# Combustion Engine – Course: Motor Vehicle Engineering 3. Textbook for Vocational Training

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## Preface

This instruction manual is intended for all students of motor vehicle repair and maintenance.

It can be used as a basis for both theoretical lessons and practical training, and as such provides an essential link between theory and practice.

The manual is divided into three self−contained sections, each dealing with one of the main sub−assemblies of the vehicle: chassis, power transmission and combustion engine.

The instruction manual contains a clear and concise description of the design and function of each of the component parts of the motor vehicle, as well as information about the maintenance, servicing and repair of vehicles.

Numerous illustrations are intended to facilitate the student's understanding of the technical and engineering problems discussed. Test questions are included at the end of each chapter. These concentrate on points of

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particular importance to students of motor vehicle engineering and enable the individual student to assess his own progress.


# 1. Types of combustion engines

Almost all types of prime movers have already been tested as drive units in motor vehicles. Next to the conventional combustion engines, gas turbines and electric motors are most frequently used.

So far, however, the combustion engine operated on petrol or diesel fuel has proved to be the most successful of them all.

Combustion engines can be divided as follows:

1. According to the type of ignition:

In this category the Otto engine is distinguished from the diesel engine.

> – The Otto engine, named after its inventor Otto operates on the principle of <u>spark ignition</u>.

A fuel–air mixture or only fuel and air is drawn injected, compressed and ignited by an electric high–voltage spark.

> – The diesel engine, named after its inventor Diesel operates on the principle of <u>compression ignition</u>.

Diesel fuel is injected into very highly compresses air, and ignites on its own due to the high compression temperature.

2. According to the type of carburation:

A distinction is made between engines with external mixture formation and those with internal mixture formation.

> – In combustion engines with <u>external</u> mixture formation the fuel air mixture is prepared in an intake pipe outside the combustion chamber.

> – In the case of <u>internal</u> mixture formation this mixture is not prepared until it reaches the combustion chamber. This mixture formation is made by injecting the fuel into the air.

3. According to the mode of operation:

There are two different modes of operation.

> – With the <u>two–stroke mode of operation</u> the piston works at every second stroke (piston stroke).
> – In case of <u>four–stroke engines</u>, the piston works at every fourth stroke.

4. According to the number of cylinders:

> – Single–cylinder engines
> – Multi–cylinder engines
> – Planetary piston engines

5. According to the cylinder arrangement: (Fig. 1/1)

> – The <u>in–line engine</u>: here the cylinders are arranged in a line.
> – <u>The V engine</u>: here the cylinder are arranged in V form.
> – <u>The opposed cylinder engine</u>: here the cylinders are arranged opposite each other.
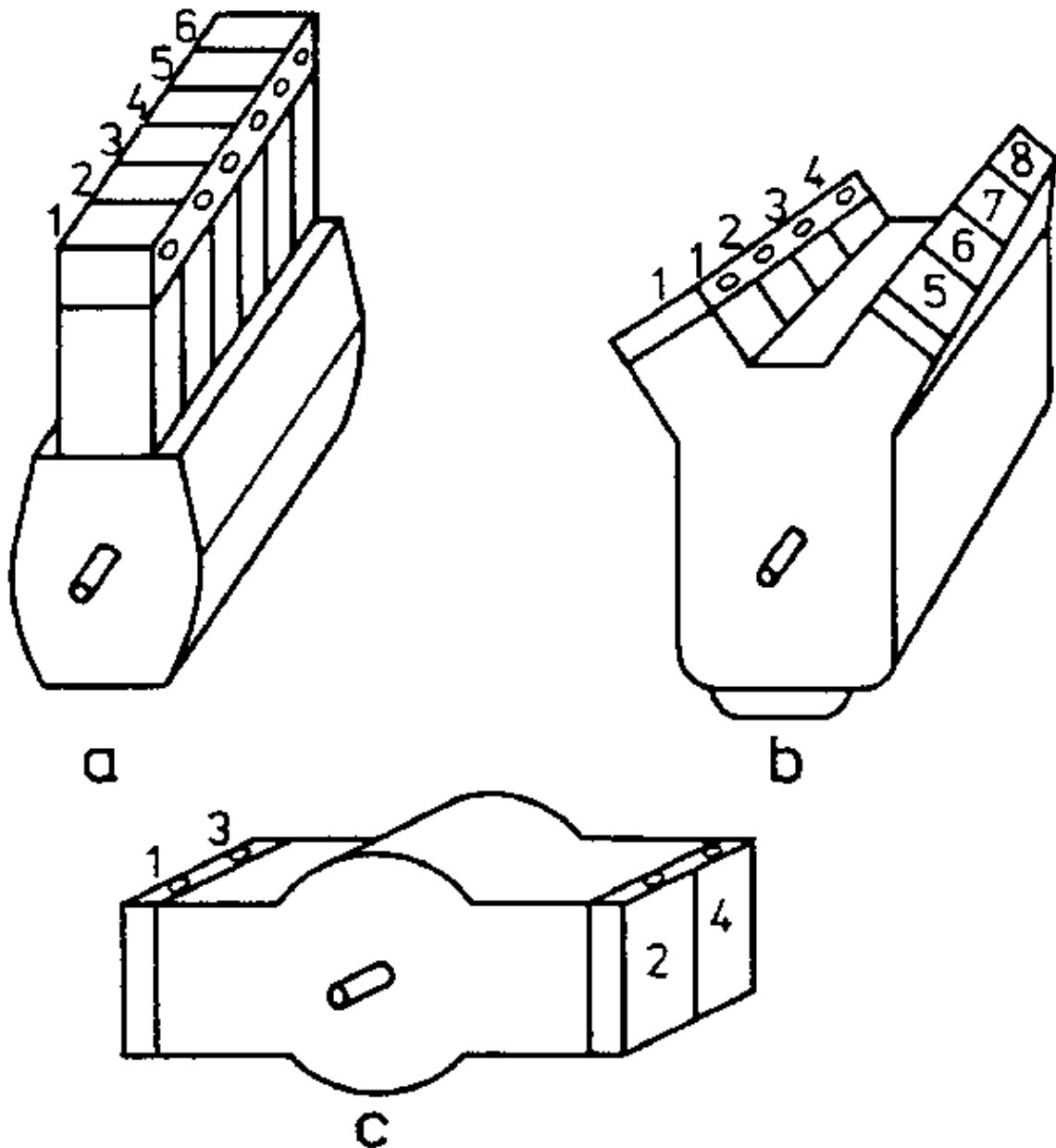
Figure 1/1 Types of engines according to the arrangement of the cylinders

a in–line engine (vertical); b V engine; c opposed cylinder engine; 1, 2, 3... number of cylinders

6. According to the type of timing:

– <u>Valve timing</u> engines. Intake and discharge of gases are controlled by valves. These are four–stroke engines.

– Engines with <u>slide valve timing</u>. Intake and discharge of gases are controlled by slide valves.

– <u>Valveless</u> engines. Intake and discharge of gases are controlled by the piston.

7. According to the type of cooling:

We distinguish between liquid cooling and air cooling.

– In the case of <u>liquid–cooled engines</u>, the combustion chamber is surrounded by a cooling shell. There are cylinders with dry liners and with wet liners. The coolant (distilled water with antifreeze additives, if required) is circulated between the combustion chamber and the cooler.

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– In the case of air–cooled combustion engines, the cylinder is directly cooled by the air stream or by a blower. The cylinder is furnished with cooling ribs for better heat discharge.

<u>Test questions</u>

1.1. What is understood by the term 'combustion engine'?

1.2. What other kinds of drives for motor vehicles do you know?

1.3. What are the criteria for classifying combustion engines?


## 2. Design of the reciprocating–piston engine

Since the engines used in motor vehicles are almost exclusively reciprocating engines, we are concentrating entirely on this type.

The reciprocating engine consists of the following main subassemblies:

- Crankshaft
- Connecting rod
- Piston with gudgeon pin
- Cylinder liner
- Cylinder head with combustion chamber

All reciprocating engines are of the same design. The term reciprocating engine is derived from the straight up and down movement of the piston in the liner. The connecting rod is connected to the piston by the gudgeon pin and transforms the straight movement of the piston into a rotational one via the crankshaft. The crankshaft is supported in the crankcase and secured to prevent axial shifting. A flywheel is flanged to the PTO side of the engine. Here the power generated is transferred to the clutch.

In the Otto engine, the fuel–air mixture is produced by a carburettor. It is connected to the combustion chamber of the engine by an intake manifold. The exhaust duct is also in the combustion chamber. The burnt gases are discharged into the open through this duct passing the exhaust manifold, the pre–silencer, the main silencer and the exhaust pipe. The mixture is ignited by the spark plug which is screwed into the combustion chamber.

The position in which the piston is closest to the cylinder head is called <u>top dead cent</u>re.

The largest distance of the piston from the cylinder head is called <u>bottom dead centre.</u>

The path to be covered by the piston between top and bottom dead centre is called the piston stroke (or simply stroke). Every piston engine is supplied with a particular amount of thermal energy by the fuel; this heat is transformed by the engine into power, however, the process is connected with very high energy losses. Only a portion of the energy supplied can be utilized as brake power for the engine. The ratio between energy supplied and energy losses and effective engine power is shown in the Fig. 2/1.
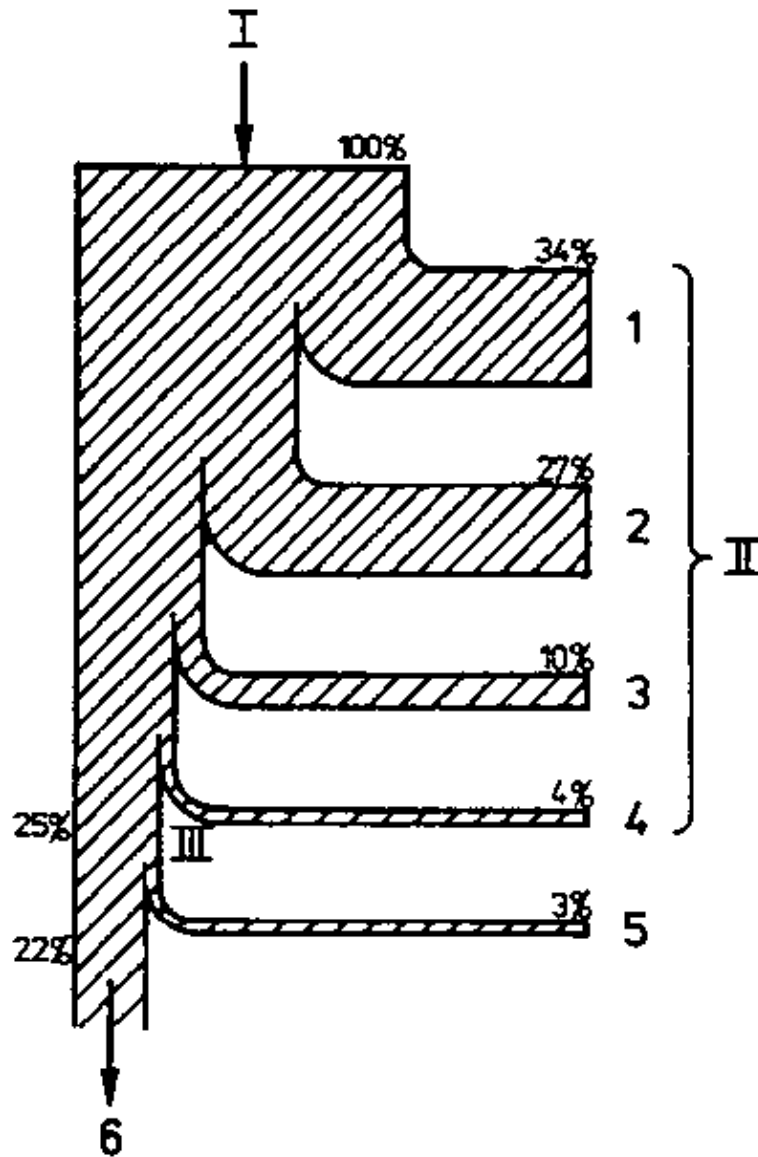
Figure 2/1 Ratio of energy fed into the engine vs. energy losses and efficiency of the engine.

I Thermal energy of the fuel supplied, II Energy losses of the engine composed of the following shares: 1 Losses due to exhaust gases; 2 Losses due to cooling; 3 Losses due to friction and radiation; 4 Losses due to dynamo, fan or blower; III Effective power of the engine from which losses in the gearbox due to friction (5) must be deducted; 6 reflects the output that can be converted into the travelling performance proper.

The energy supplied to the engine can be subdivided as follows:

– the brake power which will be transformed into mechanical power;

– the cooling heat which will be discharged into the cooling water or the cooling air;

– the exhaust heat which is energy carried off in the exhaust gases;

– the residual heat which is carried off by radiation and conductivity;

– the engine friction which is the energy lost by friction of the moving parts of the transmission system of the engine.

In the diagram the losses are given in percentages. The values given can only be mean values because the power range will vary depending on the type of the engine.

## 2.1. The cylinder

Every combustion engine which is designed as a reciprocating engine has a combustion chamber in the cylinder head. Note the following types (Fig. 2/2):

- the Ricardo head
- cylindrical combustion chamber
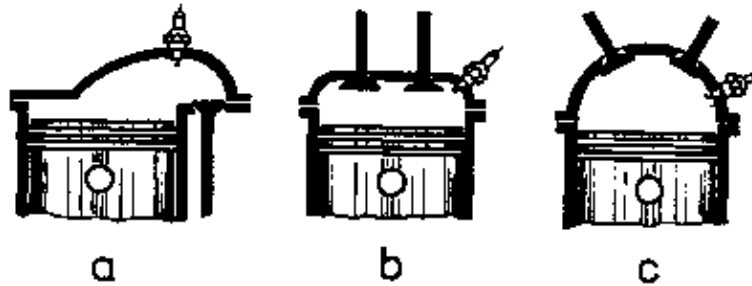- hemispherical combustion chamber.



