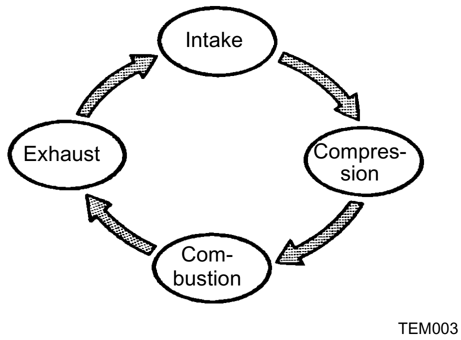
In this manner, the reciprocating engine, which uses gasoline for fuel, converts the reciprocating movement of the pistons, caused by the explosive combustion of the air-fuel mixture, to the rotation movement of the crankshaft for use as its motive power.

2-2. OPERATING 4-STROKE ENGINE

To keep the engine running continuously, it is necessary to perform the steps involved in the combustion process repeatedly. After the air is sucked into the cylinder, it is compressed first and made to explode (combustion) after diesel injection to generate motive power. Then the gas resulting from the combustion is ejected from the combustion chamber. These four steps - intake, compression, combustion and exhaust - make up one cycle and they are repeated over and over. In the 4-cycle engine, the piston goes through 4 strokes (while the crankshaft rotates twice) to complete one cycle.



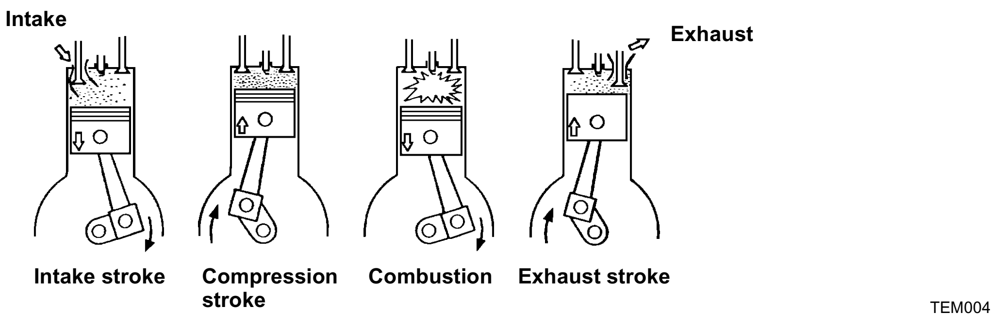
The engine cycle

(1) INTAKE STROKE

The intake valve is open while the piston moves down and the air-fuel mixture is sucked into the cylinder (combustion chamber).

(2) COMPRESSION STROKE

As the piston begin to move up, the intake valve closes to seal the combustion chamber and the air-fuel mixture is compressed. The air-fuel mixture is compressed to one-seventh to one-tenth of its original volume, and its pressure and temperature increase.



Stroke engine

(3) COMBUSTION STROKE

Right before the compression stroke is completed, Diesel is injected. The high temperature generated by the compressed air producing rapid combustion ignites the air-diesel fuel mixture. The temperature and pressure of the gas mixture within the cylinder rise rapidly, causing the gas to expand and this pushes the piston down and rotates the crankshaft.

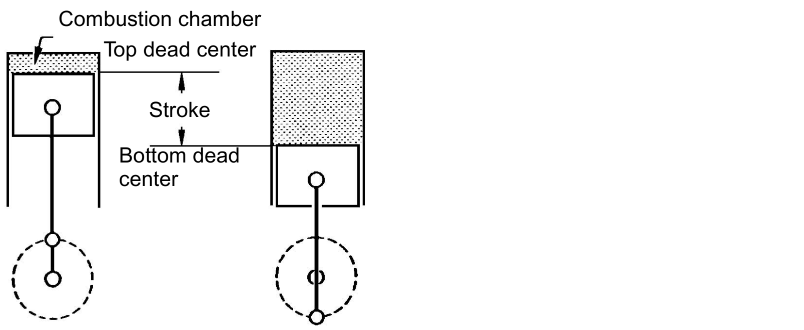
(4) EXHAUST STROKE

Just before the piston completes its downward stroke, the exhaust valve opens to let the combustion gas escape by its own pressure. The returning piston ejects the remaining gas. When the piston almost completes its upward stroke, the next intake stroke begins.

[Reference]

The topmost point inside the cylinder where the piston reaches is called the top dead center, and the bottommost point is called the bottom dead center. The distance, which the piston travels between the top dead center and bottom dead center, is called the stroke. The volume of space created above the piston when at the top dead center is called the combustion chamber.

The injection timing is designed to inject before top dead center. The standard value is expressed as BTDC 10 degrees (Before Top Dead Center).



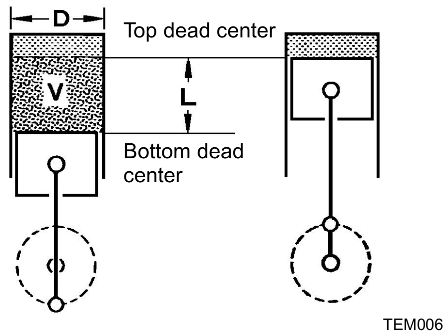
Top dead center and bottom dead center

3. ENGINE PERFORMANCE

Catalogues or brochures describe the following characteristics which are used to measure an engine's performance: piston displacement, compression ratio, power output, torque and fuel consumption.

