ProVQ™

Contents

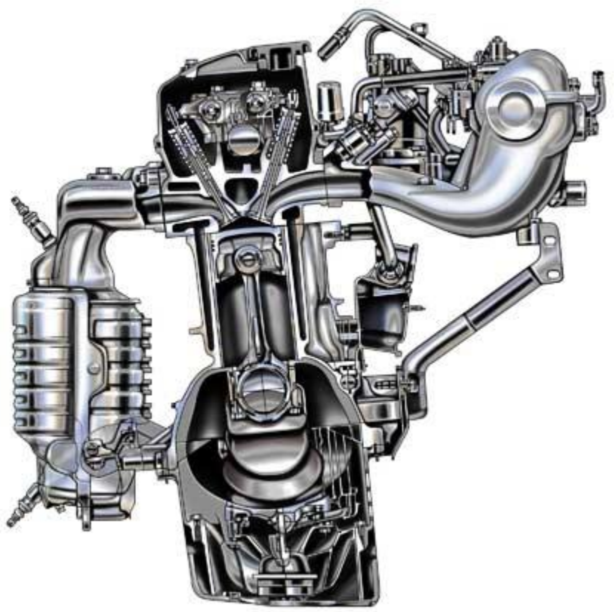
The internal combustion engine

Petrol engines

Engines consist usually of 2, 4, 5, 6, 8, 10, 12 or more cylinders (there are rare exceptions e.g. 16 cylinder engines).

Engines may be arranged in a straight line, flat or 'vee' configuration.

Before explaining the principles of operation of the four-stroke engine some of the main parts must be identified.



Inlet valve
Opens at the correct time to allow the air/fuel mixture into the cylinder.

Exhaust valve
Opens at the correct time to allow the burnt exhaust gasses out of the cylinder.

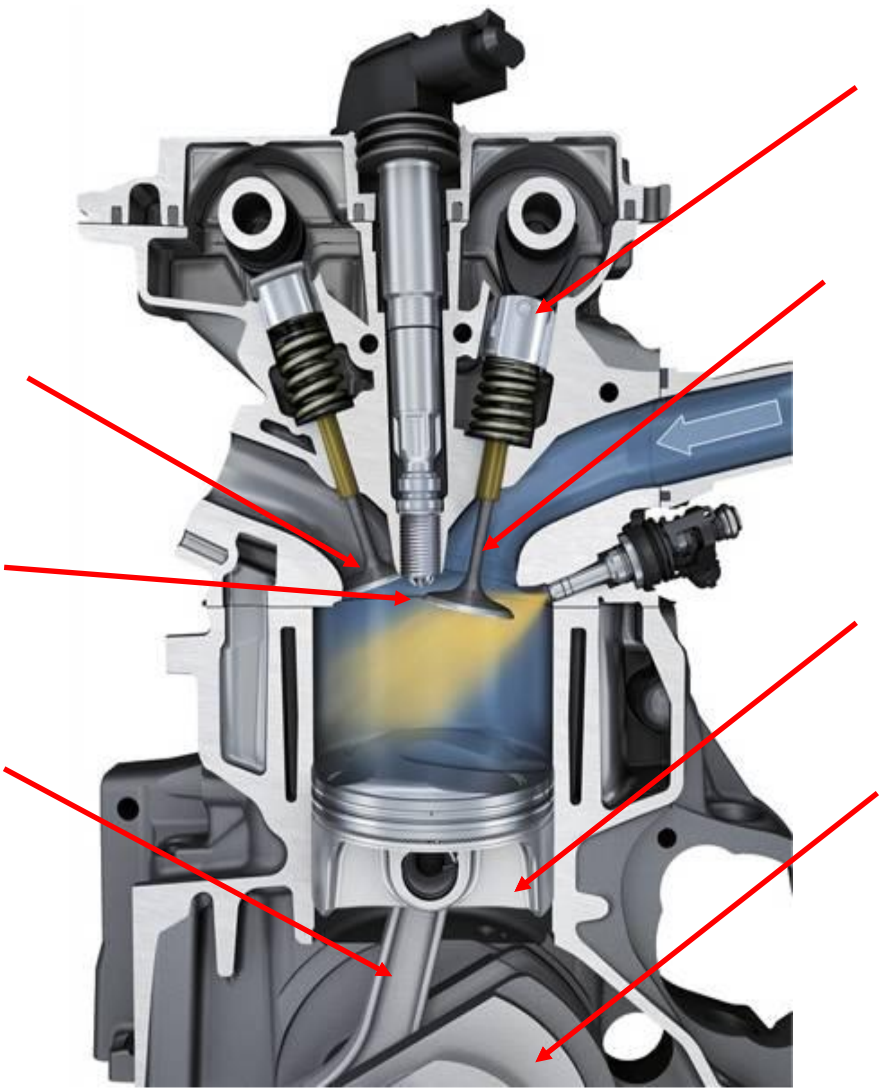
Spark plug
Ignites the air/fuel mixture in the cylinder, which creates rapid burning producing tremendous pressure in the cylinder this pressure is transferred to the piston.

Piston
The piston travels up and down the cylinder. The pressure on the piston is then transferred to the crankshaft. A gas tight seal is formed between the piston and cylinder bore by using piston rings.

Crankshaft
The pressure on the piston is transferred to the crankshaft via the connecting rod, which converts the reciprocating action of the piston to rotary motion of the crankshaft, which turns the attached flywheel.

Flywheel
Stores energy to keep the engine running during none power strokes.

Label the parts below:



ProVQ™

Progress Check

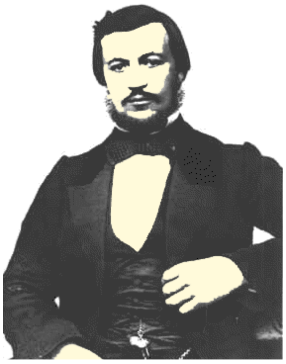
Engine components

The following exercise should be carried out in the workshop. You will need to rotate a partly dismantled engine and note how the components work and the function of each component.

Complete the following table by filling in the blank spaces

Component	Function
Spark plug	Ignites the air/fuel mixture in the cylinder
Inlet valve	
	Opens at the correct time to allow the burnt exhaust gasses out of the cylinder
Piston	
	A gas tight seal is formed between the piston and the cylinder bore
	The pressure on the piston is transferred to the crankshaft
Crankshaft	
	Stores energy to keep the engine running during none power strokes.

N.A. Otto



N A Otto

Nicolaus August Otto invented the four stroke cycle and was born on 14th June 1832 in Holzhausen (Germany).
It was in 1891 that Otto began his first experiments with four-stroke engines. Together with Eugen Langen in 1864 he founded the first engine company N.A Otto and Cie. He died on the 26th Jan 1891aged 58 in Cologne. Elected to the Automotive Hall of Fame in 1996.

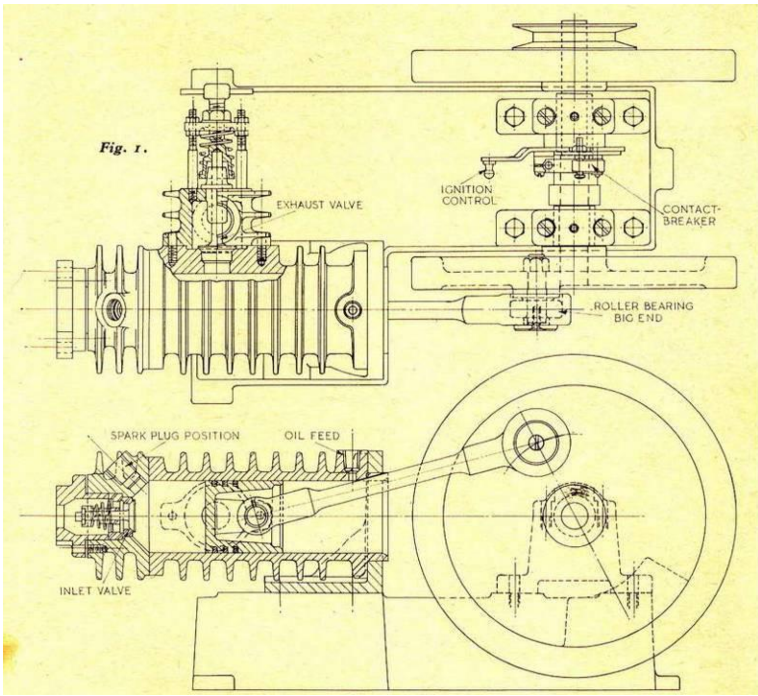
The basic operating principles of the four-stroke engine have been around for more than 100 years. Rest assured that under all
those sensors and electronics the same basic principles of engine operation still exist.

Basic Four Stroke Cycle Engine operation

The spark ignition 4-stroke cycle engine requires 4 basic operations

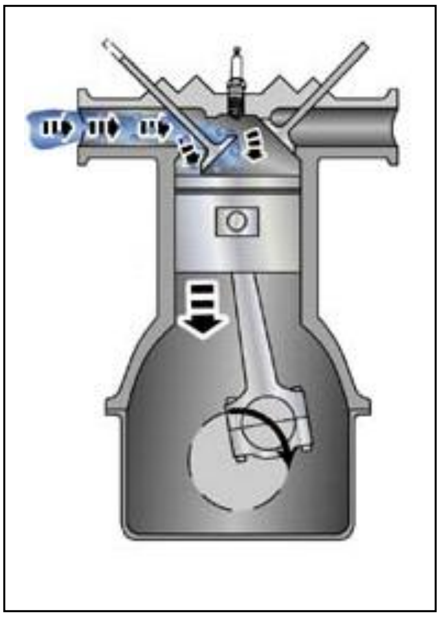
Induction → Compression → Power → Exhaust

An example of an Otto cycle 4 stroke engine



The induction stroke

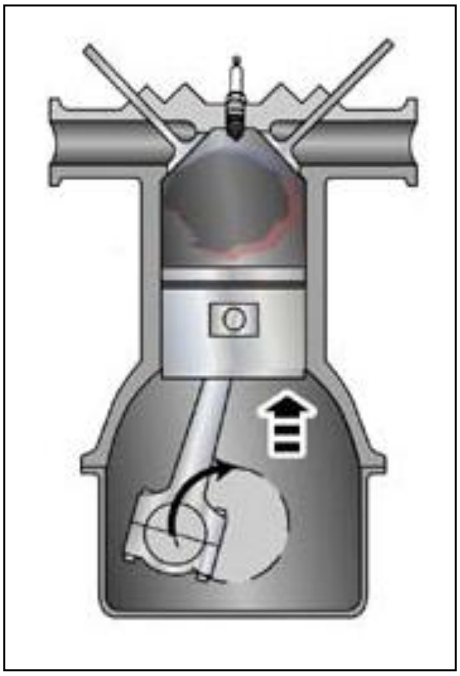
On the induction stroke, the inlet valve opens and the piston moves down, creating a depression (a pressure which is less than atmospheric pressure). The mixture of air/fuel, which is vaporised, is pushed into the cylinder via the open inlet valve by atmospheric pressure (a high pressure always flows to a low pressure trying to make pressure equal again).



The compression stroke

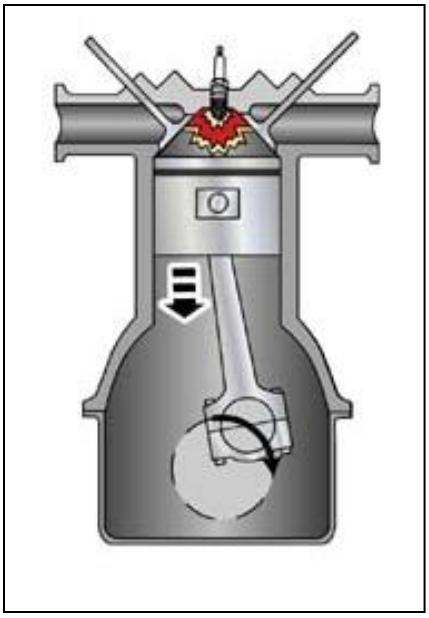
When the piston reaches its lowest limit of travel it then moves upwards allowing the compression stroke to begin. At this point the inlet valve closes. The exhaust valve remains closed, resulting in the cylinder being sealed. As the piston moves upward the air/fuel mixture (a gas) is compressed to about one tenth its original volume. Thus the compression of the mixture increases the pressure and temperature in the cylinder resulting in a volatile air fuel mixture which is keen to ignite

Note: put your thumb over a bicycle pump outlet and try to push your thumb off the outlet using air pressure, work the pump fast, did you feel the temperature rise.



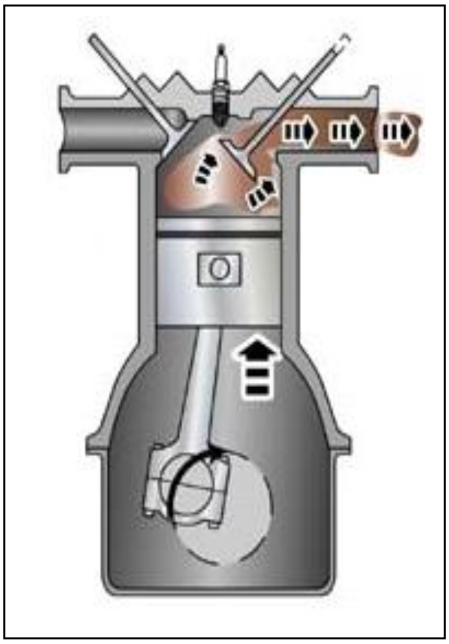
The power stroke

As the piston reaches the top of its travel during the compression stroke, a spark from the spark plug ignites the mixture. The mixture burns very rapidly and the cylinder pressure increases to approximately 40 times atmospheric pressure. The pressure acting against the piston forces it down the cylinder. The energy is transmitted through the connecting rod to the crankshaft, which rotates due to the force acting on it.

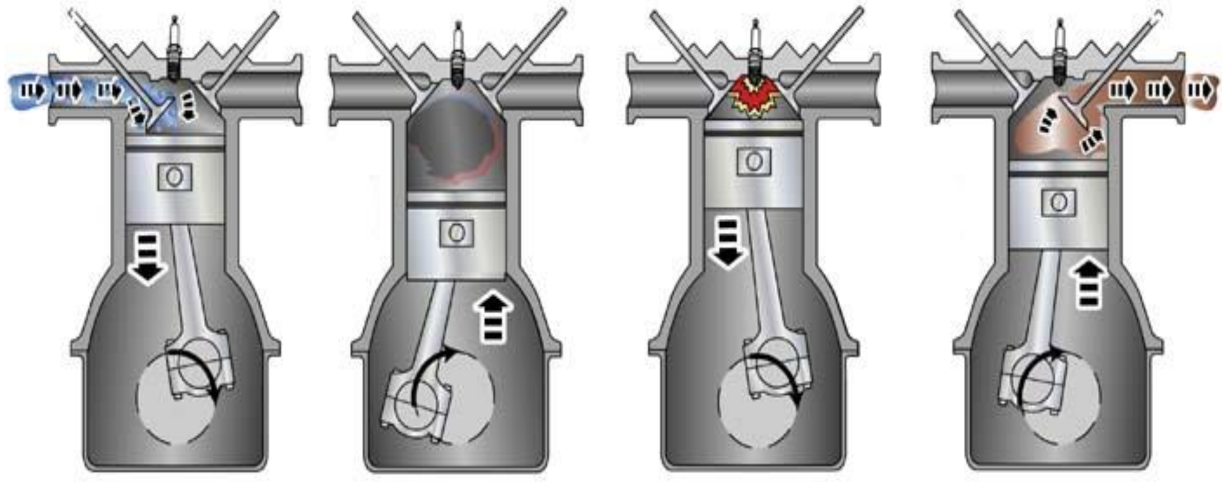


The exhaust stroke

As the piston reaches the bottom of its travel (stroke) the exhaust valve opens. The expanding gas escapes to atmosphere via the exhaust valve port. The piston then starts to move up the cylinder forcing the remaining burnt gasses out through the exhaust valve port. When the piston reaches the top of its travel the exhaust valve closes and the inlet valve opens again, the four stroke cycle then repeats continuously during engine operation.



Summary



Induction stroke | Compression stroke | Power stroke | Exhaust stroke

Progress Check

See if you can complete the table below

Stroke	Piston Travel		Intake Valve	Exhaust Valve
Induction	Down	Intake air/fuel is drawn into the cylinder	Open	Close
Compression				
Power				
Exhaust				

The crankshaft rotates twice to complete the four cycles, but the camshaft, which operates the valves only rotates once, therefore the camshaft rotates at half engine speed (a 2:1 ratio).

Progress Check

Can you fill in the gaps from the list of missing words?

piston inlet valve upwards temperature closes top energy
compressed ignites bottom exhaust four-stroke opens
vaporised compression opens pressure exhaust valve up rotates
increases

The induction stroke

On the induction stroke, the inlet valve ____________ and the ____________ moves down, creating a depression (a pressure which is less than atmospheric pressure). The mixture of air/fuel, which is____________ is pushed into the cylinder via the open ____________ by atmospheric pressure (a high pressure always flows to a low pressure trying to make pressure equal again).

The compression stroke

When the piston reaches its lowest limit of travel it then moves ____________ allowing the compression stroke to begin. At this point the inlet valve ____________.The exhaust valve remains closed, resulting in the cylinder being sealed. As the piston moves upward the air/fuel mixture (a gas) is ____________ to about one tenth its original volume. Thus the compression of the mixture increases the ____________ and ____________ in the cylinder resulting in a volatile air fuel mixture which is keen to ignite.

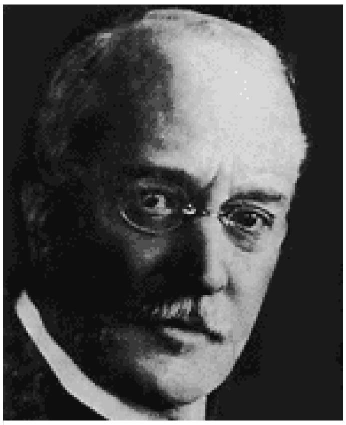
The power stroke

As the piston reaches the ____________ of its travel during the ____________stroke, a spark from the spark plug ____________ the mixture. The mixture burns very rapidly and the cylinder pressure ____________ to approximately 40 times atmospheric pressure. The pressure acting against the piston forces it down the cylinder. The ____________ is transmitted through the connecting rod to the crankshaft, which ___________due to the force acting on it.

The exhaust stroke

As the piston reaches the ____________of its travel (stroke) the ____________ valve opens. The expanding gas escapes to atmosphere via the exhaust valve port. The piston then starts to move ____________ the cylinder forcing the remaining burnt gasses out through the exhaust valve port. When the piston reaches the top of its travel the ____________ closes and the inlet valve opens again, the ____________ cycle then repeats continuously during engine operation.

Rudolf Christian Karl Diesel



Rudolf Diesel

Born in Paris and was the son of an Augsburg Craftsman. Diesel was surrounded by poverty almost all his life and was very unhappy as a child. He invented the refrigeration system. He patented the cycle of operation (four-strokes) of the compression-ignition engine in 1892 and 1893. It was 1897 before he got one working. He spent the rest of his life introducing his invention to the world. Diesel had many problems with manufacturing, licensing and financial stability. Once the engine had been proven, Diesel became a rich man he was a millionaire in 1898 from the sale of the rights to his engine.

He vanished while travelling on the Harwich Antwerp ferry which was crossing the channel to England on September 29th 1913, his body was never found. His invention is widely used today in all types of transport and manufacturing.

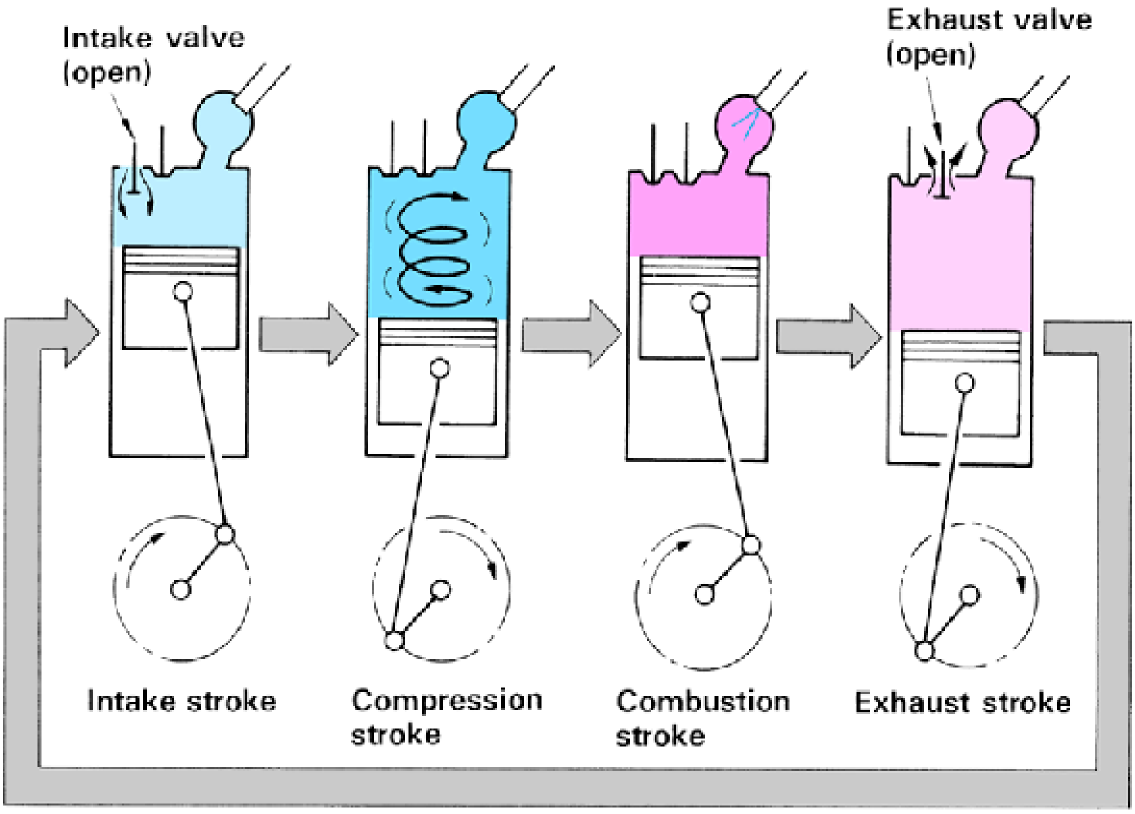
The diesel engine

Four stroke cycle

There is a close resemblance between the operation of the four-stroke petrol engine and the four-stroke diesel engine. In the diesel engine, the fuel is not mixed with the air entering the cylinder during the inlet stroke. Only air is compressed during the compression stroke, at the end of the compression stroke fuel is injected (sprayed) into the cylinder.

Since compression pressures can be as high as 23:1 and provide cylinder pressures in the region of 35 atmospheres at the end of the compression stroke. Compressing the air causes a temperature rise in the cylinder to about 600 degrees C.

The temperature is high enough to ignite the diesel fuel spontaneously as it is injected into the cylinder. The high pressure of this very rapid burning process, not unlike an explosion, causes the piston to move down the cylinder the same as the piston did in the petrol engine.



Cylinder pressure = approximately 30 bar (440 psi) and the temperature is about 500/800 degrees C.

Summary

The four strokes of the internal combustion engine are Inlet (intake), compression, power (combustion) and exhaust.

The four strokes require two revolutions of the crankshaft 720 degrees of rotation. How many revolutions would an eight-cylinder engine require to complete its four strokes? It only takes two revolutions of the crankshaft to fire all cylinders of any four-stroke engine.

The connecting rod converts the up and down movement of the piston (reciprocating motion) into the rotating motion of the crankshaft. The diesel engine differs from the petrol engine in that only air enters the cylinder during the induction stroke. The fuel is injected into the cylinder only at the end of the compression stroke. The fuel spray ignites spontaneously without the use of a spark plug, due to the high temperature of the compressed air in the cylinder.

As mentioned earlier, the diesel engine operating cycle is very similar to the operating cycle of the petrol engine, but there are some notable differences.

Progress Check

Write in the spaces, the comparable differences between the two engine cycles of a petrol and diesel engine

Spark Ignition (Petrol)	Compression Ignition (Diesel)
Power and speed are controlled by varying the quantity of fuel and air entering the cylinder	
	Due to high pressures and vibration heavier components are used
Fuel vaporises readily in the atmosphere, therefore is more volatile	
	Compression ratios are 16:1 or more
A spark plug is used to ignite the fuel	
	Air only enters the cylinder

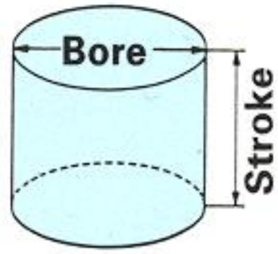
Cubic capacity

The internal diameter of an engine is called the bore. The distance the piston moves between top dead centre (TDC) and bottom dead centre (BDC) is known as the stroke.
The volume displaced or swept by the piston is known as, displacement or swept volume. If this refers to a multi cylinder engine it must include the total swept volume from all the cylinders multiplied by the number of cylinders.

Calculating the cubic capacity of an engine

Formula

$V = \pi r^2 h$



V= cylinder volume (cubic capacity)

π = 3.14 (pi)

r= cylinder bore radius (half the bore measurement)*

h= stroke (minimum to maximum piston travel)*

Example:

4 cylinder engine

Bore 86.5mm conversion to cm 8.65cm

Stroke 84.4 mm conversion to cm 8.44cm

Formula

$V = \pi r^2 h$

Volume $= \pi \times (r \times r) \times h$

π 3.14 x 4.33 x 4.33 x 8.44 = 496.88cc

Multiply by the number of cylinders

496.88 x 4 = 1987cc

*All measurements must be calculated using cm

Compression ratio

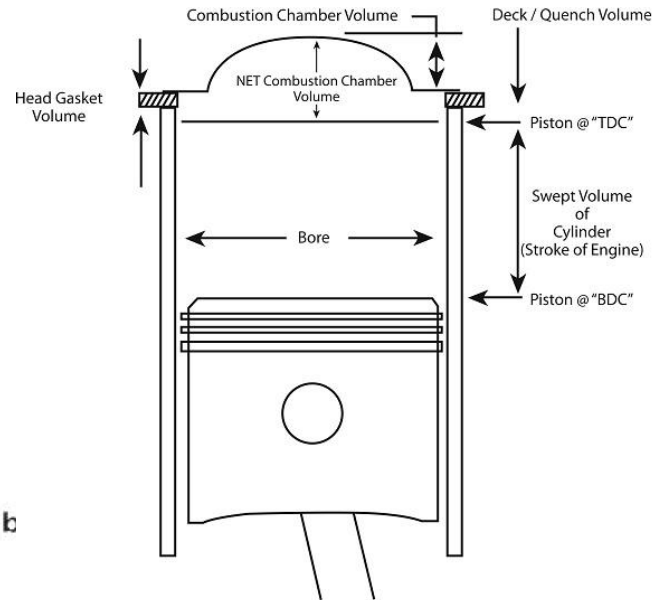
The compression ratio is important for engine performance and efficiency, the higher the compression ratio the more thermal efficient the engine is. The type of fuel used is the limiting factor with regard to a workable compression ratio. If the compression ratio is too high, the heat caused by compression of the air fuel mixture will actually cause it to ignite without a spark, this is known as pre-ignition (when air is compressed it heats up, this concept is used to make diesel engines run).

