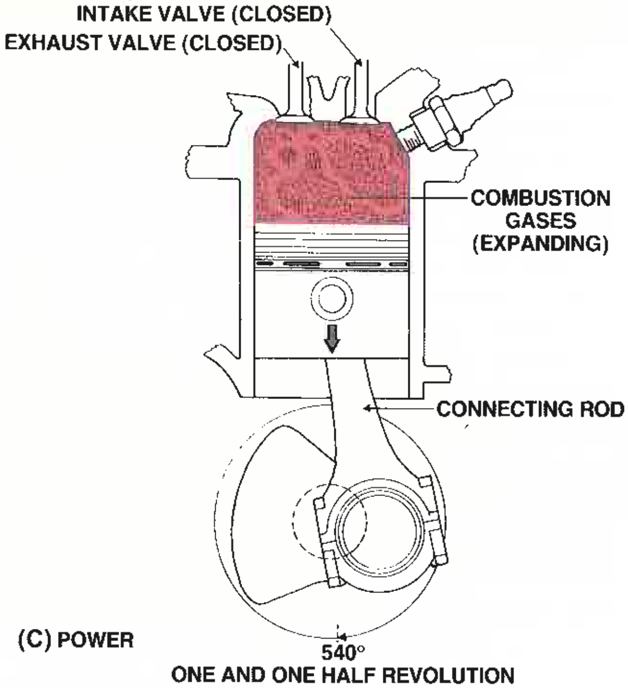
Compression Stroke

The piston now travels from BDC to TDC with the air and fuel mixture in the cylinder. This action is called the *compression stroke.* See Figure 16-17B. The compression stroke takes the air-fuel mixture and compresses it, according to the compression ratio of the engine. This compression causes the air and fuel to be mixed very effectively. Actually, the higher the compression ratio, the greater the mixing of air and fuel. This leads to improved engine efficiency.

It is very important that there are no leaks through which the compression gases can escape. Possible leaks may occur by the valves, the gasket between the head and cylinder block, and past the rings on the piston. Note that at the end of the compression stroke, the crankshaft has revolved 360 degrees or one revolution.

During the compression stroke, the air and fuel are actually heated from the action of compression. It is like using an air pump to pump up a tire. As the air at the bottom of the pump is compressed, the air gets hotter. If the compression ratio is too high, temperatures within the combustion chamber may ignite the fuel. This process, referred to as *pre-ignition,* can cause pinging. This means that the combustion in the chamber started before the piston reached TDC.

It would be very helpful if compression ratios were increased. However, as long as air and fuel are being compressed, the compression ratios must be low so the air and fuel do not preignite. Higher compression ratio engines are discussed in the diesel section of this chapter.



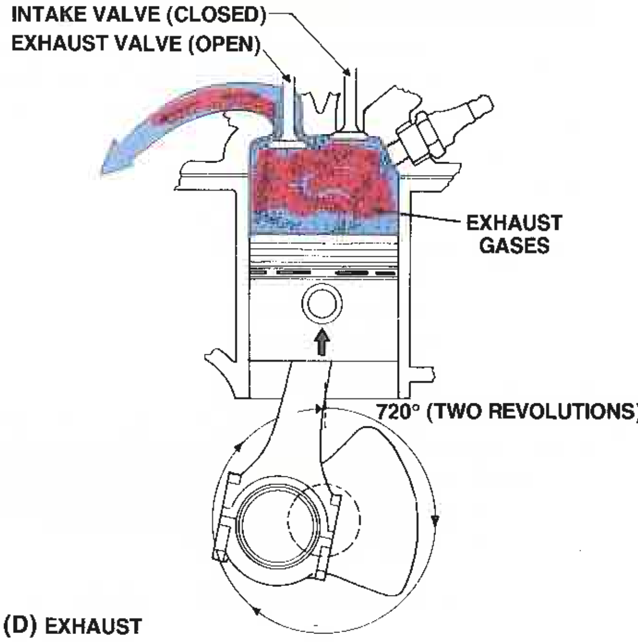


FIGURE 16-17 Continued.

Power Stroke

During the *power stroke,* shown in Figure 16-17C, both the intake and exhaust valves remain closed. As the piston rises on the compression stroke, a spark will occur slightly ahead of TDC. At this point, air, fuel and ignition are present. This causes the air and fuel to ignite. When this happens, the expansion of gases during combustion pushes down on the top of the piston. This pressure pushes the piston downward through the power stroke. This is also when BMEP is created.

Exhaust Stroke

The final stroke in the four-cycle design is called the exhaust stroke, shown in Figure 16-17D. The *exhaust stroke* starts when the piston starts moving upward again. The crankshaft continues to rotate because of the flywheel weight. At the beginning of the exhaust stroke, the exhaust valve opens. As the piston travels upward, it pushes the burned or spent gases out of the cylinder as exhaust.

Near the top of the exhaust stroke, the exhaust valve starts to close. At this point, the intake valve is already starting to open for the next intake stroke. It is important to note that the crankshaft has revolved two revolutions at this point. Only one power stroke has occurred. If the engine is running at 4,000 r/min, then there are 2,000 power pulses for each cylinder per minute.

Timing Diagrams

A *timing diagram* is a method used to identify the times at which all of the four-stroke events occur. A timing diagram is shown in Figure 16-18. The

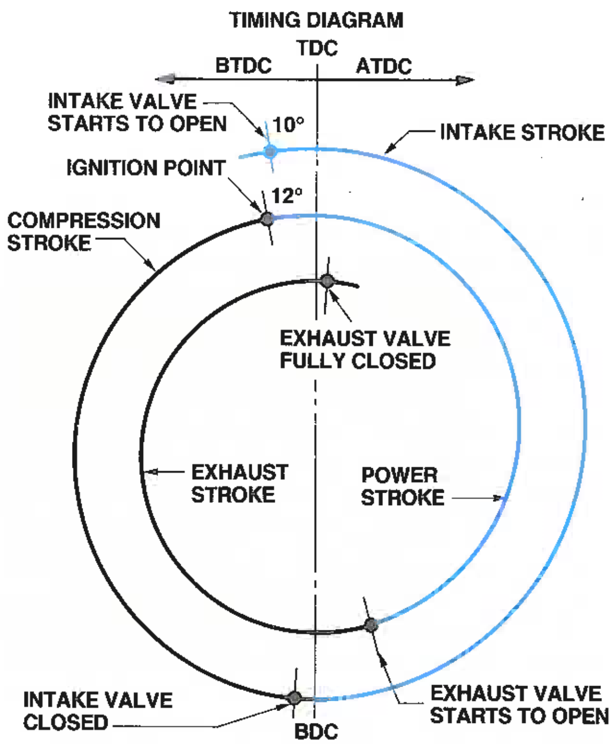


FIGURE 16-18 This timing diagram shows the point in degrees rotation that each event occurs on a four-cycle engine.