Figure 2/2 Shapes of cylinder heads

1 Ricardo head; 2 Cylindrical combustion chamber; 3 Hemispherical combustion chamber

The design of the combustion chamber is of special importance. It is not only the diesel engine that requires intensive mixing of the air for rapid combustion. In the Otto–engine, proper mixing of the fuel–air mixture ensures fast progress of the flame front, i.e. proper and rapid combustion of the mixture, resulting in high output and efficiency.

Due to the design of the Ricardo head, there its compression ratio has an upper limit. The fuel–air mixture is started to be mixed before top dead centre is reached, thus ensuring quicker ignition. This type of head is mainly used for combustion engines with side valves.

The cylindrical and the hemispherical combustion chambers are used for overhead–valve engines because the valves are suspended in the combustion chamber. Here the position of the valves is of great importance.

The cylinder head seals the top end of the cylinder (liner). The liner is shaped like a hollow cylinder (Fig. 2/3). The bottom end of the cylinder is open. Here in the cylinder, the piston moves between top and bottom dead centre. The bottom dead centre forms the lower limit of the cylinder chamber while the top dead centre is the lower limit of the combustion chamber. The path covered by the piston between the two dead centres is called the stroke.
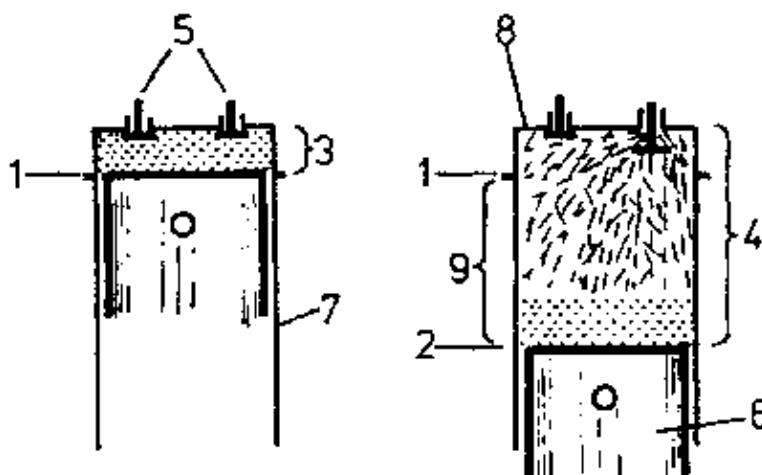


Figure 2/3 The cylinder

1 Top dead centre; 2 Bottom dead centre; 3 Combustion chamber; 4 Cylinder chamber; 5 Valves; 6 Piston; 7 Liner; 8 Cylinder head; 9 Swept volume

Here the ratio between the cylinder chamber and the combustion chamber corresponds with the compression ratio. In Fig. 2/4 the combustion chamber is 1/8 the size of the cylinder chamber. The fuel–air mixture is

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compressed to 1/8 in the space between the bottom and the top dead centre. This process is called compression. In this case the compression ratio is 8:1.

The higher the compression ratio, the higher the output of the combustion engine.

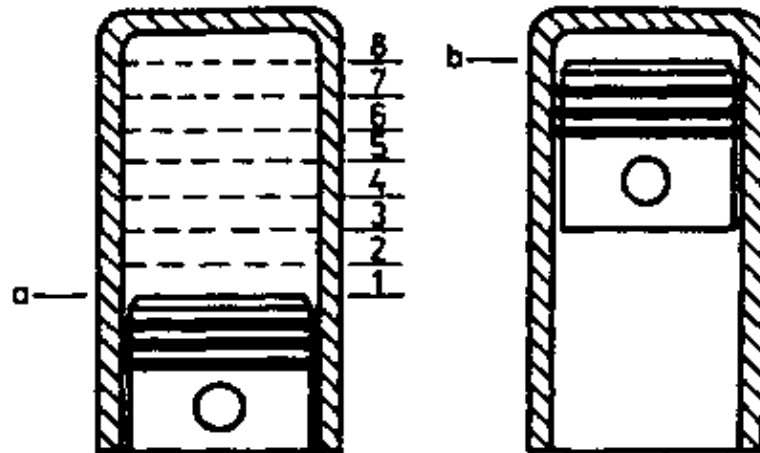An important property of the fuel is its knocking resistance.



Figure 2/4 Compression ratio 8:1

a Bottom dead centre; b Top dead centre

The knocking resistance of a fuel is clear from the octane number. Fuels with an octane number between 76 and 98 octane are used for the current combustion engines. If fuels with too low an octane number are used with combustion engines with high compression, knocking of the fuel will have a negative effect on the transmission system.

The cylinder must be very strong to withstand the entire combustion pressure. It is made of a special grey cast iron which must be hard, dense and fine grained. In special cases it is also possible to use steel liners. The liner can either be fixed in the cylinder block or be replaceable.

The liners fixed in the cylinder block are called dry liners.

Another type of liner is the wet liner. It is inserted into the cylinder block and sealed with rubber gaskets. Wet liners can also be individually replaced because they are not rigidly connected with the cylinder block (Fig. 2/5).
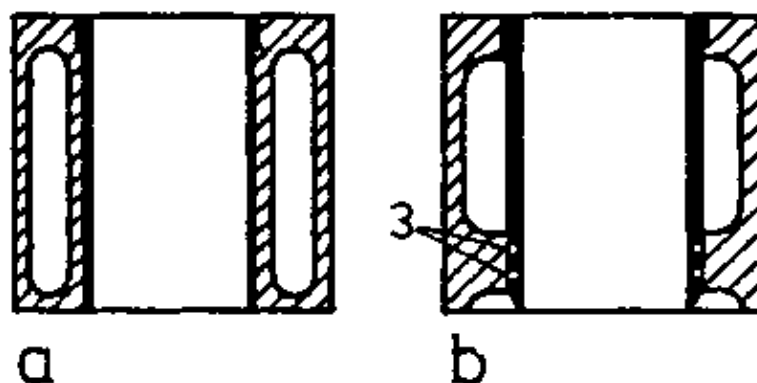


Figure 2/5 Cylinder liners

1 Dry liner; 2 Wet liner; 3 Sealing rings

As already mentioned, the top end of the cylinder is sealed with the cylinder head. In most cases the valve seats are located where the cylinder head is connected to the cylinder block. Cylinder block and cylinder head are connected by a screwed joint. A cylinder head gasket is inserted between cylinder block and cylinder head to prevent the combustion gases from escaping (Fig. 2/6).

The cylinder head gasket is made of metal–asbestos–fabric, aluminium or copper. Head gaskets made of the metal–asbestos–fabric are reinforced with metal at their openings. The profile section is also shown in Fig. 2/6. The thickness of the cylinder head gasket has an effect on the compression.

The movement of the piston between top and bottom dead centre causes wear on the cylinder.
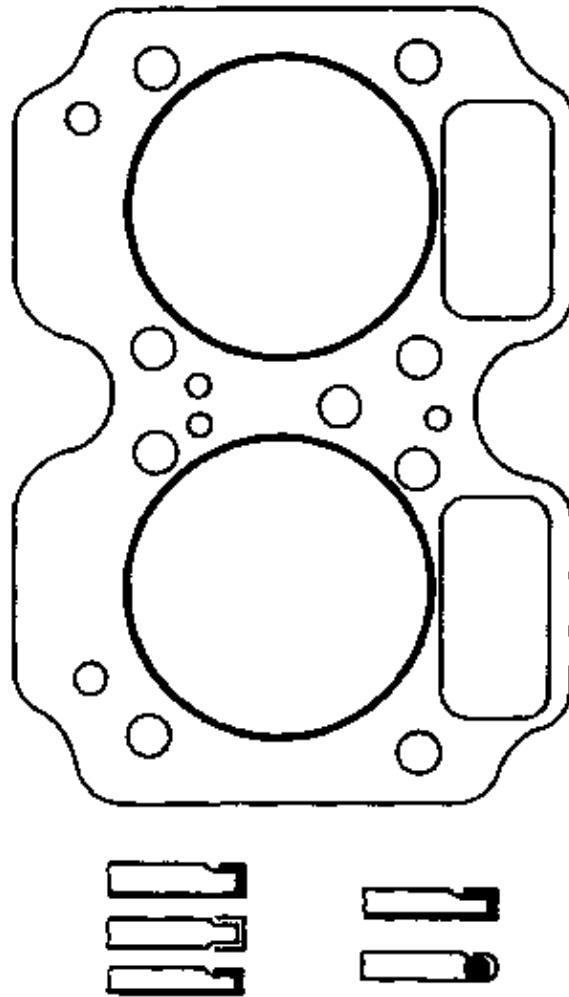
Figure 2/6 Cylinder head gasket

This wear is greatest at the point where the top piston ring is at the top dead centre. This is the point where temperatures and pressures are highest and lubrication is worst.

Moreover, the liner wall is exposed to acids which develop during combustion.

Premature wear of the liner can be combatted by using correct engine oils, by correct actuation of the choke (the engine must not be choked for too long), by maintaining the correct service temperature of the engine and by replacement of the air filter at regular intervals. Liners can be reworked.

This rework is called honing. The inner running surface of the cylinder wall is re–faced with abrasive slips mounted on a honing tool. This honing requires accurate work. Liners can only be honed to a particular wall thickness after which the wall cannot resist the pressure. If excessive wear is noted on a liner, it must be replaced by a new one. In the case of dry liners, rework can only be carried out after forcing the liner into the cylinder block.

## 2.2. The crankcase

The cylinders are either bolted individually or as blocks to the crankcase or they form an integral part of it. The crankshaft is supported in the crankcase. The camshaft can also be supported here. The oil pan is bolted to the bottom of the crankcase. The brackets for the lugs are located on the crankcase; they serve for mounting the engine on the chassis. The engine is mounted on the chassis with bounded–rubber blocks to protect the

chassis from vibrations generated during engine operation.

## 2.3. The crank mechanism

The crank mechanism of a combustion engine consists of piston, connecting rod and crankshaft with flywheel. The crankshaft serves to transform the straight up and down movement of the piston into a rotational movement. It is supported in several places in the crank–case; the bearing in the centre is designed as the main bearing.

### 2.3.1 The piston

This section deals in detail with the piston of a combustion engine. Various types of pistons are used. The piston serves to transfer the combustion pressure via the connecting rod, crankshaft and power transmission components to the driving wheels. Moreover, the piston must perform the suction stroke to let the fuel–air mixture, in, it must compress this mixture and then discharge the burnt gases. It is clear that the piston is the part of a motor vehicle which is subjected to the greatest load. The combustion pressure is dependent on the calorific value of the fuel, the compression ratio and the shape of the combustion chamber. For Otto–engines and diesel engines the value is 30 to 40 kg/cm$^2$ and 60 to 90 kg/cm$^2$, respectively.

The combustion temperature ranges between 2000 – 2500° C. The piston consists of the following parts: piston top, piston shaft, piston pin bosses and annular grooves (Fig. 2/7). In addition to all the demands made on a piston, it must properly seal the combustion chamber and move in the cylinder so that noise and wear are kept to a minimum. It must neither stick nor rub against the cylinder wall. The weight of the piston should be kept as low as possible, and ensure good heat conductivity.



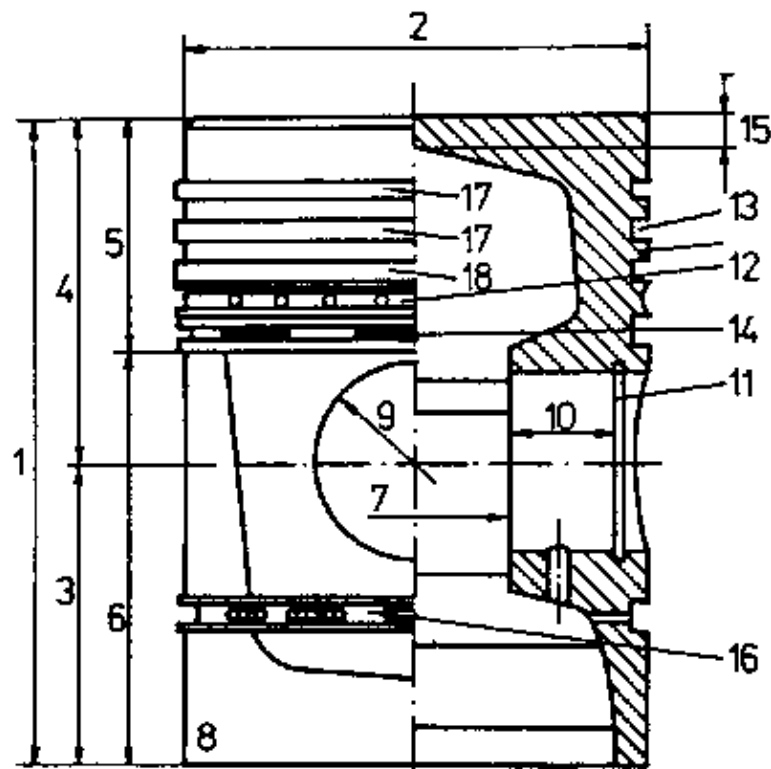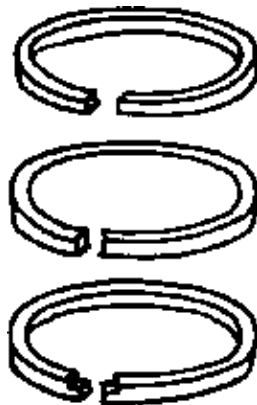Figure 2/7 The piston

1 Total length; 2 Diameter; 3 Shaft length; 4 Height of compression; 5 Annular section; 6 Piston shaft; 7 Distance between eyes; 8 Running surface; 9 Gudgeon bore; 10 Carrying bolt length; 11 Securing groove; 12 Oil groove; 13 Annular groove; 14 Upper oil scraper ring; 15 Thickness of piston crown; 16 Lower oil scraper ring; 17 Compression rings; 18 Lower compression ring

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Due to the heat generated during combustion the piston extends. This extension can result in seizure in the cylinder liner and for this reason the diameter of the piston is smaller than the diameter of the cylinder liner. This difference is called mounting clearance. When the engine is running correctly, this mounting clearance is filled by the oil film which develops on the wall of the liner. The oil film is an extremely thin layer of oil which eliminates friction between two metals and minimizes wear. Depending on the type of engine, the mounting clearance is between 0.03 and 0.08 mm. Too small a clearance can result in piston seizure, while too large a clearance can cause noisy engine run or piston chatter. The piston clearance for air–cooled engines is always somewhat larger than for water–cooled engines.