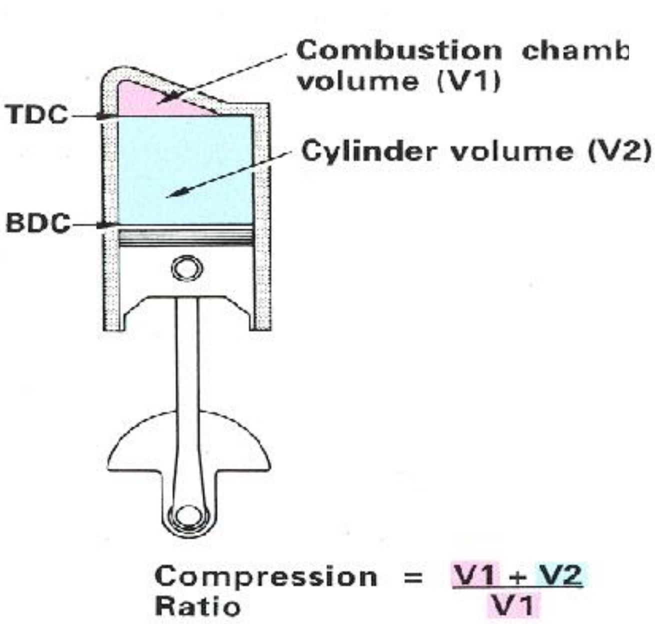
The petrol that is sold from petrol stations has limits to what compression ratios it can handle, this is usually about 10:1, the higher the octane rating of fuel the higher the compression ratios, about 13:1 in the very best case. If alcohol is used then, the compression ratio can be raised to about 15:1. Diesel engines have compression ratio of 16:1 to about 23:1.

Calculating compression ratio

The compression ratio is influenced by, how big the engine cylinder is e.g. the swept volume of the piston as it moves from BDC to TDC and what is the remaining volume at TDC above the piston.

What the cylinder volume will be squeezed into.





Example:

$$\frac{V1 + V2}{V1} =$$

$$\frac{32\ cc + 315\ cc}{32\ cc}$$

Compression Ratio = 10.8 : 1

Two stroke engines

The two-stroke petrol engine

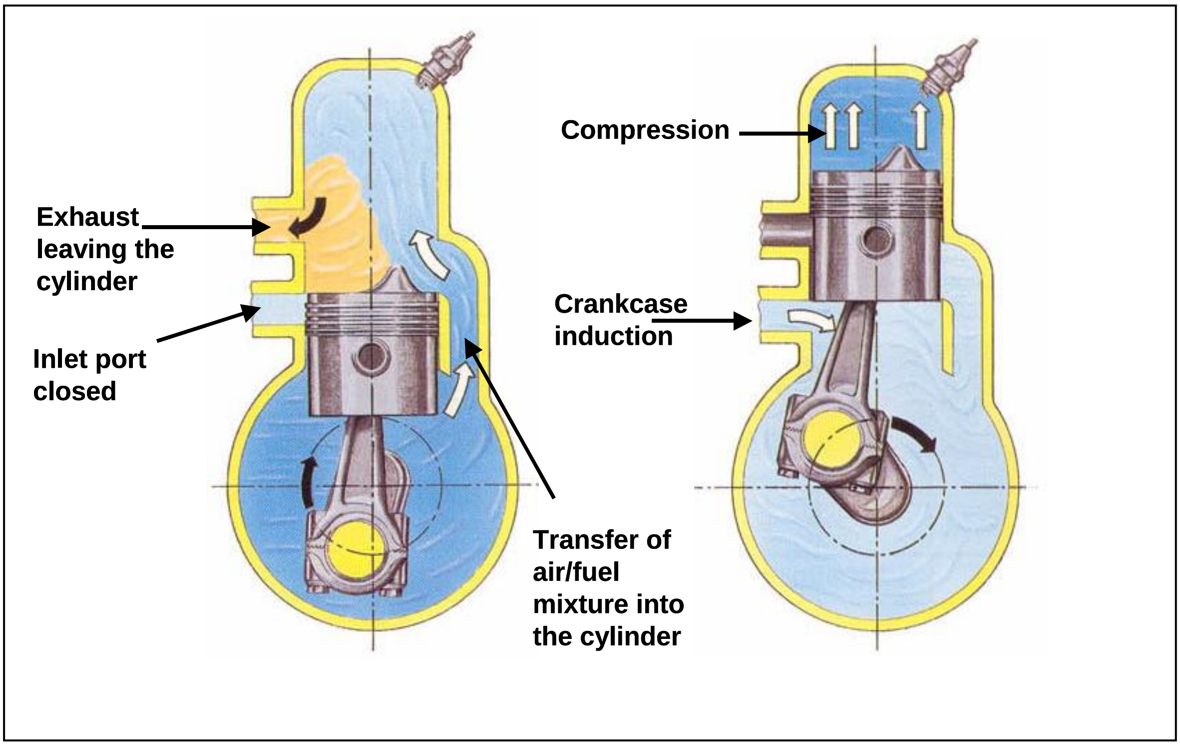
The two-stroke engine was developed by a Scotsman his name was Dugald Clerk it had two cylinders and pistons which forced the fresh mixture into the working cylinder.

Later Joseph Day modified Clerk's engine by using space in the crankcase, thus removing the need for a second cylinder.

The two stroke engine is much simpler that the four-stroke in that it has fewer moving parts, there are no valves or camshafts, lubrication is achieved by mixing oil with the petrol. The complete cycle of operation is carried out in only two-strokes of the piston, which means that some elements of phases of operation must be carried out simultaneously.

It has always been considered a disadvantage that the four-stroke has three idle strokes between working strokes, thus the need for a heavier flywheel. A common misunderstanding is that the two-stroke develops twice the power of a four-stroke but this is not the case due to lower efficiency caused by mixing new gas with burnt gas which causes some loss of fresh mixture entering the cylinder, this cannot be avoided due to the design features of the engine causing poor scavenging of the burnt exhaust gas.

Operation of the two-stroke petrol engine

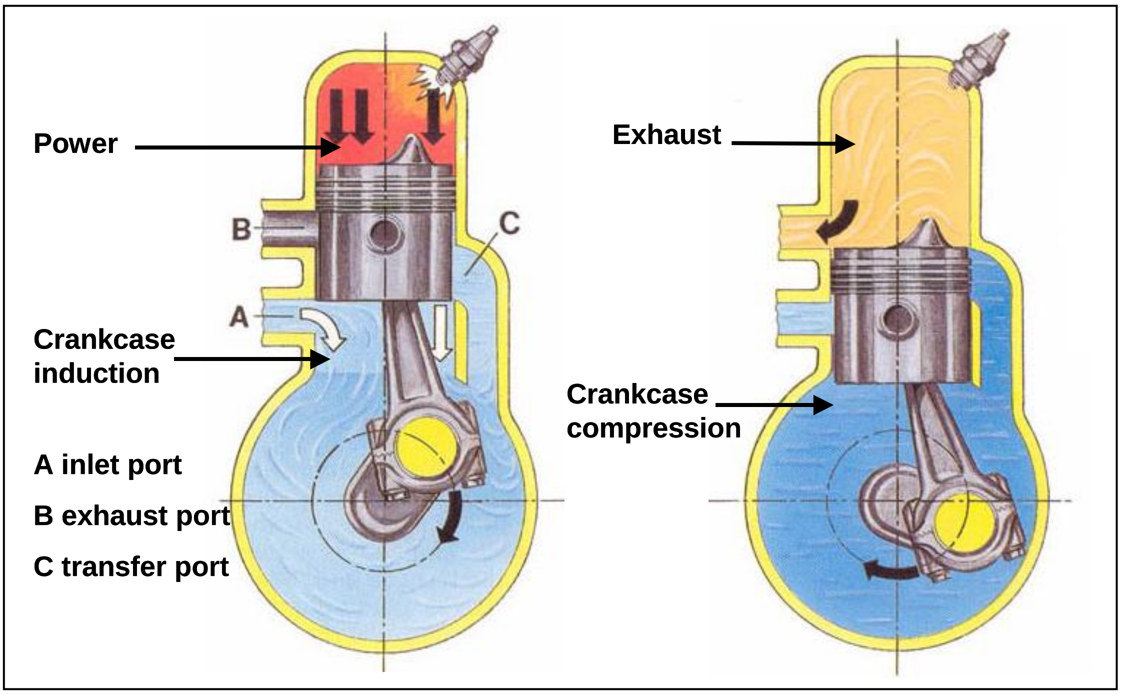


Induction/exhaust

The piston moves down the cylinder and uncovers both the transfer port and exhaust ports. The downward force of the piston on the gas underneath it increases the pressure on the fuel/air/oil mixture in the crankcase, (oil mist clings to the moving parts to lubricate them) while the fuel/air mixture is rising being pumped from the crankcase via the transfer port into the combustion chamber. The air/fuel/oil mixture is then compressed as the piston moves up the cylinder. As the piston moves up the cylinder, it creates a depression in the crankcase, the volume of the crankcase increases therefore, fuel/air/oil mixture enters the crankcase ready for the piston uncovering the transfer port.

On some engines there is a valve fitted between the carburettor and the crankcase, which stops the tendency for some of the fuel /air mixture blowing back through the carburettor where the fuel and air mix.

Operation of the two-stroke petrol engine continued



Ignition/power

Both the inlet and exhaust ports are closed, the pressure of the burning expanding gasses forces the piston down the cylinder. The pressure in the crankcase rises and during the down-stroke the piston uncovers the exhaust port allowing the burnt gasses to escape, as this happens the transfer port is uncovered fuel/air/oil mixture rises into the combustion cylinder and the process starts all over again.

Progress check

Answer the following questions:

1. One complete cycle is completed in __________degrees of crankshaft rotation.

2. The crankcase is sealed in order to _______________________________

3. Advantages of a two-stroke engine over the four-stoke are:

a) ____

b)____

c)____

The DITECH Two-stroke

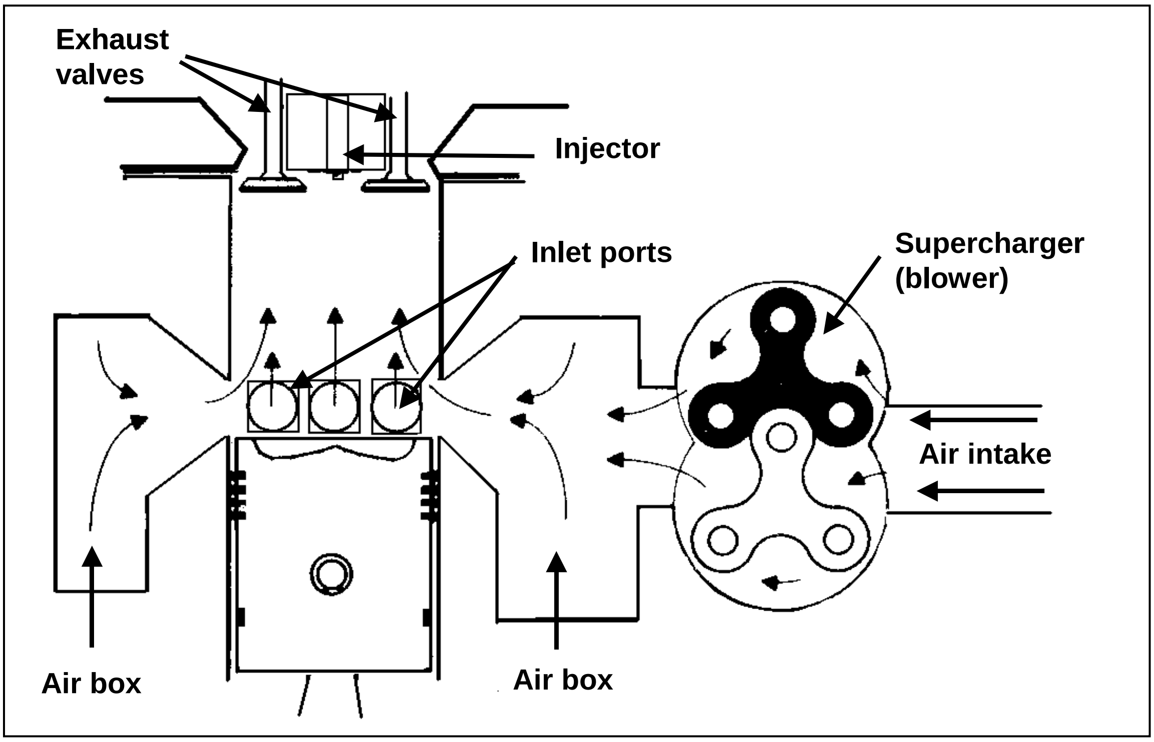
Direct injection technology

The SR DITECH is the world's first scooter to feature a revolutionary direct electronic injection engine. Unlike traditional two-stroke engines, petrol/air/oil mixture no longer takes place within the crankcase. Petrol/air mixture is injected directly into the combustion chamber electronically.

The special fuel injector mixes petrol and air from a compressor and then injects it into the combustion chamber. By keeping the oil separate and in a reservoir (the oil is pressure fed and is undiluted by fuel providing optimum lubrication), which is used for lubrication alone, pollution is therefore reduced by 80% with respect to a traditional 50cc engine. Topping up is only necessary at approximately 4,500 km.

The two-stroke diesel engine

The two-stroke diesel engine compresses air only; it then injects the fuel directly into the compressed air.



In the petrol engine two-stroke there is loss of fuel to the exhaust when both ports are open, but in the diesel this does not apply, all the fuel is burnt in the combustion chamber.

Operation of the two-stroke diesel engine

Two or four exhaust valves may be found at the top of the cylinder (some engines have used ports instead of valves e.g. Tilling Stevens TS3), which are designed to open simultaneously. The piston is designed similar to the petrol two-stroke engine in that it is elongated so that it can act as the inlet valve. At the bottom of the piston stroke it uncovers the air intake ports the intake air is pressurized by a turbocharger or supercharger.

Note: Turbochargers and superchargers are a type of forced induction system, they compress the air going into the cylinder, squeezing more air into the cylinder makes it possible to add more fuel, therefore more power is developed. The turbocharger is, driven by the exhaust gas and the supercharger is driven by belt or shaft directly from the engine.

When the piston is at the top of its travel in the cylinder the air is compressed within the combustion chamber, fuel is then injected (sprayed) into the compressed air, which reaches a temperature of about 650 degrees C. Fuel having a self-ignition temperature of about 400 degrees C ignites. This is the same combustion process of the four-stroke diesel engine.
The pressure created by the burning of the fuel, drives the piston down the cylinder, this is the power stroke.
When the piston nears the bottom of its stroke the exhaust valves open allowing the exhaust gas to rush out of the cylinder.
When the piston reaches the bottom of its stroke it uncovers the air intake ports. Pressurized air from the turbocharger, or supercharger (which ever is used) forces out the remainder of the exhaust gases, this is known as scavenging.
The exhaust valves close and the piston starts to rise up the cylinder, covering the intake ports and compressing the fresh charge of air, this is the compression stroke, the cycle repeats itself.

Summary

In the two-stroke diesel engine only air fills the cylinder, whereas in the petrol engine, air and fuel are mixed together before entering the cylinder or is mixed in the cylinder (direct fuel injection).

The diesel engine does not suffer the environmental problems that the two-stroke petrol engine does. The two-stroke diesel engine must be fitted with a turbocharger or a supercharger, making it more expensive.

Progress Check

Complete the following:

1. Heat to ignite the fuel in a diesel engine is produced by__________________

2. The combustion chamber in a diesel engine is ___________ because a _______

compression ratio is required.

3. The two-stroke petrol engine has a high loss of mixture through the ________

___________ but the two-stroke diesel does not suffer this disadvantage because

____

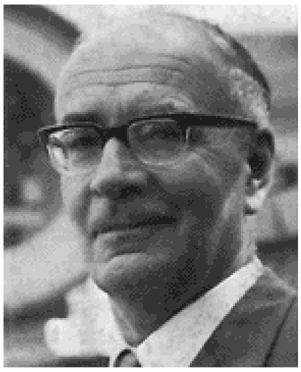
4. In the two stroke diesel engine the fresh charge of air is delivered by the

use of a ____________________________

Rotary engines

The Wankel engine

Felix Wankel was born on August 13th 1902 in Swabia Germany (Otto Daimler and Benz also came from Swabia). Felix was the only child of Rudolf, His father was killed by shrapnel in World-War 1 in 1914 at Donach.



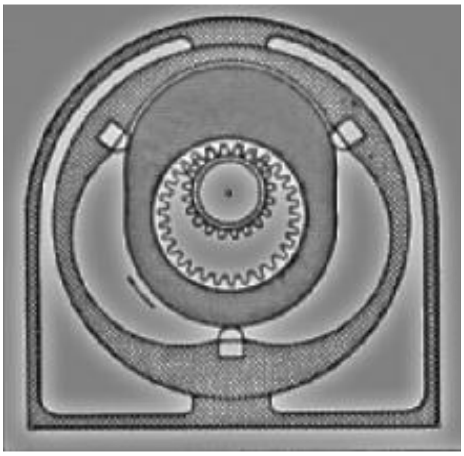
Felix Wankel 1902 -

Felix Wankel conceived the idea of a rotary engine in 1924 and attempted a patent in 1926. Prior to 1910, 2000 patents for rotary engines were filed. There were also designs of rotary engines by Hornblower, Murdoch, Bramah, Flint, Poole, Wright, Marriot, Trotter and at least a dozen others.

Felix Wankel died after a long illness on October 9th 1988.

To satisfy the criteria requirements for a rotary engine, every moving part must rotate including the timing mechanism.
Operation of the Rotary (Wankel engine)

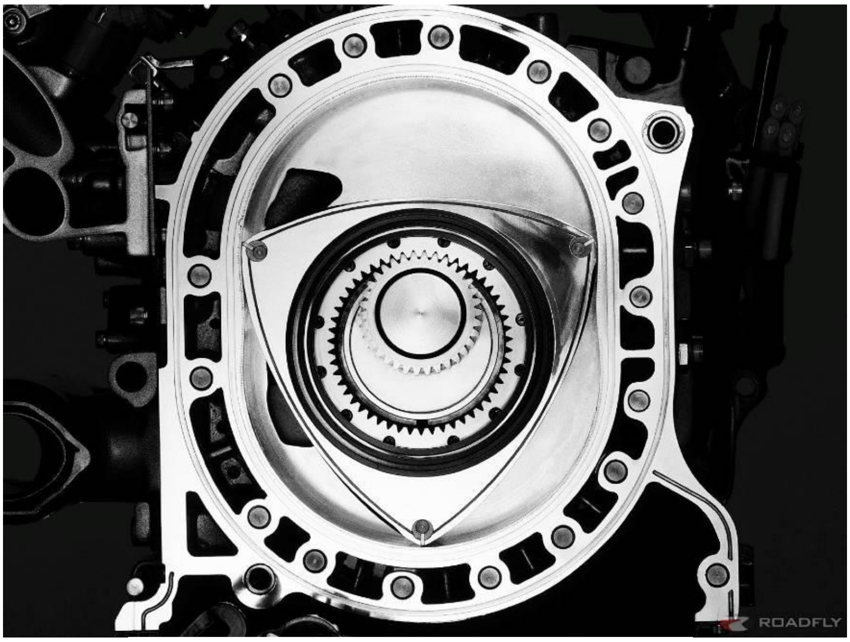
The reverse rotary engine



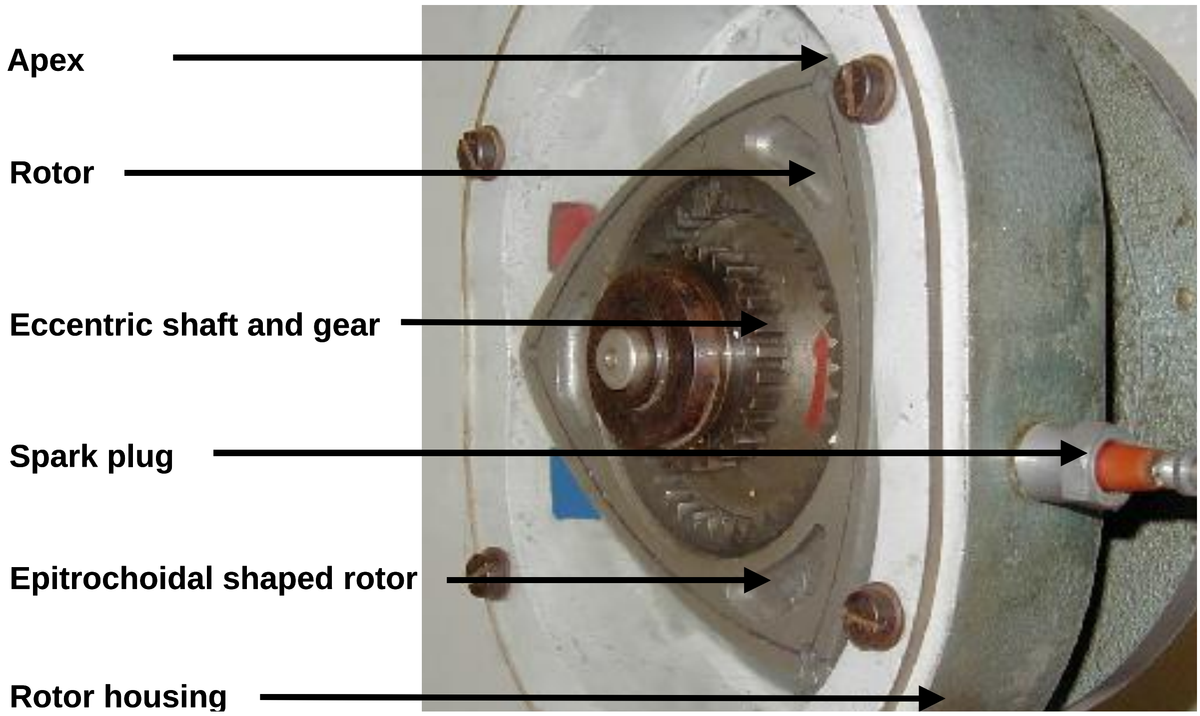
An alternative earlier design of rotary engine.

The engine consists of a rotor, which is free to rotate in an oval chamber of a special shape, which is known as a epitrochoidal.

In the centre of the epitrochoidal housing is an eccentric cam. The three edged rotor turns around the eccentric cam on ball or roller bearings. The apices are in contact with the housing bore continuously, there are three chambers, these chambers are made gas tight by the use of seals at each apex, which are in continuous contact with the bore at all times. In every three revolutions of the shaft the rotor rotates once.



A typical rotary engine

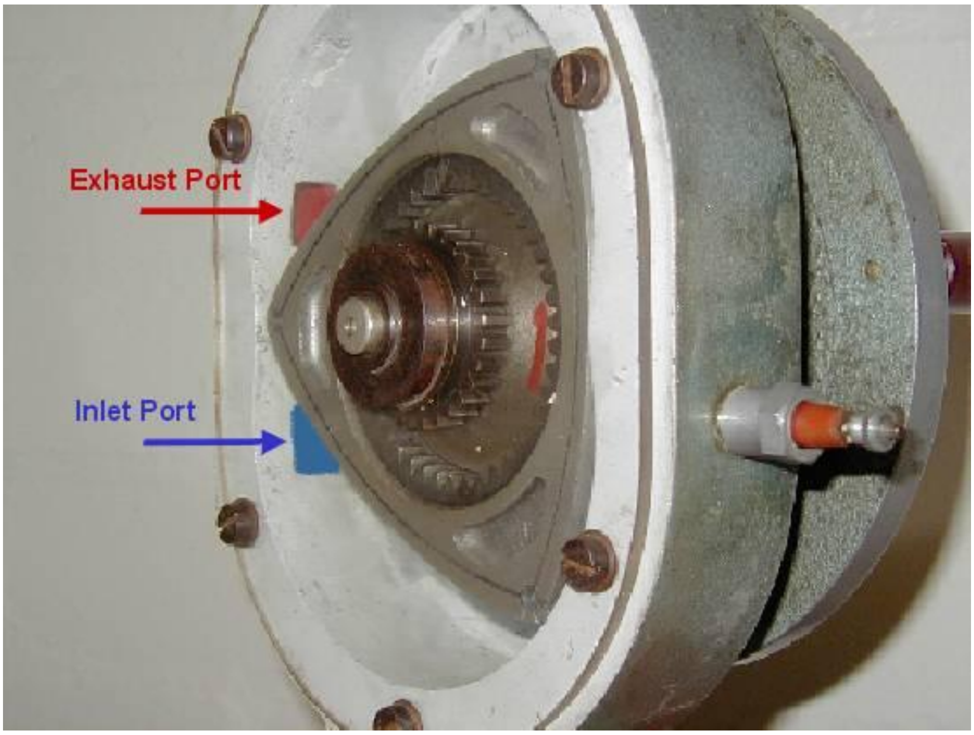


Terminology

Rotor The rotor is somewhat triangular in shape and is roughly equivalent to a piston in a conventional engine.

Apex Each rotor has three apexes, which are the points of the rotor.

Eccentric shaft
The rotors drive the eccentric shaft, which is the equivalent of the crankshaft in a piston engine.