3-1. PISTON DISPLACEMENT

Piston displacement is the volume discharged when the piston moves from bottom dead center to top dead center. Total piston displacement [expressed in cubic centimeters (CM3)] is that volume multiplied by the number of cylinders.

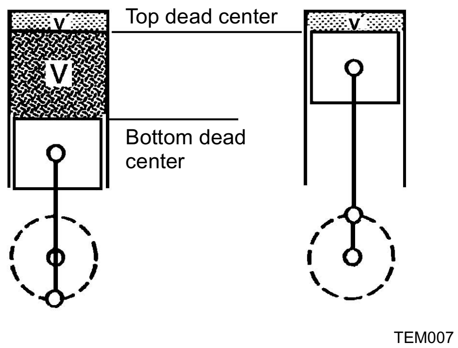


Piston displacement

3-2. COMPRESSION RATIO

Compression ratio is the ratio of the volume above the piston when the piston is at bottom dead center to the volume above the piston when it is at top dead center.

The volume above the piston when it is at top dead center is called combustion chamber volume. Thus, the volume above the piston when it is at bottom dead center equals the piston displacement plus the combustion chamber volume.



Compression ratio

Assuming the compression ratio is P, piston displacement is V (cc) and combustion chamber volume is v' (cc), the equation for the compression ratio is as follows:

$$\textbf{Compression ratio P} = \frac{V + v'}{v'} \qquad * \ 1\ cm^3 = 1\ cc$$

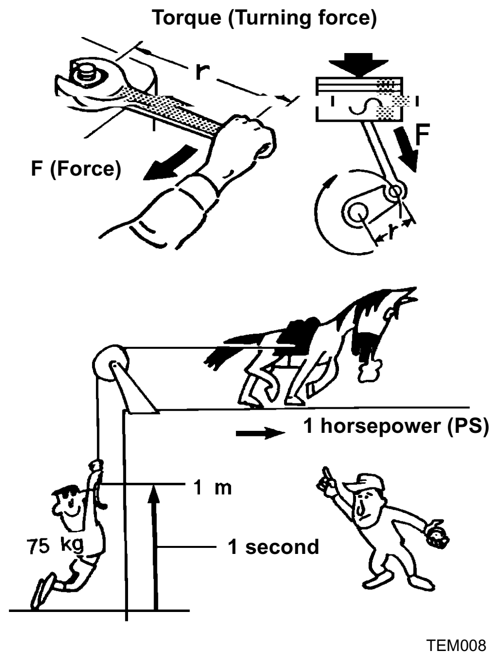
3-3. TORQUE AND HORSEPOWER

Torque is the ability to cause something to rotate, i.e., the turning force. When a bolt is tightened with a spanner, the longer the length of the spanner, the less the tightening force required. The amount of torque is obtained from the length of the spanner multiplied by the tightening force.
Torque (Turning force)

Torque (T) - Force x Distance = F (kg) x r (m)

Torque is represented by the symbol kg–m. This has been changed to N.m, conforming to the international system of units. 1 kg–m = 9.8 N m

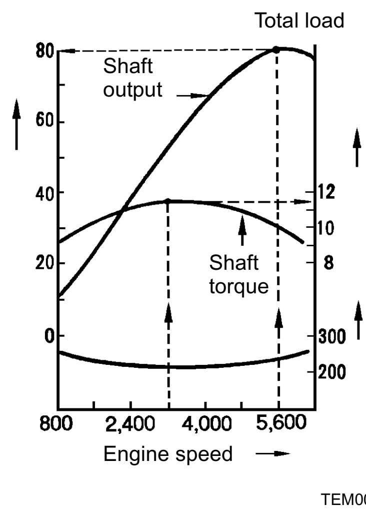
Output is the work volume and speed required to do the work, i.e., it is the work volume in a unit of time. For an engine that unit is expressed as horsepower. One (1) horsepower is the rate of work to do a work for moving one (1) meter in one (1) second with the force of 75 kg. This has been changed to kW, conforming to the international system of units. 1 PS = 0.7355 kw.



Torque and horsepower

3-4. ENGINE PERFORMANCE CURVES

Engine performance curves show the shaft horsepower (PS), shaft torque (kg–m) and rate of fuel consumption (g/PS.h) at respective numbers of revolution during full throttle acceleration operations. In the engine performance curves diagram, the horizontal axis shows the number of revolutions per minute r/min of the crankshaft and the vertical axis shows the shaft output, shaft torque and rate of fuel consumption