Pistons are mainly made of aluminium – silicon alloys. They can have a smooth or a curved crown as well as reinforcements in the piston crown. They can have a smooth shaft or a shaft with openings. The various types are used according to engine design.

### 2.3.2. The piston rings

The piston rings are used in the top part of the piston in the ring grooves. They serve to compensate the varying clearance between the piston and the cylinder wall and diameter variations of the cylinder. Since they are constantly in contact with the cylinder wall, there is constant sliding motion between piston rings and cylinder wall (Fig. 2/8).

a
Figure 2/8 Piston rings – I Compression rings
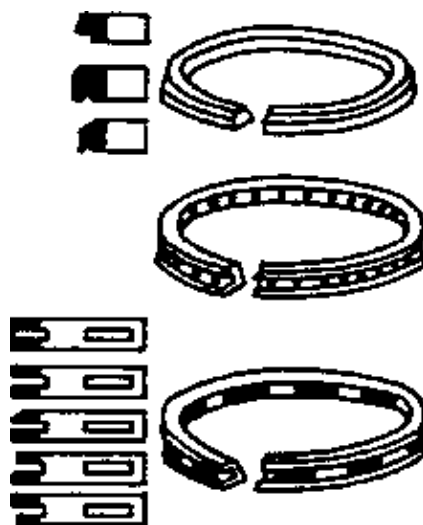
b
Figure 2/8 Piston rings – II Oil scraper rings

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The piston rings must also seal the combustion chamber from the crankcase so that the correct compression pressure can be reached. The piston rings lay against the cylinder wall and the groove flanks. In the case of four−stroke engines, the piston rings fit loosely in the grooves. In the case of two-stroke engines, the piston rings must be secured at the joint by pins. This is to prevent the piston rings turning in the grooves and to stop the slits in the rings moving round to the inlet or exhaust ports. In the case of four−stroke engines, the bottom−most ring is usually designed as an oil scraper ring. It has several openings around its circumference which have a direct connection with the bores in the piston ring groove. Excessive oil is removed by the piston rings and carried back to the oil pan.

The piston rings are usually of rectangular cross section and their working surfaces can be chromium−plated. They are made of a fine−grained grey cast iron.

Otto engines normally have 2 to 3 piston rings. Because of the higher compression, diesel engines have 4 to 5 piston rings.

### 2.3.3 The gudgeon pin

The pressure exerted by the piston is transferred by the gudgeon pin to the connecting rod. The gudgeon pin is supported by the gudgeon pin bosses. The gudgeon pin moves through the small end of the connecting rod.

There it may be supported in bushings or needle bearings so that it is free to slide. The gudgeon pin is loaded by high and constantly varying pressures.

It is made of high−quality carbonized steel. The surface of the gudgeon pin is glasshard and ground. Since it should be as light as possible, it is hollow.

Since the gudgeon pin must not touch the cylinder liner, it must be secured by the gudgeon pin boss. The gudgeon pin is shorter than the diameter of the piston; it can be secured against shifting in the gudgeon pin boss by retaining rings. The gudgeon pin can be supported in various ways:

> − pivotably supported in the gudgeon pin boss and the connecting −rod small end (this is also known as 'floating support').

> − rigidly supported in the gudgeon pin boss and pivotably in the connecting rod small end. (This is the most frequent type of support.)

> − pivotable supported in the gudgeon pin boss and rigidly in the connecting rod small end.

For rigid support of the gudgeon pin in the bosses, the piston is heated in an oil bath or on a heating plate (approx. 60° C) to allow it to expand. Then the gudgeon pin will be slightly oiled and inserted. The piston is allowed to cool and rigidly supported and secured in the boss and then it is ready for installation.

### 2.3.4 The connecting rod

The connecting rod transfers the power of the piston from the piston to the crankshaft. It consists of the small end, the shaft and the big end. The connecting rod big end can be solid or split. It is subjected to tension, pressure and axial compression. It is made of high−quality material (steel). The shaft is a double−T design. The small end accomodates a bronze bushing or a needle bearing for gudgeon pin support. There is a lateral clearance of some 2 to 3 mm between the gudgeon pin bosses. The connecting rod big end connects the rod with the crankshaft. It can be split in the middle and bolted together. Bearing shells or roller bearings can be accommodated in the connecting rod big end. They ensure easy slide on the crank−pin. The bearing shells consist of two halves which are lined with bronze or light metal. To prevent distortion the bearing shells are secured in the connecting rod big end by pins. For light−metal bearing shells, white metal is used as bearing metal. Connecting rod wear is low.

Normally the connecting rod is only damaged by rupture or bending because the bearings themselves can be replaced. Prior to installation the connecting rods must be squared to ensure proper operation of the piston. If

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the connecting rods do not form a right angle (90 deg.), it is possible to straighten them by to 1 per cent.

A torque wrench is used to bolt the connecting rod big ends because after tightening the screws, the connecting rod must be able to move slightly on the crank–pin due to its weight, but is must not have any height clearance.


**2.3.5 The crankshaft**

As already mentioned, the crankshaft transforms the straight movement of the piston into a rotational movement. A strong and well–balanced crankshaft will produce smooth and vibration–free operation of the engine. There are built–up crankshafts and solid ones. The individual parts of the crank–haft can be either connected by bolts or pressed into one another. The crankshaft is cranked according to the number of cylinders an engine has. The points of impact on the connecting rods are called the crank–pins. They are situated outside the shaft axle. The crankshaft bearings are parallel to the shaft axle. The main bearing is usually situated in the middle of the shaft. It protects the crankshaft from displacement in axial direction. The crank–pins are connected with the axial bearings by angular crank arms. The crankpins are staggered to provide balanced loading of the crankshaft.

Four–stroke engines

Single cylinder engine:

In the case of the four–stroke engine, each working stroke is followed by three idle strokes. This must be overcome by a large flywheel.

Two–cylinder engine:

The crank–pins are staggered through 180 degrees. Each working stroke is followed by an idle stroke.

Four–cylinder engine:

The crank–pins are staggered through 180 degrees. Here the working strokes follow one after another. Therefore, the dominating firing order is either 1–2–3–4 or more frequently 1–3–4–2.

The figures listed above designate the cylinders. In this respect it is assumed that the first cylinder is positioned on the P.T.O.–side.

Six–cylinder engines:

In these engines the crank–pins are staggered through 120 degrees and the working strokes overlap resulting in the following firing order: 1–5–3–6–2–4.

Eight–cylinder engines:

In this engine, the crank–pins are staggered through 90 degrees. Due to the number of cylinders, the one working stroke starts before the previous one is completed. The firing order is 1–6–2–5–8–3–7– 4.

Two–stroke engines

Two–stroke engines have a similar mode of operation to four–stroke ones, but they have twice as many working strokes. Here the three–cylinder engine has the same crankshaft shape as the six cylinder engine. However, the shaft is only half the length. The working strokes are produced as with the six–cylinder four–stroke engine.

The crankshafts almost always turn clockwise, beginning at the front face of the engine. Here the crank–pins describe an arc around the shaft axis. When describing the downward arc, the piston moves towards bottom dead centre and during the upward arc towards top dead centre. Hence two piston paths equal one full crankshaft rotation.

Single−cylinder engines and two−cylinder engines are normally double supported. In the case of engines with four cylinders, two cranks are supported by two bearings, i.e. this crankshaft is supported three times. However, there are also crankshafts in which every crank is supported by two bearings. Here a crankshaft for a six cylinder engine has seven bearings while an eight−cylinder engine has nine. The bearings of a crankshaft can be designed as slide bearings or antifriction bearings. If slide bearings are to be used for crankshaft support, the bearing blocks must be split. This means that half a bearing is rigidly fixed to the engine block or cast into it and the other half is screwed on like a bridge. The bearing shells are made of bronze of antifriction bearing metal. They are secured by pins to prevent distortion. The advantage of using antifriction bearings lies in a lower friction. However, splitting of the shaft must be possible. In the majority of cases, these crankshafts are built from individual parts which are pressed into each other. Crankshafts must be well balanced by balancing machines. Balance weights are used to oppose the centrifugal forces. They can either be bolted to the crankshaft or may be an integral part of it.

In the case of slide bearings, lube oil is supplied through the oil gallery. The barings must be exactly circular.

If wear is not excessive bearing journals and crank pins can be reworked on a crankshaft grinding machine.

Prior to fitting a crankshaft in the crank−case, the crankshaft bearings must be bored in true alignment. To do this all bearings are inserted and tightened. Boring is carried out in true alignment with borer with bits which correspond to the numbers of the bearings.

### 2.3.6 The flywheel

The flywheel helps produce smooth engine operation. Size and weight of the flywheel depend on the number of cylinders. The more cylinders an engine has, the smoother the impacts of the power pulses on the shaft are and so the lighter the flywheel can be. The flywheel is centred on the crankshaft and kept in position by a bolted connection. The starter rim is shrunk onto the flywheel in the direction of the crankcase. The starter rim is a geared ring which serves to start the engine. Setting marks for engine ignition and timing can be marked on the flywheel.

### 2.3.7 The vibration damper

Torsional vibrations occur at the crankshaft. In order to dampen these vibrations, larger engines are often equipped with a torsional vibration damper.
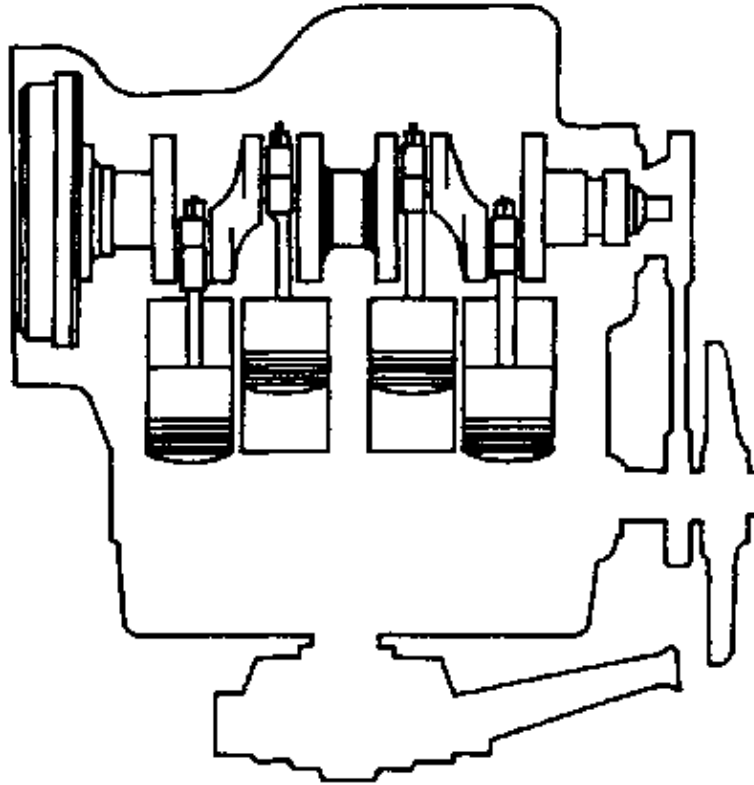
Figure 2/9 Crank mechanism of a four−cylinder engine

This is mounted opposite the flywheel and consists of a two−part balance weight in which the two halves are pressed apart by small springs and pressed against the flanks of their support. Often the vibration damper is connected with V−belt pulleys which drive the water pump and the generator as well as the compressor for the pneumatic brake system.

Fig. 2/9 shows the complete crank drive system of a four−cylinder engine.

## 2.4. The engine timing system

The timing system of the engine controls the gas exchange in a combustion engine.

Fig. 2/10 shows the timing system of a four−stroke engine with valves. This type of motor timing is the valve timing system. The valve timing system consists of the following components:

- Valves with valve springs
- Transmission components
- Camshaft.

In engine production conical valves are used. The valve disc is connected with a valve stem in the top of which there is a circular groove. It protects the spring plate from displacement. The spring plate is keyed. The springs are required for pressing the valve disc into its seat and to seal the oil gallery and the combustion chamber. Valve stems must be aligned accurately. Since they are prone to wear, which prevents accurate timing, they can be replaced. The valves are not only exposed to mechanical wear, but also to high thermal load as they extend into the combustion chamber.
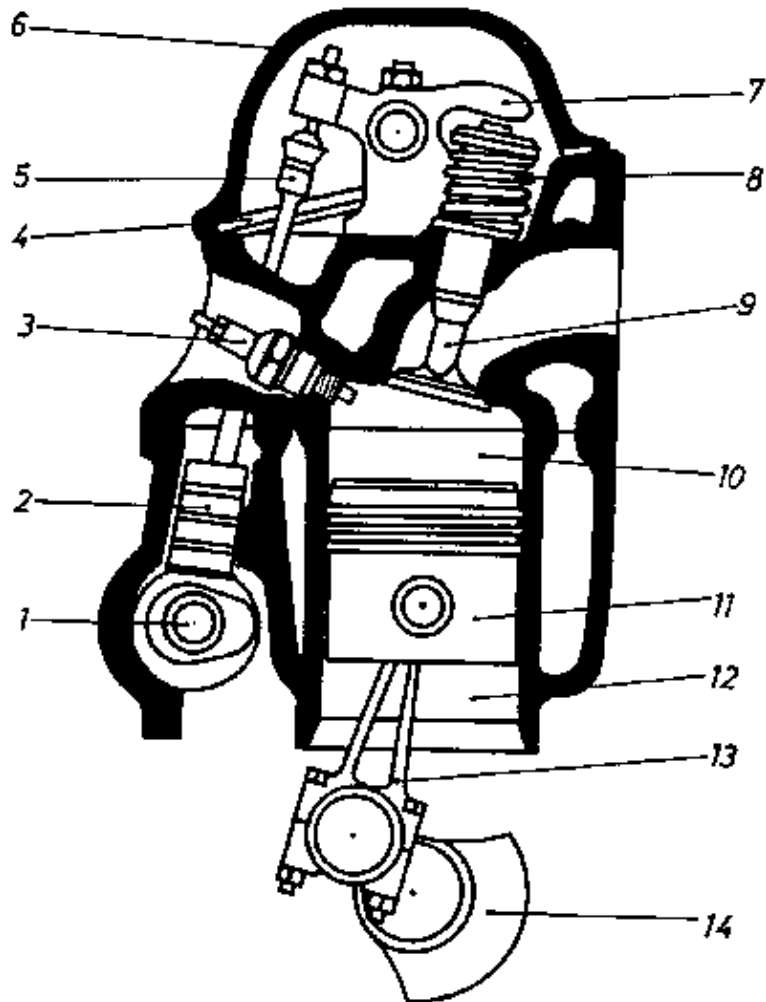
Figure 2/10 Engine timing

1 Camshaft; 2 Tappet; 3 Spark plug; 4 Cover seal; 5 Push rod; 6 Valve cover; 7 Rocker arm; 8 Valve spring; 9 Valve; 10 Combustion chamber; 11 Piston, 12 Liner; 13 Connecting rod; 14 Crankshaft

This is especially true of the outlet valves because they are surrounded by the hot gases during opening, whereas the inlet valve is constantly cooled by new gases during the inlet process. Helical springs are often used as valve springs.