diagram is set on a vertical and horizontal axis. There are 360 degrees around the axis. Events of the four-cycle engine can be graphed on the circle. One way to look at the diagram is to think of these events in terms of the position of the crankshaft through 360 degrees rotation. For example, at the top of the diagram, the piston would be located exactly at TDC. Any event that happens before TDC is referred to as BTDC (before top dead center). Any event that happens after top dead center is called ATDC (after top dead center). The mark at the bottom of the graph would illustrate the position of the piston at BDC. Two circles are shown. This is because two circles represent two complete revolutions of the crankshaft. During the four strokes of operation, the crankshaft revolves two complete revolutions, or 720 degrees of rotation.

Four-stroke Timing Diagram Procedure

Referring again to Figure 16-18, follow through the four-stroke design on the timing diagram. Note that the events and degrees may vary with each engine and manufacturer. The cycle starts with the intake valves opening slightly before TDC. It should be fully open at TDC. It takes this many degrees of crankshaft rotation to open the intake valve completely.

As the piston travels downward on the intake stroke, the intake valve starts to close shortly before BDC. It is fully closed after BDC. At this point the intake stroke is completed.

The compression stroke starts when the intake valve is fully closed. The piston travels upward, compressing the air and fuel mixture. As the piston is traveling upward, the air-fuel mixture is being mixed by the compression of gases. Also, the temperature is rising inside of the combustion chamber. About 12 degrees before TDC, ignition from a spark plug occurs. The point of ignition is several degrees before TDC. It takes about 12 degrees for the combustion to actually build up to a maximum. At TDC, the combustion is at a maximum point. Now, the piston is ready to be pushed downward.

If the timing of the ignition were sooner, or more than 12 degrees before TDC, then the combustion would occur too soon. This would then reduce the BMEP during the power stroke. If the timing of the ignition were too late, or after TDC, then the BMEP would also be less. It is important that maximum power from the combustion of gases occurs just when the piston is at TDC.

The power stroke starts when the piston starts downward. In this case, the power stroke is shown on the inside circle of the timing diagram. As the combustion occurs, the gases expand very rapidly. This expansion causes the piston to be forced down. This action produces the power for the engine.

Near BDC, at the end of the power stroke, the exhaust valve starts to open. By the time the piston gets to BDC, the exhaust valve is fully open. As the crankshaft continues to turn, the piston travels upward. This action forces the burned gases out of the exhaust valve, into the atmosphere. The exhaust valve is fully closed a few degrees after TDC. The time in which both the intake valve and the exhaust valve are open, (near TDC) is called *valve overlap.*

Advance and Retarded Timing

The timing of the ignition is the only part of the timing on most engines that can be adjusted. If the ignition time is moved or adjusted more BTDC, the condition is called *advance timing*. If the ignition time is moved or adjusted toward or after TDC (ATDC) the condition is called *retarded timing*.

Two-Cycle Engine Design

The two-cycle engine design is used on many small engines, such as outboard motors, lawn mowers, chain saws, snowmobiles, cycles, and other recreational vehicles.

Two-cycle Engine Operation

Figure 16-19 shows an example of two-cycle engine operation. Note that many of the engine parts are the same as for the four-cycle engine. One difference is that the cylinder does not use the standard type valves to allow air and fuel to enter the engine. In order to follow the operation, consider the events both on the top and on the bottom of the piston. In operation, as the piston in Figure 16-19A moves upward, compression is produced above the piston. A vacuum is also created within the crankcase area below the piston. The vacuum is used to bring in a fresh charge of air and fuel past a reed valve. Note that oil must be added to the air-fuel mixture at this point. This is because there is no oil in the crankcase as with four-cycle engines. The oil in the fuel acts as the lubricant. Normally, an oil to gas ratio of between 20:1 up to 50:1 or higher is used, depending upon the year and manufacturer of the engine.

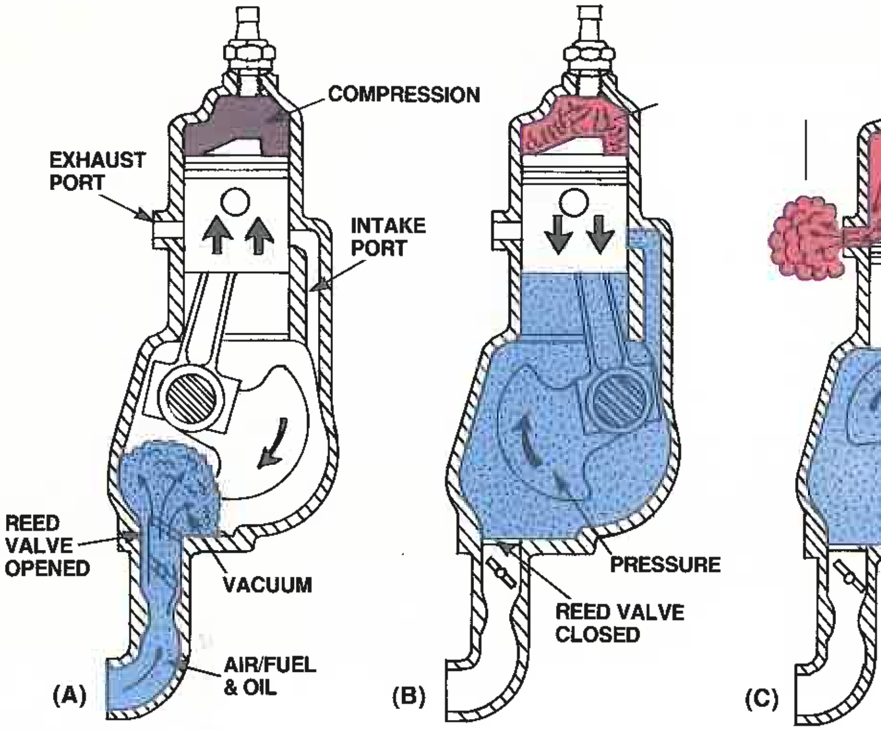


FIGURE 16-19 The two-cycle engine uses the pressure and vacuum created below the piston to draw in a fresh charge of air/fuel/oil to be used in the combustion chamber. *Courtesy DCA Educational Products*

As the piston continues upward on the compression stroke, eventually, a spark and thus combustion occurs, Figure 16-19B. This pushes the piston downward. As the piston moves farther down, a high pressure is created in the crankcase area. The reed valve is forced closed by the pressure, sealing the crankcase area. When the piston gets low enough in its stroke, it eventually opens both the intake and exhaust ports, Figure 16-19C. *Ports* are simply holes cut into the cylinder to allow air and fuel to enter and exhaust escape.