A single element is equivalent to a single cylinder two-stroke engine, if two elements are used then the engine would be the equivalent of a four cylinder four-stroke engine, this engine would be referred to as a two rotor or twin rotor engine.

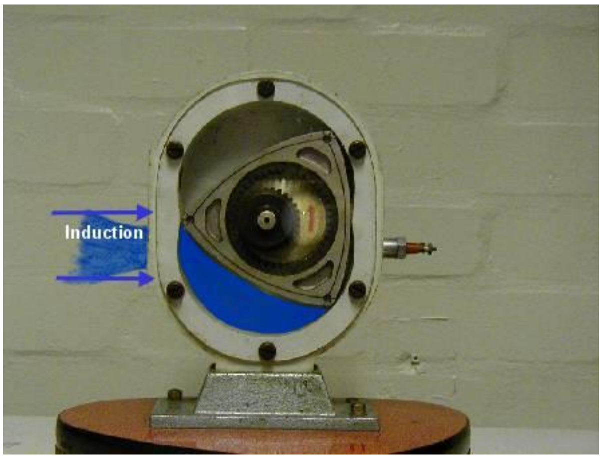
The Wankel engine has 48% fewer parts, which is about a third of the bulk weight of a reciprocating engine. Higher engine speeds are possible due to rotating motion rather than reciprocating motion, but this advantage is offset by the fact that there is a lack of torque at low speeds, which accounts for a greater fuel consumption.

The high surface area heat contact during combustion demands extensive water-cooling.

Induction

The intake ports are uncovered by the rotor, at which time, the chamber opening to the port will be increasing volume.

Rotation is anti-clockwise (looking from the flywheel end of the engine)

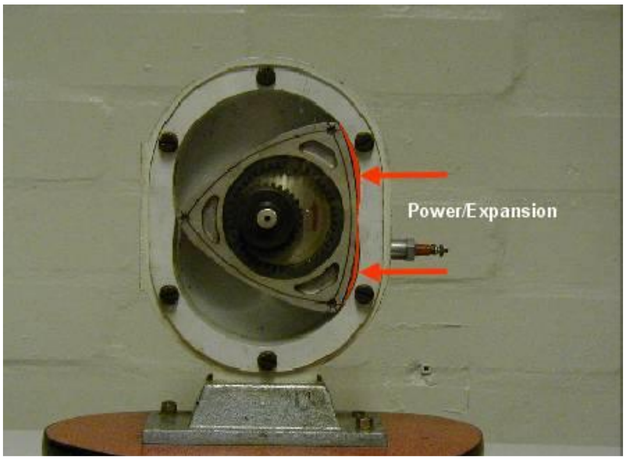


Compression

The rotor is moving in its housing such that the volume of its closed chamber is decreased.

Power

The expanding gas forces the rotor in a direction that expands the chamber containing the burning gases and in the process rotates the eccentric shaft.



Exhaust

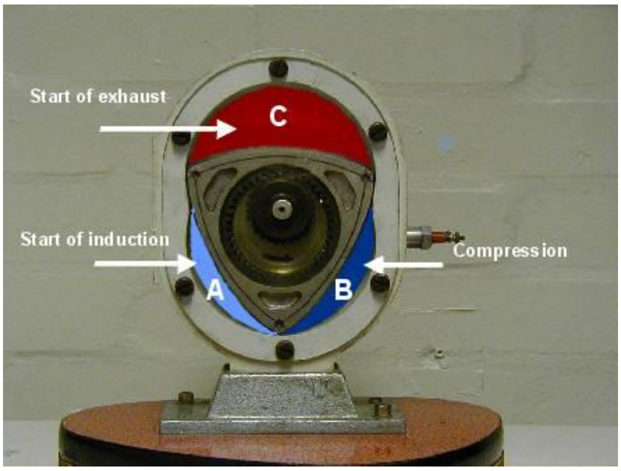
The leading apex of the combustion chamber uncovers the exhaust port in the rotor housing through which the burnt gas is discharged.

Summary

Fresh air/fuel mixture is being induced into chamber A, from the inlet port.

Chamber B is decreasing in size and is approaching the end of the compression stroke.

Chamber C is at the beginning of the exhaust stroke, and this chamber is just opening to the exhaust port.

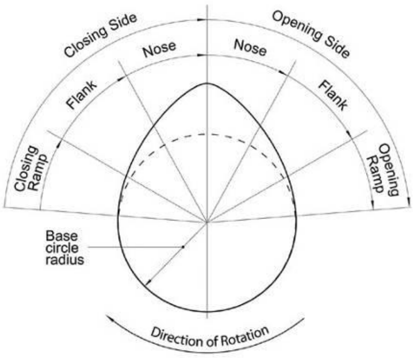


Progress check

Sketch the position of the rotor when on the power stroke. State what is happening in the other two chambers.

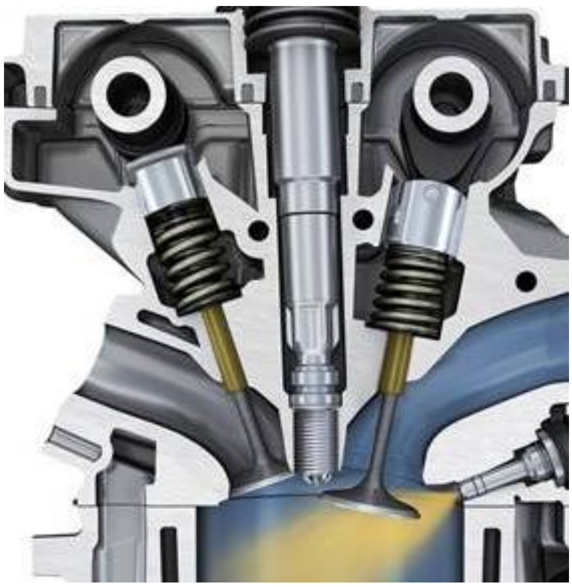
Camshafts

The relationship between the rotation of the camshaft and the rotation of the crankshaft is of critical importance. Since the valves control the flow of air/fuel mixture intake and exhaust gases, they must be opened and closed at the appropriate time during the stroke of the piston. The camshaft turns at half the speed of the crankshaft (ratio 2:1).
The camshaft has lobes that are machined shapes that contact with the valve gear. The lobes force the valve springs to compress and thus lifting the valve off its seat.

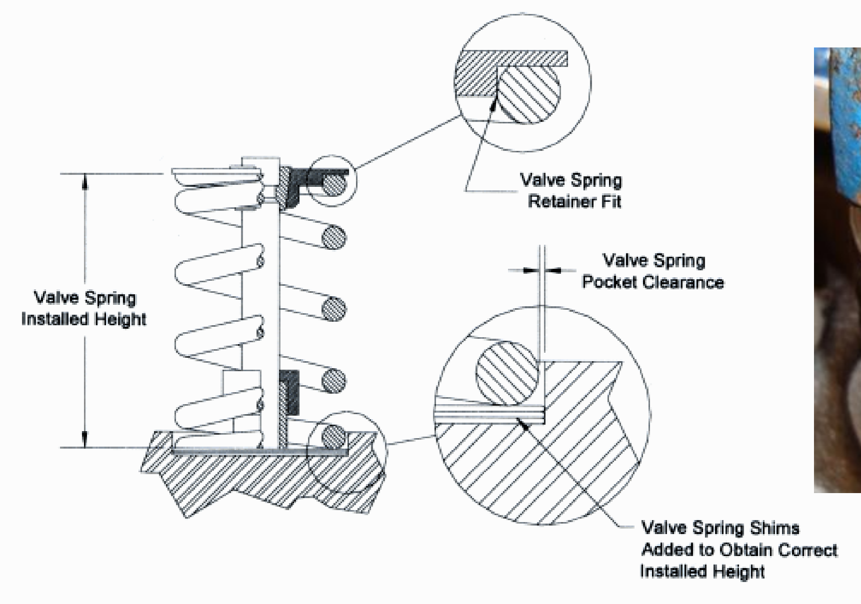


Valves

Valves are fitted into the cylinder head and directly allow air only or an air fuel mixture into the cylinder and exhaust gasses out of the cylinder. Therefore valves must be designed to, make a gas tight seal when in the closed position, offer a minimum of resistance to the gasses when open and operate with minimum wear.



The valves are fitted with return springs to ensure that they close quickly. This is very important at high engine speeds to ensure the valves and pistons do not connect. Spring strength depends on maximum engine speeds and normal operating engine speed.



The spring is attached to the valve by 'collets' which act as a wedge using the spring tension to locate under a groove or ridge in the valve stem.

Valve materials

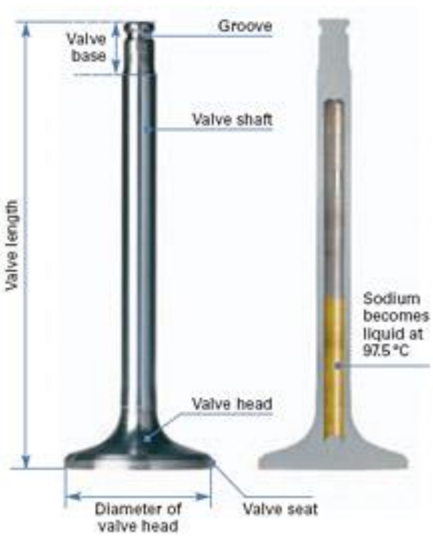
The valves have to be made from a material that is very strong and can cope with the extreme heat conditions of combustion.

Inlet valves

Inlet valves are usually made from high tensile alloy steel usually containing, nickel, chromium and molybdenum.

Exhaust valves

Exhaust valves can have a complex make up due to the extreme temperatures of combustion. Some exhaust valves are coated with aluminium to improve heat transfer. Other cooling methods can involve the use of sodium. These valves are hollow inside the stem and partly filled with sodium. Sodium has a melting point of 97.5°C, therefore during operation the sodium melts inside the valve and splashes from end to end assisting the transfer of heat from the valve head.

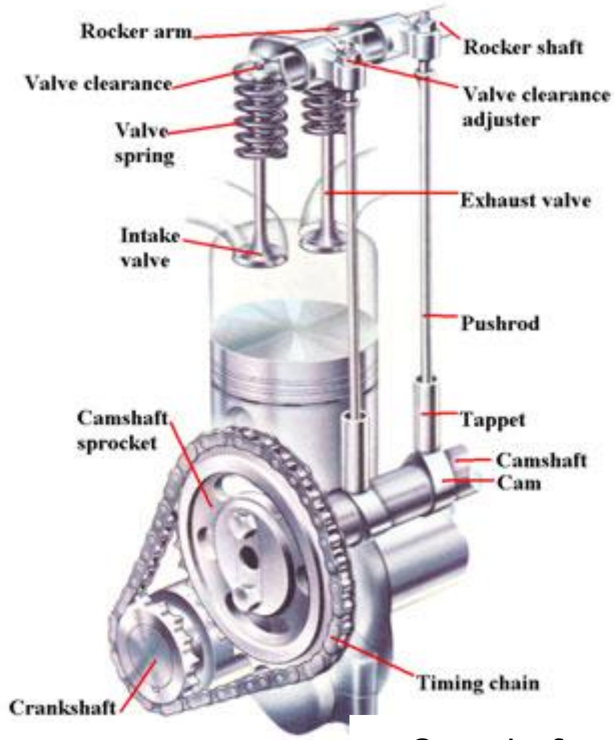


Overhead valve

Valves are arranged in a straight line above the cylinders. The valves are operated by push rods from a camshaft in the crankcase.

The main disadvantages of this system compared to the overhead camshaft system are:

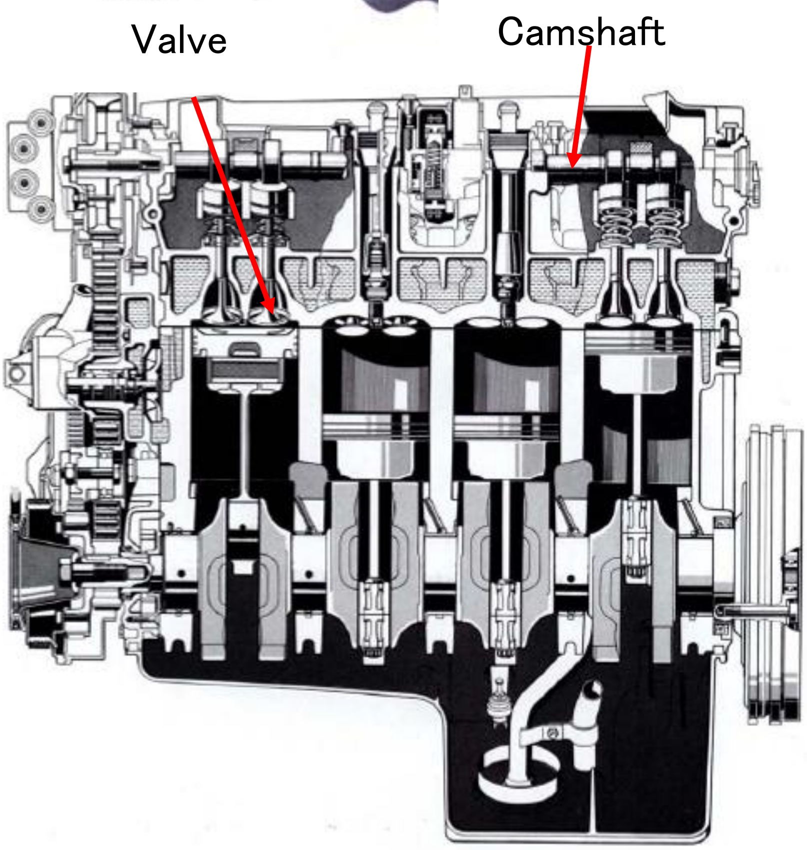
- more moving parts leading to increased wear
- expansion and contraction of the push rods, cylinder head and block affects the valve clearance.



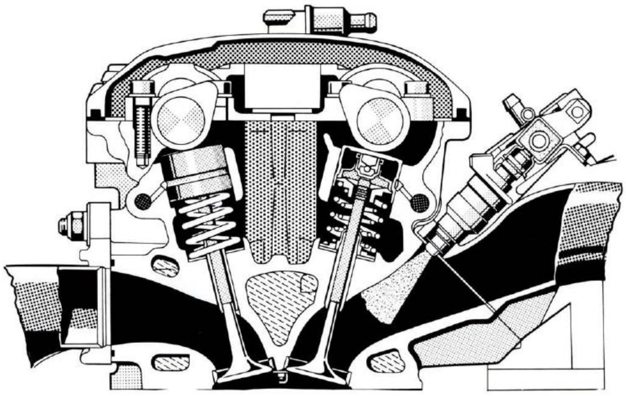
Overhead camshaft

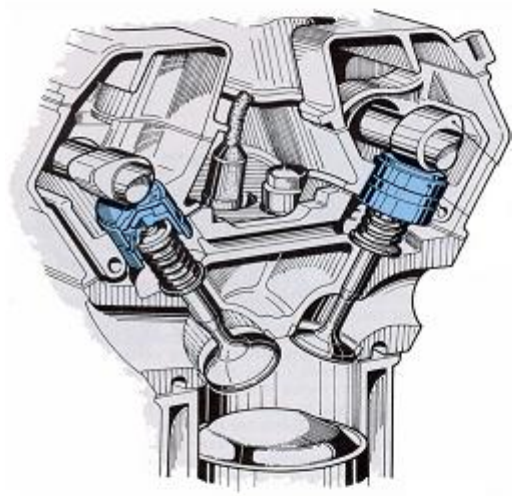
- the overhead camshaft layout is very popular it has less moving parts than the push rod operated valve system
- the overhead camshaft arrangement lends itself readily to multi-valve arrangements.

An alternative is the direct acting camshaft arrangement as shown



Double overhead camshafts



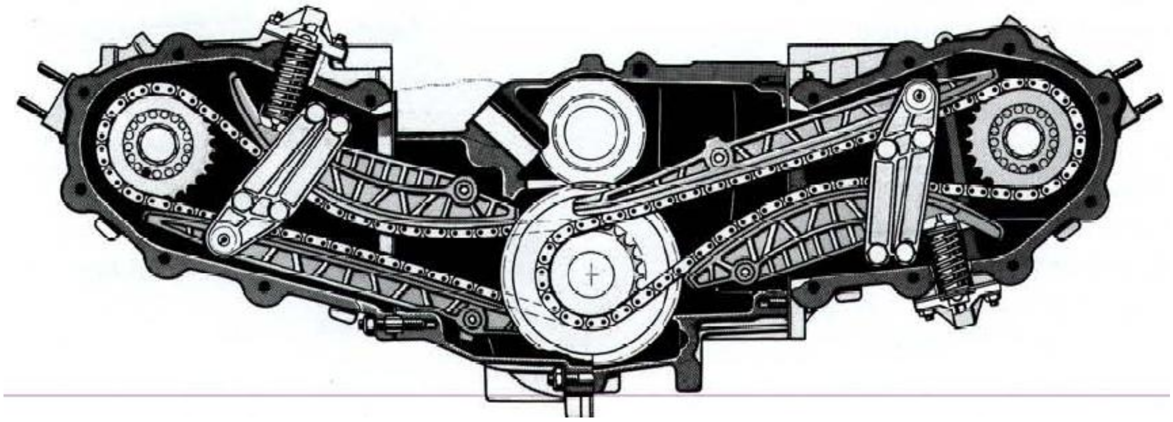


In this layout both the inlet and exhaust valves have their own direct camshaft. One benefit is that the valves being mounted at greater angles provides less resistance in the air flow in and out of the cylinder. This increases efficiency and power output. This layout also makes accommodating multi valve arrangements much easier.

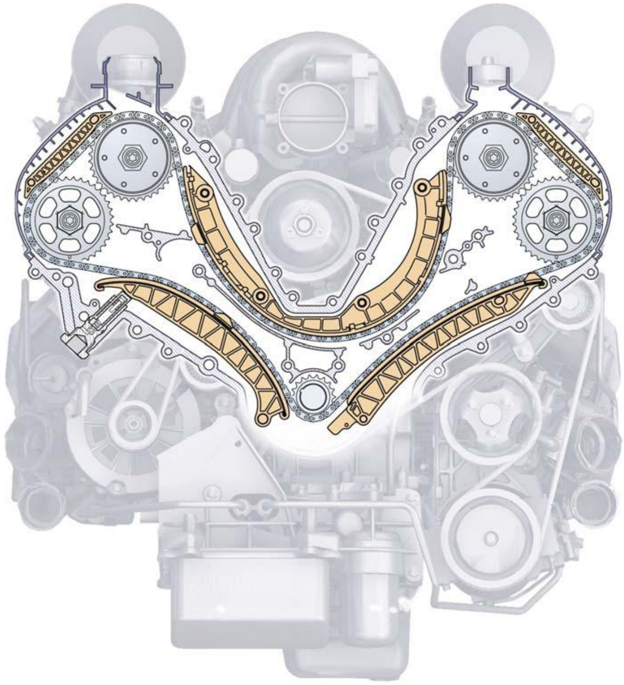
Valve train operation

Chain drive

If the crankshaft and the camshaft are close together a short chain can be used to connect the crankshaft sprocket to the camshaft sprocket. The camshaft sprocket is twice the size of the crankshaft sprocket this provides a 2:1 gear ratio the camshaft rotates at half the engine speed. Compensation for wear is achieved by using a chain tensioner, this is usually automatically adjusted by spring or oil pressure it is fitted on the slack side of the chain.

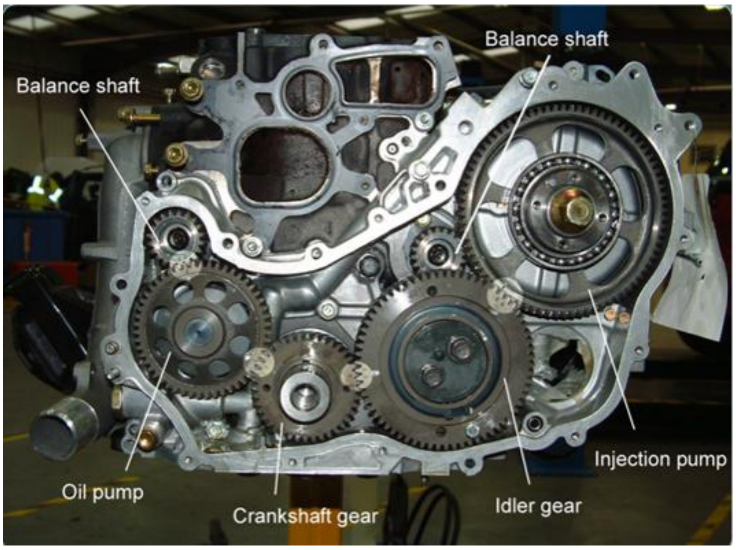


When chains are used to carry the drive up to the cylinder head from the crankshaft a more complex arrangement is used to prevent chain flutter or noise. Manufactures have got to take into consideration the length of the chain, the thermal expansion of the cylinder block and the cylinder head.



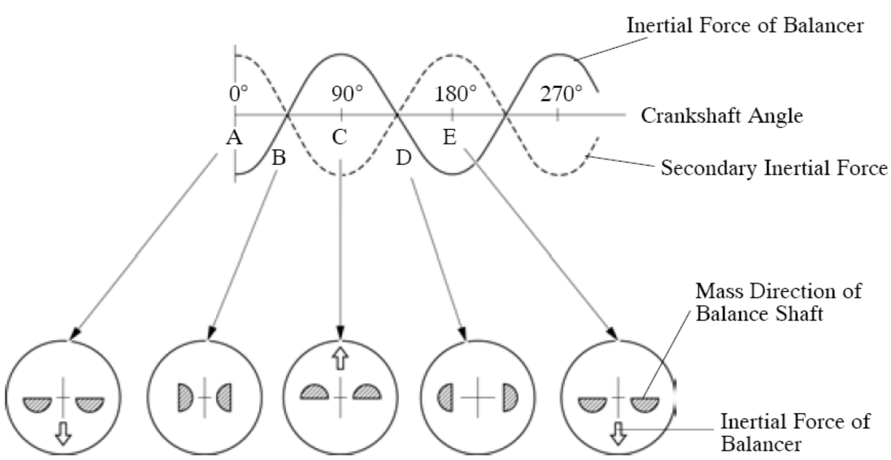
Gear drive

When the crankshaft is fitted close to the camshaft a gear drive can be used, if there is a lot of distance between the two shafts, the gear train may include an idler gear to cover the increased distance between the gears. To reduce noise helical gears are used.

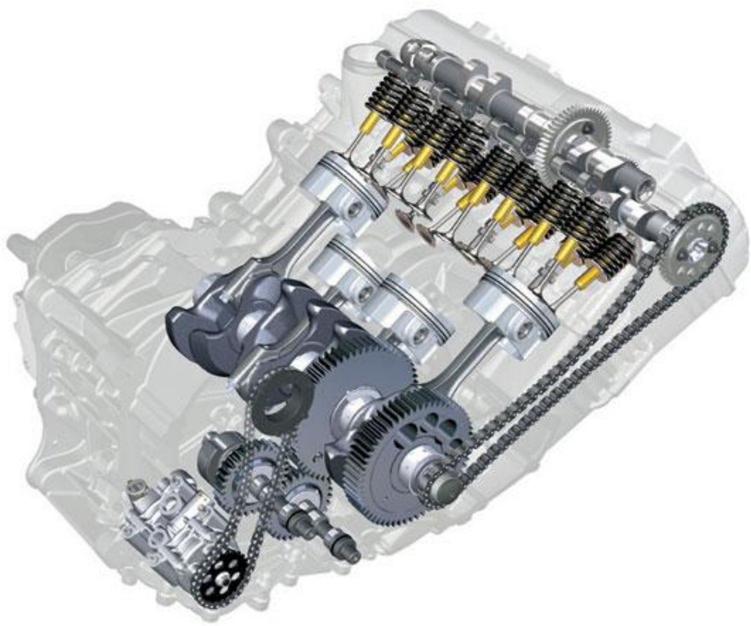


Balance shafts

In the in-line 4-cylinder engine cylinders No. 1 and No. 4 are exactly at the opposite (180°) to No. 2 and No. 3. Therefore during operation the inertia force almost cancel each other. Because the position at which the piston reaches its maximum speed is located toward the top-dead-centre from the centre of the stroke, the upward inertial force is greater than the downward inertial force.
This unbalanced secondary inertial force is generated at twice the speed of the crankshaft.To cancel the imbalanced secondary inertial force, two balance shafts are rotated at twice the crankshaft speed and generate inertial force in the opposite direction. In order to cancel the inertial force generated by the balance shaft itself, the balance shaft actually consists of two shafts rotating in opposite directions.



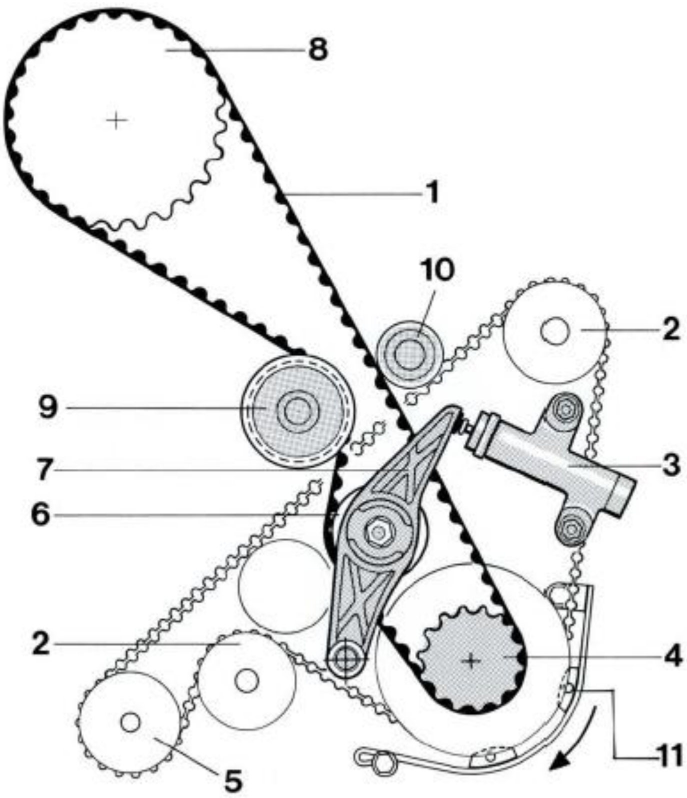
Mass Direction of Balance Shaft at Crankshaft Angle



Balance Shafts

Belt drives

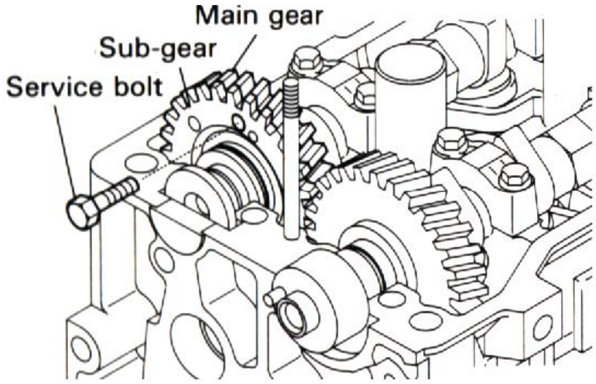
Overhead camshafts are normally driven by a belt, there are teeth on the inside of the belt, these teeth run completely around the belt, the teeth ensure correct valve timing is maintained (no slip).