Another type of motor timing is roller–type <u>slide valve</u> timing. By turning the roller–type slide valve, the intake and outlet passages are opened.

The transmission components of the engine timing system include:

  – camshaft located near the crankshaft:

    • valve tappet
    • push rod
    • rocker arm;

  – overhead camshaft:
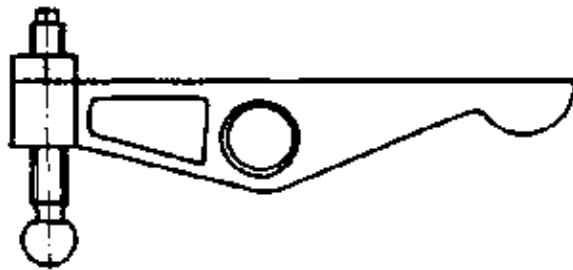
    • rocker arm (Fig. 2/11)

Figure 2/11 Rocker arm

The camshaft can be driven by the crankshaft in various ways. Fig. 2/12 shows the drive of an overhead camshaft by means of a timing chain.
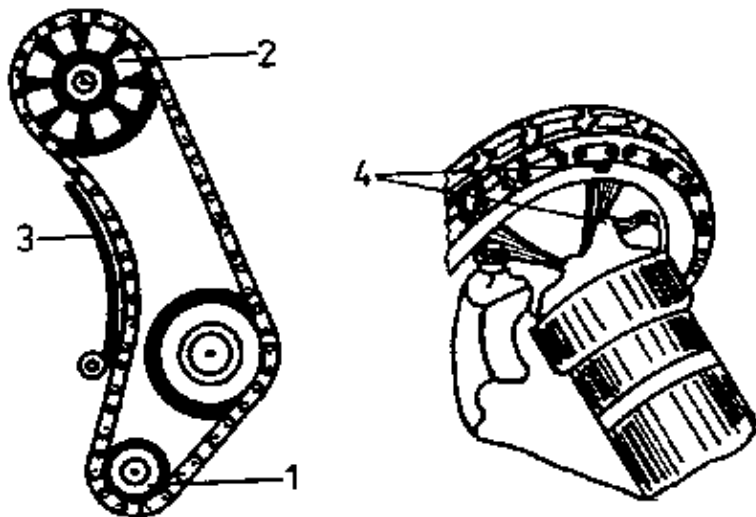


Figure 2/12 Drive of an overhead camshaft by means of a timing chain

1 Crankshaft; 2 Camshaft sprocket wheel; 3 Timing chain tensioner; 4 Timing chain marks for adjusting the camshaft

The figure also shows the marking for correct setting of the camshaft. Fig. 2/13 shows the drive of the camshaft located near crankshaft by a toothed belt. There is also a mark on the cylinder head for correct setting of the camshaft. In the case of large engines, the camshaft is driven by means of spur gears. They are also marked. If the markings do not agree, the timing is wrongly set and the engine will not run. Fig. 2/14 shows a diagram of the timing gears.
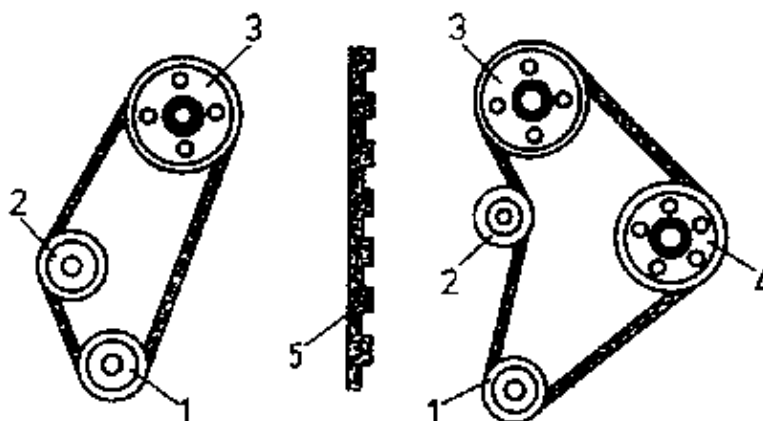


Figure 2/13 Drive of an overhead camshaft by means of a toothed belt

1 Crankshaft; 2 Tightening idler; 3 Camshaft sprocket; 4 Injection pump; 5 Profile of the toothed belt
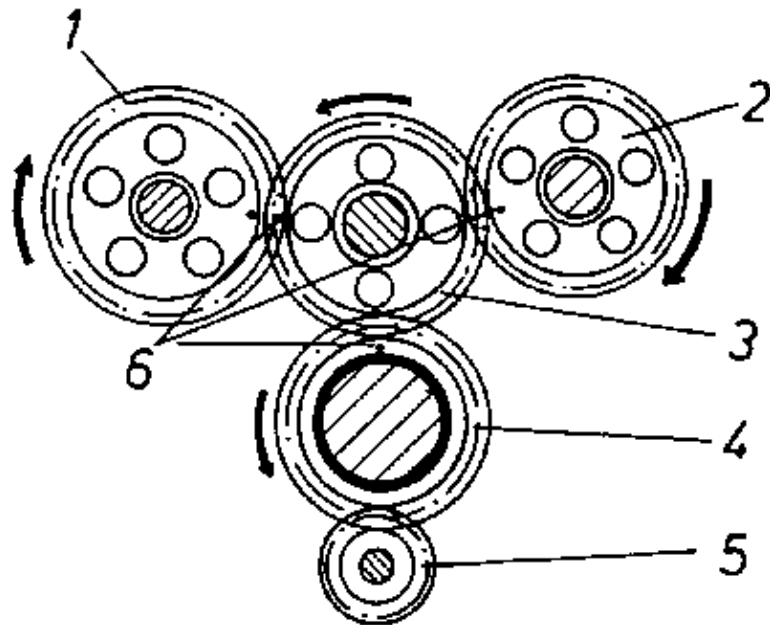
Figure 2/14 Layout of timing gear

1 Camshaft sprocket; 2 Injection pump gear; 3 Intermediate gear; 4 Crankshaft; 5 Drive of oil pump; 6 Timing chain marks for adjustment

The engine timing system with valves uses either vertical valves or overhead valves.

Fig. 2/15 shows the engine timing system with vertical valves. Here the valve stem is seated on a setting screw which extends into a valve tappet. There are two types of vertical valves: vertical valves and side valves. An engine with side valves is also called an sv engine.
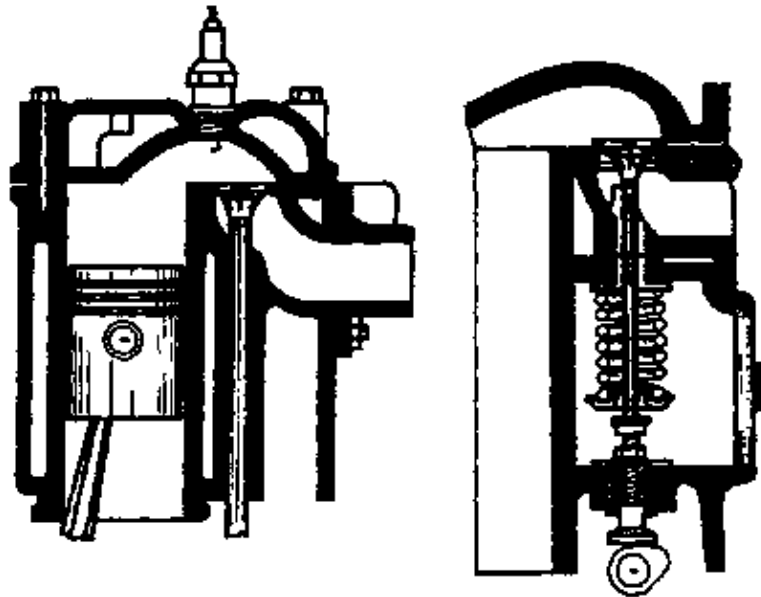


Figure 2/15 Engine timing by means of vertical valves

Another type of engine timing is the timing system with overhead valves. Fig. 2/16 shows the arrangement of overhead valves with an overhead camshaft and with a camshaft located near crankshaft. The latter is known as ohv (overhead valve) timing. However, overhead valves can also be controlled by an overhead camshaft. This can be done in two ways: by transmission of the movement to the valve by the rocker arm, and by transmission of the movement by direct impact of the cams on the valve stem. When the valves are driven directly by the cams, it is called ohc (overhead camshaft) timing.
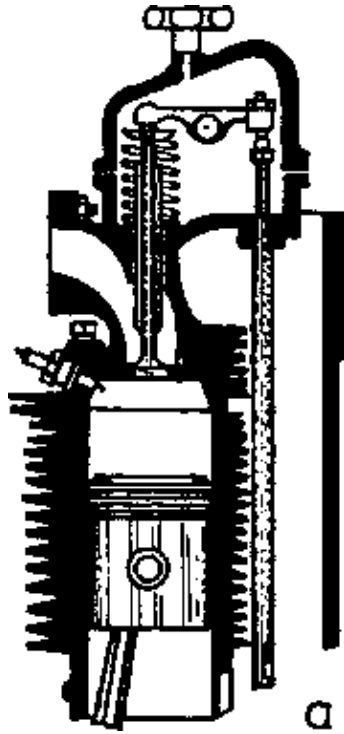
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Figure 2/16 Engine timing by means of overhead valves – with camshaft located near the crankshaft
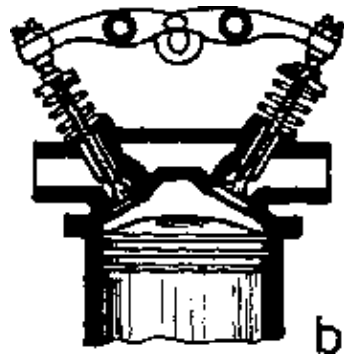


Figure 2/16 Engine timing by means of overhead valves – with overhead camshaft

The correct valve clearance is set by means of the setting screw provided on the rocker arm (Fig. 2/17).

The camshaft allows valve movement. Around the circumference there are curved raised sections called "cams". Their number is always equal to the number of valves. The valves can be lifted abruptly of smoothly. This is also true of the closing procedure. Valves which are lifted abruptly have a higher efficiency, but wear much more quickly. However, abrupt lifting and closing will always depend on the shape of the cam.
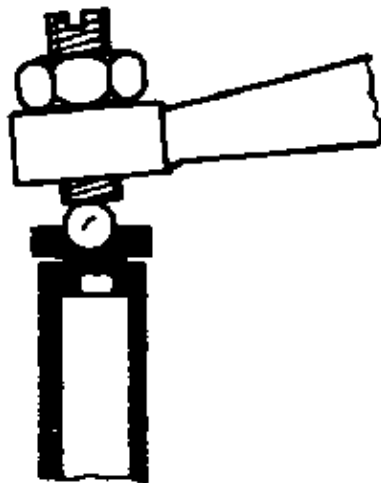


Figure 2/17 Setting screw for valve clearance

The relative position of the cams on the camshaft depends on the working sequence of the individual cylinders.

The camshaft is driven by the crankshaft. It is supported in slide bearings or antifriction bearings to prevent bending during operation. The camshaft is lubricated in connection with engine lubrication.

There must always be a clearance between the transmission parts and the valve stem, i.e. valve clearance. This clearance is specified by the manufacturer.

Fig. 2/18 shows these valve clearances. They can by set in various ways.