When the ports are open, the crankcase pressure forces a mass of air/fuel/oil mixture into the combustion chamber. This mass also helps to remove any exhaust gases by way of the exhaust port. As the piston starts upward, the ports are closed. Compression and power continue on top of the piston, while suction and a small pressure continue on the bottom of the piston.

Two-cycle Timing Diagram

To better understand the two-cycle engine, a timing diagram is again used. Remember that the vertical axis represents the TDC and BDC point on the piston and crankshaft. The events of the two-cycle process can now be graphed on the timing diagram, as shown in Figure 16-20. Although each engine diagram may differ slightly, the diagram shows several common points.

1. Timing for combustion occurs slightly before TDC.
2. During the power stroke, the exhaust valve opens slightly before the intake.
3. During the compression stroke the exhaust valve closes slightly after the intake port.
4. When the piston is at the bottom of its travel, both intake and exhaust are occurring.

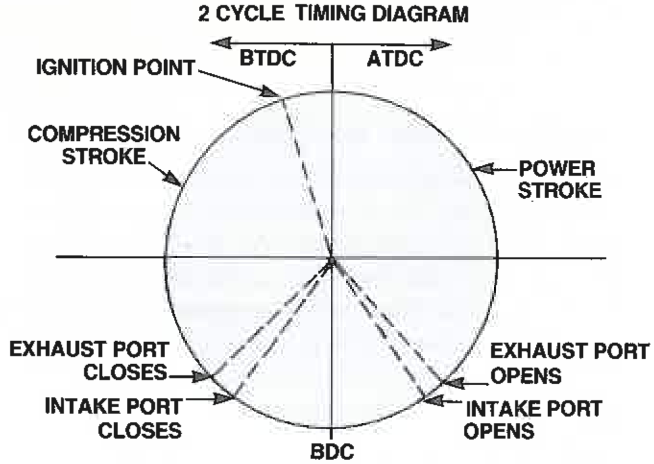


FIGURE 16-20 This timing diagram shows the events that occur during two-cycle engine operation.

Advantages and Disadvantages of Two-cycle Engines

There are several distinct advantages and disadvantages of the two-cycle engine.

Advantages

1. Two-cycle engines are very responsive because there is a power pulse every revolution. (Note that the two-cycle engine has a power pulse every revolution.) This means it takes less time to get from 500 r/min at idle, to say 4,000 r/min maximum speed.
2. Two-cycle engines are usually lighter in weight than four-cycle engines. This is because they usually have fewer parts.
3. Two-cycle engines can be operated at varying angles of operation. This is because there is no crankcase that holds oil. This is one among several reasons that two-cycle engines are usually found on recreational vehicles.

Disadvantages

1. Two-cycle engines lose some of their efficiency for several reasons. These include:
   a. Poor volumetric efficiency. Air and fuel can only enter the cylinder for a very short period of time. This reduces the total amount of air and fuel that can enter the engine, thus reducing efficiency.
   b. Poor combustion efficiency. The oil in the air/fuel mixture reduces combustion efficiency.
   c. Less BMEP. Total force during the power stroke will be reduced because the power stroke is shortened. The power stroke ends when the exhaust port is opened.

Loop Scavenging Two-cycle Engine

Two-cycle engines have been improved from the standard design. *Loop scavenging* is a two-cycle design used to improve the ease at which air and fuel can enter and leave the cylinder. The main difference is that the reed valve system previously discussed is replaced with an intake port located on the bottom of the cylinder. The intake port is opened and closed by the position of the piston skirt. Events occur both on top and bottom of the piston.

The events occur in three phases. In phase 1, the piston moves upward and the piston skirt opens the intake port in the cylinder. The vacuum below the piston draws in fresh fuel, air, and oil for lubrication. During phase 1, compression above the piston is also occurring. During phase 2, power is produced on top of the piston. Below the piston, compression occurs on the air/fuel and oil mixture. During phase 3, the exhaust port and the intake port to the cylinder are opened. This causes the air/fuel/oil mixture below the piston to enter the cylinder. The spent exhaust gases in the cylinder are also exhausted to the atmosphere. Figure 16-21 shows a typical example of a two-cycle, loop scavenging-type engine used in a snowmobile.

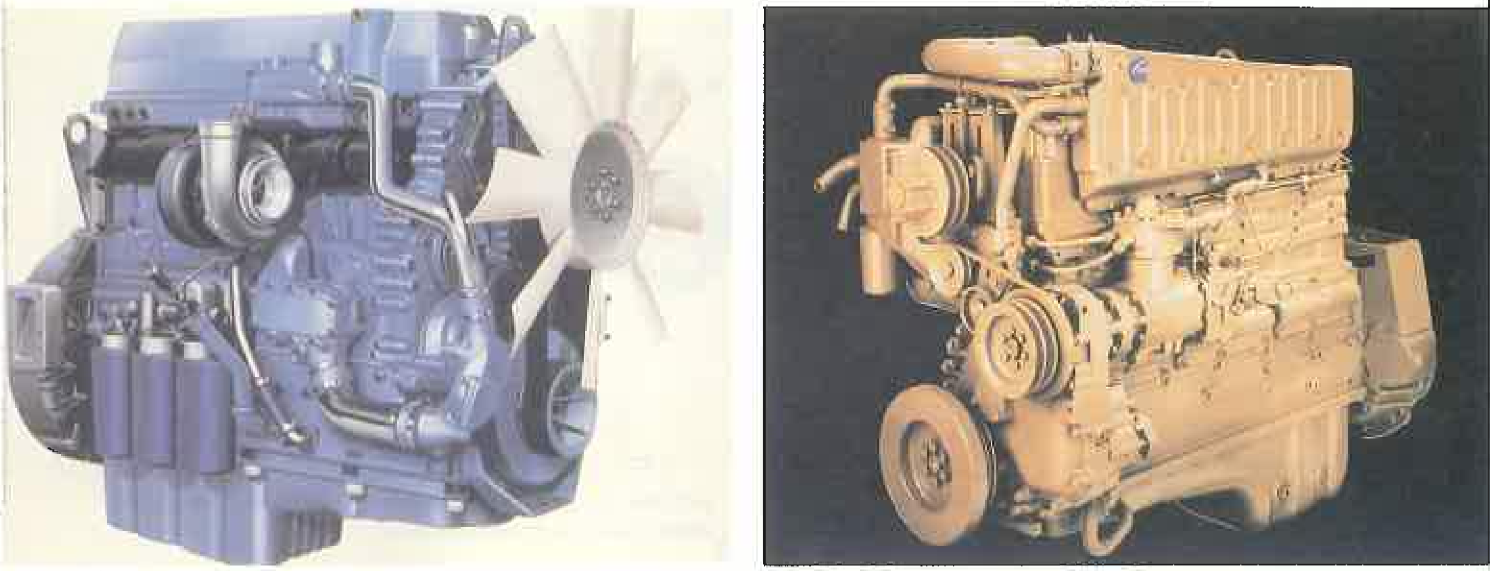
FIGURE 16-21 One of the more popular applications for the two-cycle, loop scavenging-type engine is in a snowmobile. This is a three-cylinder, two-cycle engine. *Courtesy of Polaris Industries L.P.*