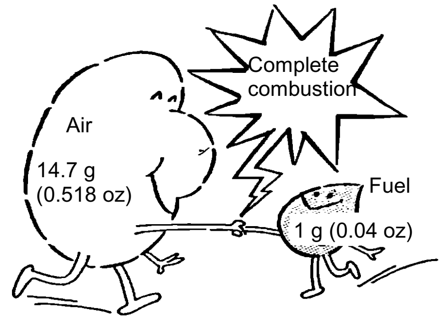


How to read engine performance curves diagram

4. ENGINE COMBUSTION
4-1. DESCRIPTION
(1) AIR -FUEL RATIO

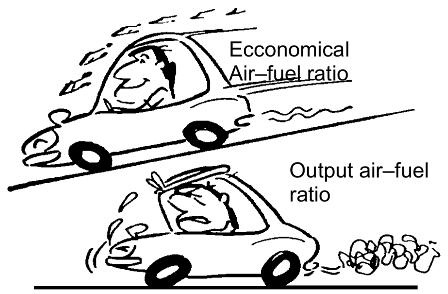
The air and fuel mixture rate necessary for combustion is called air-fuel ratio (mixture ratio) and is represented by weight percentage, not volume percentage.

$$\textbf{Air Fuel ratio} = \frac{\textbf{Air volume (g)}}{\textbf{Fuel (g)}}$$



Ideal air–fuel ratio

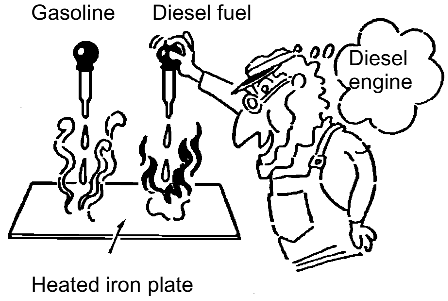
In order to completely burn 1 gram (0.04 oz.) of gasoline, theoretically 14.7 grams (0.518 oz.) of air is necessary. Air-fuel ratio in this case is called **ideal air-fuel ratio**.



Economical air–fuel ratio and output air–fuel ratio

(2) IGNITABILITY AND INFLAMMABILITY

When fuel is heated in air, it ignites at a certain temperature without an open fire or electric spark. This characteristic is called ignitability (combustibility) and the temperature at that time is called the ignition point or fire point. When diesel fuel and gasoline are dropped on a heated iron plate, diesel fuel ignites quickly but gasoline does not, because the ignition point of diesel fuel is approximately 350°C (662°F) and that of gasoline is approximately 550°C (1,022°F).

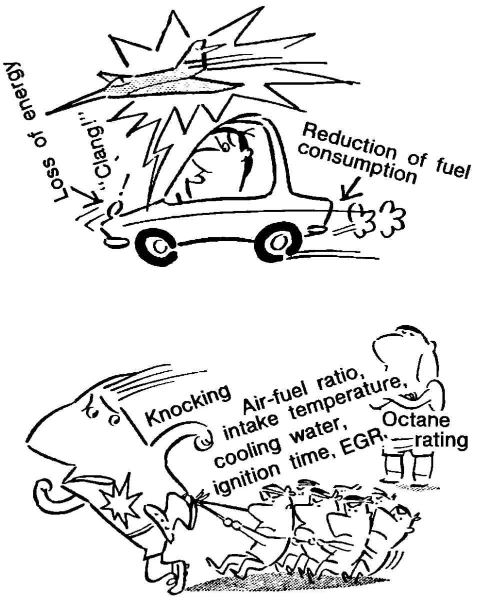


Ignitability and inflammability

This lower ignition point of diesel fuel is important in relation to diesel fuel combustion. When fuel is heated in air, hot vapor is generated, and if an open fire or electric spark is brought close to the vapor, the vapor ignites and begins to burn. This characteristic is called inflammability, and the minimum temperature at which fuel catches fire is called flash point. Flash point of gasoline is -40°C or less and that of diesel fuel is 50°C or more. For this reason. gasoline is easily inflamed under normal temperatures.

(3) KNOCKING

When an excessive load is applied to a gasoline engine (for instance when an automobile accelerates suddenly or is driven up a steep slope), the engine sometimes produce a rapping noise that sounds as if someone is tapping on the cylinder wall with a hammer. This phenomenon is called knocking. Knocking means that before the flame completes its spread after ignition, the mixture charge remaining at the end of the combustion chamber is compressed and ignites spontaneously and burning rapidly under high temperature and pressure. Consequently, the pressure wave knocks against the cylinder wall or piston head resulting in a metallic noise being produced. If knocking occurs rapidly, and the pressure and temperature increase quickly, the effect is hazardous to the piston head, gasket, valve, etc. General measures to prevent this phenomenon include the following:



TEM013

- Lower the compression ratio
- Use a gasoline with a high octane rating.
- Adjust (delay) the ignition timing.
- Octane rating represents the anti-knocking quality of gasoline, and the higher the rate the less knocking.