The most common of these is the setting of the clearance by means of a screw. Another method is the use of adaptors. The valve clearance is necessary both to compensate for thermal expansion and to ensure proper and safe closing of the valves.
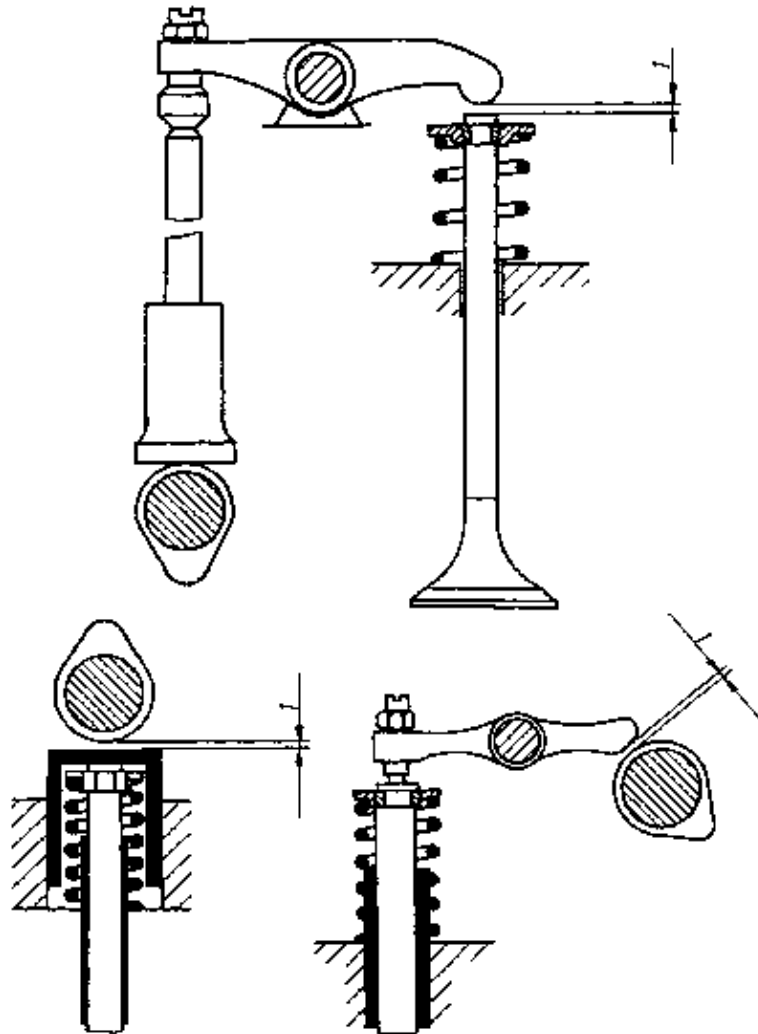
Figure 2/18 Valve clearances for various valves

       1 Amount of clearance

If there is no clearance, signs of burning may appear on the valves, engine output will decrease and blow/back into the carburettor may occur. The valve clearance can either be the same for both the intake and the outlet valve, or it can be larger for the outlet valve than for the intake valve.

Test questions

2.1. Describe the design of a reciprocating– piston engine.

2.2. What do you understand by a reciprocating–piston engine?

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2.3. What does the crank mechanism consist of?

2.4. What do you understand by top and bottom dead centre?

2.5. What do you understand by the term combustion chamber?

2.6. Describe the design of a cylinder.

2.7. What do you understand by the stroke volume?

2.8. What do you understand by the terms wet and dry liner?

2.9. Why is a gasket inserted between cylinder head and cylinder block?

2.10. Why does the thickness of the cylinder head gasket effect the compression ratio of the engine?

2.11. What is the cause of cylinder wear?

2.12. What are the functions of the crankcase?

2.13. What are the functions of a piston in an engine?

2.14. What demands are made of a piston?

2.15. Explain the design of a piston.

2.16. What are the functions of the piston rings and the oil scraper rings?

2.17. What is the function of the gudgeon pin?

2.18. What types of gudgeon pin support do you know?

2.19. What is the function of the connecting rod in a combustion engine?

2.20. Why is it necessary to square the connecting rod?

2.21. What types of bearings for connecting rods do you know?

2.22. Describe the design of a crankshaft.

2.23. What do you understand by the terms crankshaft bearing and connecting rod big end and small end bearing?

2.24. What is the function of the main bearing?

2.25. What do you understand by the term four–stroke engine?

2.26. What do you understand by the term two– stroke engine?

2.27. Why is it necessary to balance crank shafts?

2.28. What is the function of a flywheel?

2.29. Why are torsional vibration dampers used in large engines?


## 3. Mode of operation of the Otto engine

The following section deals with the mode of operation of the Otto engine.

There are two types of Otto engines: four-stroke and two-stroke engines. With regard to their combustion the two engine types have the same mode of operation, however, in the case of the two-stroke engine, the combustion process is condensed to two rotations of the crankshaft. The outer shape of the engines is also similar.

Their main difference is the charging and discharging process. In the case of the four-stroke engine, these processes are controlled by valves while in the two-stroke engine they are controlled by the power piston.

### 3.1. The four-stroke engine

The four-stroke engine works in 4 working strokes. These strokes are shown in Fig. 3/1.
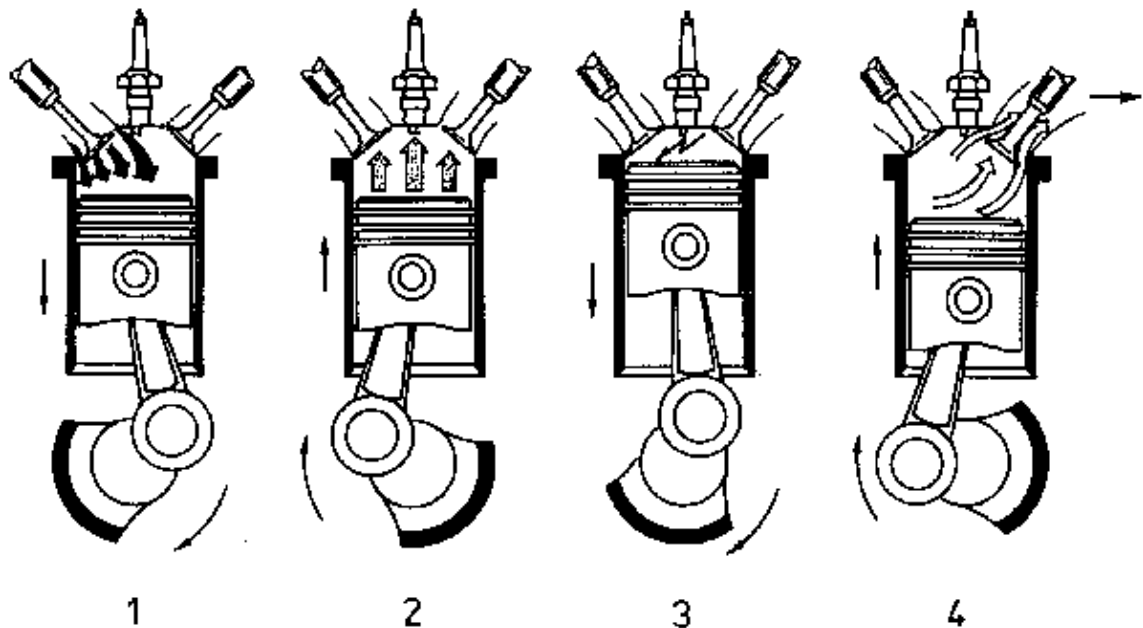


Figure 3/1 Working cycles of the four stroke engine

1 Induction stroke; 2 Compression stroke; 3 Power stroke; 4 Exhaust stroke

The individual working strokes have the following functions:

– Suction = The intake valve is open. The piston moves towards bottom dead centre.

During this process the fuelair mixture is let in from the carburettor through the intake passage. When this process is finished, the intake valve closes again.

– Compression = Both valves of the cylinder are closed. The piston moves towards top dead centre. The fuel-air mixture will be compressed. When the piston reaches top dead centre, the degree of compression is highest. The connecting rod passes the top dead centre and enters into the downward arch.

– Ignition = Having reached its highest degree of compression, the mixture is ignited by an electric spark generated by the spark plug. The piston is pressed in the direction of the bottom dead centry be the released energy.

– Exhaust = When the piston moves back in the direction of top dead centre, the exhaust valve opens and the burnt gases are discharged.

In the Otto engine, the fuel-air mixture is ignited by an electric high-tension spark (approx. 13 000 to 15 000 Volts). This is called 'externally supplied ignition'. Therefore, this engine requires an ignition system.

The processes mentioned above last for only a fraction of a second in which short period of time, the charging and discharging process in the cylinder must have finished. In order to achieve proper charging and

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discharge, the valves are set so that they do not open or close directly in the dead centres. There is an overlapping of valve times.

When the inlet valve begins to open, the exhaust valve is still not fully closed. These timing cycles differ for individual combustion engines and are fixed by the manufacturer.

The timing cycles are in close relation to the crank circle and are marked in angular degrees on the flywheel or the V-belt pulley. This is to ensure that when the engine is overhauled the camshaft can be re-set. The timing cycle fixed for every engine ensures the highest output and efficiency possible. However, this requires that the valve clearance specified by the manufacturer be maintained exactly. The manufacturer also specifies whether this clearance is to be set when the engine is cold or when it is warm. A feeler gauge is used for setting the valve clearance. The feeler gauge should be inserted between valve stem and rocker arm or cam so that it can still be moved slightly.

## 3.2. The two-stroke engine

In the case of the two-stroke engine, the relatively complicated timing mechanism of the valves is not required. However, for this type of engine the crankcase must be well sealed as intake and precompression occur in it. In principle, there are two types of timing used today?
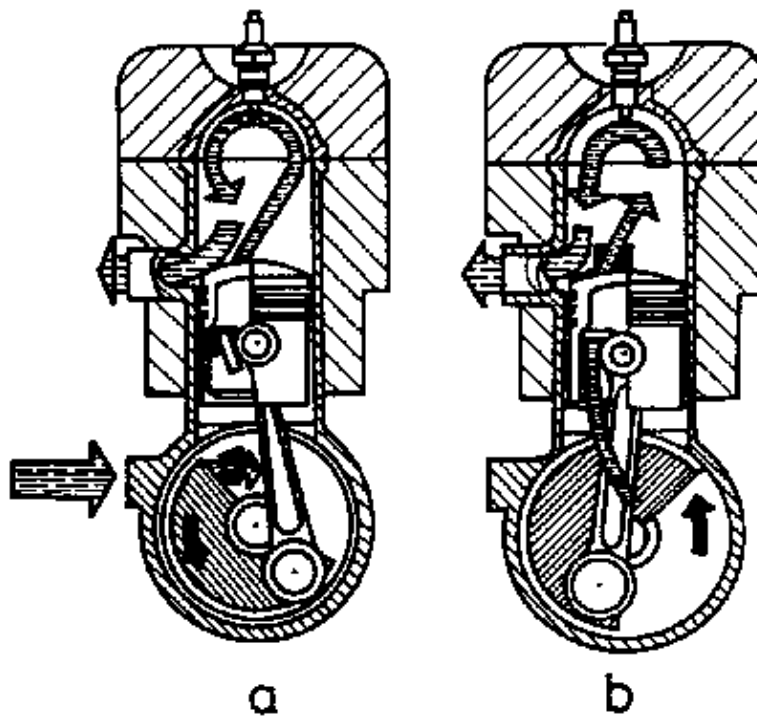


Figure 3/2 Timing by rotary slide valve

1 Inlet, overflow and outlet ducts uncovered
2 Inlet duct covered by rotary slide valve

– Rotary slide valve control
– Loop scavenging.

Fig. 3/2 shows the principle of rotary slide valve control.

When the fuel-air mixture has been ignited, the piston approaches bottom dead centre. The intake port is still closed by the rotary slide. When the piston has passed this point and the upward movement has begin, the exhaust port, the transfer port and the intake port are uncovered. When the piston moves upward, the fresh air mixture is taken into the crankcase and compressed. As a result the piston is pressed down and the mixture flows through the transfer port into the combustion chamber. Since transfer port and exhaust port are open at the same time, some of the fresh gases are discharged again. Due to the scavanging effect, the burnt gas is pressed out of the combustion chamber again and at the same time the intake port is covered by the rotary slide. When the loop scavanging principle is used there is no rotary slide (see Fig. 3/3). The fuel-air

mixture is not taken in directly by the crankcase. During the ignition process, the lower control edge uncovers the intake port. The suction developing there takes the mixture into the crank−case and precompresses it. Then the intake port is covered by the piston while the exhaust port and the transfer port are uncovered by the upper control edge. The transfer port connects the crankcase with the combustion chamber.
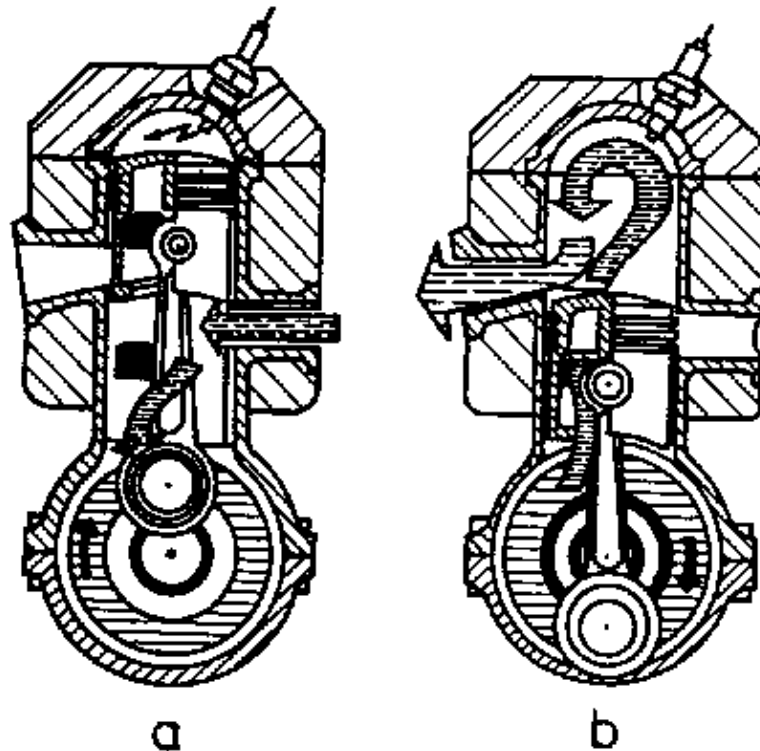


Figure 3/3 Loop scavenging

1 Ignition procedure, inlet duct opened;
2 Inlet duct closed; out let duct and overflow duct opened

Acavanging starts again. The burnt gases are pressed out of the engine.

In order to combat the scavanging losses, which are relatively high, and to ensure better charging of the two−stroke engines, a charging pump can be used. It operates in a special cylinder and can be driven directly or indirectly by the crankshaft. Such a charging pump operates on the principle that its piston does the intake timing. It is used, for example, in racing engines in order to increase the output of the engine.

### 3.3. The fuel system of the Otto engine

It is the function of the fuel system to produce the fuelmixture and to supply it to the cylinder in the quantities required.