1 - Camshaft drive belt
2 - Balance shafts
3 - Hydraulic belt tensioner
4 - Drive gear
5 - Tensioner pulley for balance shaft drive belt
6 - Tensioner pulley for camshaft drive belt
7 - Tensioning lever
8 - Camshaft gear
9 - Water pump gear
10 - Idler pulley
11 - Tensioner blade for balance shaft belt

Belt and gear drive-petrol engine

In this arrangement only one cam is driven by the timing belt. The other camshaft is gear driven. A scissor gear (sub-gear) is fitted, so it eliminates any tooth chatter (the gear is spring loaded which takes up clearance in between the gear teeth).



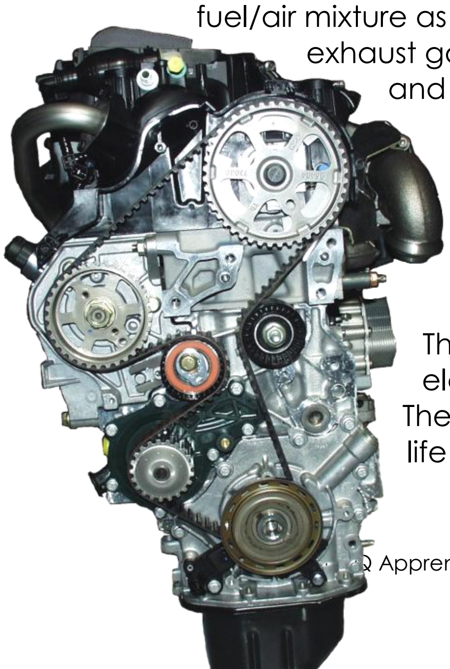
The main advantage of the belt drive is that it is much cheaper than the chain or gear type, it requires no lubrication and is an efficient way of driving a camshaft that is mounted a good distance from the crankshaft. Maintenance is simple; the belt can be removed easily to enable the removal of the cylinder head.

The main disadvantage is the life of the belt; it needs to be changed more frequently than the chain or gear and does not warn of an impending failure, it silently fails. Although these belts are made of rubber reinforced by fibreglass to make breakages rare, when they fail a great deal of damage can be caused to the engine, if for example the piston strikes an open valve.

Whenever a chain belt or gear is removed the valve timing must be reset

Valve timing

To obtain the maximum power output it is necessary to fill the cylinder with as much fuel/air mixture as possible. It is also necessary to remove as much of the exhaust gas as possible. Incorrect valve timing causes uneven idling and a loss of engine power.



If the timing belt or chain became worn the valve timing would become retarded.

Timing belt type-diesel

The timing belt is made from heat resistant rubber and is non-elastic the teeth are covered with wear resistant canvas. The tension of the belt is adjusted by the timing belt idle, the life expectancy of a belt is in the region of 60,000 miles, it is important that manufactures recommendations are adhered to. Some manufactures install a timing belt wear indicator light which warns the driver when is time to replace the belt.

It should be noted that the valve drive mechanism is required to drive the injection pump and in some cases the oil pump, greater load demands are placed upon the timing belt gears or chain

Valve timing-petrol engine

Inlet valve timing

At the beginning of the four-stroke cycle, the inlet valve starts to open just before top dead centre (BTDC), this is to ensure that it is fully open early in the induction stroke.
This ensures the incoming fuel/air mixture keeps up with the piston as it moves down the cylinder the result is a better filling of the cylinder.

The degree of early opening 6 - 10 degrees depends upon the type of engine and normal cruising required. To take full advantage of the speed of flow of the incoming fuel/air mixture the inlet valve is kept open after bottom dead centre (ABDC). Late closing allows time for the inertia of the fast column of gas in the induction manifold to help the mixture to push its way into the cylinder although the piston has started to move a little up the cylinder again on the compression stroke.

A closing angle of between 40 and 50 degrees is common. This system of early opening and late closing of the inlet valve ensures the highest possible volumetric efficiency (see multiple valves and turbo charging).

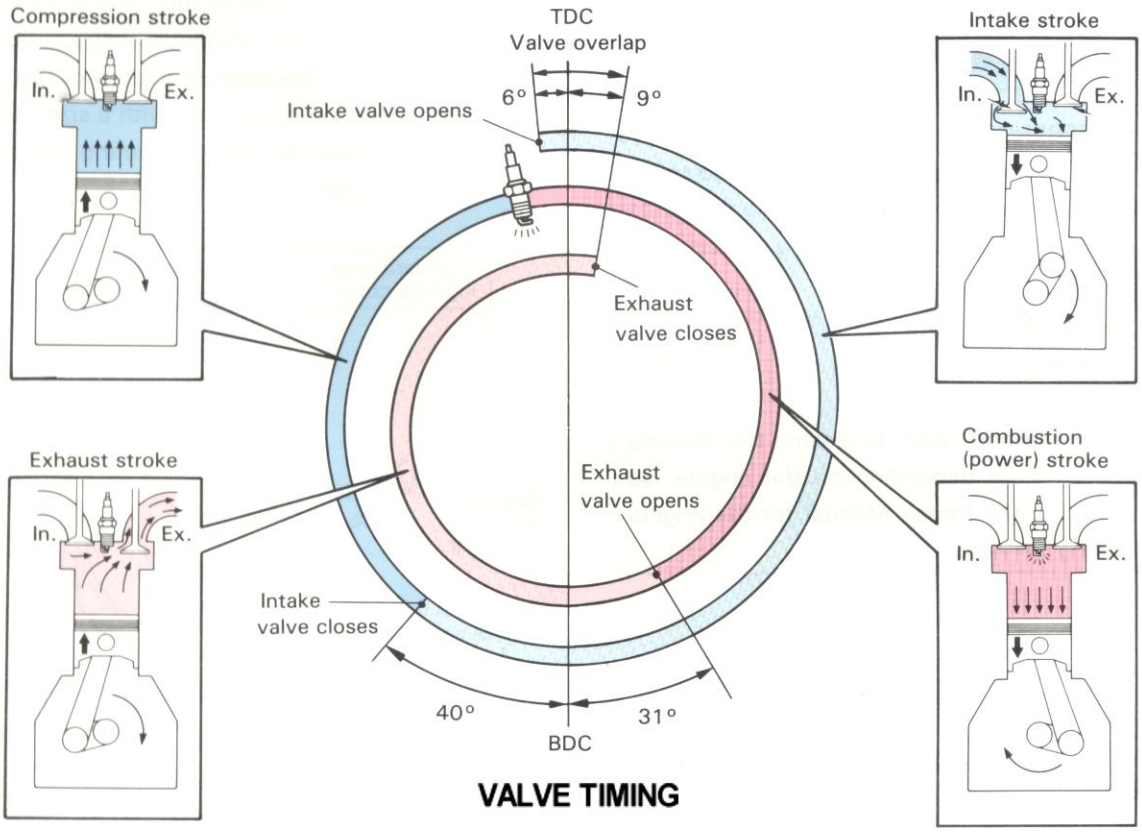
Exhaust valve timing

The exhaust valve opens before bottom dead centre (bbdc) (early opening), this allows the burnt gas pressure in the cylinder to fall to nearly atmospheric pressure by escaping past the open valve, this occurs before the piston starts to move up the cylinder.

Early opening of the exhaust valve prevents 'back pressure' on the piston during the exhaust stroke when it pushes the burnt gas out of the cylinder.

The exhaust valve closes just after top dead centre (ATDC) (late closing). Keeping the exhaust valve open later allows the exhaust gas to rush out of the cylinder at very high speed, the movement of the gas continues after the piston has stopped moving up the cylinder, this creates a scavenging affect and clears the combustion chamber of remaining gas.

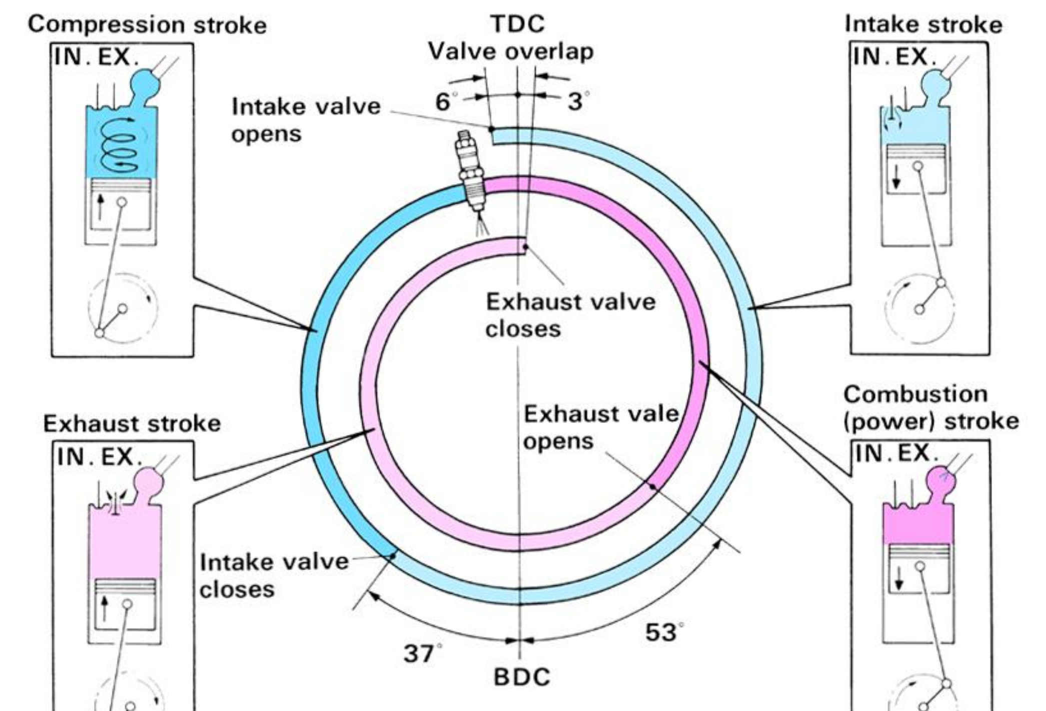
Valve timing diagram-petrol



Timing by crank angle

The amount of early opening or late closing of the valves is measured by the position of the crankshaft. When stated that the inlet valve opens 6 – 10 degrees before top dead centre and closes 40 – 50 degrees after top dead centre, it means that the valve begins to open when the crankshaft is 6 – 10 degrees before top dead centre and closes when the crankshaft is 40 – 50 degrees past bottom dead centre.

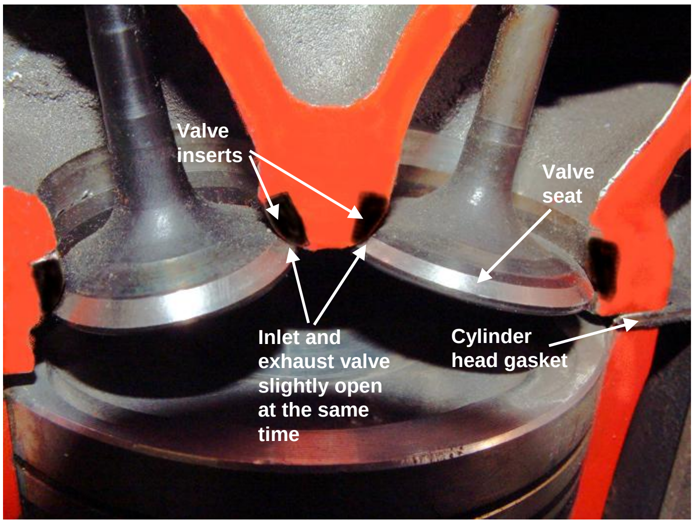
Valve timing diagram-Diesel



Diesel valve timing diagram

Valve overlap

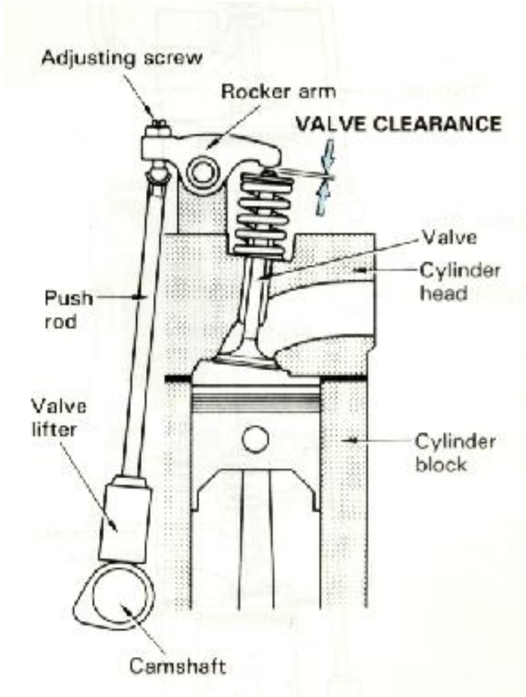
The fact that the inlet valve opens early and the exhaust valve opens late means that both valves are open together, this is known as valve overlap, with proper timing the incoming new mixture does not have time to leave the cylinder through the exhaust port before the exhaust valve closes.
The new incoming mixture helps push out the old burnt gases, also a depression is created due to the outgoing exhaust gas, which helps the start of filling the cylinder.



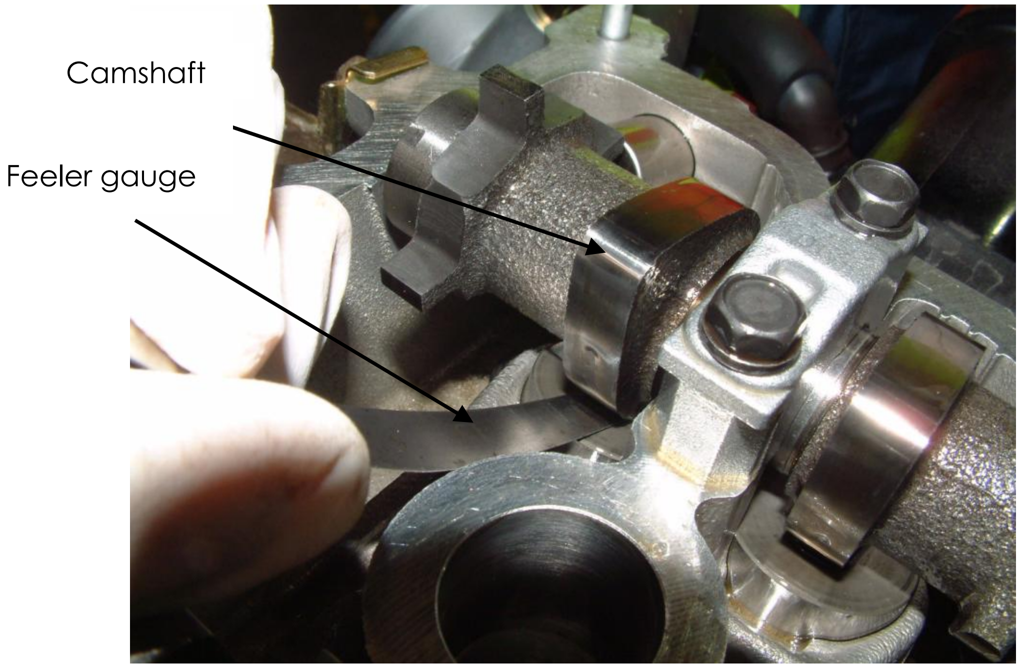
Valve clearance

Valve clearance is important with regard to valve timing and must be carefully adjusted to manufacturers recommended settings. The effect of too little clearance is that the valve will open too early and close later than intended, while too much clearance will cause the valve to open late and close early.

Incorrect tappet clearance on one cylinder or more cylinders will cause the valve timing to vary between different cylinders. Less than the recommended clearance will cause valves and their seating to burn, more that the recommended clearance will cause noisy running and lack of power.

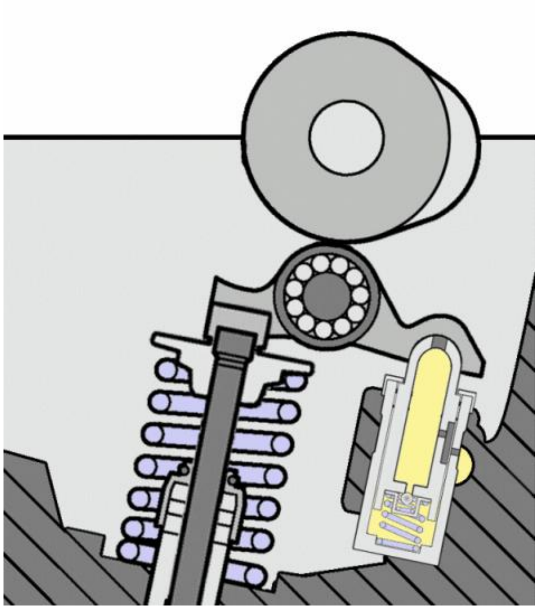


Valve clearance measurement



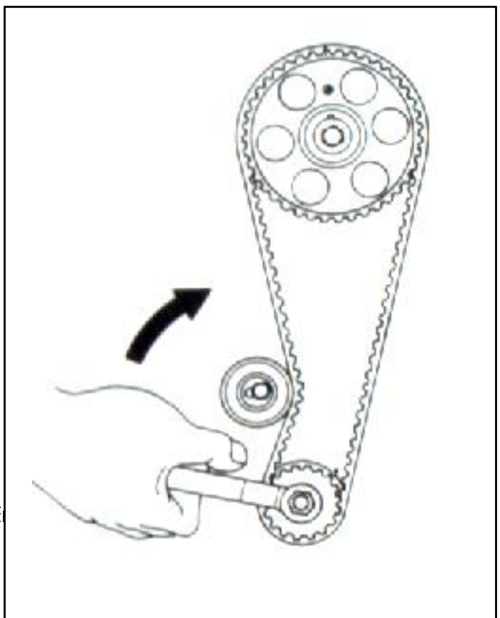
Hydraulic lash adjusters

A hydraulic lash adjuster, also known as a hydraulic tappet is used for maintaining zero valve clearance in an internal combustion engine. The conventional means of adjustment requires a small clearance to be left between the valve and its rocker or cam follower to allow for thermal expansion and wear. The hydraulic lash adjuster was designed to ensure that the valve train always operates with zero clearance, leading to quieter operation and eliminating the need for periodic adjustment of valve clearance.



The hydraulic lifter consists of a hollow expanding piston situated between the camshaft and valve. It is operated either by a rocker mechanism, or in the case of one or more overhead camshafts, directly by the camshaft. The lifter is filled with engine oil intermittently from an oil gallery via a small drilling. When the engine valve is closed, the lifter is free to fill with oil. When the valve is opening and the lifter is being operated by the camshaft, the oil feed is blocked and the lifter acts just as a solid one would, oil being incompressible

There are a number of potential problems with hydraulic lifters. Frequently, the valve train will rattle loudly on startup due to oil draining from the lifters when the vehicle is parked. This is not considered significant provided the noise disappears within a couple of minutes, typically it usually only lasts a second or two. A rattle that does not go away can indicate a blocked oil feed or that one or more of the lifters has collapsed due to wear and is no longer opening its valve fully.



Setting valve timing

Valve timing can be set at inlet valve opening, inlet valve closing, exhaust valve opening or exhaust valve closing.

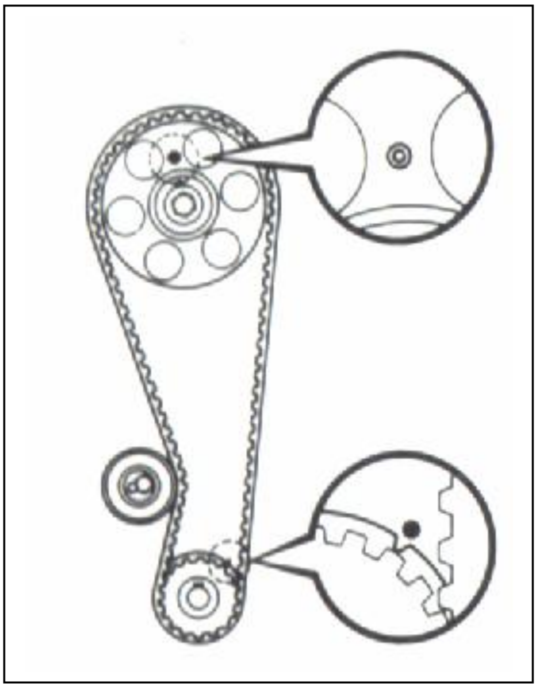
In practice the inlet valve opening is the one at which the valve timing is usually set, by reference to timing marks on the flywheel or crankshaft pulley, or by measuring the vertical distance the piston is from TDC. (this measurement is taken from the piston crown by means of a clock gauge or dial indicator).

Indications for checking or resetting valve timing are generally markings on the faces of the timing chain sprockets (chain driven), on the timing gear wheels (gear driven) or camshaft-timing pulley (belt driven). Crankshaft position markings may be found on the front or rear face of the flywheel or on the crankshaft pulley.

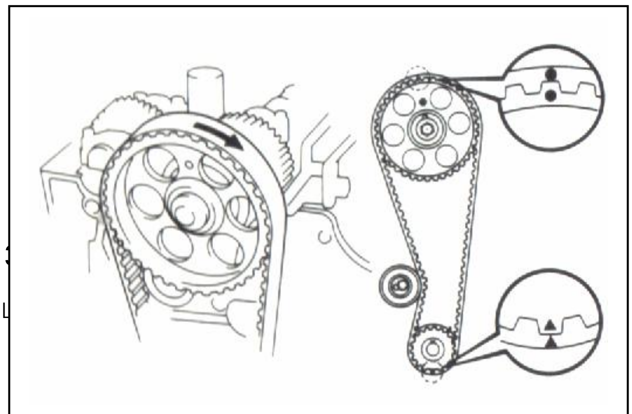
Timing marks

Correct alignment of these marks is essential for efficient performance of the engine.

Caution: if the timing is incorrect by too much then damage to the engine may result when attempting to start it. It is wise, if unsure, to rotate the engine by hand two complete turns before attempting to start it using the starter motor, this will ensure clearance between the valves and the pistons, therefore reducing the chance of damage due to contact.

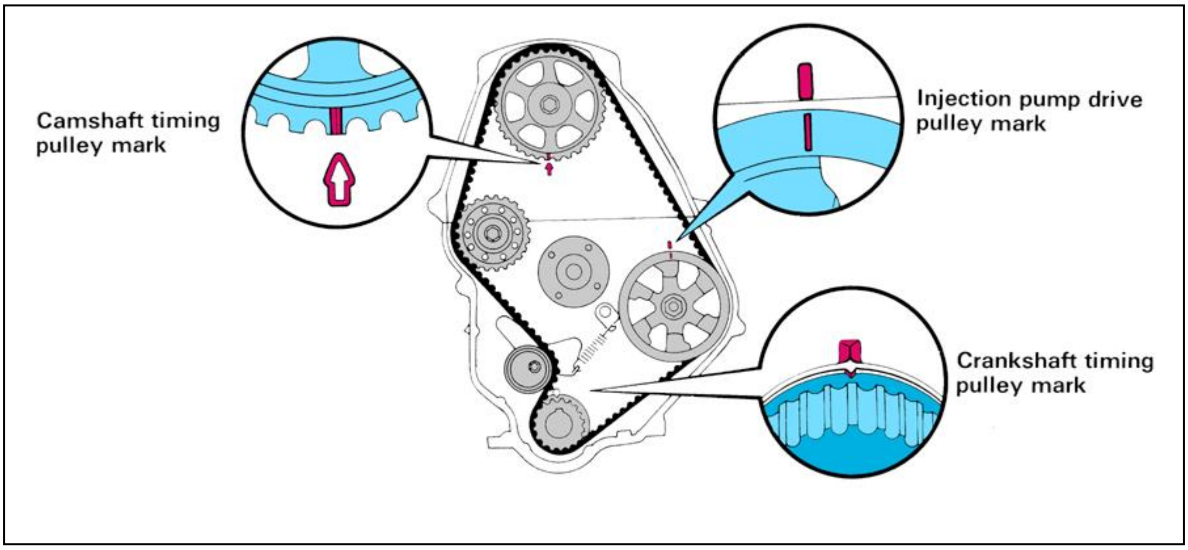


If the timing belt is removed to be re-used draw a direction arrow on the belt to ensure correct direction of travel. Place match marks on the



pulley and belt as shown. Don't forget that correct timing belt tension is very important.

Example of a diesel timing belt layout



Timing marks are shown on the injector pump drive pulley. Timing of the valves and pump must be set if the timing belt has been removed or replaced.

Power

An engines power is determined by the amount of air that it can consume per minute i.e. its cylinder capacity and the speed at which it runs. The greater the speed of the engine the faster the power strokes occur. Engine speed is limited by the weight (mass) of the internal parts. That is why multi cylinder engines have lighter

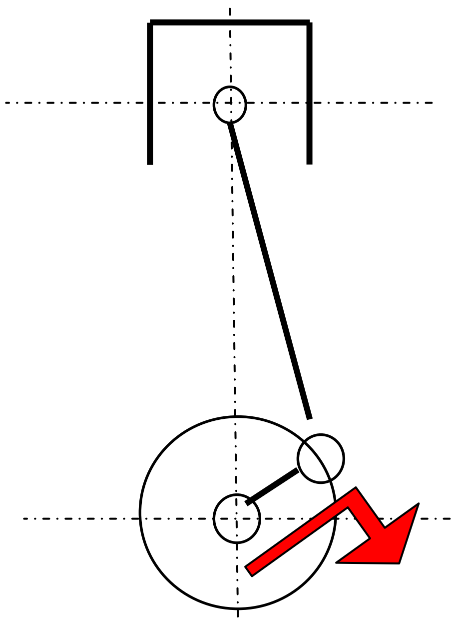
internal mass and a shorter stroke than that of a single cylinder engine. This advantage of the multi cylinder engine can run at higher speeds, have a good balance and develop greater power.
Power is the rate of doing work and is measured in Newton metres per second or Watts, named after James Watt.