Diesel Engine Design

The diesel engine is much the same as the gasoline engine in many of its principles. It is considered a four-cycle engine. The diesel engine is considered an internal combustion engine. It is also considered a compression ignition engine rather than a spark ignition engine. One of the most common applications for diesel engines is in trucks, as shown in Figure 16-22.

Diesel Compression Ratio

One major difference between a diesel engine and gasoline engine is that the diesel engine has a very high compression ratio. Compression ratios of 20:1



(A) (B)

FIGURE 16-22 Diesel engines are mostly used in trucks as well as in many other heavy-duty applications.
Courtesy of (A) Detroit Diesel Corporation and (B) Cummins Engine Co. Inc.

up to 25:1 are very common. This high compression ratio means that any fuel that is in the cylinder during compression will become ignited. Therefore, only air is brought into the cylinder during the intake stroke. A carburetor is not needed to mix the air and fuel; fuel is injected in a diesel engine. With high compression ratios, temperatures inside the combustion chamber may be as high as 1,000°F. This would be enough to ignite most fuels. This is why the diesel engine is called a compression ignition engine.

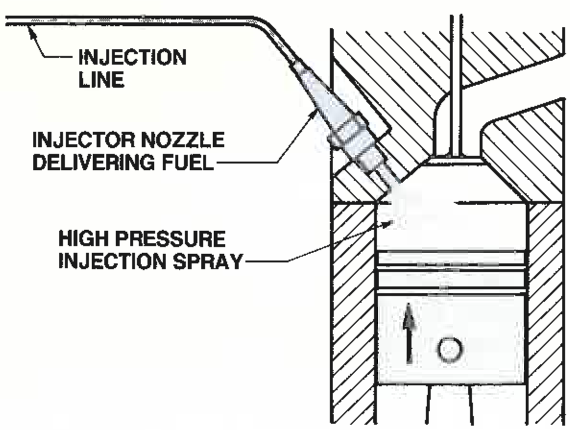


FIGURE 16-23 In a diesel engine, fuel in injected directly into the combustion chamber, under very high pressure, near the top of the compression stroke.

Fuel Injection

A fuel injector injects fuel into the combustion chamber on diesel engines, at or slightly before TDC. This process is called *fuel injection*. A *fuel injector* is a device that pressurizes fuel to nearly 20,000 pounds per square inch (psi). This fuel is injected into the combustion chamber, as shown in Figure 16-23. At this point, all three ingredients (air, fuel, and ignition) are present to produce combustion. The power and exhaust strokes are the same as for the gasoline engine.

Gasoline and Diesel Engines Compared

Figure 16-24 shows some common comparisons between the gasoline and diesel four-stroke or four-cycle engines.

1. The intake on the gasoline engine is an air-fuel mixture. The diesel engine has air only during the intake stroke.
2. The compression pressures on the gasoline engine are lower. This is because the compression ratios are also lower.
3. The air and fuel mixing point on the gasoline engine is at the carburetor or at the fuel injectors. The mixing point on the diesel engine is near top dead center or slightly BTDC by the fuel injector.
4. Combustion is caused by a spark plug on the

gasoline engine. The diesel engine uses the heat of compression for ignition.

5. The power stroke on the gasoline engine produces around 460 psi; the diesel engine produces nearly 1,200 psi. This is because there is more energy in diesel fuel as compared to gasoline.
6. The exhaust temperature of the gasoline engine is much higher. This is because some of the fuel is still burning when being exhausted. The diesel engine has a much cooler exhaust.
7. The efficiency of the diesel engine is about 10% higher than the gasoline engine. This is mostly because there are higher compression ratios and more energy in a gallon of diesel fuel.

COMPARISON BETWEEN GASOLINE AND DIESEL ENGINES		
	GASOLINE	DIESEL
Intake	Air-Fuel	Air
Compression	8-10 to 1 130 psi 545°F	16-20 to 1 400-600 psi 1,000°F
Air-Fuel Mixing Point	Carburetor or Fuel Injection	Near Top Dead Center By injection
Combustion	Spark Ignition	Compression Ignition
Power	460 psi	1,200 psi
Exhaust	1,300°-1,800°F CO = 3%	700°-900°F CO = 0.5%
Efficiency	22-28%	32-38%

FIGURE 16-24 A comparison between gasoline and diesel engines.

GM Two-cycle Diesel Engine

Another type of two-cycle engine is manufactured by General Motors (GM). This two-cycle engine is shown in Figure 16-25. The major difference is that a blower forces air through an air box, ports, and into the cylinder when the piston is at BDC, as shown in Figure 16-25A. The piston then comes up on the compression stroke, Figure 16-25B.