#### 3.3.1 The carburettor

The carburettor mixes the liquid fuel with the required quantity of air and converts it into a flammable fuel−air mixture. The air flowing through the carburettor is atomized and is not converted into the gaseous state until it is in the cylinder. The oxygen required for combustion is present in the air taken in Fig. 3/4 shows the design of a carburettor. In the intake duct there is a nozzle which is connected to the float chamber. Due to the accelerated intake of air, the fuel is drawn from the nozzle and flows into the combustion chamber in a atomized state. The intake duct can be in various positions. Fig. 3/4 shows the principle of the updraught carburettor.
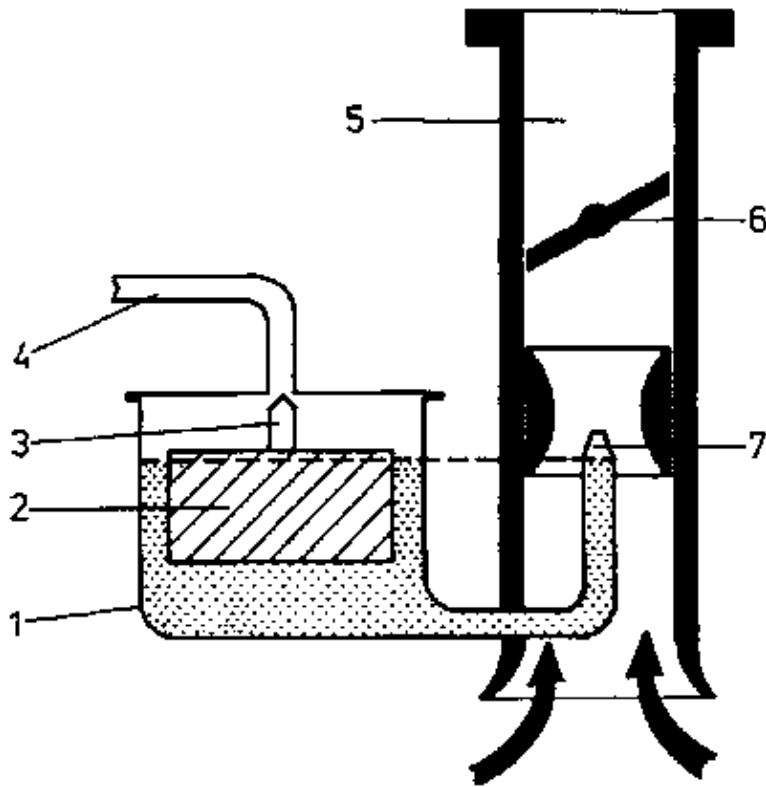
Figure 3/4 Design of the carburettor (updraught carburettor)

1 Float chamber; 2 Float; 3 Float needle valve; 4 Fuel inlet; 5 Intake port; 6 Throttle valve; 7 Jet; 8 Intake air
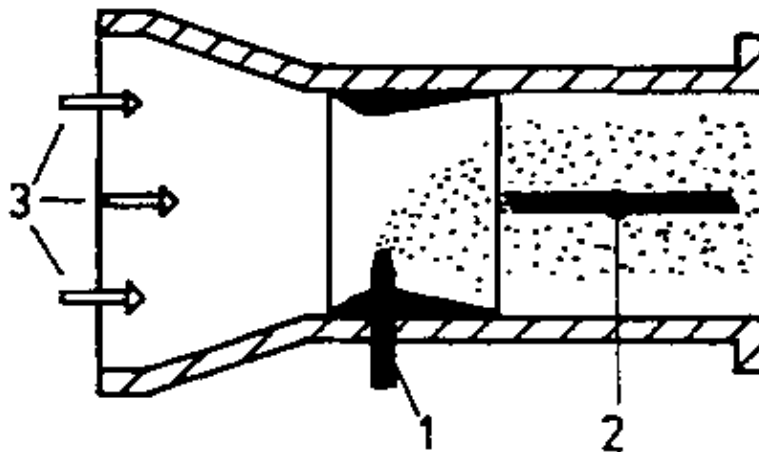


Figure 3/5 Horizontal carburettor

1 Jet; 2 Throttle valve; 3 Intake air

Fig. 3/5 shows a cross–draught carburettor. In the case of an updraught carburettor, the intake pipe is arranged in a vertical position, while in the cross–draught carburettor it is arranged horizontally.

Every carburettor has a reservoir, called the float chamber. This chamber houses the float with the float needle valve. The float is a very light hollow body through which the fuel is carried. This flow actuates a float needle valve which controls the fuel intake. If the fuel level in the float chamber decreases, the valve opens and the fuel flows in until it reaches level at which the valve closes. The float must always be tight so that no fuel can get into it. Otherwise it will sink in the petrol, the float needle valve could no longer operate and the float chamber would overflow.
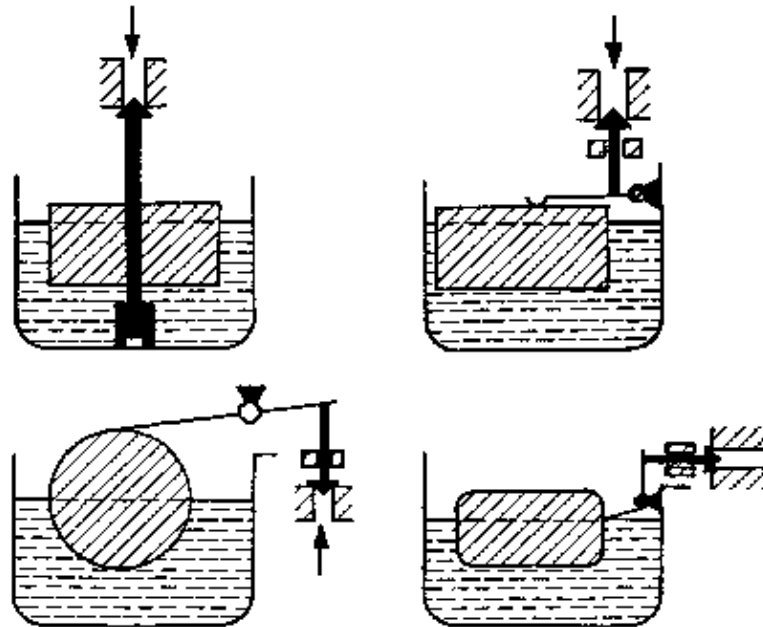
Figure 3/6 Methods of actuating the needle valves

Fig. 3/6 shows various possibilities of actuating float meedle valves.

In order to increase the flow rate of the air taken in, the suction pipe is narrowed at the height of the nozzle by a venturi tube. Above the venturi tube in the suction pipe a butterfly valve is mounted. In its home position, the butterfly valve covers the venturi tube. By means of the accelerator pedal, the butterfly valve can be adjusted infinitely as far as the fully opened position.
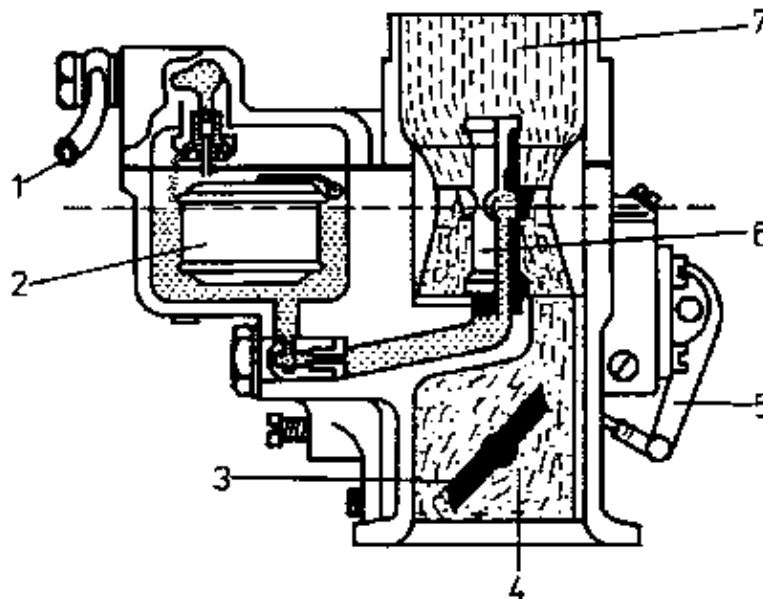


Figure 3/7 The carburettor

1 Fuel inlet; 2 Float; 3 Throttle valve; 4 Carburation; 5 Throttle linkage; 6 Jet; 7 Intake air

Fig. 3/7 shows a diagram of a complete carburettor system. To supply the engine with sufficient fuel in all speed ranges <u>compensating equipment</u> is required.

The compensating equipment is to ensure that the engine is supplied a mixture low in fuel when the speed is low and a mixture high in fuel when the speed is high. This compensating equipment differs from carburettor to carburettor. However, all compensating equipment should ensure the right coordination between the compensating jet, the main jet and the venturi tube. The aim is to achieve low fuel consumption, good acceleration and high performance.

Every carburettor has an <u>idling system</u> to allow the engine to run even when the butterfly valve is almost closed. If an engine is idling, a high air speed will only occur at the butterfly valve, which is almost fully closed,

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and the suction tube wall. This causes a strong air current. There is a small bore at this point which controls the throughput of the fuel by an idling jet. A special duct connects the float chamber with the idling jet. If the engine is accelerated and the butterfly valve opened, the effect of the idling system decreases to a complete standstill. This state is reached when the speed of the air in the venturi tube is higher than that at the butterfly valve.

In order to ensure good acceleration, i.e. trouble−free transition from idling to full load, the carburettors are equipped with an accelerator pump. A small amount of the fuel is injected into the venturi tube through a special passage. The accelerator pump is actuated by the shaft of the butterfly valve.

If the engine is cold, the fuel from the idling system is not sufficient to ensure the safe start of the engine. Due to the low speed during starting, the underpressure in the carburettor systems is too low.

When the outside temperatures are low, the relatively low speed is further decreased as the friction losses in the combustion engine are also increased by the viscous oil. The fuel then fed in small quantities is deposited on the walls of the suction tube and the combustion chambers are not filled. This means that the air in the individual combustion chambers contains insufficient fuel to obtain a flammable fuel−air mixture. To overcome this problem, every carburettor was an auxiliary starting carburettor system.

An air choke, usually located upstream of the carburettor, throttles the intake air during the starting process, thus generating an underpressure which produces an oversaturated mixture.

When the choke is closed the auxiliary equipment, which is called the auxiliary starting carburettor, supplies the mixture which is free of fuel upon actuation of a lever. When actuated, air chock or auxiliary starting carburettor consume a great amount of fuel. When they are actuated for too long, the oil will be diluted, resulting in decreased lubricity. Therefore it is necessary to close the starting carburettor or the air choke again as soon as the engine is running.

Today there is a growing tendency to use automatic starting systems in motor vehicles. They are the equivalent of chokes or auxiliary starting carburettors, however, they are automatically actuated by in−built components which are heatsensitive. These can be bimetal fibres or thermostatic elements. They can be heated by switching on the ignition, by the cooling water or by the exhaust gases. When the system is sufficiently heated, the starting carburettor will be closed after a particular period of time.

### 3.3.2 The fuel supply system

The explanation above is based on the presumption that sufficient fuel is present in the carburettor. This section explains the way in which the fuel reaches the carburettor. There are two systems:

  – gravity petrol system
  – fuel feed system

The gravity petrol system is the easiest way of feeding fuel to the carburettor. The tank is located above the carburettor and due to the forces of gravity, the fuel runs down into the carburettor. This type of fuel supply is mainly used in twowheeled vehicles or motorcycles. The disadvantage is that the tank must be as close to the engine as possible. Another disadvantage is that the carburettor will overflow if the float needle valves do not close exactly. To prevent serious damage in case of such mal−functions, overflow bores are provided on the housing.

If the carburettor is located higher than the tank, the fuel must be supplied by a fuel supply pump. The fuel supplied in this way is called 'pump−fed petrol'. The fuel supply pumps can be driven either mechanically or pneumatically. Most frequently a diaphragm pump is used, serving at the same time for sealing the supply chamber from the drive casing.

Fuel pumps are driven from the crankcase of the combustion engine. Fig. 3/8 shows a fuel pump with lever drive. This type of fuel pumps in only used in the Otto engine. The diaphragm is moved by a drive pin via a pump lever. The pump lever is moved from the pump shaft by a separate cam on the camshaft. When the diaphragm moves downwards the spring of the diaphragm is tensioned. This process is known as the suction stroke. By releasing the diaphragm spring, the delivery stroke is initiated. During the suction stroke the fuel is let into the pump through a sieve. Here the intake valve is open. When the delivery stroke begins, this valve is

closed and the discharge valve opened. Then the fuel is supplied to the float chamber of the carburettor. The injected quantity corresponds with the load range of the engine.
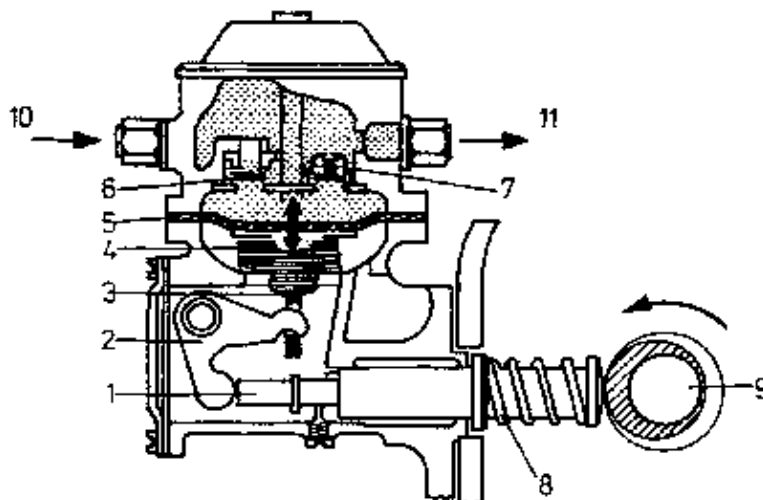


Figure 3/8 Mechanical fuel feed pump

1 Pump shaft; 2 Pump lever; 3 Driving tappet; 4 Diaphragm spring; 5 Diaphragm; 6 Inlet valve; 7 Outlet valve; 8 Return spring; 9 Camshaft; 10 Fuel from tank; 11 Fuel to carburettor

Since two–stroke engines do not have a camshaft, and some of the fuel must still be supplied to the carburettor, a pneumatically driven fuel supply pump is required (Fig. 3/9). On the supply side, it is equipped with the same components as a mechanically driven fuel supply pump. However, this type of pump can cause problems with the injected quantities required, because the driving vibrations are very low. This results in very short diaphragm movements in comparison to mechanically driven fuel pumps. The pneumatically driven fuel pump is driven by the underpressure generated in the crank–case during the suction stroke of the piston. This means that not only is the fuel air mixture taken in, the diaphragm is also moved.