Power is equal to force x distance and is measured in Watts

Torque

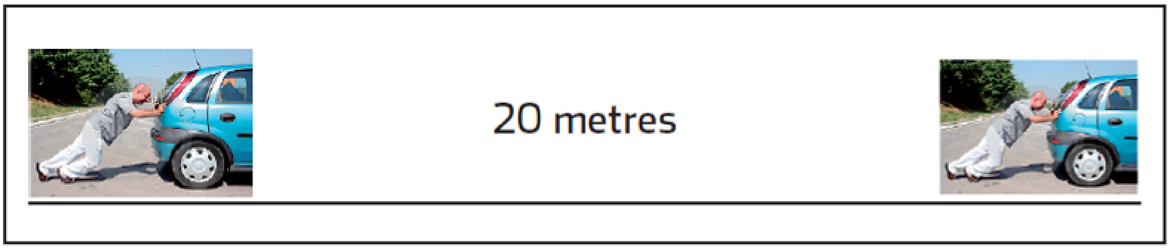
Torque is a twisting force; when applied it will turn something or try to turn something. This means that torque doesn't need to be moving anything, just trying to. Importantly you cannot apply a torque if there is no resistance. Torque is measured in Newton metres, named after Sir Isaac Newton. Torque is the result of force acting at a distance from the centre of turn or radius. The more force the greater the torque, the bigger the radius the greater the torque.
The torque of an engine is an indication of the turning force available at the crankshaft. It is only created during the power stroke therefore the greater the expansion of combustion gases, the greater the force acting on the piston.

Torque is calculated as: torque = force x radius



Work

Work is done when a force is applied and movement takes place. If a bolt is being tightened and movement takes place, then work is being done. But if the bolt is tight and no movement takes place then no work is being done. In both situations torque is applied. Here is where confusion can happen. Work is also measured in Newton metres; this time it is the force applied in Newton's and the distance moved in metres.



If the man pictured (above) has to apply a force of 400 Newton to make the car move, and moves the car 20 metres he is said to have done 20 x 400 = 8000Nm of work.
To try and separate Nm of torque and Nm of work we use the unit Joule so we can say he has done 8000Joules or 8kJ of work.

Brake horse power (BHP)

When engines were first developed they were compared with what they were replacing and this normally meant horses. In the early 1700s James Watt conducted an experiment to find out how powerful a horse was and calculated that it could raise 33,000 lb one foot in one minute or more reasonably 330 lb 100feet in one minute. This became the standard in the UK and the US. Europe, however, adopted another version of horsepower Ps Din Pferdetarke Deutsches Institut fur Normung (it just means horse power German standard). Since the 1970s the UK motor industry has dithered - you will see power quoted in magazines in kW, BHP and Ps DIN.

$$\text{BHP} = \text{torque (lbft)} \times \frac{2\pi \times \text{rpm}}{33000}$$

Converting kW to BHP:

1Ps DIN is equal to 0.735 kW
1BHP (US) is equal to 0.745 kW
If you like, 100bhp is 74.5kW or 100Ps DIN is equal to 73.5kW

Multiple valves per cylinder

An engine converts heat energy into mechanical energy, the more heat energy the more mechanical energy (power) produced. Engine designers strive to produce as much heat energy inside the cylinder as possible; there are two ways to do this, to pump more fuel into the cylinder or burn the fuel more efficiently and effectively.

The chemical reaction of the burning process demands a large amount of oxygen, in normal engines the amount of oxygen falls short of requirements, which leads to incomplete combustion.

The valve acts like a regulator and restricts the passage of inlet and exhaust gases, thus filling and emptying the cylinder effectively is linked to the valve.

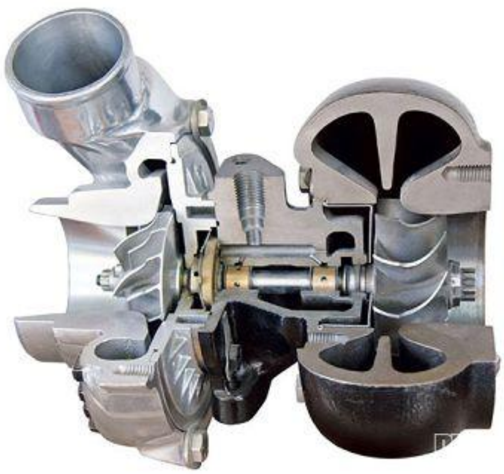
The major aim of all engine designers is to ensure that the cylinder gets as much fuel/air mixture possible.

Increasing the cross-sectional area of the cylinder:

Increasing the bore of the cylinder may cause two major problems first it will cause a corresponding decrease in the stroke length (the distance the piston moves up the cylinder, remember the two stroke and four stroke cycle) so that the cylinder volume remains the same. An engine with a very short stroke will suffer from limited torque and be high on revolutions per minute, after a certain limit it is undesirable. In the second case if the bore size is not restricted and the stroke is allowed to increase then the overall size of the engine and overall size of the vehicle will also increase, leading to a poor power-to-weight ratio.

Fitting a turbo-charger

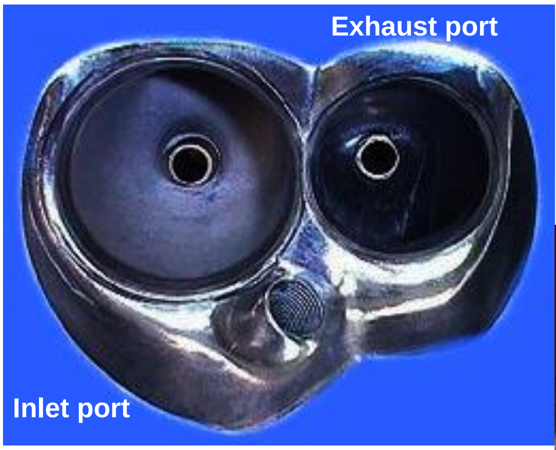
The turbo-charger supplies pressurised air to the cylinder without altering the timing of the valves, therefore more fuel/air mixture can enter under pressure into the cylinder increasing volumetric efficiency. Although the turbocharger may be a very viable option, it is expensive and adds significantly to the cost.
In certain cases a turbocharger may not always be a viable option.



Increasing and utilizing the cross-sectional area of cylinder:

Increasing the number of valves means we can increase the volumetric efficiency of the engine (allow more air into the cylinder within a limited time).

Using just two valves leaves most of the cylinder bore area unused, by reducing the size of the valves it is possible to fit three valves per cylinder, if the valves are made smaller it makes it possible to fit four valves per cylinder or five or even six.



Two valve wedge combustion chamber

Nissan three valve combustion chamber, one exhaust port and two inlet ports

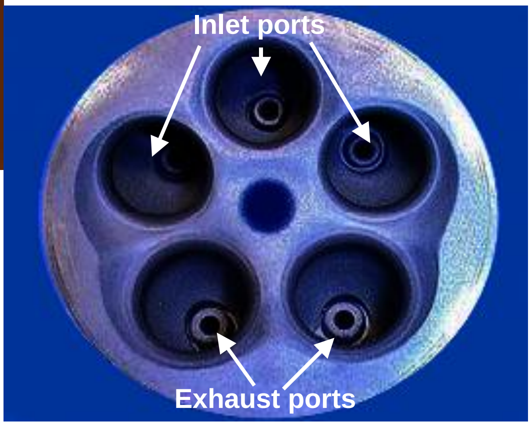
So the more valves fitted the greater is the volumetric efficiency, the greater is the power produced. The main disadvantage of increasing the number of valves is that the strength of the cylinder head would be affected, so five and six valve engines are not as popular as the four valve.

Note: Maserati flirted with the six-valve configuration for a while but reverted to the standard layout.

Honda tried an experiment with an oval piston and eight valves per cylinder but this idea was soon discarded, it was too complex.

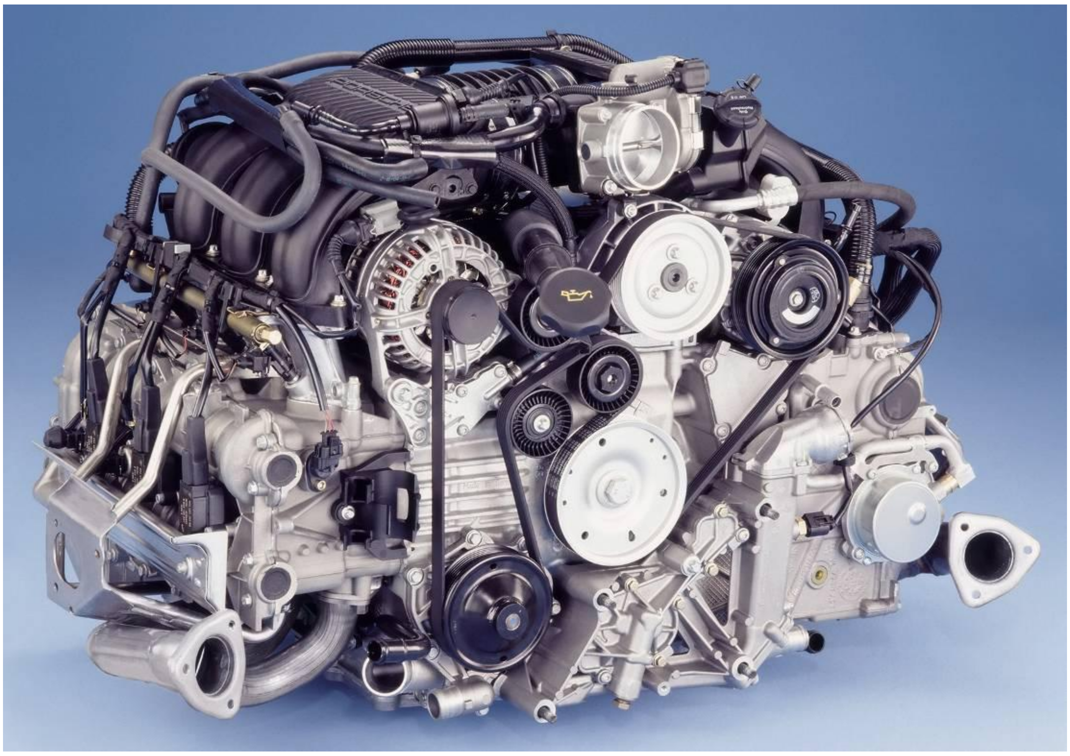
Four valve layout

Five valve combustion chamber. Three intake ports at the top and two larger exhaust valves are at the bottom



Types of engine configuration

Flat (horizontally opposed cylinder engine) configuration



A flat engine, known as an opposed cylinder engine, has cylinders which are laid flat in a two bank configuration, this design requires very little vertical clearance, but is much wider than the standard in line engines or 'vee' type configurations, therefore additional width is required. Cooling is more efficient due to the increased surface area of the cylinders.

Engine balance is superior to that of the in-line engine; torque is smooth allowing a lighter flywheel to be used.

Advantages

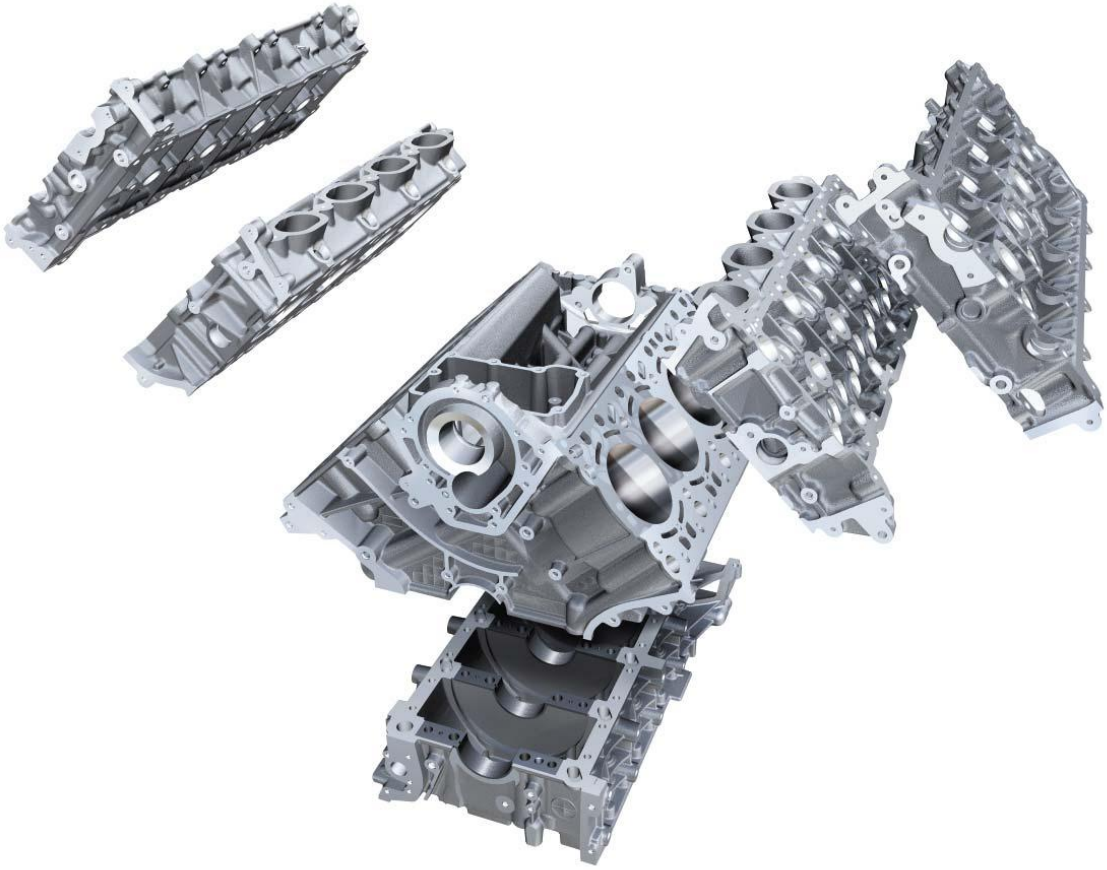
- Low centre of gravity
- Engine balance
- Compact design

Disadvantages

- Complex cooling system designs
- Complex manifold designs

'Vee' V-type engine configuration

An engine classified as a vee or V-type is one were there are two banks of cylinders attached to a single crankshaft. These engines can have cylinders positioned in a 60 or 90 degrees to each other. The main advantage is that the block can be shorter and lower in height than the in-line engine of the same number of cylinders and capacity. Reduced bonnet height, increased passenger space and storage area are all advantages gained from this type of engine configuration.



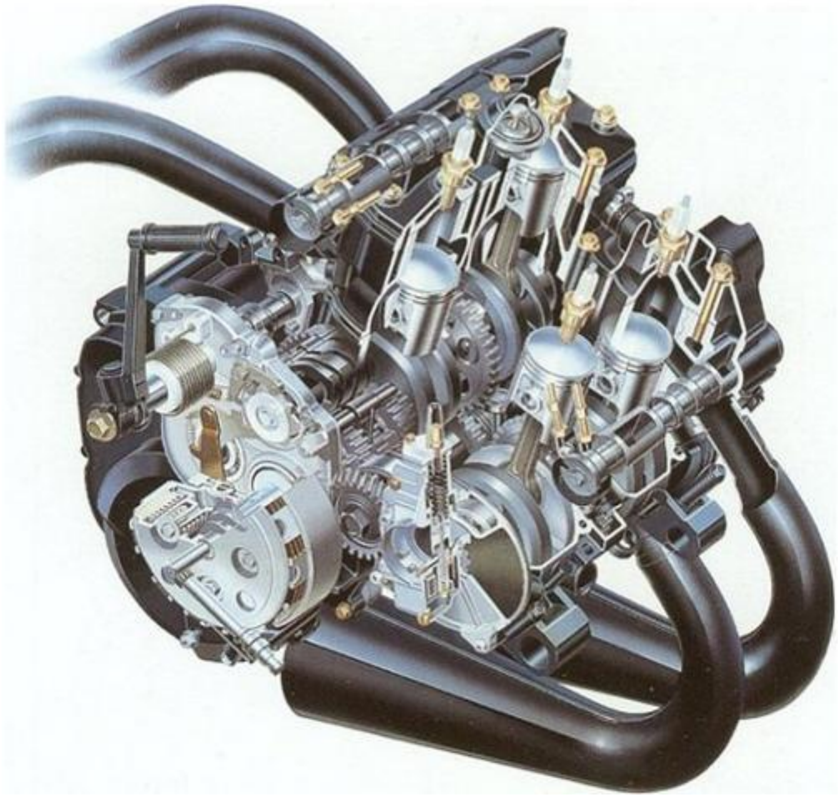
Advantages

- Compact design
- Light weight in comparison to other layouts

Disadvantages

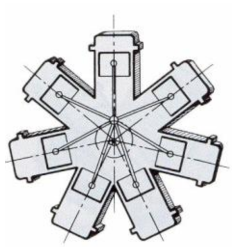
- Requires complex balance design
- More labour intensive to repair.

Square-four engine configuration

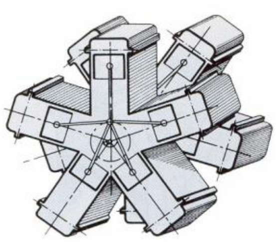


Four cylinders can be arranged to form a square, this is two, two-cylinder engines arranged 'side- by-side'. Crankshafts are inter-connected, by gears, the arrangement of the cylinders in staggered pairs results in a more compact and shorter engine.

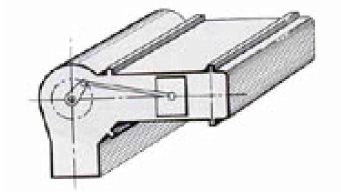
Some less familiar cylinder arrangements



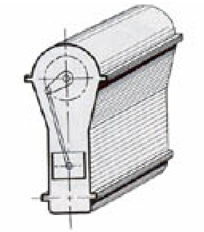
Radial



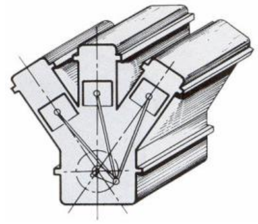
Twin radial



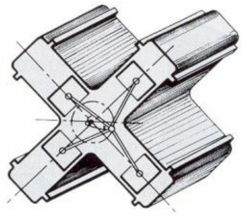
Horizontal in-line



Inverted in-line



Triple in-line or double 'V'



Quad opposed cylinder

Comparison between a single and a multi-cylinder engine

Single cylinder engine

The simplest form of an engine is the single cylinder which may operate on the two and four-stroke cycle. When operating in the four-stroke cycle the crankshaft receives one power stroke in every 720 degrees of rotation.

When operating in the two-stroke cycle there is one power stroke for every 360 degrees. The crankshaft torque is uneven and therefore a heavy flywheel has to be used to carry the crankshaft over the idle strokes or non-power strokes.

Note: The power stroke does not provide a constant force on the crankshaft, but is instead sudden and short and the power rapidly falls off.

Two-cylinder engine

Crankshaft torque is smoother than that of the single cylinder when operated on the four-stroke cycle there is a power stroke every 360 degrees of crankshaft rotation, this arrangement is often used for motor cycle engines.

Four-stroke inline engine

This is the most popular arrangement for use in motor vehicles, the cylinders are arranged in a line above the crankshaft. Piston one and four are at top dead centre together when piston two and three will be at bottom dead centre.

This arrangement provides a power impulse every 180 degrees of crankshaft rotation. The torque output is smoother, due to the fact that, as one power stroke is ending another is beginning, so a flywheel is still required to smooth out the torque output, but it need only be light in comparison.

As this engine is like a two cylinder placed end-to-end the overall balance is good and the rocking effects of the power strokes are neutralised, although it is not completely in balance. Because the forces do not work in opposition, lighter piston and connecting rods can be used.

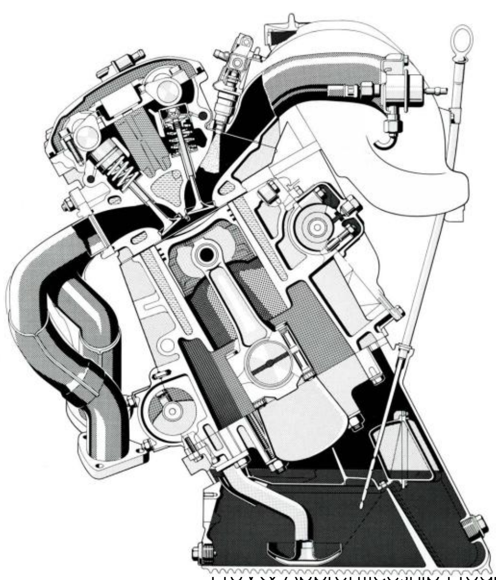
By increasing the number of cylinders a very smooth engine can be achieved.

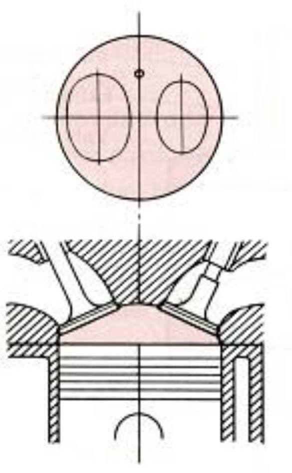
Combustion chambers

Hemispherical

This type of combustion chamber shape has a small surface area, which reduces heat loss and provides a higher thermal efficiency when compared to other types. It also maximises gas flow in the cylinder.

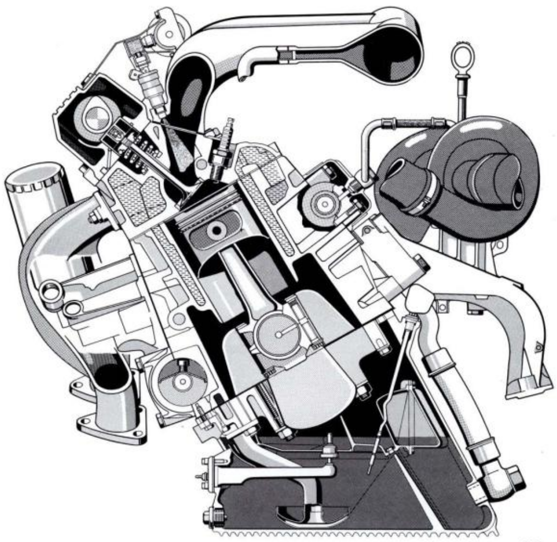
The hemispherical shape is an ideal design of combustion chamber. The main disadvantage is that it has a more complicated valve mechanism.

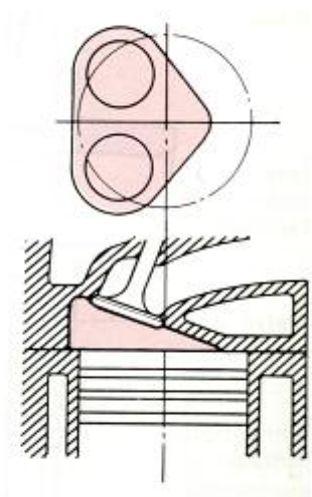




Wedge type

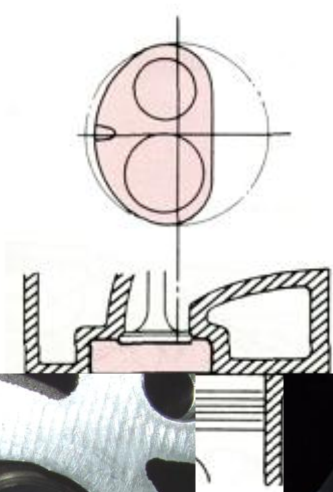
This type of combustion chamber also has low thermal loss. The main advantage is its valve mechanism is far simpler than the hemispherical type.



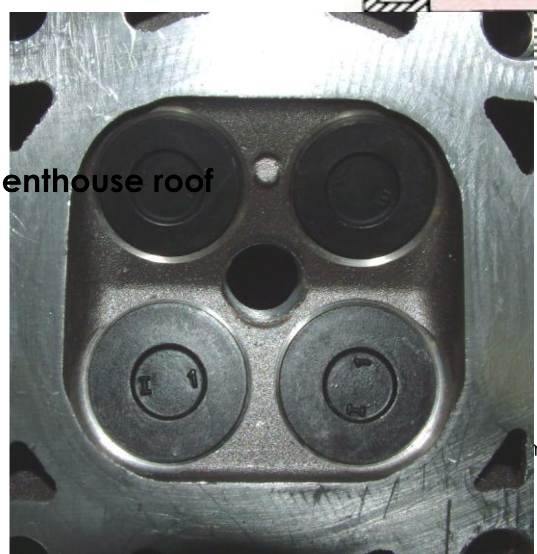


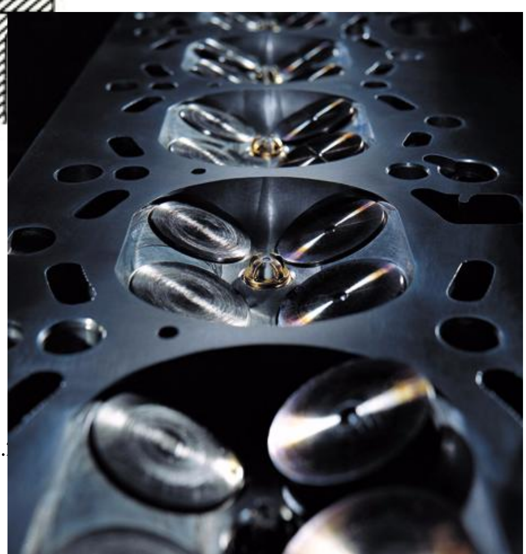
Bath tub type

The construction is simple and cost is low. The main disadvantage of this type of combustion chamber is that the valves are limited in diameter.
The intake and exhaust efficiency is poor compared to the hemispherical type.