Fuel is injected near TDC. The fuel is then ignited by the heat of compression. The power stroke forces the piston downward. At the end of the power stroke, the exhaust valves open. When the intake ports in the cylinder are uncovered, the fresh air pressure from the blower helps to push the exhaust gases out through the exhaust valves. The

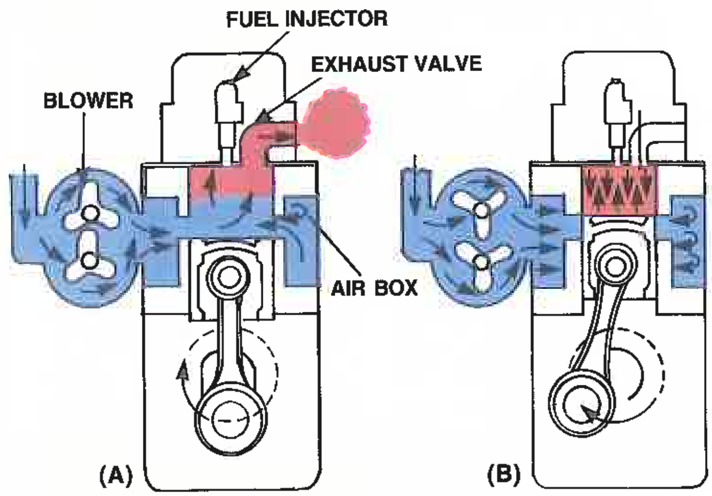


FIGURE 16-25 A two-cycle diesel engine is used in many heavy-duty applications.

advantage to the engine design is that no oil is mixed with the fuel, as with other smaller two-cycle engines. However, a significant amount of frictional horsepower is lost to operate and turn the blower to pump the air.

Rotary Engine Design (Wankel)

In the late 1960s a relatively new engine design was introduced into the power technology markets. Called the *rotary engine*, it is also referred to as the *Wankel engine*. The rotary design has been in existence for some time, and was most popular during the 1970s. Lately, because of improved materials, there has been a renewed interest in developing the rotary engine. In this heat engine, rotors instead of pistons are used to convert chemical energy into mechanical energy. The engine is an intermittent combustion, spark ignition, rotary design (not reciprocating).

Rotary Cycle Operation

Referring to Figure 16-26A, this is called the intake position. The upper port is called the intake port. The lower port is called the exhaust port. There are no valves. The position of the center rotor opens and closes the ports much as the piston does on a two-cycle engine. The rotor moves inside of an elongated circle. Because of the shape of the housing, certain areas are enlarged or compressed during rotation. As the rotor is turned, an internal gear causes the center shaft to rotate. This is the location of the output power.

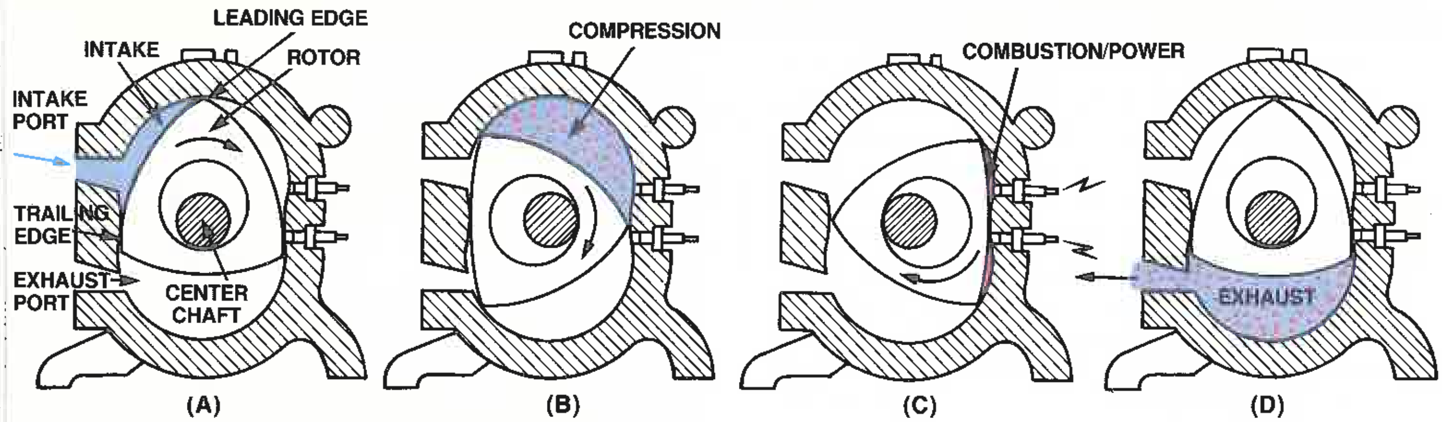


FIGURE 16-26 A rotary engine uses a rotor placed in a special-shaped housing. As the rotor turns, intake, compression, power, and exhaust occur.

When the leading edge of the rotor face sweeps past the inlet port, the intake cycle begins. Fuel and air (14.7:1 air to fuel ratio) is drawn into the enlarged area. This continues until the trailing edge passes the intake port.

As the rotor continues to rotate, the enlarged area is now being compressed. This is called the *compression position*, Figure 16-26B. The compression ratio is very close to that of a standard gasoline engine (8.5:1). This is because both air and fuel are being mixed.

When the rotor travels to the combustion/power position, Figure 16-26C, the air and fuel are completely compressed. At this point, ignition occurs from two spark plugs. Most often, two spark plugs are used for better ignition. All three ingredients for correct combustion are now available. The air and fuel ignite and the combustion causes expansion of gases. This expansion pushes the rotor face downward, causing the rotor to receive a power pulse.

Referring to Figure 16-26D, this is called the exhaust position. As the rotor continues to travel or rotate, the leading edge uncovers the exhaust port. The rotor's movement within the housing causes the exhaust gases to be forced out of the engine.

So far, only one side of the rotor has been analyzed. Note that when intake occurs, compression is occurring on another face of the rotor. Exhaust is also occurring on the third face of the rotor. This means that there are three power pulses for each rotation of the rotor.

The rest of the rotary engine uses many of the same components and systems as the standard gasoline or diesel engine. The carburetor design is the same. The starter, alternator, and external components are the same.

Continuous Combustion Engine Designs

Although gasoline and diesel engines are quite common, other types of engines are also used as power sources in industry and technology. One engine studied for several years is the Stirling engine, a continuous combustion design.

Stirling Engine

The Stirling engine operates very smoothly with complete combustion and low emission characteristics. Both General Motors and Ford Motor Company have studied Stirling engines. Several designs have been tested. The most popular uses a swash plate design.

The engine has four pistons, as shown in Figure 16-27. An external combustion chamber is used.