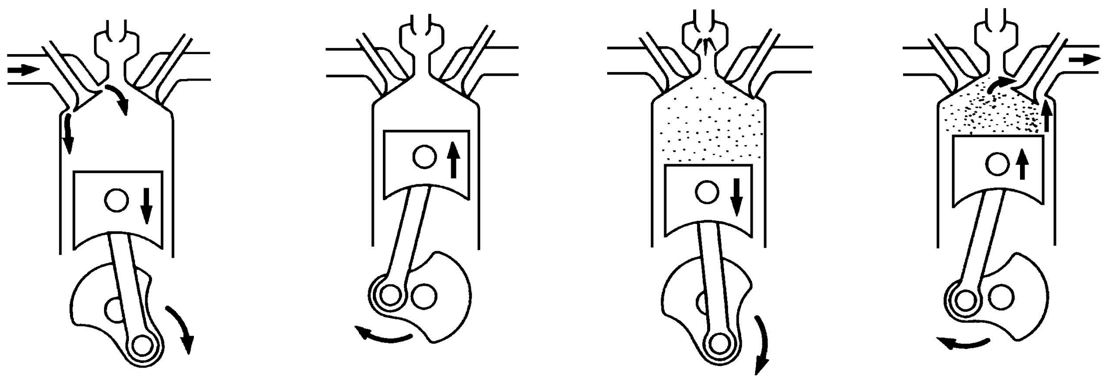
5. DIESEL ENGINE

5-1. DESCRIPTION

The diesel engine, featuring high thermal efficiency, was invented in 1892 by Rudolf Diesel and uses fuels heavier than gasoline. It provides such advantages as safe of fuel handling, low fuel consumption, and long durability. A large number of diesel engines are used in trucks, buses, ships and other applications.

5-2. OPERATION OF 4-STROKE DIESEL ENGINE

Compared with the operation of the gasoline engine, the diesel engine differs in the intake stroke and combustion stroke, as shown below.



(1) INTAKE STROKE

The gasoline engine draws a mixture of air and fuel into the cylinder. But in diesel engine, air alone enters the cylinder.

(2) COMPRESSION STROKE

In the diesel engine, fuel is ignited by the heat of the compressed air, so the air must be compressed in such a way that its temperature reaches the ignition temperature of the fuel. Generally, this temperature is 400 to 500°C. In the diesel engine, the compression ratio is two or three times as high as in the gasoline engine.

(3) COMBUSTION STROKE

The ignition method of the diesel engine is different from that of the gasoline engine. The gasoline engine uses spark plugs to electrically ignite the air-fuel mixture. In the diesel engine, however, the fuel is injected from the injection nozzle at the end of the compression stroke. The injected fuel is spontaneously ignited by the high temperature of the compressed air.

(4) EXHAUST STROKE

The burned fuel, or gas is then discharged through the exhaust valve in the same manner as in the gasoline engine. So, it is very important that the proper amount of fuel is injected into the cylinder at the proper time. This was very difficult in the early days of development of the diesel engine. This problem was solved by the injection pump invented in 1927, and since then the diesel engine has come into wide use.

5-3. COMPARISON OF DIESEL ENGINE WITH GASOLINE ENGINE

ITEM	DIESEL ENGINE	GASOLINE ENGINE
Fuel	Light oil	Gasoline engine
Intake gas	Air only	Gasoline
Fueling device	Injection pump	Carburettor (or fuel injector)
Control of output	By changing the amount of fuel injected	By changing the amount of air-fuel mixture
Ignition	Self-ignition	Ignition by electrical spark
Compression ratio	High (15 - 23)	Low (7 - 10)
Compression pressure	High [1,961 - 2, 942 kPa (19.6 - 29.4 bar, 20-30 kg/cm^2, 284-427psi)]	Low [981 - 1,471 kPa (9.8 - 14.7 bar, 10-15kg/cm^2, 142-213psi)]
Combustion pressure	High [4,904 - 8,826 kPa (49.0 - 88.3 bar,50-90 kg/cm^2, 711-1280psi)]	Low [2,942 - 4,904 kPa (29.4 - 49.0 bar,30-50 kg/cm^2, 427-711psi)]
Startability	Good (Needs some time)	Good
Response	Poor	Good
Engine construction	Mechanical strength is large	Mechanical strength is small
Weight of engine	Heavier than gasoline engine	Small
Noise	Greater than gasoline engine	Quiet

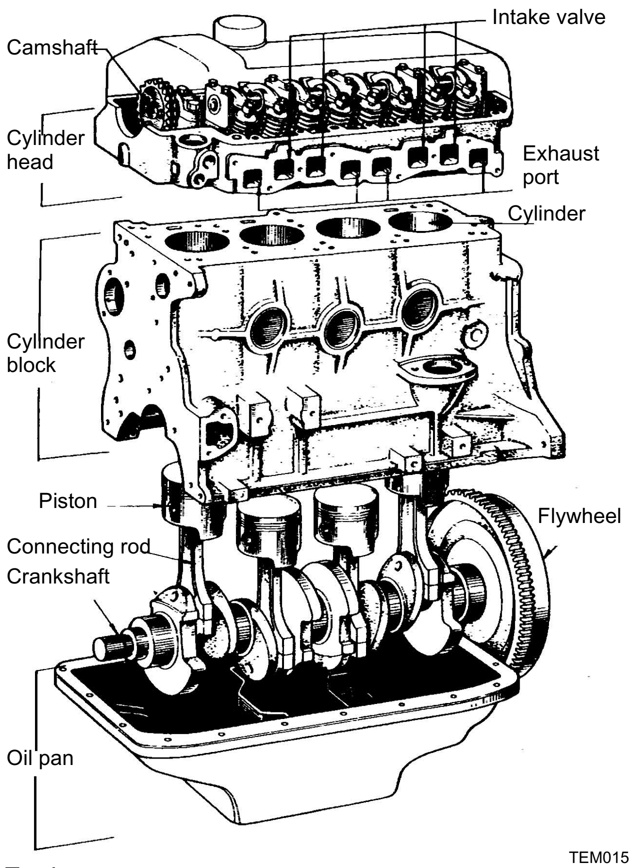
ENGINE STRUCTURE

1. DESCRIPTION

The engine proper is the main part of an engine. Its appearance varies according to engine type (four cycle or two cycle), arrangement of cylinders, type of cooling (water or air), etc., but the basic structures are similar.