Penthouse roof

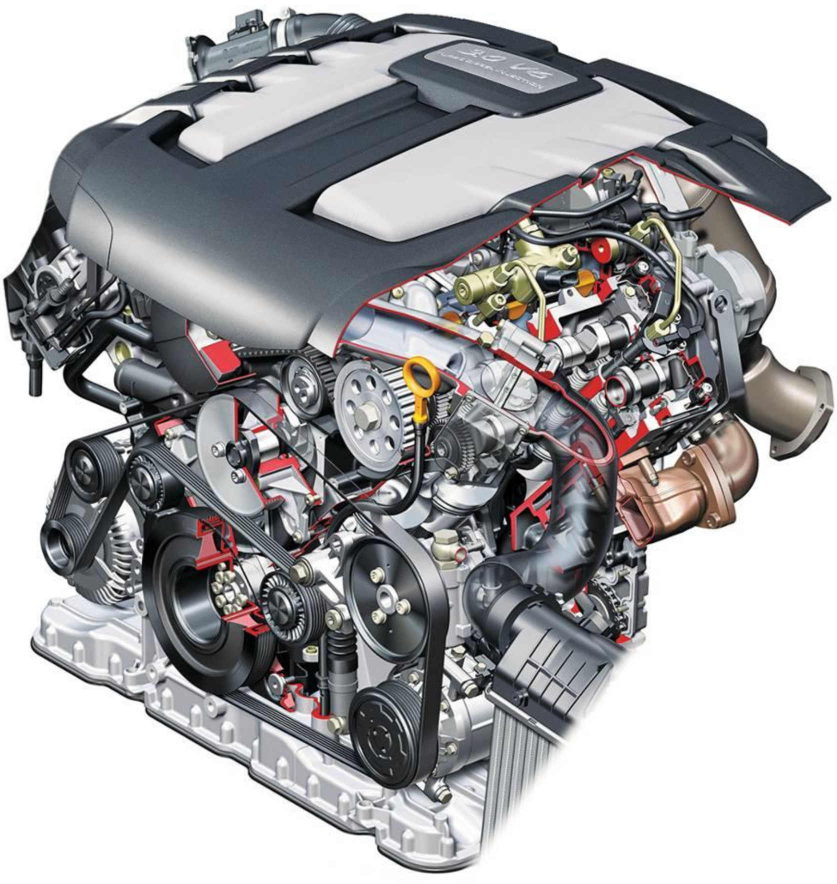




This type is used in virtually all engines that have multi-valves per cylinder; this is because the camshaft arrangements can be easily installed. It is called a pent house roof due to its trapezoidal cross section. This combustion chamber provides a larger amount of squish effect and faster combustion due to having the spark plug in the centre of the combustion chamber, similar to the hemispherical combustion chamber.

Diesel combustion

As mentioned previously, the air inside the cylinder under compression becomes hot and fuel is then injected into this air, which burns very rapidly forcing the piston down the cylinder. Petrol engines admit fuel/air into the cylinder and it is ready mixed and is ignited by a spark.



Because diesel engines have greater compression pressures and temperatures than petrol engines and due to the combustion process a much heavier and stronger engine construction is required.

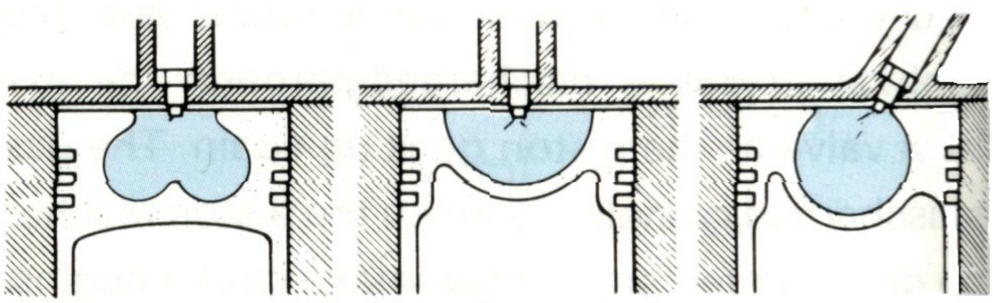
Types of diesel engine combustion chambers

The direct injection type

Careful design of the combustion chamber ensures good performance of the diesel engine, since this is one of the most important considerations with regard to engine performance. Adding air swirl by designing a specially formed intake port or adding a pre-combustion chamber improves the combustion efficiency and therefore increasing power output.

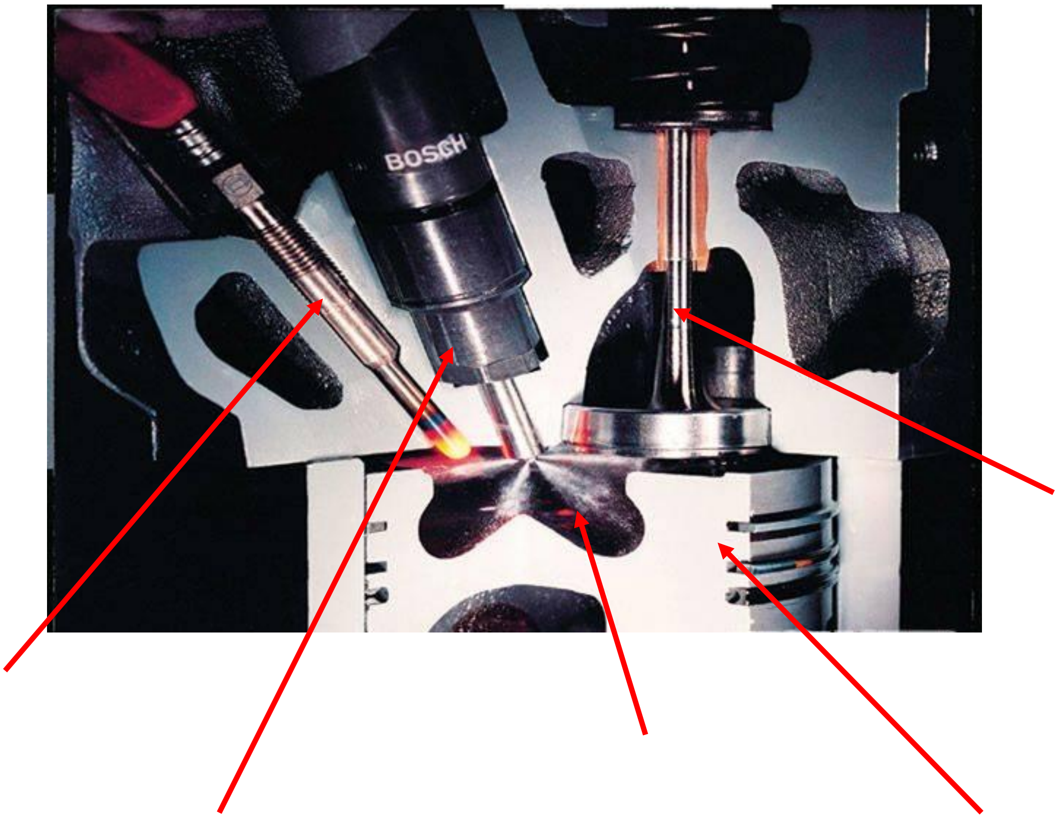
Direct injection

The combustion chamber is provided in the piston crown and may have one of several shapes: Multi-spherical, hemispherical and spherical.
Diesel fuel is injected at very high pressure (1500 bar 22,000 psi) into the cylinder just before TDC.



Multi-spherical **Hemispherical** **Spherical**

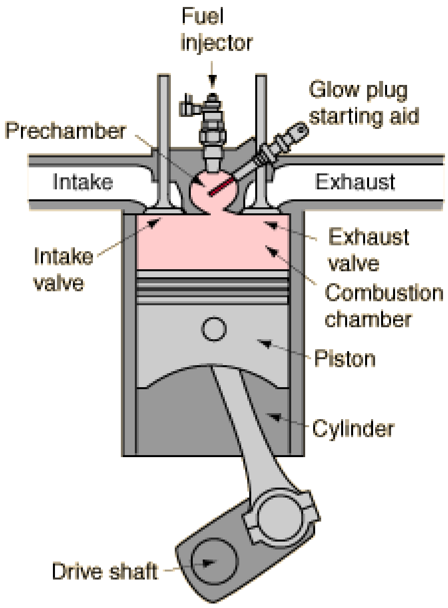
Label the diagram below:



Indirect injection

Swirl chamber (pre chamber)

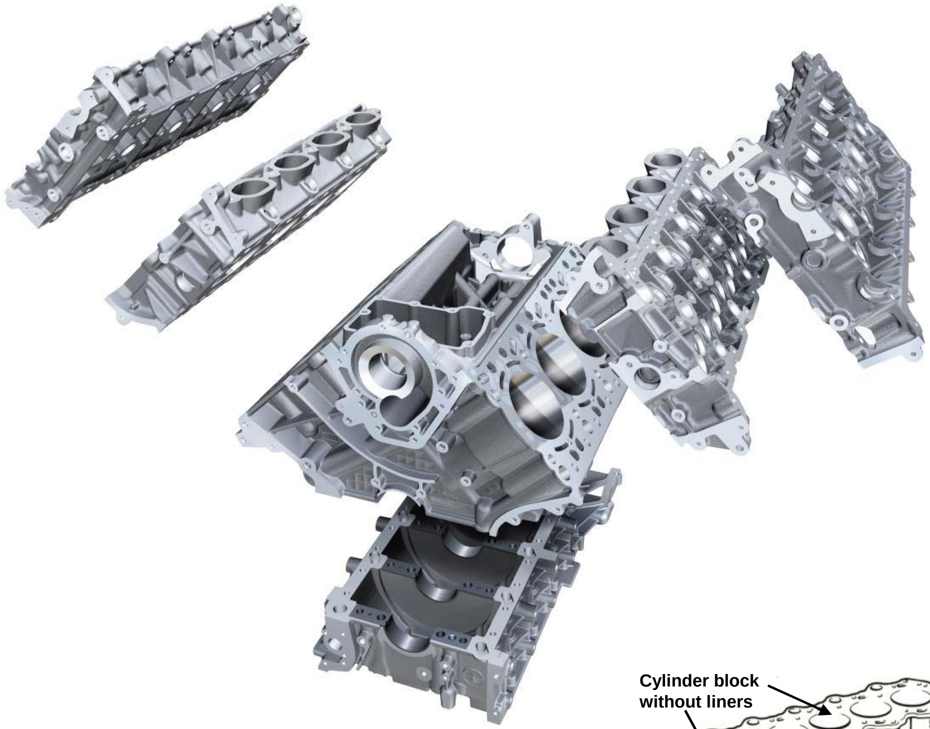
The air being compressed enters a swirl chamber, which causes turbulence (an increase in air speed) fuel is then injected into the swirl chamber, which starts to self ignite. Further combustion of the fuel takes place in the main combustion chamber as the piston descends down the bore.



The cylinder block

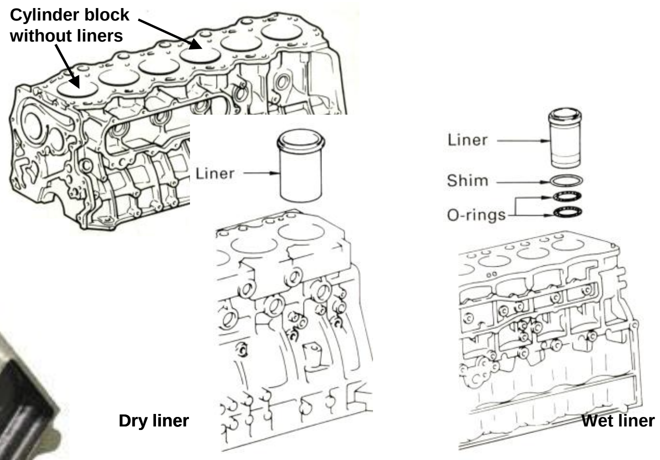
Petrol engines

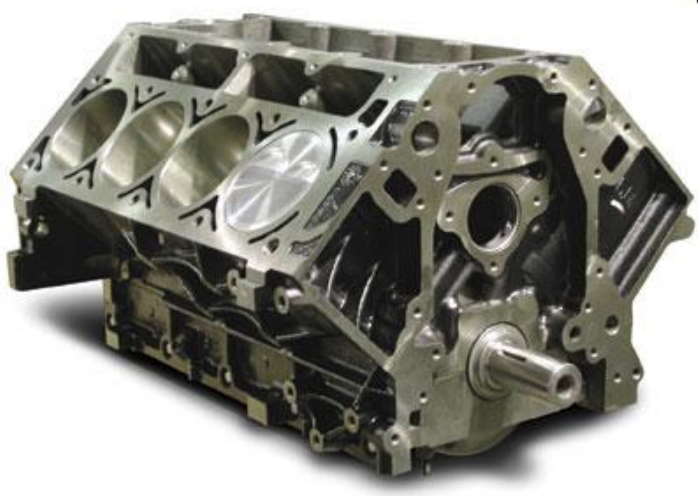
Cylinder blocks are made from cast iron or aluminium alloy. Aluminium alloy radiates heat easily and is much lighter that cast iron, cast iron is more rigid. The cylinders may be integral with the cylinder block in the case of cast iron, but cylinder liners must be used for the aluminium alloy block. The cylinder liners may be wet or dry type. The cylinders are sealed on top by the cylinder head, which is separated by the cylinder head gasket ensuring a gas, oil and water- tight seal. The crankcase is at the bottom of the block and fitted to the crankcase is the oil sump. The cylinders are surrounded by water jackets for cooling purposes.



Aluminium Block

Liner types

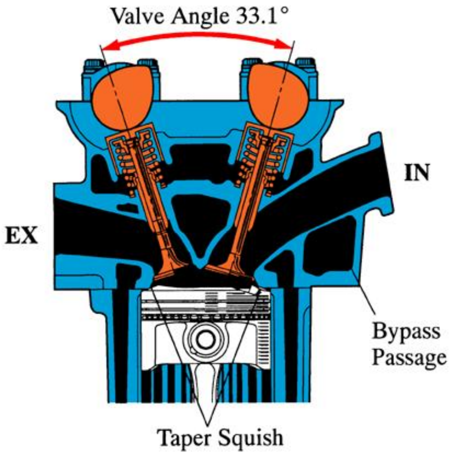


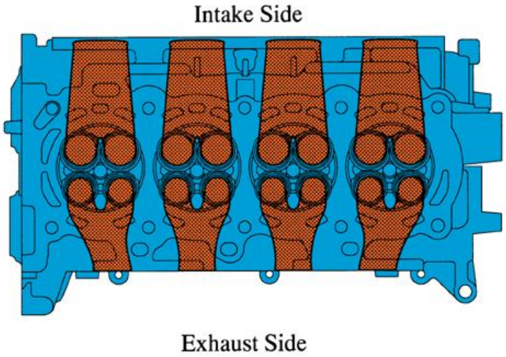


Cast iron block
The cylinder head

Petrol engines

The cylinder head must be able to withstand high temperatures and pressures. Cylinder heads are made from cast iron or aluminium alloy the same as the cylinder block it has water jackets for cooling. The combustion chambers and valve mechanisms are housed in the cylinder head.



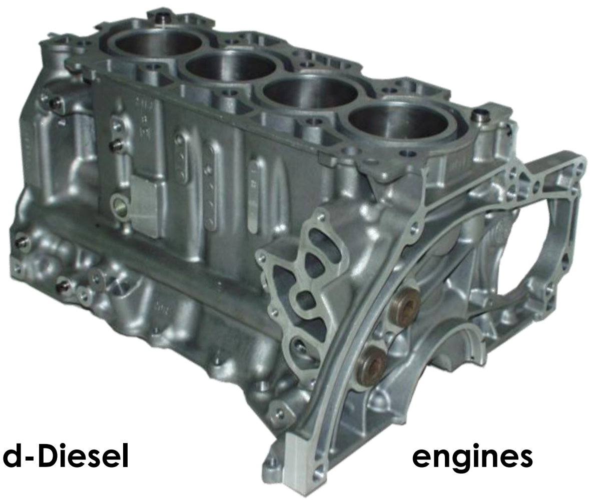


The cylinder block

Diesel engines

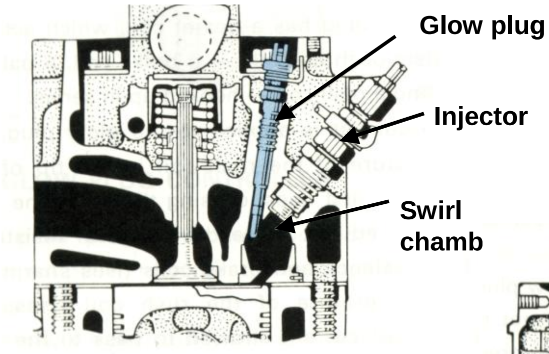
The cylinder block is usually made from ordinary or treated cast iron, it is very similar to that of the petrol engine, but it must be stronger due to the higher levels of stress, and vibration.

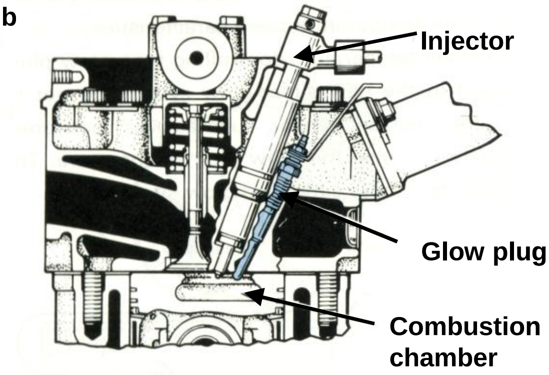
The pistons slide in removable liners, which may be dry slip or wet type. Some cylinder blocks don't have liners they are specially constructed of special alloys, which can withstand the frictional wear, this allows for a slight decrease in the size and weight of the engine.



Cylinder head-Diesel engines

Due to the combustion chamber having higher compression ratios, the combustion chamber is smaller in comparison to that of the petrol engine. Similar to the cylinder block the cylinder head is built stronger and is therefore heavier and sturdy so that higher combustion pressures and greater vibration can be withstood. The cylinder head contains the swirl chamber this contains the injector nozzle, which sprays the fuel into the cylinder, and a glow plug, which acts as an electrical heater to assist starting when the engine is cold.

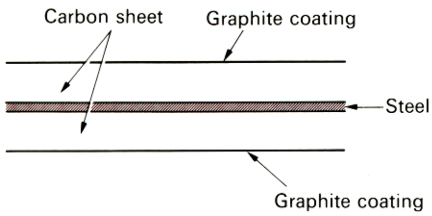




Gaskets

Gaskets are thin sheets of flexible materials that are used to separate two metal components. They allow metal parts to be mated together without losing fluids that are transferred between the two.

Normally when two pieces of metal are mated, there are minute machining differences in the surfaces that would allow high pressure fluids or gasses to escape and relieve pressure. In an internal combustion engine, fluid flow between parts is vital for engine operation. Gaskets help the engine transfer these fluids with less loss. Gaskets are commonly made from brass, steel, carbon, graphite coatings and rubber compounds. In addition to providing more conductive passages for fluids to flow, they also serve as insulation to isolate some parts from shock or vibrations that could cause leaks, and create tighter fitting parts that are more likely to stay in place.

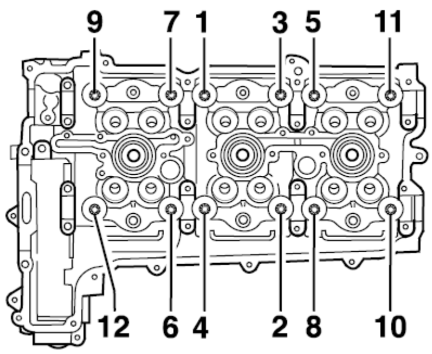


The cylinder head gasket

The gasket is fitted between the cylinder bock and cylinder head it has to withstand heat and pressure under all conditions such as temperature changes. Often the cylinder head gasket is made from carbon clad sheet steel the carbon is coated with graphite to aid removal of the cylinder head if maintenance becomes necessary (prevents it sticking the cylinder head and block together making separation difficult)

It is important that the cylinder head is tightened to the cylinder block according to manufacturer's recommendations; otherwise distortion to the cylinder head may occur, or the life of the cylinder head gasket may be shortened.

Tightening sequence	Designation	Value	Unit
Step 1	Initial tightening	30 (22)	Nm (ftlb.)
Step 2		Loosen in reverse order	
Step 3	Joining torque	20 (15)	Nm (ftlb.)
Step 4	Final tightening	70	Degrees (torque angle)
Step 5	Final tightening	70	Degrees (torque angle)

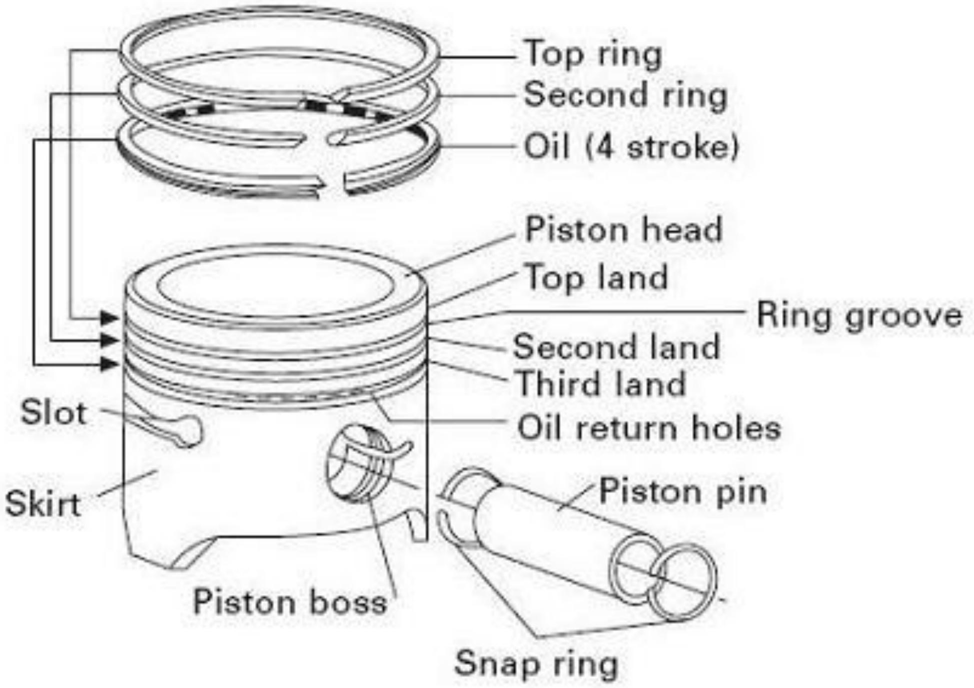


Piston construction

The most important function is that the piston should be able to withstand the combustion pressure and to be able to transmit the force to the crankshaft via the connecting rod. Pistons must also withstand high temperatures and speed for sustained periods. Normally pistons are made from aluminium alloy because it has the ability to conduct heat easily and is light in weight. Cast iron is sometimes used for heavy engines occasionally a piston with a cast iron crown and aluminium skirt may be used.

Pistons must have clearance in the cylinder to enable them to move up and down freely but also to allow for expansion. Piston clearance depends largely on the size of the piston and cylinder but would generally range between 0.02 to 0.12 mm.

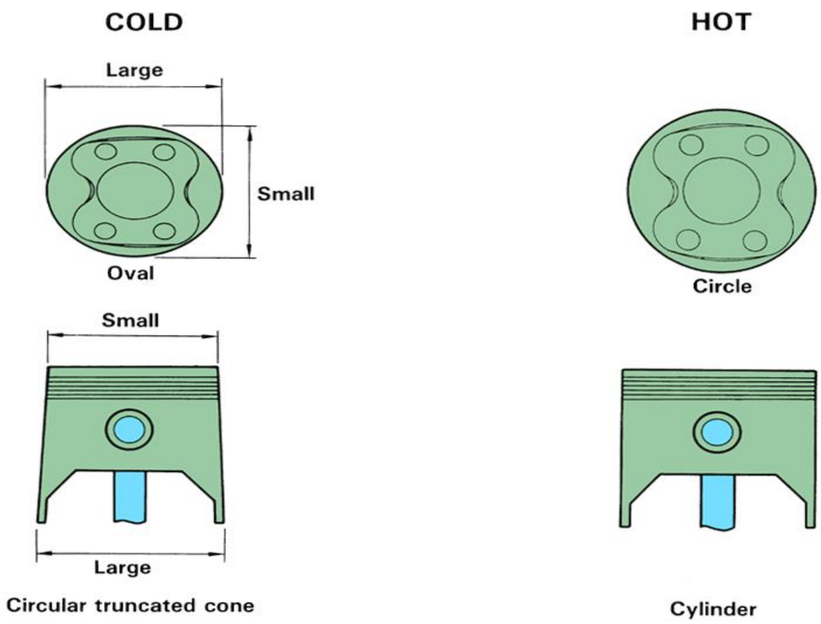
The parts of a piston



Piston shape

Pistons are tapered - they are smaller at the top (the crown) than the bottom (the skirt). There is therefore a greater clearance between the piston and the cylinder at the top of the piston than at the bottom.

Pistons are designed slightly oval in some cases, this is due to having a greater mass of metal around the gudgeon pin bosses and the fact that heat cannot escape as easily (more mass of metal the longer it takes for heat to disperse).



When the engine is at normal temperature the piston becomes round and its contour matches that of the cylinder.

Piston rings

Piston rings prevent fuel/air mixture and combustion gas from leaking past the piston. They prevent oil from entering the combustion chamber. Also they conduct heat to the cylinder walls therefore helping the cooling process.

Piston rings are normally made of chromium cast iron.