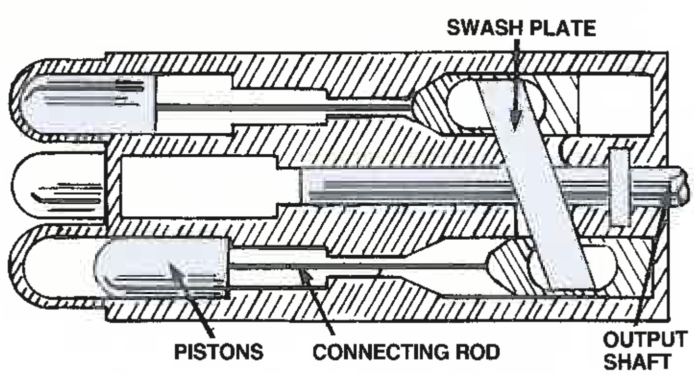


FIGURE 16-27 A Stirling engine has four pistons, a swash plate, and an external combustion chamber.
Courtesy from Energy Technology: Sources of Power, Davis Publications, Inc. 1980

The combustion is considered continuous. The heat from combustion causes the four pistons to be forced downward. Each piston is attached to a swash plate. Mechanically, the *swash plate* is a disc attached in an angular position to the output shaft of the engine. As the pistons are forced downward, the connecting rods sequentially push the swash plate in a rotary motion. The power pulses must occur in the correct order. Referring to Figure 16-28, as number 1 piston fires, it pushes the swash plate clockwise. Then number 4 piston must fire. Then number 3, then number 2, and so on. The engine runs smoothly because of the swash plate. The purpose of the swash plate is the same as the crankshaft action on a conventional internal combustion engine. It changes reciprocating motion to rotary motion.

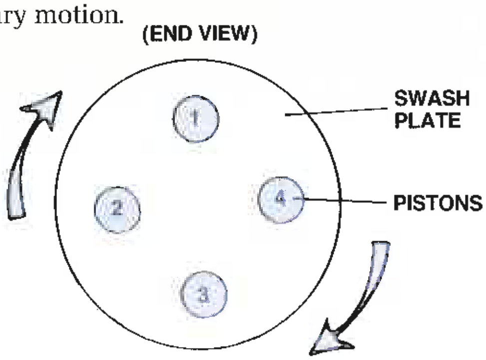


FIGURE 16-28 The swash plate is used to convert the motion of the pistons into rotary motion, needed for pushing a vehicle forward. *Courtesy from Energy Technology: Sources of Power, Davis Publications, Inc. 1980*

Stirling Gas Cycle

The Stirling gas cycle is shown in Figure 16-29. Thermal energy from any resource, such as coal, oil, or diesel fuel is applied to the heater. All heaters are connected together, although, in the diagram, they appear to be separated. The heat causes the gases to expand above the number 1 piston. Also, the area below the number 1 piston is connected to the cooler near the number 4 piston. This causes the gases below the number 1 cylinder to contract. The difference in pressure across the number 1 cylinder forces the piston downward.

As the number 1 piston moves down, the gases below the piston are forced through the cooler, generator and heater to the number 4 piston. As the gases pass through the cooler, they contract. The gases are then heated by the generator and heater.

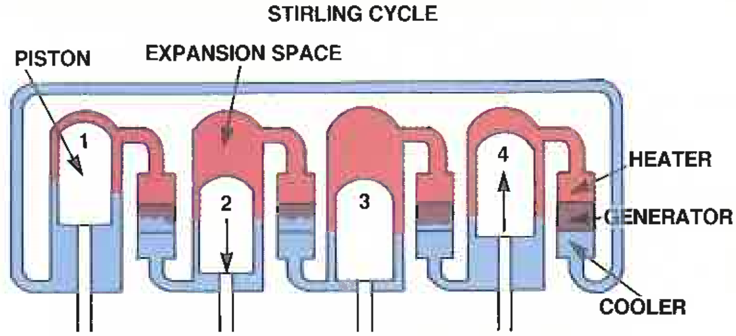


FIGURE 16-29 The Stirling engine has four pistons with a firing order of 1, 4, 3, 2. *Courtesy from Energy Technology: Sources of Power, Davis Publications, Inc. 1980*

The gases expand and build up pressure above the number 4 piston. At the same time, the gases below the number 4 piston are near the number 3 cooler. This contracts the gases. Now there is a pressure differential across the number 3 piston. This process continues to number 2, then to number 1 piston again. The firing order is then, piston #4, 3, 2, 1.

The Stirling engine gets four power pulses per revolution against the swash plate. There is also a suction on the bottom of the piston. This design has a great potential for even higher efficiency. The Stirling engine is considered a very quiet and smooth-running engine.

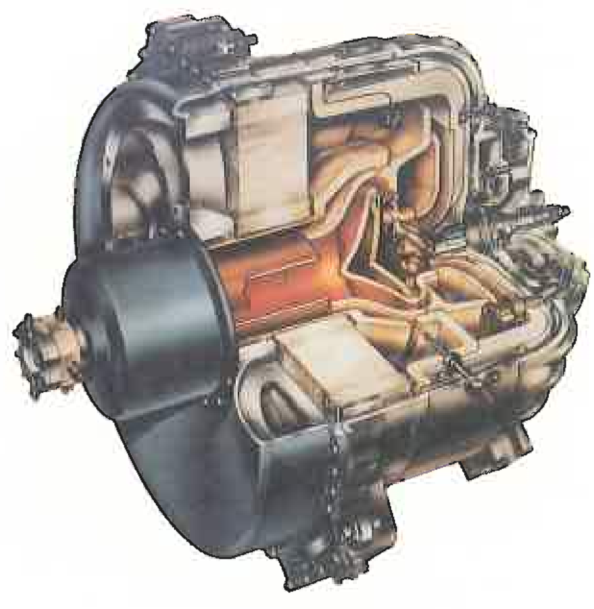


FIGURE 16-30 The gas turbine all-ceramic engine can operate at the high temperatures and speeds necessary for good fuel economy. *Courtesy of Garrett Corporation*

Gas Turbine Engine

Another type of heat engine used in both transportation and industrial applications is the gas turbine engine shown in Figure 16-30. This all-ceramic engine is classified as continuous and internal combustion. The motion produced by the turbine is considered rotary motion.

The gas turbine engine has been tested by several manufacturers in the past 15 years. However, because of its high cost, it still has not been used extensively in automotive markets. However, gas turbines are used in other transportation applications, including helicopters.