The left figure is an example of a four cycle, water cooled, four cylinders in-line, overhead camshaft (OHC) engine.
The engine proper is composed of the cylinder head, cylinder block, piston, connecting rod, crankshaft, camshaft, flywheel, etc.

Additionally, the engine proper contains lubricating oils, cooling water, intake and exhaust passages, etc. and is the base on which respective auxiliary equipment are mounted.



Engine proper

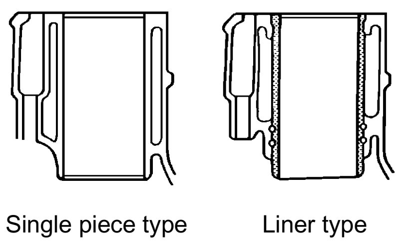
2. CYLINDER & CYLINDER BLOCK

A cylinder consists of a combustion chamber together with a cylinder head and piston, and a cylindrical case in which the piston reciprocates. Power is produced inside the cylinder by the reciprocating motion of the piston which is subject to pressure and heat from ignited gases. The part of the, engine containing cooling water passages, lubricating oil Passages and crankshaft bearings is called the cylinder block.

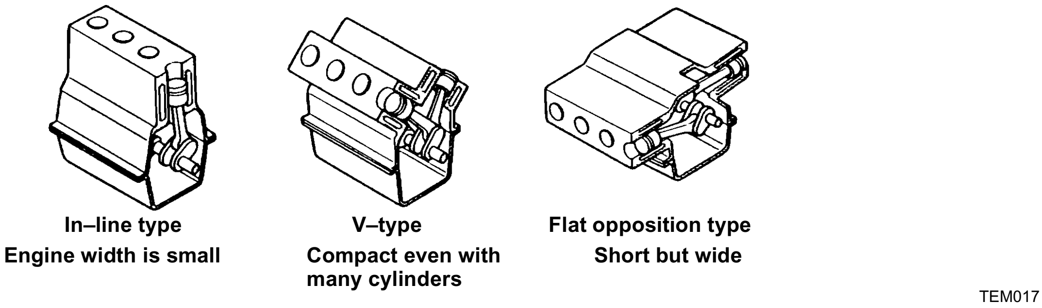
2-1. CYLINDER

(1) CLASSIFICATION BY LINERS

Cylinders are classified into two types, a cylinder block in which a cylindrical liner is press-fitted, and a cylinder block in which the cylinder is machined.



(2) CLASSIFICATION BY CYLINDER ARRANGEMENT



Arrangement of cylinders and features

1) In-line type

The most common type of cylinders are placed in a row, making the engine narrow. Total engine length increases as the number of cylinders is increased. (SR, RB series engines)

2) V-type

Cylinders are arranged in a V-shape. Compared with the in-line type, the V-type engine can be compact even if the number of cylinders is increased. With fewer crankshaft bearings, friction loss in this engine is less.(VG and VQ series engines)

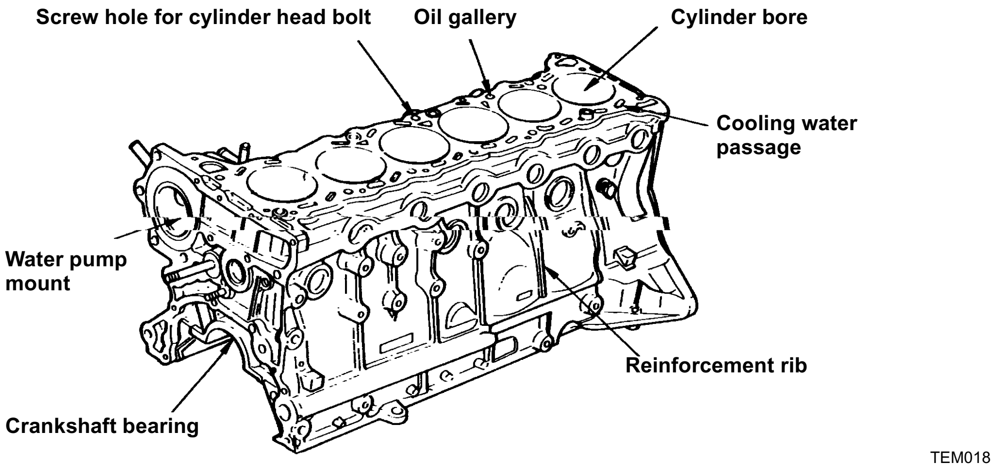
3) Flat opposition type

Cylinders are arranged in two rows opposing each other centering on the crankshaft. In this type, engine height can be reduced but width is increased. This type of engine allows for less vibration.