Identify the names of the 3 piston rings:

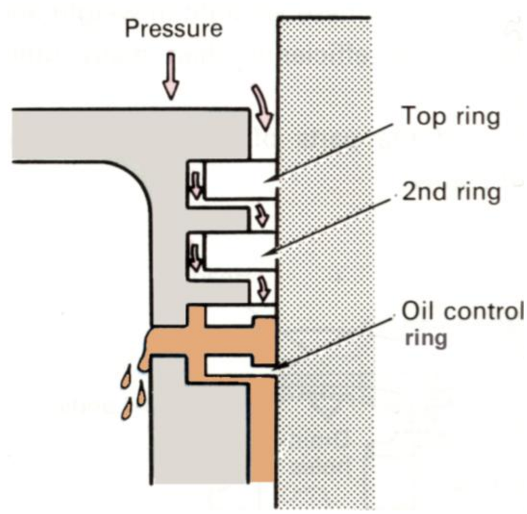
1. ______________________________

2. ______________________________

3. ______________________________

Compression rings

This type of piston ring prevents leakage of air/fuel mixture and burnt gases from entering the crankcase. Often there are two compression rings but more can be fitted depending upon the type of engine.



Piston rings are marked top, second ring etc sometimes they are numbered, 1 being the top ring and 2 the second ring and so on.

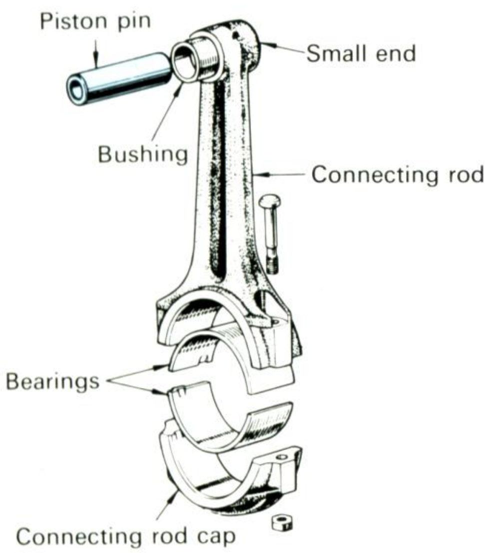
Oil control rings

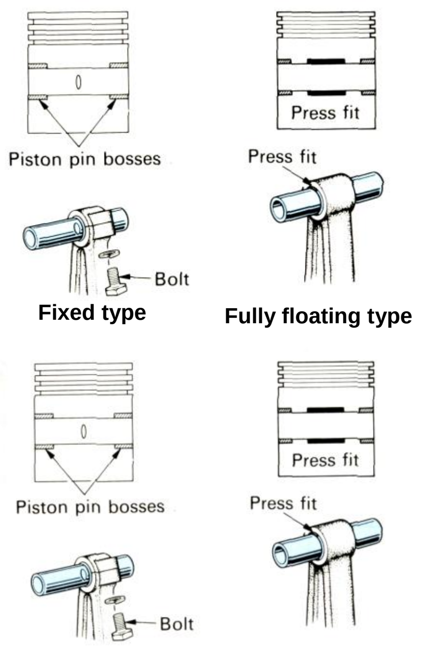
This type of piston ring scrapes off excessive oil from the sides of the cylinder bore to prevent it from entering the combustion chamber. If two compression rings are used the oil ring would be called the third ring and so on.

Piston pins (gudgeon pins)

The piston is connected to the connecting rod by a piston pin (small or little end). The pin is kept in position by a circlip or a bolt, some types are a press fit (interference fit) in the connecting rod.

Press fit or bolted are referred to as semi-floating, the pin can only rotate in either the connecting rod or the piston, but not both. If the pin can rotate in the piston and connecting rod it is referred too as a fully floating type.





Diesel pistons

Diesel pistons must be stronger than petrol designs to withstand the extra stresses caused by the large compression pressures. Because the combustion chamber is small there is little clearance between the valves and the piston, therefore the top of the piston is provide with a machined cut-out which in the direct injection type forms part of the combustion chamber shape. Note: in the direct injection type of combustion chamber the fuel is injected directly into the chamber above the piston. In the indirect injection type of combustion chamber the injector injects into a pre-combustion chamber (swirl chamber).

Indirect injection

Direct injection

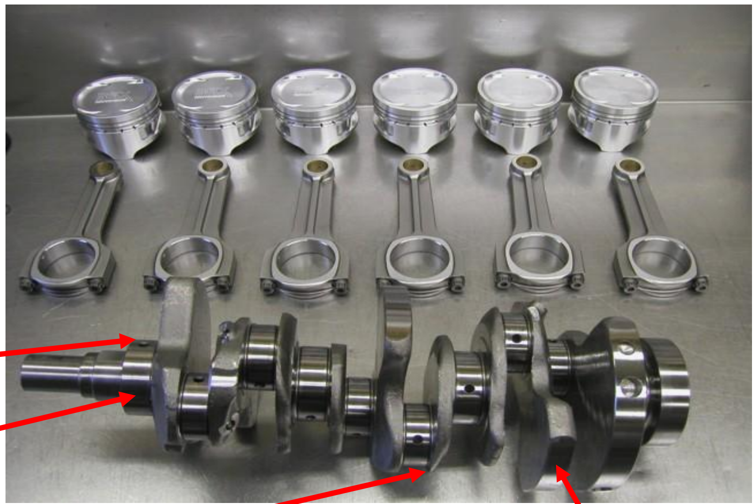
Connecting rod

The purpose of the connecting rod (con rod) is used to transmit the force exerted on the piston to the crankshaft. It houses the small end bearing and the big end bearing.
Just before TDC, the position of the crankshaft pin journal oil hole and the oil jet coincide, and oil is sprayed out through the oil jet. If the connecting rod is assembled with the front and back reversed, the cylinder will receive insufficient lubrication.

The crankshaft

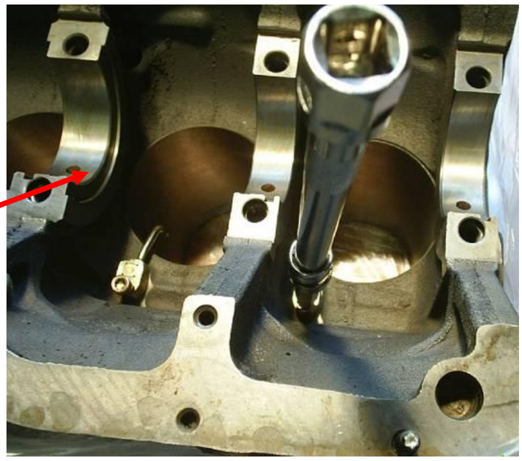
The reciprocating motion of the connecting rod is converted to rotary motion by the crankshaft. The crankshaft must rotate at high speed and be able to withstand the torque produced by the engine, for this reason it is usually made from high-grade carbon steel, which has a good wear resistance.

The crankshaft contains oil holes to supply lubricating oil to the crankshaft journals, connecting rod bearings, pistons, cylinders etc.



Thrust bearings

Thrust bearings are fitted to take up end float in the crankshaft this end float is adjusted by selecting and using thrust bearings of different thickness.



Crankshaft bearings

Due to the loads caused by combustion pressure, and that the crankshaft and components rotate at high speeds, bearings must be fitted. Crankshaft bearings are lubricated by the engine oil; the bearings take the form of a 'shell', which is made of steel the bearing surface is coated with white metal, Kelmet or aluminium.

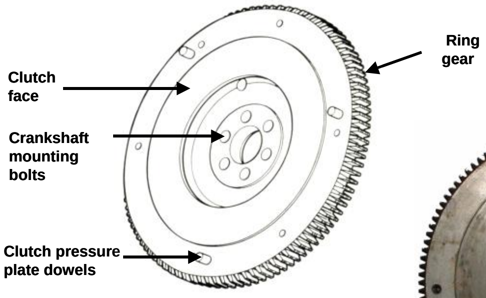
White metal: consists of tin, lead antimony and zinc, it is often used in low power engines.

Kelmet metal: consists of a copper and lead alloy, it is very strong and has greater fatigue resistance than white metal; it is used for high performance engines.

Aluminium Metal: is alloyed with tin it has good wear resistance and handles heat better than Kelmet and White metal.

The flywheel

The flywheel is a heavy cast iron wheel, which is bolted to the crankshaft usually at the rear. Its purpose is to maintain rotational force developed during combustion through the idling strokes of the engine (inertia). It also helps to smooth out fluctuations between power strokes, between engine cylinders and during exhaust, induction and compression strokes. The starter ring gear is fitted around the flywheel's circumference, which allows the starter pinion to engage with it for starting purposes.



Advantages and disadvantages of petrol engines when compared to the diesel engine

Advantages of the petrol engine

- light weight compared to a diesel engine
- Easy to maintain
- low engine noise & vibration
- Higher rev range providing high power output
- Cheaper to manufacture due to lower stressed components
- Cleaner emissions

Disadvantages of the petrol engine

- Requires an ignition system which affects reliability
- lower torque output than a diesel engine
- Poor fuel consumption
- Petrol is more volatile than Diesel (risk of explosion).

Advantages and disadvantages of diesel engines when compared to the petrol engine

Advantages of the diesel engine

- greater thermal efficiency
- more economical
- does not require an ignition system
- torque (output power) remains virtually unchanged over a wide speed range, low speed high torque
- suitable for commercial vehicles.

Disadvantages of the diesel engine

- greater noise level and vibration
- more expensive due to the need for a stronger structure
- heavier
- require careful maintenance and servicing due to a precise high pressure fuel injection system
- high compression pressures demand better starter systems e.g. bigger batteries.

Lubrication

Oils

What is the purpose of a lubricant?

A lubricant is the material that lies between two surfaces that are moving with respect to each other (hydrodynamics). The presence of a lubricant affects the friction between the two surfaces. It is usually used to reduce friction, thereby reducing heat and wear, but it is also often used to cool, clean and protect the surfaces from corrosive chemical attack.

A lubricant can be liquid or a solid. Greases are liquids that have been thickened by the addition of chemical or solid materials. Teflon® and graphite are examples of solid lubricants.

Mineral or synthetic?

Mineral oil

Mineral oil is made from crude oil extracted from the ground. The oil contains molecules that naturally degrade the lubrication properties of the oil. This in turn means that the oil does not have as longer service life when compared with the likes of synthetic blends. Mineral oil has improvers blended to improve performance,

Detergents- keep the contaminants suspended in the oil
Anti oxidants- prevent the natural components in the oil from forming deposits.
Anti foaming agents- reduce oil foaming
Viscosity improver- to reduce the effect of viscosity change due to temperature

Mineral oil is noticeably cheaper when compared to synthetic blends.

Synthetic oil

Synthetic oil is made from artificially synthesized mineral based oil which was originally designed for jet engines. It has a higher purity and good mechanical properties at extremes of high and low temperatures.
Because these synthetic oils have little or no viscosity improver content, they do not degrade as quickly as traditional motor oils. Oil changes can be longer, sometimes as long as 20,000 - 30,000 miles.
Using a synthetic oil can improve fuel consumption and reduce engine wear but is more expensive than conventional crude oil.

What is viscosity?

Viscosity is a measure of a fluid's resistance to flow. For lubricating oil in general, viscosity is the most important physical property. It is viscosity, as well as the pressure and speed of movement, which determines the thickness of an oil film between two moving surfaces. This in turn determines the ability of the oil film to keep the two surfaces apart, the rate heat is generated by friction and the rate the oil flows between the surfaces and thus carries the heat away.

The oil should have a viscosity at the operating temperature that is correct for maintaining a fluid film between the bearing surfaces, despite the pressure tending to squeeze it out. Excessive viscosity should be avoided because this can create more drag and therefore unnecessary heat generation.

Viscosity is also useful for identification of grades of oil and for following the performance of oils in service. An increase in the oil's viscosity during use usually indicates that the oil has deteriorated to some extent; a decrease normally indicates dilution with fuel.

What is an SAE grade?

SAE stands for the Society of Automotive Engineers, based in the USA. The SAE grade specifies the most important parameter for engine oil mainly its viscosity. In other words it tells you the "thickness" of the oil. The lower the number, the "thinner " the oil; thus SAE 30 is less viscous than SAE 40.

What is a multi-grade oil ?

These are oils designed to give better viscosities at both high and low temperatures than regular mono-grade oils. The viscosity of all oils falls as they get hot – and multi-grade oils are formulated to minimise this effect. Multi-grade oils are defined by a viscosity rating at a low temperature, as well as one at 100 C.

What does 'W' stand for?

This is the common terminology used to indicate a multi-grade oil. 'W' signifies the winter rating of the oil, showing that it will perform well in cold weather. The lower the number prefixing the 'W', the lower the temperature the oil can withstand. Thus 10W- indicates a lower viscosity at low temperature than 20W-. The second figure shows the viscosity at 100 C, which is close to the oil temperature in most liquid cooled engines.

What does the specification API stand for?

API stands for the American Petroleum Institute. This body has specified the performance standards that oils used in road vehicles should meet, notably for cars and trucks made in the USA. For oils destined for use in passenger car engines, the letters API are followed by a set of two letters such as SJ, etc. This indicates the Service Level for passenger car oils. These specified performance levels have evolved through the years, from API SA to SM, in response to the changes in passenger car engine technology that, in turn, has imposed ever more severe operating conditions on the oil to achieve satisfactory lubrication.

The highest API for passenger car motor oils today is API-SM.

Similarly, the API designates the performance of diesel engine oils with a letter sequence such as API CF or API CH-4, and for automotive gear oils they use API GL-4.

The highest API for commercial engine oils (diesel oils) today is API CI-4 Plus.

Many other specifications are used to denote lubricant performance: notably the ACEA (European), JASO (Japan) and the US Military classifications.

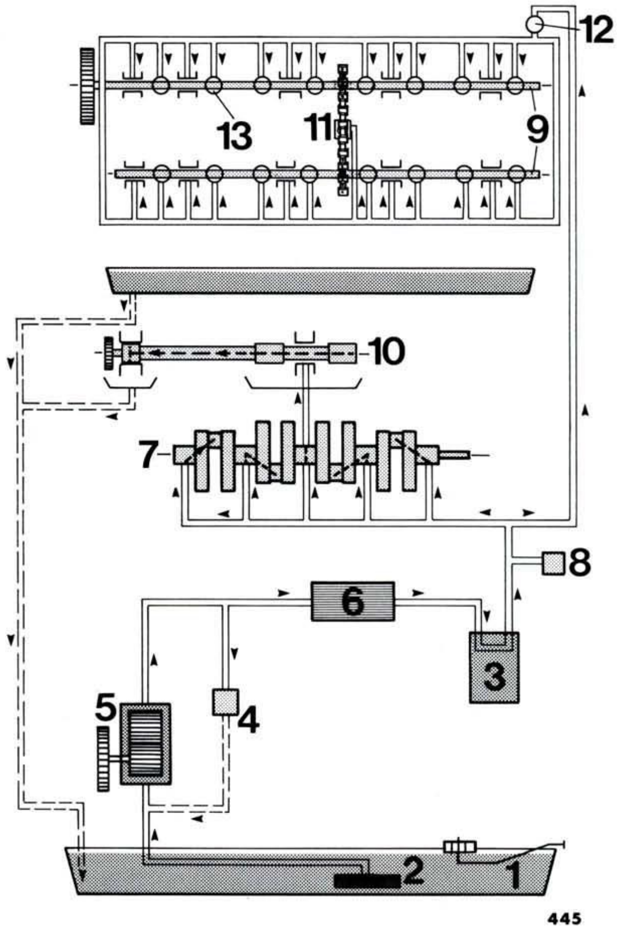
Boundary lubrication

Boundary lubrication is a fluid film that develops between potentially rubbing surfaces, the film thickness ensures that metal to metal contact wear is avoided. Boundary lubrication is used for all the components that are not part of the pressurised circuit. The oil can be splash, drip or sprayed.

Vehicle lubrication types

Over the years engine designers have spent many years designing the most efficient ways to integrate a lubrication system into the modern engine. These systems can range from being simple splash fed (boundary) systems to full dry sump lubrication systems.

Combination Splash and Force Feed (wet sump)



1 = Oil level sensor (Standard during Modelyear)
2 = Oil filter screen
3 = Oil filter
4 = Oil relief valve (open at 5 bar)
5 = Oil pump
6 = Oil cooler
7 = Crankshaft
8 = Oil pressure sensor
9 = Camshafts
10 = Balance shaft
11 = Chain tensioner
12 = Oil pressure reducing valve
13 = Bucket tappets

In a combination splash and force feed oil is delivered to some parts by means of splashing and other parts through oil passages under pressure from the oil pump.

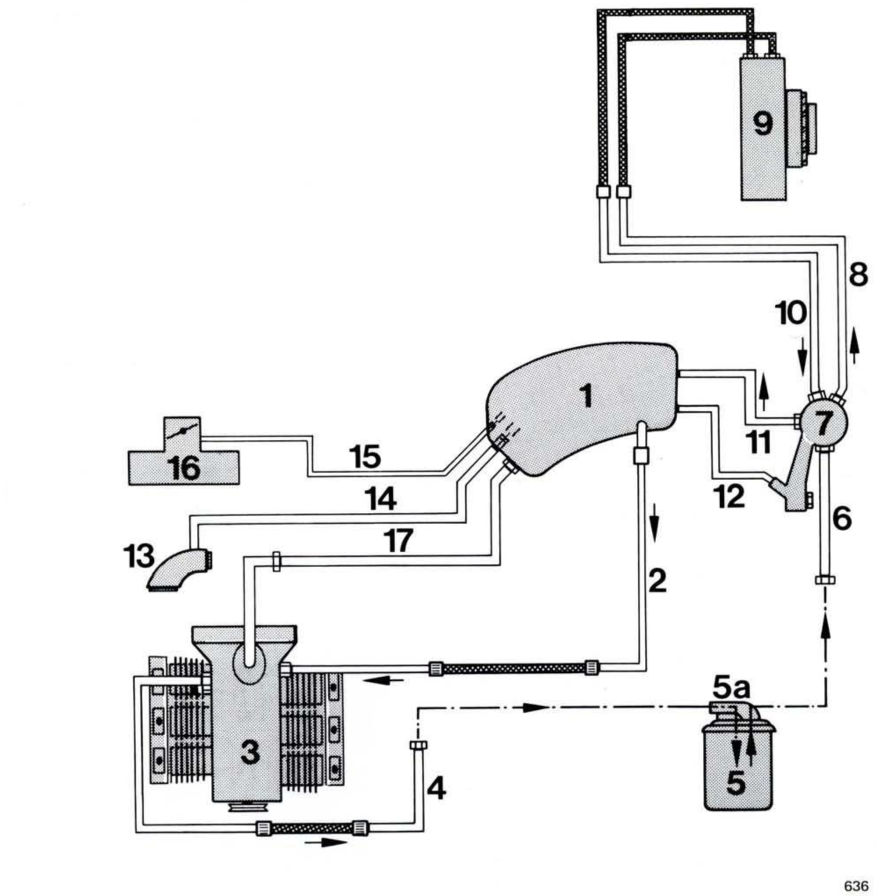
The oil from the pump enters the oil galleries. From the oil galleries, it flows to the main bearings and camshaft bearings. The main bearings have oil-feed holes or grooves that feed oil into drilled passages in the crankshaft. The oil flows through these passages to the connecting rod bearings. From there, on some engines, it flows through holes drilled in the connecting rods to the piston-pin bearings.

Cylinder walls are lubricated by splashing oil thrown off from the connecting-rod bearings. Some engines use small troughs under each connecting rod that are kept full by small nozzles which deliver oil under pressure from the oil pump. Others use jets that spray oil directly to the bore, con rod and piston. These oil nozzles deliver an increasingly heavy stream as speed increases.

At very high speeds these oil streams are powerful enough to strike the underside of the piston directly. This causes a much heavier splash so that adequate lubrication of the pistons and the connecting-rod bearings is provided at higher speeds.

If a combination system is used on an overhead valve engine, the upper valve train is lubricated by pressure from the pump.

Dry Sump System



1 – Oil tank
2 – Oil supply pipe
3 – Crankcase (engine)
4 – Oil return pipe, rear
5 – Oil filter
5a – Oil filter flange
6 – Oil return pipe, front
7 – Oil thermostat
8 – Oil cooler supply pipe
9 – Oil cooler with two-stage blower
10 – Oil cooler return pipe
11 – Oil return hose
12 – Oil drain hose (molded)
13 – Cowl
14 – Crankcase venting pipe with 6mm dia. orifice in oil tank
15 – Bypass air pipe with 1.5 mm dia. orifice in oil tank
16 – Throttle valve assembly
17 – Oil tank venting pipe

The dry sump lubrication system is the ultimate oiling system for internal combustion engines. The simple fact that all Formula One, Indy cars, Le Mans and Sports Racing cars as well as Super Speedway Stock Cars use dry sumps, proves this point.

In order to have a good understanding of the dry sump system, let's first revisit the wet sump system. Wet sump oiling systems are used on 99% of all cars. They utilise a conventional sump with a dipstick, where the oil is stored and supplied to the oil pump. The sumps capacity can range from 3 litres to 10 litres or more, depending on the engine. The oil is sucked up a pickup pipe into the oil pump, where it is filtered and supplied to the engine under pressure. While this system is very adequate for motorway use, it presents problems under racing conditions. Aside from the size of the sump, and necessity of a deep sump, the oil is subjected to extreme cornering forces in racing, and the oil simply "crawls" up the sides of the sump and away from the pick-up. Although there are many good designs, with trap doors, etc., racing cars generate lateral and acceleration/deceleration forces that overcome the best wet sump designs. Aside from the obvious pressure loss, this also results in a reduction in power.

The main purpose of the dry sump system is to contain all the stored oil in a separate tank, or reservoir. This reservoir is usually tall and round or narrow and specially designed with internal baffles, and an oil outlet (supply) at the very bottom for uninhibited oil supply. The dry sump oil pump is a minimum of 2 stages, with as many as 5 or 6. One stage is for pressure and is supplied the oil from the bottom of the reservoir, and along with an adjustable pressure regulator, supplies the oil under pressure through the filter and into the engine. The remaining stages "scavenge" the oil out of the dry sump pan and return the oil (and air) to the top of the tank or reservoir. If an oil cooler is used usually it is mounted inline between the scavenge outlets and the tank. The dry sump pump is usually driven by a gear or timing belt and pulleys, off the front of the crankshaft, at approximately half crankshaft speed. The dry sump pump is designed with multiple stages, to insure that all the oil is scavenged from the pan. This also results in removing excess air from the crankcase, and is the reason they are called "dry sump" meaning the sump is essentially dry. Increased engine reliability from the consistent oil pressure provided by the dry sump system is the reason dry sumps were invented. The many other benefits are, shallower sump allowing engine to be lowered in chassis, horsepower increase due to less viscous drag (oil resistance due to sloshing into rotating assembly) and cooler oil.

We have also increased these advantages further through advanced designs of catch trays, and scavenge pickup designs and locations, as well as our utilization of precision machined alloy castings, which add stiffness to the block and afford better sealing. All in all, the dry sump system came out of necessity to maintain oil pressure, and evolved into a very sophisticated system which increases reliability as well as horsepower while allowing the engines to be mounted with the lowest centre of gravity.

Summary

Advantages of a wet sump

- Simple design
- Efficient operation

Disadvantages of a wet sump

- Supply problems during large acceleration / braking and cornering manoeuvres
- Requires a deep sump

Advantages of a dry sump

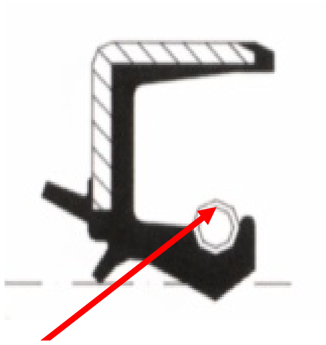
- Oil supply is unaffected by movement in the sump
- Less contact with blow by gases and contaminants
- No sump means lower centre of gravity
- Larger quantity of oil reduces overheating

Disadvantages of a dry sump

- Complex design
- More components adds to weight

Oil seals

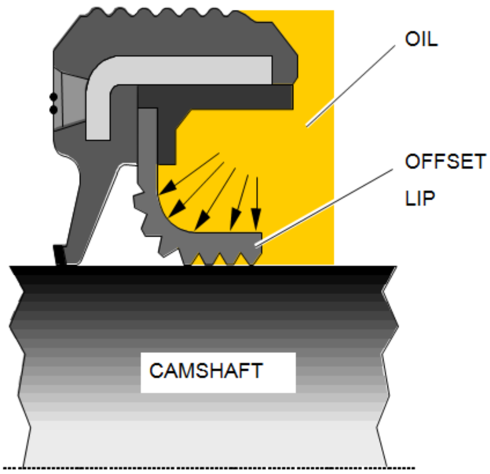
Oil seals consist of a specially shaped synthetic rubber and with a supporting steel shell. The seal is fitted for example into a recess in the crankcase housing. The lip is held in contact with the crankshaft by a radial spring and the sharp edge of the seal points inwards to the oil, this ensures that oil does not leak out of the sump via the crankshaft which could lead to contamination of the clutch assembly.



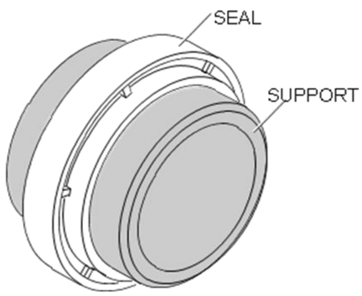
Spring

This type of seal uses a small internal spring to keep an even pressure on the shaft surface. Once the seal loses its tension the seal will start to leak. If the pressure behind the seal increases above the tension limit of the spring this too will cause the seal to fail.

Modern designs



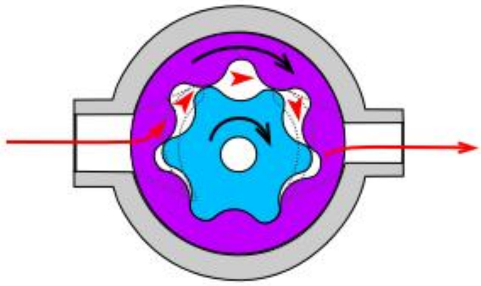
Modern engines feature revised seal types that use the oil pressure to maintain the seal. The surface area is increased in the lip allowing the oil pressure to act directly on the back of the seal. These seals are not reusable and have to be handled with care.



Oil Pumps

A gear pump uses the meshing of gears to pump fluid by displacement. They are one of the most common types of pumps for hydraulic fluid power applications. There are two main variations; external gear pumps which use two external spur gears, and internal gear pumps which use an external and an internal spur gear. Gear pumps are positive displacement (or fixed displacement), meaning they pump a constant amount of fluid for each revolution.