Another type is the electrically driven fuel pump. The advantage of this fuel pump is that the fuel supply starts as soon as the ignition is switched on. The difficulties which might arise with mechanical or pneumatic pumps due to low batteries or the effect of cold do not occur here. Centrifugal pumps, diaphragm pumps or piston pumps can be driven electrically. As is the case in other pumps, the fuel is filtered by an upstream sieve, thus opposing any disturbance in the pumping operation.
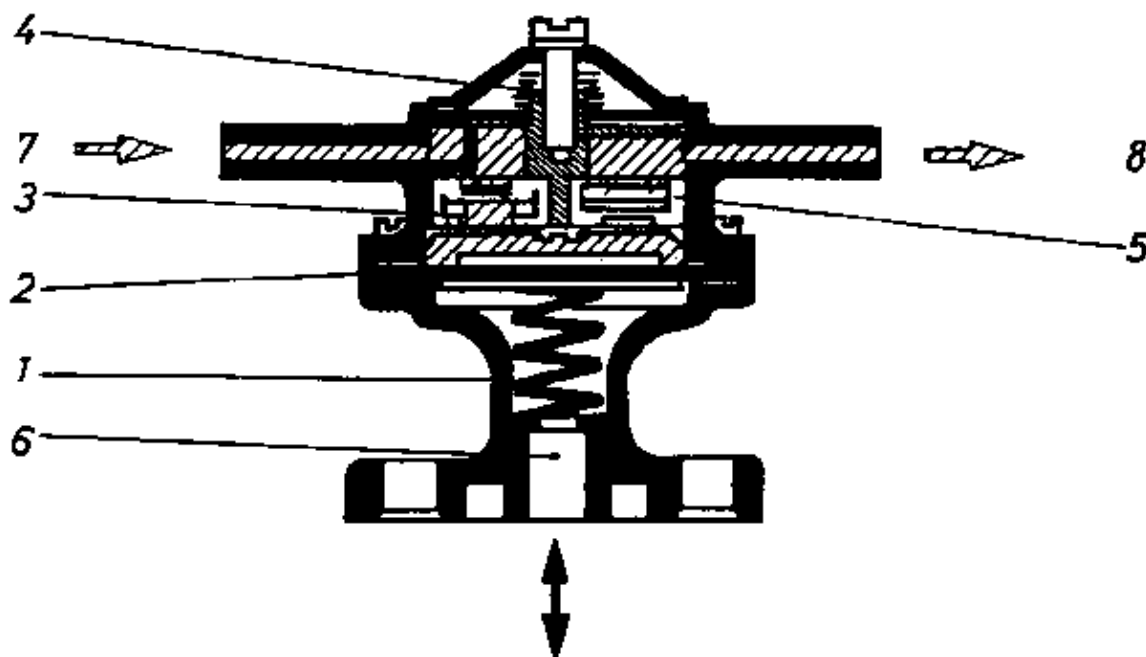


Figure 3/9 Pneumatic fuel feed pump

1 Diaphragm spring; 2 Diaphragm; 3 Inlet valve; 4 Holding spring for screen; 5 Outlet valve; 6 Connection to crankcase; 7 Fuel from tank; 8 Fuel to carburettor

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### 3.3.3 Petrol injection

Besides the formation of the fuel–air mixture in the carburettor, there is also the possibility of petrol injection. In the case of petrol injection, the fuel–air mixture can be produced through internal or external mixing. In the case of internal mixing the fuel is injected into the combustion chamber, while in the case of external mixing it is injected into the suction duct. Petrol injection gives the following functional advantages:

– The suction tube may have a large cross section.

– All cylinders contain almost the same amount of fuel and the composition of the mixture is almost the same.

– Since the composition of the mixture in the cylinders is the same, the compression ratio can be increased and the fuel content of the mixture lowered. This lowering of the fuel content in the mixture is possible for the entire load range of the combustion engine.

– Thus the mixing process becomes in dependent of the flow in the suction tube which results in an immediate response of the engine upon actuation of the accelerator, and smooth acceleration.

– In two–stroke engines this advantage is manifested by the fact the scavanging losses do not cause any fuel losses.

– Also during fuel injection, the crank transmission does not come in contact with the fuel.


### 3.3.4 Supercharging of combustion engines

In an attempt to further increase the output and the efficiency of the engine, the supercharging of engines is becoming more and more important. Supercharging gives the following advantages: decrease in fuel consumption, improvement of torque characteristics and favourable exhaust emission.
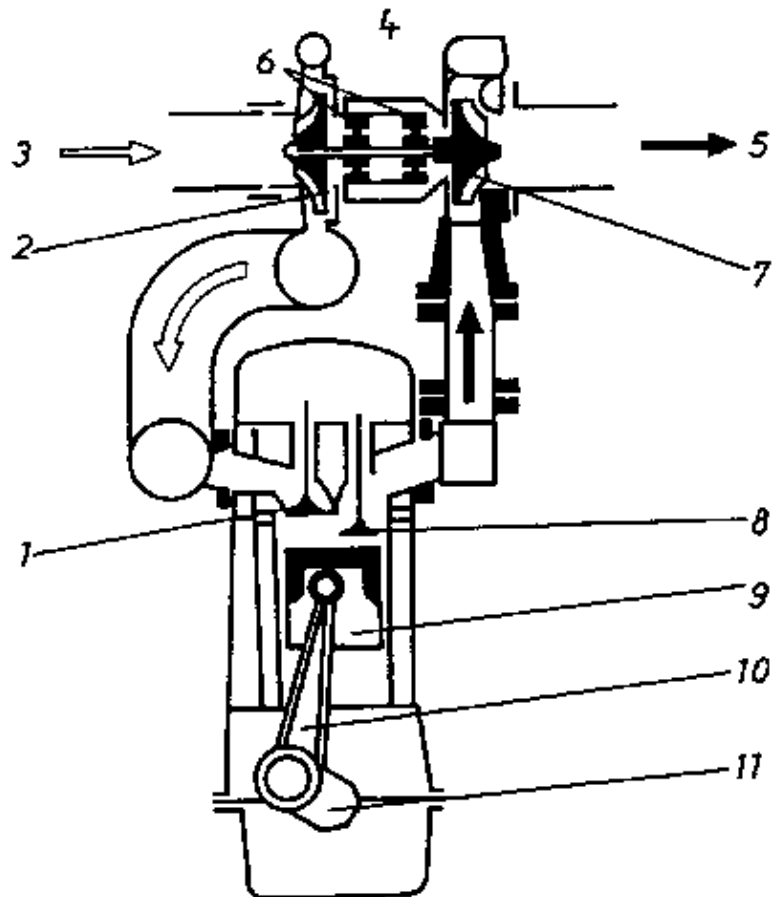
Figure 3/10 The exhaust gas turbo−supercharger

1 Inlet valve; 2 Turbocharger; 3 Fresh−air charge; 4 Turbine; 5 Removal of exhaust gas to silencer; 6 Pillow block; 7 Rotor; 8 Outlet valve; 9 Piston; 10 Connecting rod; 11 Crankshaft

Fig. 3/10 shows the diagram of an exhaust gas turbo−supercharger. The exhaust turbo−charger consists of an exhaust gas turbine and a compressor. The exhaust gas turbine is driven by the discharged burnt gases. This turbine is connected with the compressor by a shaft and causes the latter to rotate. This rotation allows fresh air to be sucked in and accelerated. This process causes pre−compression and thus a greater fresh charge is obtained. The exhaust turbo−charger is not only used in Otto engines, but also in diesel engines.
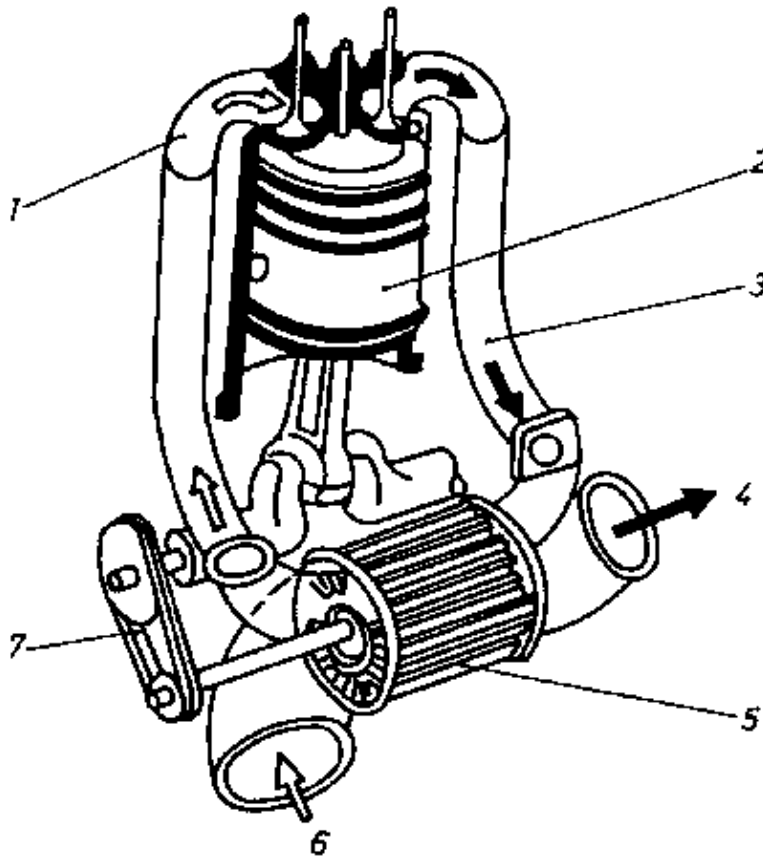
Figure 3/11 The Comprex shock wave supercharger

1 Infeed of charge air; 2 Engine piston; 3 Exhaust gas of engine; 4 Discharge of the relieved exhaust gas; 5 Cellular wheel; 6 Fresh−air inlet; 7 Belt drive

Another type of supercharger is the Comprex−pressure wave charger. Here the turbine is replaced by a cell wheel which is driven by the crankshaft via a vee−belt. In some respects this system of supercharging produces better results than even the turbo−charger. These advantages include improvements in the duration of acceleration and the smoke integral. However, the Comprex−pressure wave charger is used only in some types of diesel engine.

Test questions

3.1. Describe the mode of operation of a four−stroke Otto−engine.

3.2. Describe how the valve clearance is to be set.

3.3. Explain the mode of operation of a two− stroke engine.

3.4. What do you understand by the term timing by rotary slide valve?

3.5. What do you understand by loop scavanging?

3.6. What is the function of the carburettor of an Otto engine?

3.7. What do you understand by a down− draught carburettor and a cross− draught carburettor?

3.8. What is the function of the float? Describe the design and the various possibilities of actuating float needle valves.

3.9. Describe the function of a idling system.

3.10. What do you understand by the terms 'gravity−fed petrol' and 'pump−fed petrol'?

3.11. What is the function of a fuel pump? Describe the design of such a pump.

3.12. What are the advantageous of fuel injection in Otto engines?

# 4. Mode of operation of the diesel engine

The diesel engine, like the Otto engine, is a reciprocating piston engine. The basic design of the two engines is very similar. The following describes the differences between the Otto engine and the diesel engine.

In contrast to the Otto engine, the diesel engine only takes in air which will be highly compressed. The compression heat generated during this process is enough to ignite the fuel injected. Therefore, in the case of diesel engines we speak of self–ignition. The mixture is formed inside the engine. The diesel engine has no carburettor, it is equipped with an injection pump. Due to the self–ignition, there is no electric ignition system required. In Otto engines light oils (petrol) are used for forming the mixture. The diesel engine, however, can use heavy oils (diesel fuel, crude oil and others). In the Otto engine, the formation of the mixture is completed before combustion begins whereas in the case of the diesel engine it can still continue when combustion has begun. The average rated speed of the diesel engine is must lower than the speed of the Otto engine: Otto–engine: 3000 – 6500 $min^{-1}$; diesel engine: 1500 – 3600 $min^{-1}$.

In the diesel engine gears need not to be changed as often as in the Otto engine because the have different torque behaviour. As compared to the Otto engine, the fuel consumption of the diesel engine is relatively low.

## 4.1. Feed pump and filter

Both diesel engines and Otto engines are built in two–stroke and four–stroke models. The following deals with the fourstroke diesel engine. Fig. 4/1 shows the entire fuel system of a diesel engine.

It consists of a tank with level indicator, feed pump, filter combination, injection pump, injection nozzles and lines.