2-2. CYLINDER BLOCK

Names and function of respective parts of the cylinder block are as follows:

- Water jacket-Passages of engine coolant that cool down heat generated with a engine.
- Oil gallery-Passages through which lubricating oil that has been sucked up by pump is distributed.



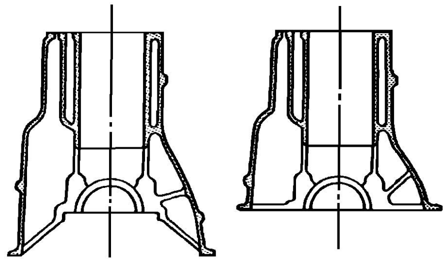
Cylinder block

(1) DEEP SKIRT TYPE

The deep skirt type has the advantage of greater strength in the longitudinal direction, and is used in many engines.

(2) HALF SKIRT TYPE

The half skirt type has the advantage of being light weight. (VG and VQ series engines)



Type of cylinder block

3. CYLINDER HEAD

The cylinder head is mounted on the upper surface of the cylinder block and, together with the piston forms the combustion chamber. Located on the cylinder head are mounting holes for the water jacket which cools the combustion chamber and surrounding areas, suction and exhaust ports, the intake manifold, exhaust manifold, and lubricating oil passages: The cylinder head structure varies depending on the shape of the combustion chamber, camshaft location, valve mechanism, etc. Cylinder heads are made of cast iron and aluminum cast. Many cylinder heads are made of aluminum cast which has high thermal conductivity. (Gasoline engines).

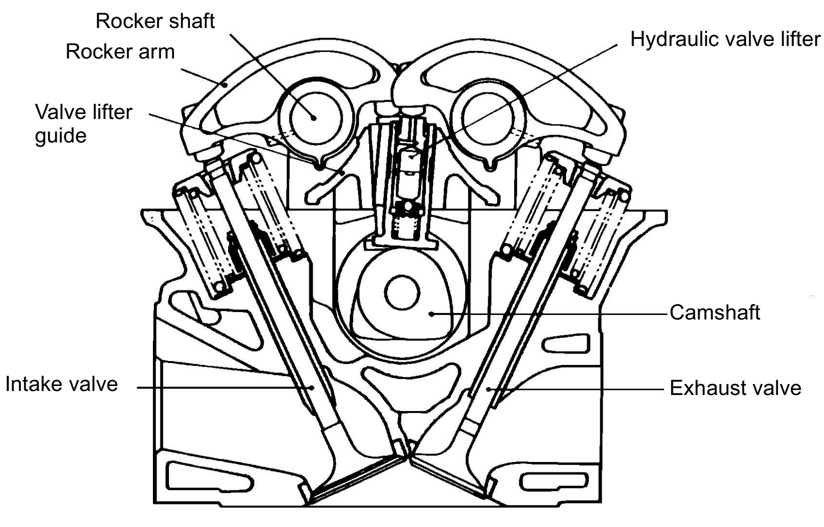
3-1. STRUCTURE

(1) INTAKE PORT (passage of intake gas)

This is the intake air passage that connects the intake manifold and combustion chamber. It is shaped so that the resistance of the passing will be minimized.

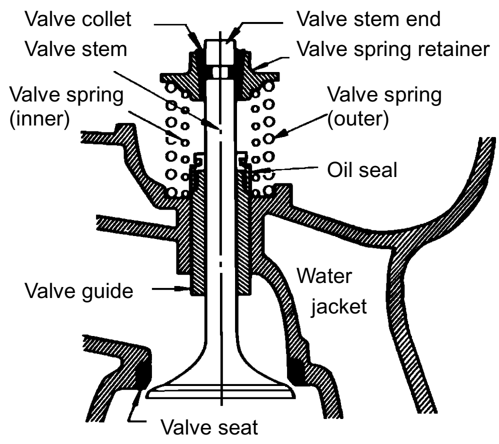
(2) EXHAUST PORT (passage of exhaust gas)

This is the exhaust gas passage that connects the combustion chamber and exhaust manifold in which the combustion gas flows while expanding.



(3) VALVE GUIDE

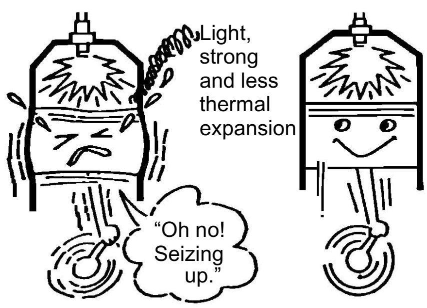
The valve guide, in which the valve stem slides, is made from an iron group sintered alloy and press–fitted to the cylinder head.