Gas Turbine Cycle

The layout of turbine parts is shown in Figure 16-31. The gas turbine burns diesel fuel. A centrifugal *air compressor*, rotating at 35,000 r/min, forces *pure* air (not air and fuel) into the engine. The heat of compression increases the temperature to about 500°F.

Air passes through the compressor and through a regenerator. The *regenerator* is designed to pick up excess heat from the exhaust. As the exhaust gases flow through the regenerator, the heat is conducted into the metal of the regenerator. The regenerator turns only 18 r/min so heat is easily absorbed. As the intake air passes through the regenerator, it picks up this excess heat. The process brings the air temperature up to about 1,200°F.

The air is then sent into the burner or combustion chamber. Air and fuel are added to an already burning flame. Coming out of the burner, the hot gases flow through a vortex chamber and into the gasifier or compressor turbine. The temperature at this point is nearly 2,100°F. The compressor turbine turns nearly 35,000 r/min. Its major purpose is to turn the air compressor at that speed.

The remaining energy in the gases from the first (gasifier) turbine enters the second turbine, called the *power turbine*. It is connected to the part of the application that requires torque. The temperature of the gases going into the power turbine is nearly 1,400°F. This energy turns the power turbine to produce torque. The gases then pass through the regenerator and out into the atmosphere.

The turbine engine also has potential for heavy-duty applications in the transportation sector. It averages about 45% efficiency. However, the cost of this engine is still well above that of a comparable gasoline or diesel engine. The advantages include smooth running, use of multiple fuels, higher efficiency, and no liquid cooling system. The disadvantages include high cost, no dealerships for repair, no parts distribution systems available, and too much power for the average vehicle.

Steam Turbine Engine

Another form of turbine is called the *steam turbine* heat engine. This engine is usually used in industrial generator applications. The big difference between

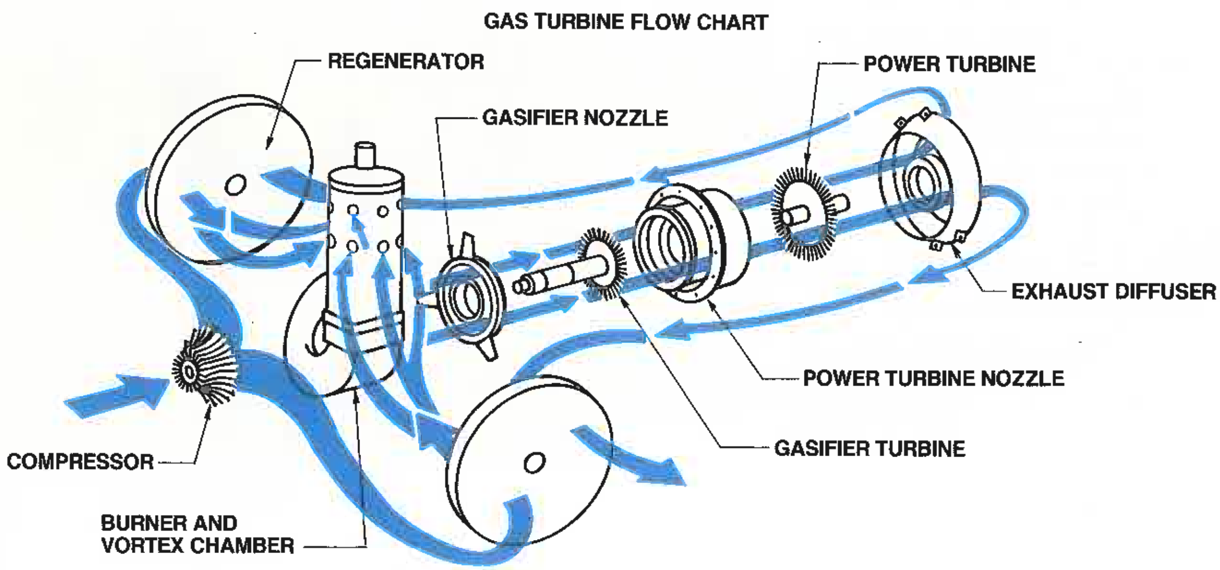


FIGURE 16-31 The gas flow is shown through the turbine parts. *Courtesy of General Motors Corporation*

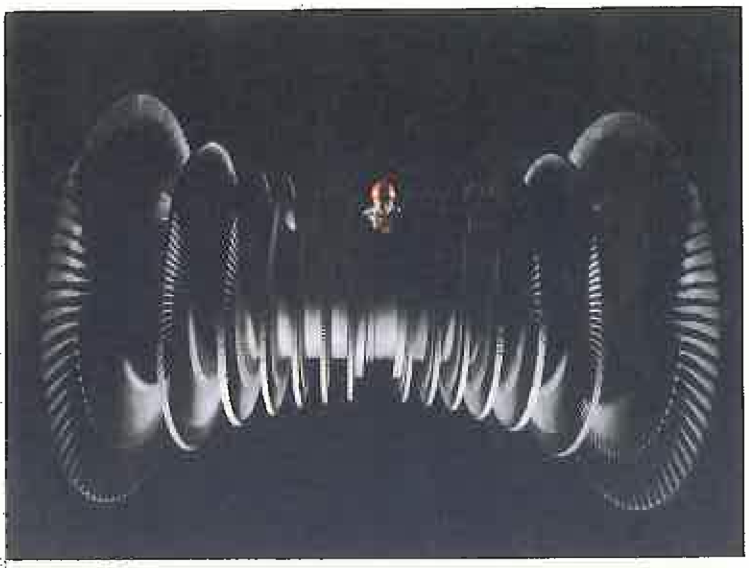


FIGURE 16-32 Turbine blades used in a steam turbine engine. *Courtesy of Union Electric Co.*

FIGURE 16-33 An example of a large steam turbine unit used in a nuclear power plant. *Courtesy of New York Power Authority*

a steam turbine and a gas turbine is the type of power used to turn the turbine. A steam turbine uses steam heated by coal or oil in a power plant system. The steam turbine is much larger than a gas turbine and produces a higher torque for turning the generator. Figure 16-32 shows an example of a set of turbine blades used in a commercial steam generator. Figure 16-33 shows a partial view of a large commercial steam turbine. Only half of the turbine is shown; the other half is below the surface of the floor. This steam turbine is used to turn a generator to produce electricity.