As the gears rotate they separate on the intake side of the pump, creating a void and suction which is filled by fluid. The fluid is carried by the gears to the discharge side of the pump, where the meshing of the gears displaces the fluid. The mechanical clearances are very small. The tight clearances, along with the speed of rotation, effectively prevent the fluid from leaking backwards.



The rigid design of the gears and houses allow for very high pressures and the ability to pump highly viscous fluids.

Outlet

Inlet

Many variations exist, including; helical and herringbone gear sets (instead of spur gears), lobe shaped rotors similar to Roots Blowers (commonly used as superchargers), and mechanical designs that allow the stacking of pumps. The most common variations are shown above (the drive gear is shown blue and the idler is shown purple).

Oil filters

The requirements of an oil filter

- lubricate internal parts
- help cool the engine by transferring heat
- absorb contaminants
- suspend wear particles
- suspend soot that forms as a result of combustion.

Some contaminants go into suspension and some are chemically grabbed by the additives, which constitute up to one-fourth of motor oil's makeup.

Acting by itself, oil would soon become saturated with contaminants and allow the internal parts to wear. That's why we have filters.

Oil cooling

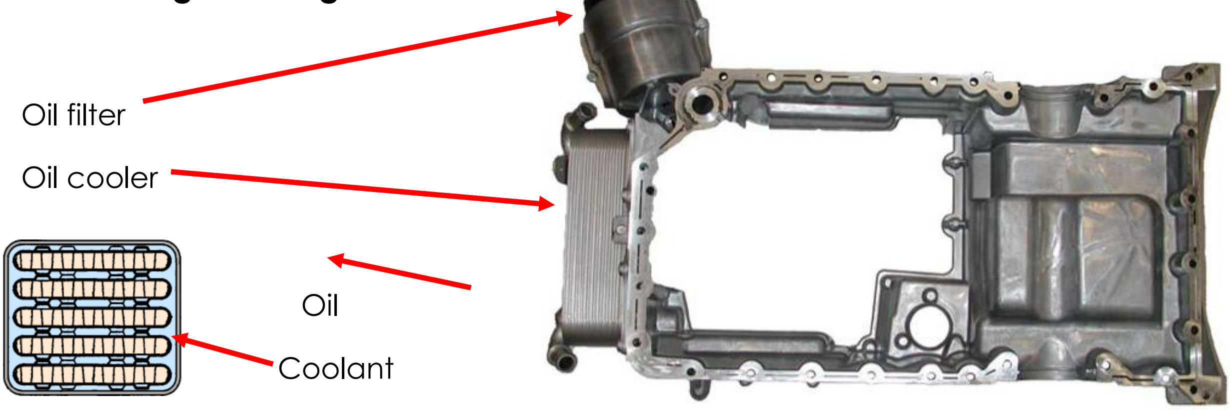
Almost one third of the heat generated by the engine must be removed by the vehicle's two cooling systems:

(1) The top of the engine: the area around each cylinder in the engine block, the combustion chamber areas in the cylinder heads and the intake manifold, dissipate heat through the engine's radiator coolant system.

(2) The rest of the engine: the crankshaft, bearings, camshaft, lifters, connecting rods and pistons are only cooled by engine oil.

The ideal operating range for engine oil is around 83°C - 94°C. While operating within this range, the oil works as a lubricant, coolant, and cleansing agent in the engine. Modern engines generally run with radiator coolant temperatures between 93°C and 94°C with oil temperature ranges between 10°C - 50°C HOTTER. Oil that exceeds 104°C starts to lose its ability to lubricate and cool causing premature component failure.

Oil housing featuring oil cooler

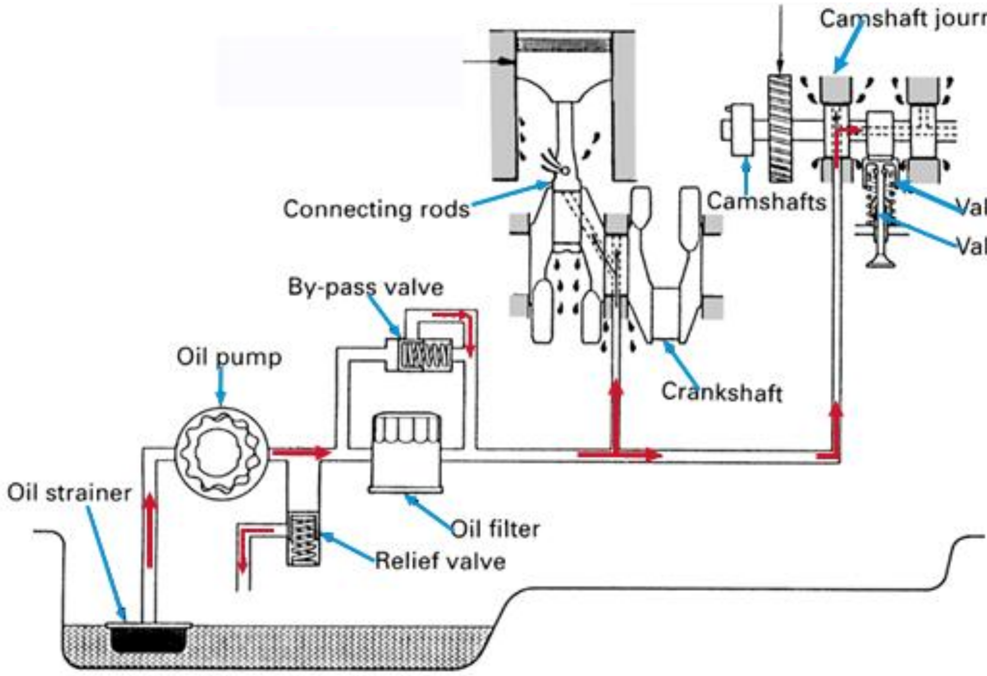


Bypass filter

A bypass oil filter is where 10 percent of the oil was filtered through a metal strainer type filter. This was later combined with a cotton filter and a sight glass. The other 90 percent of the oil was sent to the engine unfiltered. As long as the oil contamination rates were low and the oil was changed frequently, the bearings had some reasonable life expectation. Most automotive oil filters were the bypass-type until the mid-1940s.

Full flow filter

As engine designs evolved so did filtration technology. A system was designed where all of the oil was filtered before entering the oil galleries. This ensures any particles are removed that could reduce the life of the engines moving parts.



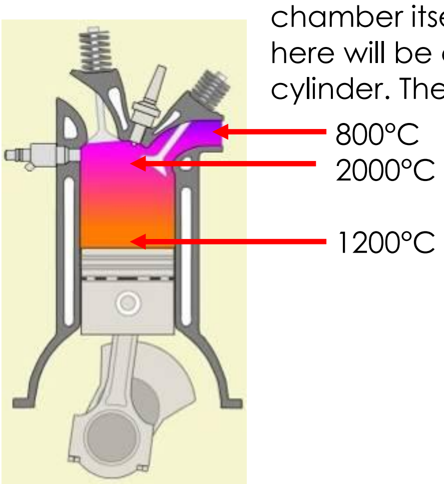
Valves

Most pressurised lubrication systems incorporate a pressure relief valve to allow oil to bypass the filter if its flow restriction is excessive (5.5 Bar); this protects the engine from oil starvation. Filter bypass may occur if the filter is clogged or the oil is thickened by cold weather. The bypass valve is frequently incorporated into the oil filter. Filters mounted such that oil tends to drain from them usually incorporate an anti-drain back valve to hold oil in the filter after the engine (or other lubrication system) is shut down. This is done to avoid a delay in oil pressure build-up once the system is restarted; without an anti-drain back valve, pressurized oil would have to fill the filter before travelling onward to the engine's working parts. This situation can cause premature wear of moving parts due to lack of oil in the meantime.

Cooling, heating and ventilation

The cooling system plays a vital role in an engines operation. During combustion the temperatures in the cylinders can rise to around 800°C - 2000°C. These temperatures are often above the melting points of the components that are involved in the combustion process. So it is the job of the cooling system to remove heat at a rate that can regulate an optimum working temperature.

A correctly designed liquid cooling system for example will remove a varied amount of heat from various engine locations. A good example of this is in the combustion chamber itself and around the exhaust valves. The temperature here will be considerably higher than at the lower part of the cylinder. Therefore the cooling system is designed to remove a larger amount of heat from this area than at the base of the cylinder.



Circulation control of the coolant is vital so that different parts of the engine get different flow rates in order to operate at an optimum temperature. This combined with cleaver thermal design of the engine now leads to greater thermal control of the modern engine.

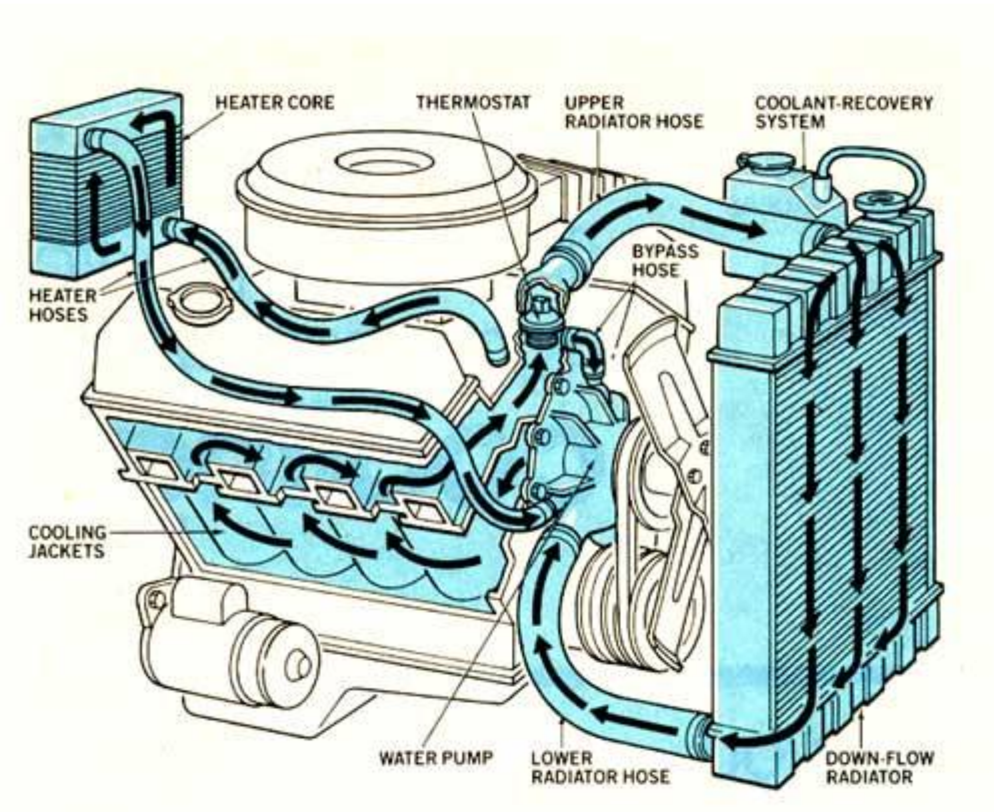
(Temperatures are approx)

Liquid cooling system

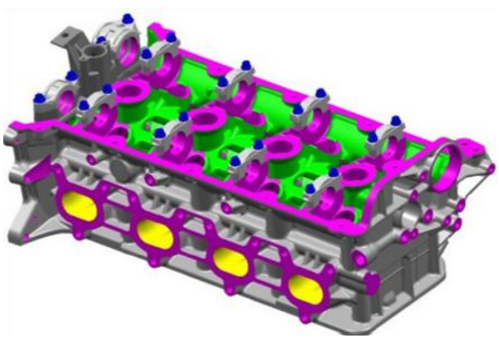
The liquid cooling system is the most popular type used today by the majority of vehicle manufacturers. The coolant is made up of mainly water due to its excellent specific heat capacity and a chemical, commonly ethylene glycol to lower the waters freezing point. An anti corrosion chemical may also be added to ensure waterways and components do not corrode. Coolant is usually premixed to a 50/50 concentration (-34°C) so be sure not to dilute with water during maintenance.

Having a water base has one major problem. As mentioned earlier the optimum operating temperature is around 94°C which poses a problem for water as its boiling point at atmospheric pressure (1 Bar) is 100°C. The only way to overcome this problem is to subject it to a higher pressure (approx 1 Bar over pressure) this increases the boiling point to approx 120° C. This enables the coolant to remain a constant liquid.

The liquid cooling system

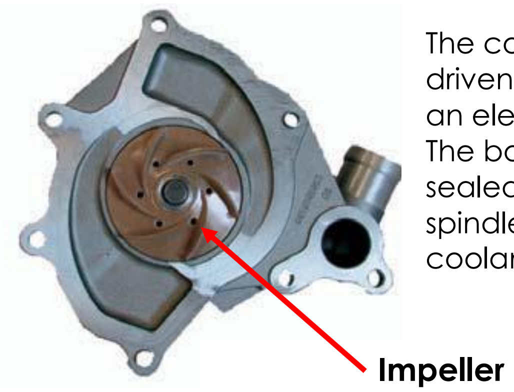


Thermal efficiency of a cylinder head



Coolant around the cylinder walls

Coolant pump



The coolant is usually driven by a pump that is directly driven by, a timing belt, auxiliary belt and in some cases an electronic pump.
The body of the pump is usually alloy and carries a sealed for life double row ball bearing. Mounted on the spindle is the impeller. The impeller creates the flow of coolant around the system.

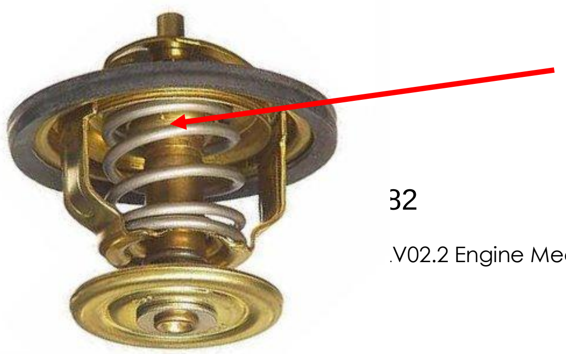
Thermostat (coolant regulator)

The operation of the thermostat is to ensure the engine reaches optimum operating temperature as quick as possible. This is achieved by effectively shutting off the radiator from the rest of the cooling system. The result is that the coolant flows around the engine cylinders and cylinder head. The coolant may flow through a small radiator inside the vehicle known as the heater matrix to ensure the vehicle occupants have heat available as soon as possible.

Thermostat operation

The thermostat is traditionally a wax element type. This features a wax filled capsule with a thrust pin located in the centre. When the wax is cold the pin locates in the centre creating a secure seal. As the temperature rises to around 89°C the wax starts to melt, this increases the volume in the capsule causing the thrust pin to overcome the return spring pressure allowing the seal to be lifted off its seat and coolant to flow through.

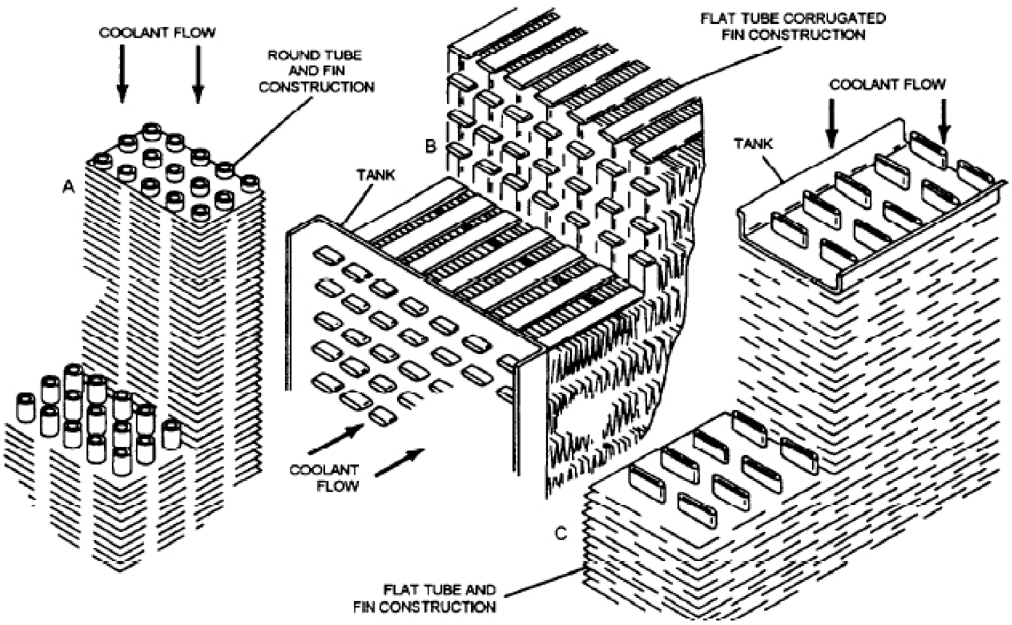
Label the parts below:



Radiator

The radiator is a heat exchanger between the liquid coolant and the outside air. To be effective the contact area exposed to the outside air should be as large as possible and cause little air flow resistance. This will maximise the efficiency of the cooling.

Construction types:



Vertical flow

Vertical flow is a traditional configuration designed to use natural convection (downward movement) as the coolant reduces temperature while flowing down the radiator. The speed of the coolant pump overcomes the natural circulation but the direction of the flow remains the same. To ensure the radiator is filled with coolant the filler is usually located on the top of the radiator at the highest point. Modern car design resulted in smaller fronted vehicles that were considerably wider. This forced radiator designers to adopt revised methods of liquid cooling.

Cross flow

New wider radiators that were short in height and often fitted lower than the engine required a pump driven system to ensure coolant flowed across the radiator. The cross flow system uses two main hoses, the top hose or hot inlet hose and the bottom outlet hose. This system also requires the use of an additional reservoir to act as an expansion tank.

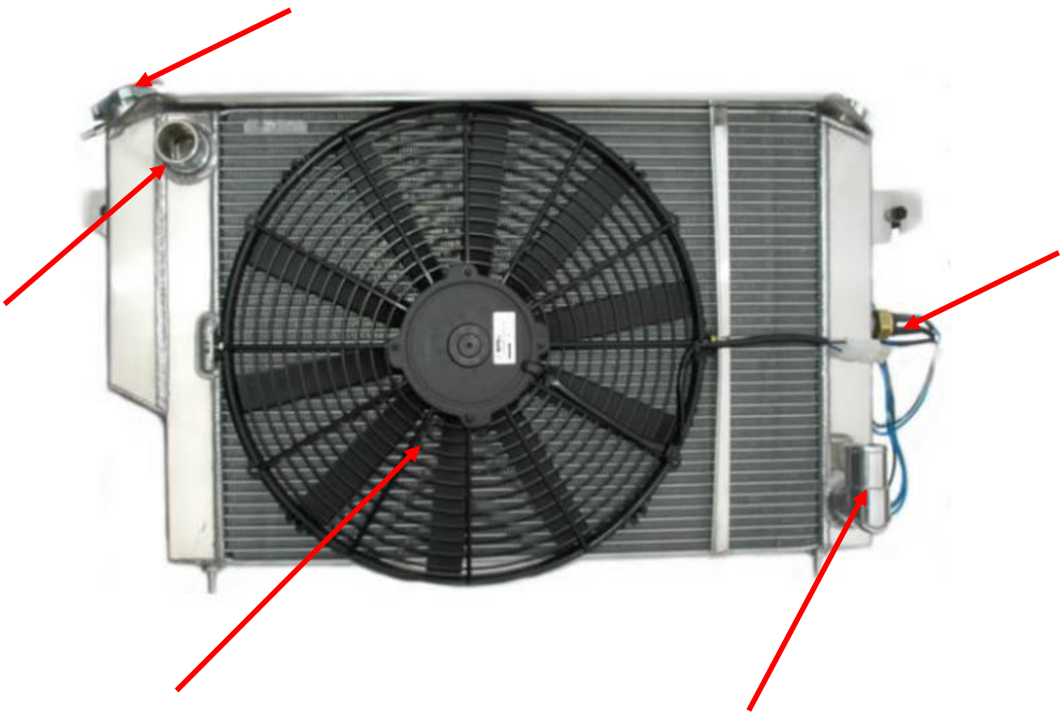
Pressure cap

Even the cap that seals the radiator has some cleaver features, it provides an additional pressure (around 1Bar) which raises the boiling point of the coolant. The cap also allows the hot expanded coolant to flow into the expansion tank. During cooling it allows the coolant to flow back into the system.

Additional cooling

Situations can arise where insufficient cool air is affecting the exchange of heat or an excess of heat has built up requiring a much larger air flow to remove the heat sufficiently. To overcome such situations an external fan may be fitted either in front or behind the radiator. The fan can be driven by the engine (viscous fan)or electronically. The fan force feeds the radiator fresh air resulting in a greater exchange of heat.
The fan is traditionally operated by a thermostatic switch. Modern cooling systems have now adopted an electronically controlled thermo management system that can optimise cooling without limiting engine power due to the high electrical load generated by fan operation.

Label the following parts:

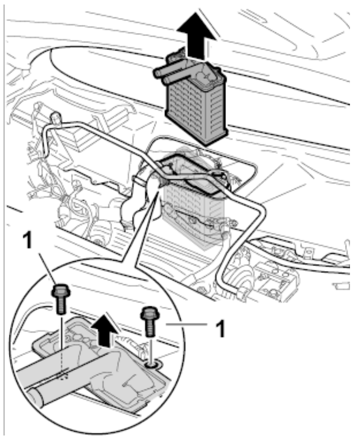


Viscous fan

This type of fan requires no thermostatic switch. It uses a metallic spring in the centre of the fan to transmit engine temperature to a clutch device that slips when the engine is cold. Upon reaching around 75 degrees the metallic spring expands the coil and uncovers an opening that allows a silicon based fluid to enter the clutch housing. This causes the fluid to be subjected to a shearing action. The silicon based fluid resists the shearing force and locks the clutch causing the fan to be driven by the engine. The cooling fins are use to exchange the heat generated by the fluids resistance.

Heater matrix

The heater matrix is an internal heat exchanger integrated into the engine cooling system. It used to radiate the heat of the coolant with the air inside the vehicle. Ventilation flaps control amount of inside air that exchanges with the heater matrix allowing driver control of the cabin temperature.

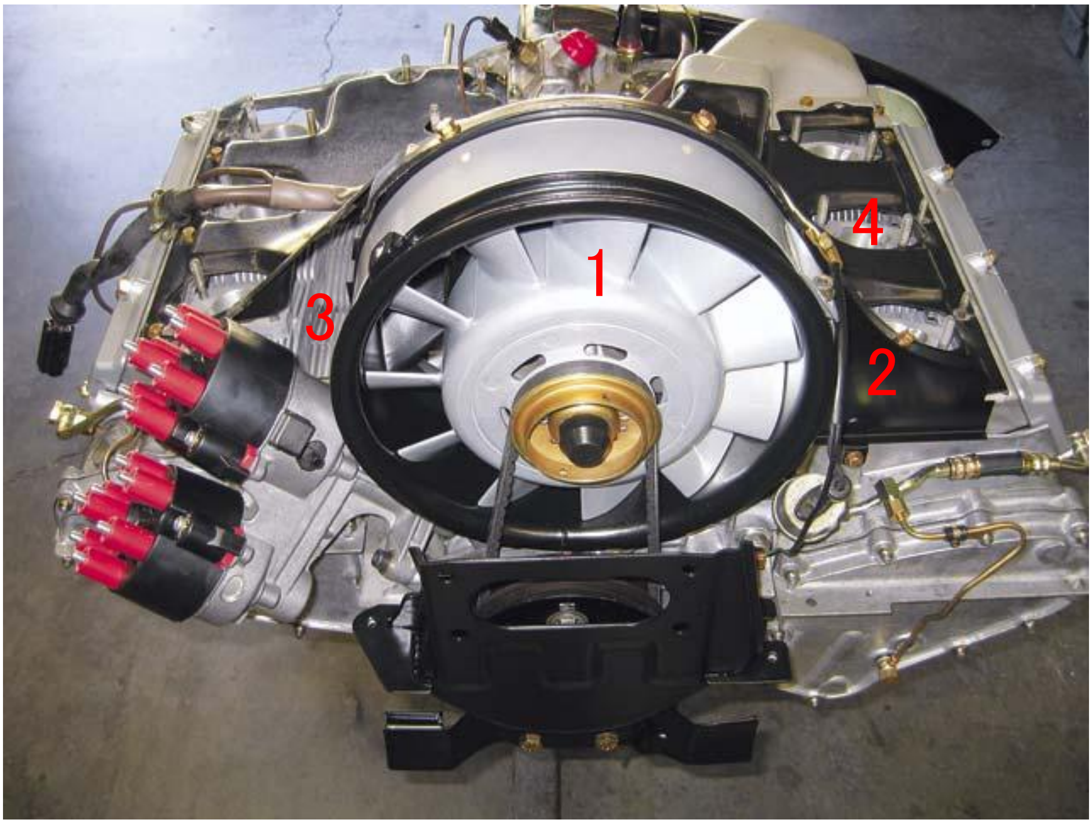


Air cooled engines

Air cooled engines have been around since the engines invention. They rely on the heat generated in the cylinder and cylinder head to exchange with the surrounding air. The cylinders feature large cooling fins to maximise the surface area of the engine. The system has the benefits of being lighter than a liquid cooled engine, engine warm up is faster and the system is never prone to freezing or leaks associated with the liquid cooling system.
The down side is that an air cooled engine requires a constant amount of air flowing over the engine in order to operate efficiently. This often requires the engine to drive a powerful fan through specially moulded engine cowls to maximise air flow.

Air cooled engines cost more to manufacture as the cylinders usually have to be made separately. Air cooled engines also suffer when in stationary traffic and if the ambient temperature is high. These issues combined with poor cabin heating contributed to most manufacturers moving in the direction of the liquid cooled engine.

Air cooled engine



Identify the following parts:

1 ______________________________

2 ______________________________

3 ______________________________

4 ______________________________

Summary

Advantages of liquid cooled engine:

- Accurate control of operating temperature
- Accurate control of expansion tolerances in the components e.g. piston shape .

Disadvantages of a liquid cooled engine:

- Heavier engine due to the weight of the coolant
- Greater amount of components required

Advantages of an air cooled engine:

- Fewer components required
- Light weight compact design

Disadvantages of an air cooled engine:

- Noisier operation
- Poor cooling when stationary