TEM021

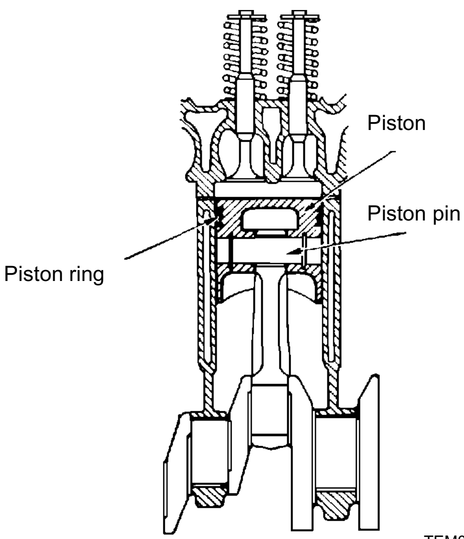
4. PISTON

For good intake, compression, combustion and exhaust operations, it is necessary to maintain a good seal between the piston and cylinder. It is also necessary that the pistons have the structure and strength to resist thermal expansion under exposure to high temperatures and pressures. Further, the piston must be of a light weight material and be shaped to reduce inertia loads for high speed reciprocating motion.



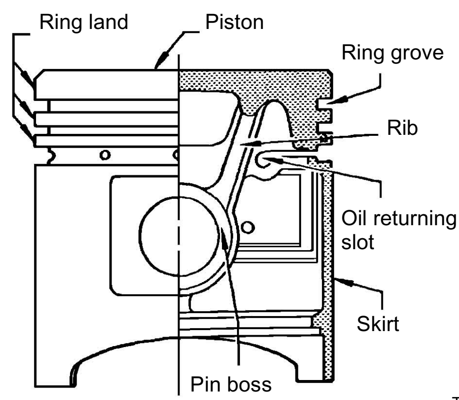
TEM022

4-1. STRUCTURE



TEM023

Installation of piston



TEM024

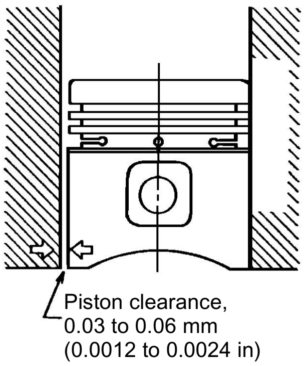
Structure of piston

(1) RING GROOVE
Ring groove is the place in which the piston ring is inserted. In many cases, three ring grooves are provided.

(2) OIL RETURN SLOT
The oil return slot is located on the oil ring groove. Oil scraped off by the ring flows through this slot and into the oil pan.

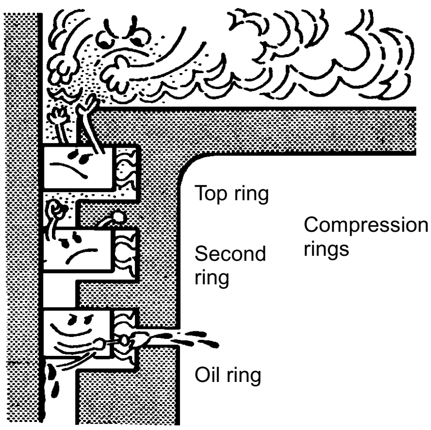
(3) SKIRT
The lower part of the piston from the center of the pin is called a skirt.

4-2. PISTON-TO-CYLINDER CLEARANCE
The assembled piston needs to have a specific clearance [about 0.03 to 0.10 mm] between the cylinder wall. If the clearance is insufficient, the piston could possibly seize due to thermal expansion. On the other hand, if clearance is excessive, it will result in compression failure, increased oil consumption, or piston slapping noise. To eliminate these problems, a piston must be selected with outside diameter, which properly fits the finished dimension of the cylinder bore.



Piston to cylinder clearance

5. PISTON RING
5-1. DESCRIPTION
There is a slight clearance between the piston and cylinder wall to allow for thermal expansion during operation. Because of this clearance, compression rings are required to prevent compressed air–fuel mixture and/or high pressure burned gas from leaking from the combustion chamber into the lower part of the cylinder block. Oil rings serve to control lubricating oil (thickness of oil film) on the cylinder wall. Another important function for these piston rings is to cool the piston by conducting heat to the cylinder wall. Accordingly, the piston rings need to fit closely with the cylinder wall and are, therefore, designed to expand outward (tensile force).



Roles of piston

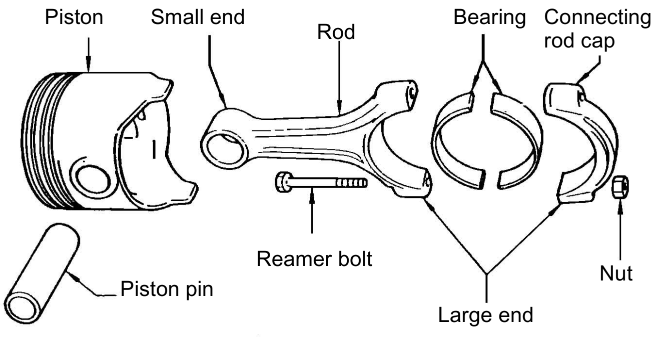
6. CONNECTING ROD AND PISTON PIN

6-1. DESCRIPTION

Connecting rod connects the piston with the crankshaft. It converts the reciprocating motion of the piston to the rotary motion of the crankshaft. The connecting rod needs to be light weight, and of sufficient strength to withstand strong compression and tension (vigorous motion similar to that of piston) during engine operation.