Air Force Jet

Reaction-type engines are used as propulsion to produce thrust. Many military aircraft also use jet engines for propulsion. A U.S. Air Force F-16C streams contrails off its forebody, as it climbs with maximum thrust (engine power) during a predelivery check over Fort Worth, Texas.

All aircraft are given a predelivery check to determine their operational characteristics, propulsion system operation, handling, safety, and maneuverability. These data are important to monitor the quality of each engine and propulsion system manufactured. Courtesy of *General Dynamics Corporation*

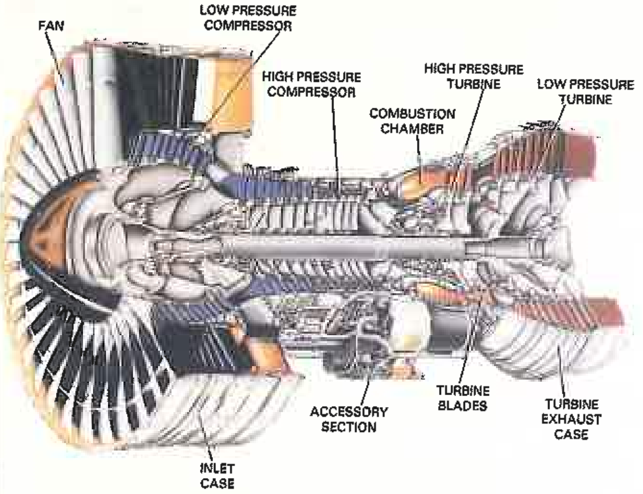


FIGURE 16-34 Cut-away view of a jet reaction-type engine. *Courtesy of Pratt & Whitney Aircraft Division*

Jet (Reaction) Engine

As stated earlier in the text, thrust is needed to propel a spacecraft forward. Thrust, also called *reaction*, can be produced by jet engines as well as rocket engines. Thrust can be explained by referring to Newton's second and third laws. Newton's second law states that "an unbalance of force on a body tends to produce an acceleration in the direction of the force." Newton's third law states that "for every force there is an opposite and equal force." These two laws working together cause a jet engine to produce thrust. An unbalanced condition is produced inside of the engine's combustion chambers. This causes acceleration of gases to escape. The force of the gases has an opposite and equal force toward the front of the engine. This causes the object to move forward.

Jet engines are designed much the same as smaller gas or steam turbines. The difference is in the type of compressor and the number of turbines. Figure 16-34 shows a typical cut-away view of a reaction-type engine. The compressor is made of several *axial* stages. Rather than one burner, several are used to ignite the fuel. As the hot gases leave the burners, they cause several turbine stages to turn. These turbine stages are usually used to turn the compressor. The remaining energy in the exhaust gases comes out of the rear of the engine. Because of the difference in pressure inside of the burners, thrust or reaction is produced. This thrust causes the vehicle to move forward.

Summary

- The types of heat engines include internal, external, intermittent, and continuous combustion, reciprocating and rotary engines.
- The basic parts of a heat engine are the cylinder block, cylinders, pistons, connecting rods and crankshaft, cylinder head, combustion chamber, valves/ports, camshaft, flywheel, and carburetor and fuel injectors.
- All engines have several systems that enable the engine to operate efficiently. These include the cooling, fuel, lubrication, ignition, starting, charging, air/exhaust, computer, and pollution control systems.
- Any combustion requires air, fuel and ignition mixed together at the right time for correct operation.
- The best air to fuel ratio is 14.7:1 by weight.
- A rich mixture of air and fuel is 13:1; a lean mixture is 17:1.
- The bore and stroke are used to calculate the displacement of a heat engine.
- Compression ratio is the ratio of the volume above the piston at TDC compared to the volume at BDC.
- The four-cycle engine has intake, compression, power, and exhaust cycles, all of which must occur at the correct time.
- Timing diagrams are used to graphically represent the events of two- and four-cycle engines.
- Two-cycle engines have a power pulse every crankshaft revolution, whereas four-cycle engines have a power pulse every other crankshaft revolution.
- Loop scavenging is another design used in a two-cycle engine to cause the air/fuel/oil mixture to enter the engine.
- Diesel engine compression ratios are much higher than they are for gasoline engines.
- Diesel engines use high-pressure injection to get the fuel into the cylinder.
- A two-cycle diesel is also manufactured by GM which uses a blower to get the air into the cylinders.
- The rotary engine uses a triangular rotor placed in a special housing to create intake, compression, power, and exhaust.
- Continuous combustion engines commonly used include the gas turbine, steam turbine, and jet (reaction) heat engine.

REVIEW

1. The order of events on a four-cycle engine are ________________, compression, ________________, and ________________.
2. The carburetor is considered a/an ________________ as part of the systems model.
3. The three ingredients necessary for an internal combustion engine to operate include, ________________, fuel, and ________________.
4. An engine has a bore of 3.5 and a stroke of 3.2. The piston displacement of this engine is ________________.
5. The volume above a piston at BDC is equal to 10.5 cubic inches. The volume above the piston at TDC is equal to 1.3 cubic inches.The compression ratio of this engine is equal to ________________.
6. The spark on a four-cycle engine usually occurs at about ________________ degrees ________________ top dead center.
7. The Stirling engine changes the piston motion to rotary motion by using a ________.
8. The ________________ is used in a gas turbine to change the thermal energy in the combustion into rotary motion.
9. Identify six classifications of engines, and state the definition of each.
10. What are the purposes of the cooling, ignition, and computer systems used on a gasoline engine?
11. Define a rich and a lean air to fuel mixture.
12. Identify the difference between TDC and BDC.
13. Describe the four events on a four-cycle engine.
14. Describe how loop scavenging is different from using a reed-valve two-cycle engine.
15. Draw a two-cycle timing diagram, and indicate when the intake, compression, power and exhaust occur. Also show when the intake and exhaust ports open and close.
16. State three differences between a diesel and a gasoline engine.
17. Describe the four events on a Wankel or rotary engine.
18. Define complete operation and parts of a gas turbine engine using regenerators.

CHAPTER ACTIVITIES

ENGINE TIMING

INTRODUCTION

When studying internal combustion engines, the timing of the four-cycle events is very important toward understanding engine operation. During this activity, you will be able to identify and plot all timing events of a small, four-cycle gas engine.

TECHNOLOGICAL LITERACY SKILLS

Problem solving, data collection, data analysis, plotting data, instrumentation.