6-2. STRUCTURE

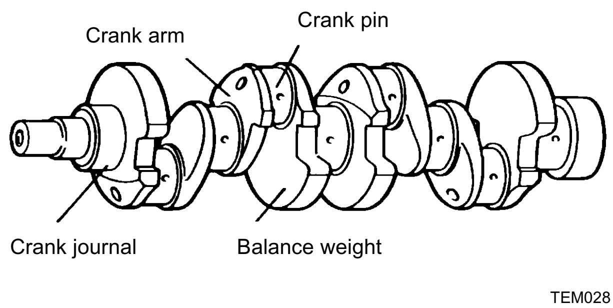
As shown at the right figure, a connecting rod is composed of the small end which is connected to the piston with the piston pin, the large end which is divided into the upper and lower portions and is connected with the crank pin of the crankshaft.



Connecting rod structure

7. CRANKSHAFT

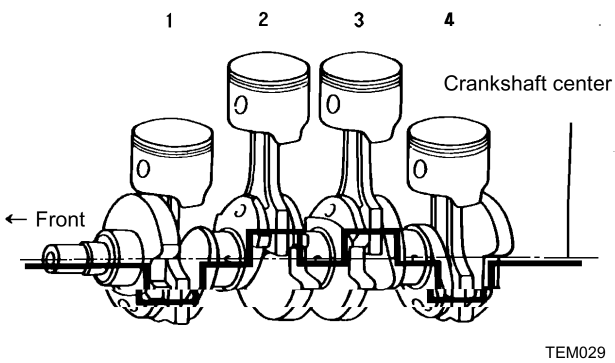
The crankshaft receives combustion pressure via the piston and the connecting rod, which converts the reciprocating motion of the piston to a rotary motion.



Crankshaft (4 cylinder)

In a four cycle engine, the crankshaft rotates two times in completing one cycle (intake, compression, combustion and exhaust). In a four cylinder engine, combustion takes place once per cylinder while the crankshaft rotates two times (720 degrees). In other words, combustion takes place once every 180 degrees crankshaft rotation.

As shown at the right figure, the cylinders are numbered front to back No.1, No.2, No.3 and No.4 and the firing order is either 1-3-4-2 (in Nissan vehicles) or 1-2-4-3. In either case, the pistons No.1 and No.4 and No.2 and No.3 are set in motion in pair.



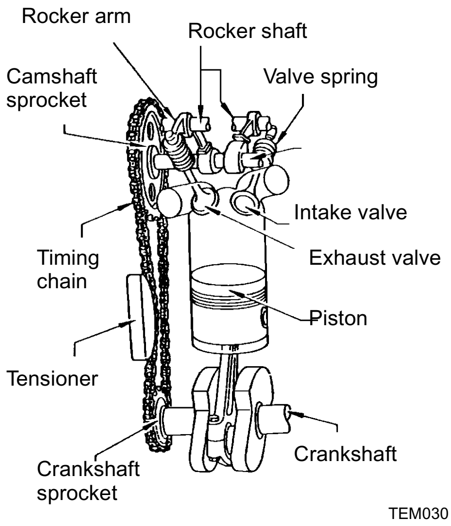
Example of cylinder in–line engine

VALVE MECHANISM

1. DESCRIPTION

1-1. VALVE TIMING MECHANISM

The following figure shows an example of a valve opening and closing mechanism of an OHC (overhead camshaft) type engine. Part of the combustion chamber valve is mushroom shaped and firmly fits in the intake and exhaust ports by means of a spring.



Structure of the valve opening and closing mechanism

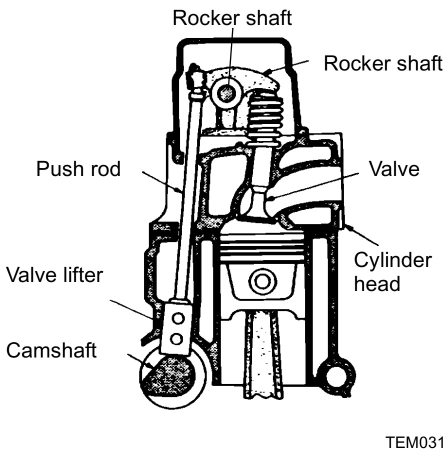
The camshaft is a shaft which has a number of cams grouped in numbers equaling the number of valves per each cylinder, and is driven by the crankshaft via the timing chain. The rotary motion of the camshaft is converted to a reciprocating motion, which is transmitted to the rocker arm, which then pushes the valve open, overcoming the tension of the valve spring.

In four cycle engines, the valve is opened only for intake and exhaust strokes during each cycle (intake, compression, combustion and exhaust). The cams for the intake valve and exhaust valve respectively work once during each cycle. That is, the camshaft rotates once. Therefore, **the camshaft rotates once per two rotations of the crankshaft**.

1-2. VALVE ARRANGEMENT TYPES

(1) OVERHEAD VALVE (OHV)

The intake and exhaust valves are located above the piston, the camshaft is in the cylinder block and it pushes up the rocker arm on the cylinder head via the valve lifter and push rod which are connected with the camshaft. At the same time, the other end of the rocker arm moves downward pivoting on the rocker shaft and pushing the valve open.



OHV type