Fig. 4/2 shows the function of the feed pump. Normally it is flanged to the injection pump. and is driven by the camshaft. The piston of the feed pump can be actuated by a lever. The pumping piston is pressed up to top dead centre by a pushrod which is not rigidly connected with it. The fuel is supplied in the direction of the injection pump. This process is called the delivery stroke. Now the piston is moved back towards bottom dead centre by a built–in spring. This is the suction stroke.
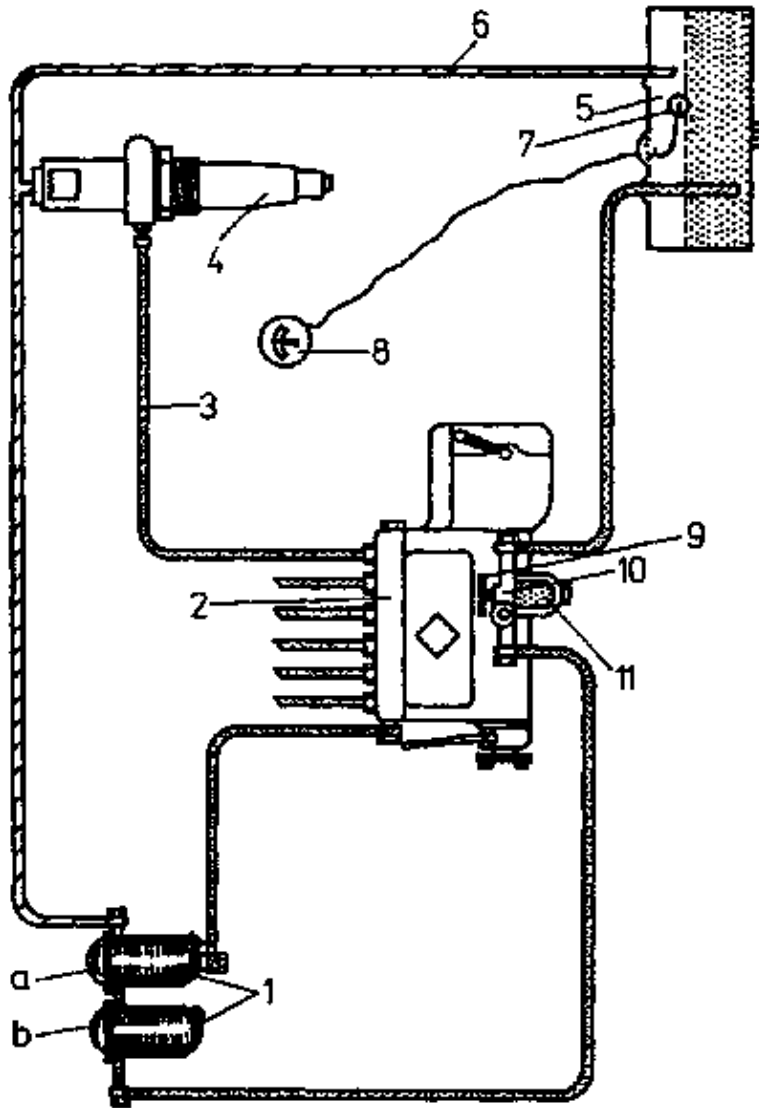
Figure 4/1 Fuel system of the diesel engine

1 Filter combination (a fine filter, b coarse filter); 2 Inject ion pump; 3 Pressure line; 4 Injection nozzle; 5 Tank; 6 Return line; 7 Level indicator; 8 Tank dial; 9 Manual pump; 10 Fuel feed pump; 11 Precleaner with sight glass

The fuel is taken in form the tank. During the delivery stroke, the fuel is circulated in the pump casing. When the counterpressure of the fuel exerted on the bottom side of the piston becomes too high, the pushrod will run free until the counterpressure reduces again.
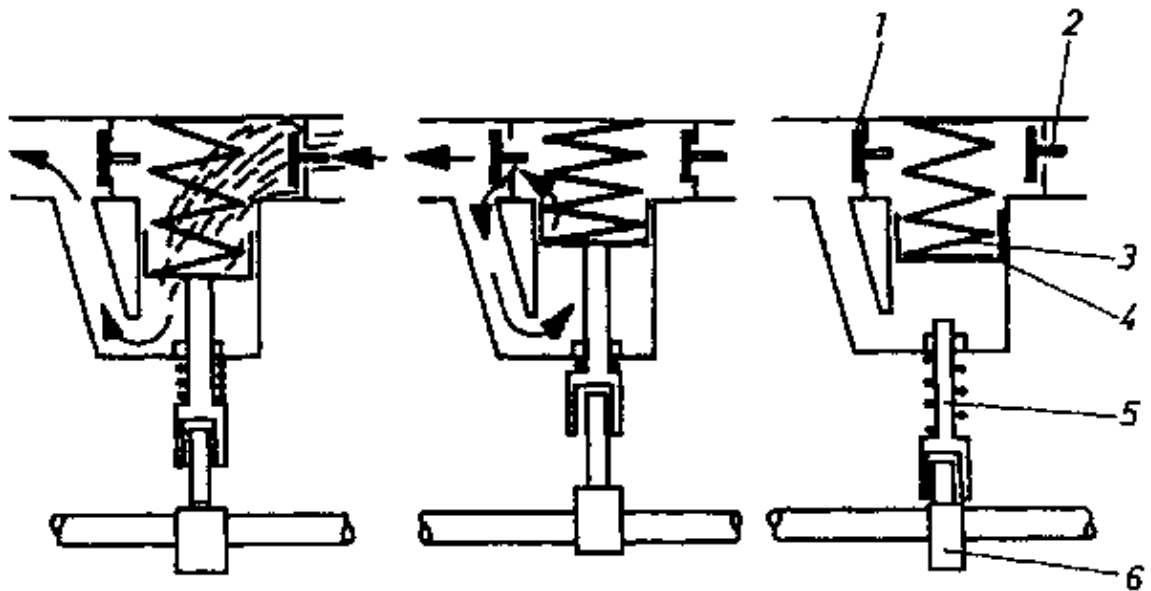
Figure 4/2 Function of the fuel feed pump

1 Pressure valve; 2 Suction valve; 3 Spring; 4 Piston; 5 Tappet; 6 Cam

Thus the injected quantity will always automatically match the consumption and there oversupply is impossible. On the feed pump is a sight glass which contains asieve for impurities.

Now the fuel is pressed through the piping into the filter combination. The fuel filter is located upstream of the injection pump so that no impurities will enter the pump. The filter combination (Fig. 4/3) consists of a pre–filter and a fine–mesh filter. Both are rigidly connected by a channel in the crank–case cover.

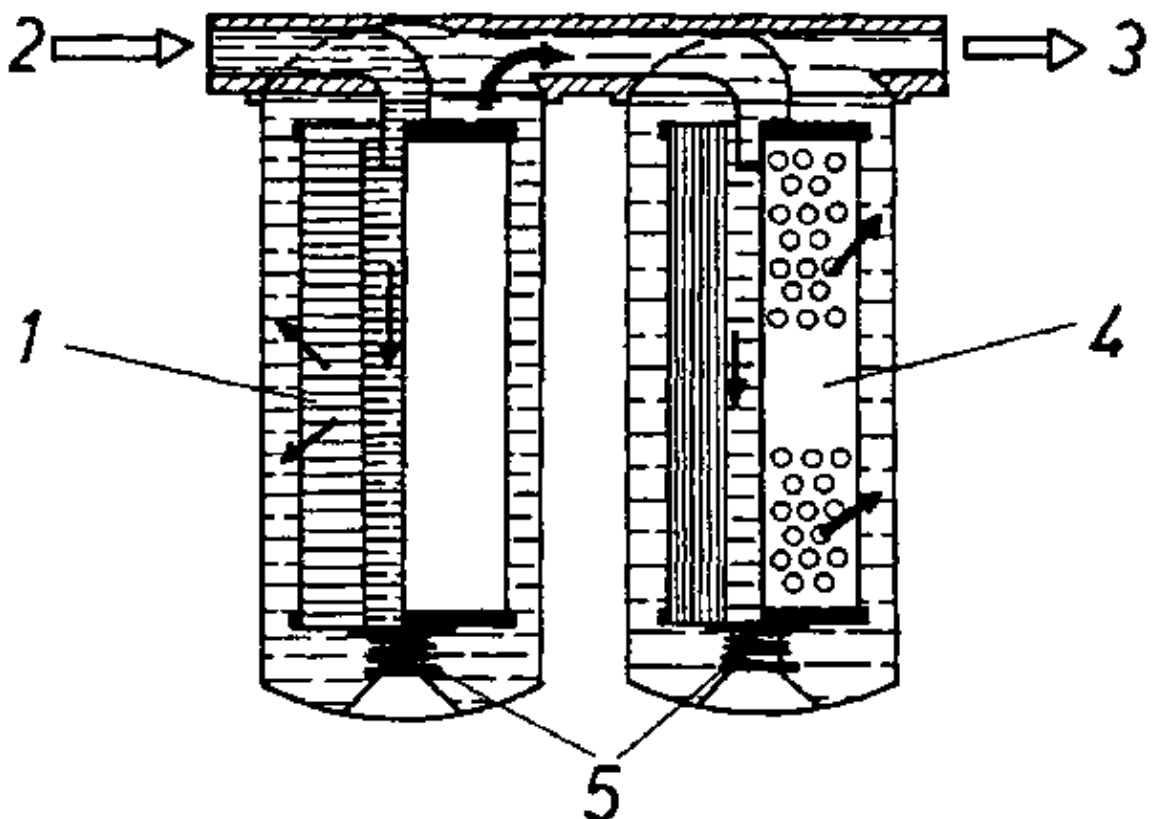

Figure 4/3 Filter combination

1 Prefilter cartridge; 2 Fuel from feed pump; 3 Fuel cleaned to injection pump; 4 Filter cartridge; 5 Compression spring

Moreover, there is an air vent screw and a safety valve in the cover. The safety valve is coupled with a return pipe to the tank. If there is an overpressure in the filter combination, the valve will be opened and the excess

fuel will flow back into the tank.

The filter housing and the cover are bolted together. The filter inserts are located in the filter housing. A felt insert is provided in the rough or pre–filter while a paper insert is placed in the fine–mesh filter. The fuel is pressed from inside through the filter insert into the housing and then flows through a channel into the fine–mesh filter insert. Here again it is pressed from the inside outwards and flows through a pipe to the injection pump. To ensure correct functioning of the injection pump and the injection nozzles, the mechanical purity of the fuel must be guaranteed. Therefore, the filter inserts must be replaced at particular intervals. The lifetime of a filter insert is specified by the manufacturer of the combustion engine. Filter inserts can be washed in fuel. However, filter inserts made of paper must be replaced by new ones.

## 4.2. The injection pump

From the filter combination, the fuel flows into the injection pump and is fed from here under high pressure through the injection nozzles into the combustion chamber. The injection pump contains pump elements, the number of which depends on the number of cylinders, which are accommodated in a light metal housing.

Each individual pump element consists of a plunger and a cylinder. The plunger is moved up and down by a camshaft in the injection pump. To force the plunger back into its home position, a thrust spring is provided. The plunger fits the cylinder exactly so that no special sealing against the cylinder is required, even in the case of very high pressures. The fit ranges from 0.001 to 0.002 mm.

The most commonly used injection pumps are rotary injection pumps.

These pumps have a joint inlet chamber for all pump elements. Each pump element is connected with the inlet chamber by an inlet hole and a back flow hole.
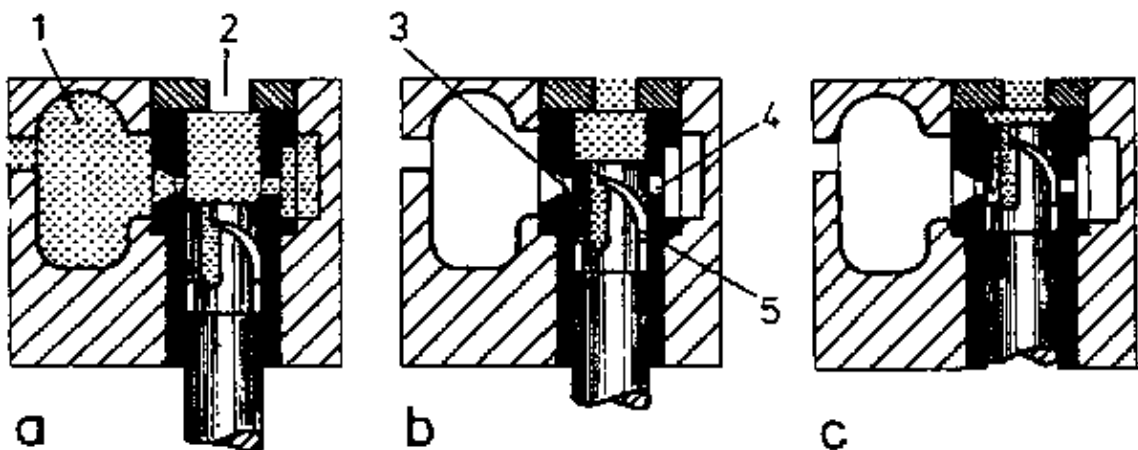


Figure 4/4 Mode of operation of the injection pump

A End of suction stroke; B Beginning of delivery; C End of delivery
1 Suction space;
2 Pressure line;
3 Suction port;
4 Return port;
5 Helix

Fig. 4/4 shows the mode of operation of the rotary piston injection pump. When the plunger is moved downward, fuel is let in through the inlet hole. This process is called the suction stroke. When the plunger is pressed upward by the cam, the inlet hole and the back–flow are covered.

Now the fuel can be supplied under high pressure through the pressure line to the injection nozzle. A pressure valve is provided upstream of the cylinder so that the fuel cannot flow back into the pump element. The plunger has a helix control edge with a vertical groove to allow the volume injected to be changed in accordance with the engine speed. The vertical groove connects the plunger chamber and the room beneath the helix control edge. The fuel is only supplied for as long as the inlet hole and the backflow hole are covered by the plunger.

As the helix control edge passes over the backflow hole, the pressure in the plunger chamber falls. The fuel flows through the vertical groove into the pressure compensating chamber which is connected with the backflow line. The injection time depends on the time the two cylinder holes are covered. The plunger of the pump is connected with a toothed gear which can be turned by a rack, also called the control rod. The further to the right the control rod turns the plunger, the earlier the backflow hole is uncovered by the helix control edge. When the vertical groove reaches the backflow hole, the delivery is zero. (See Fig. 4/5). The delivery always begins at the same time, but finishes at different times, depending on the position of the plunger, so producing the various injection–pump deliveries. The control rod turns all the plungers at the same time, thus setting the effective stroke. The control rod is moved by the accelerator, through in some cases manual control is possible.
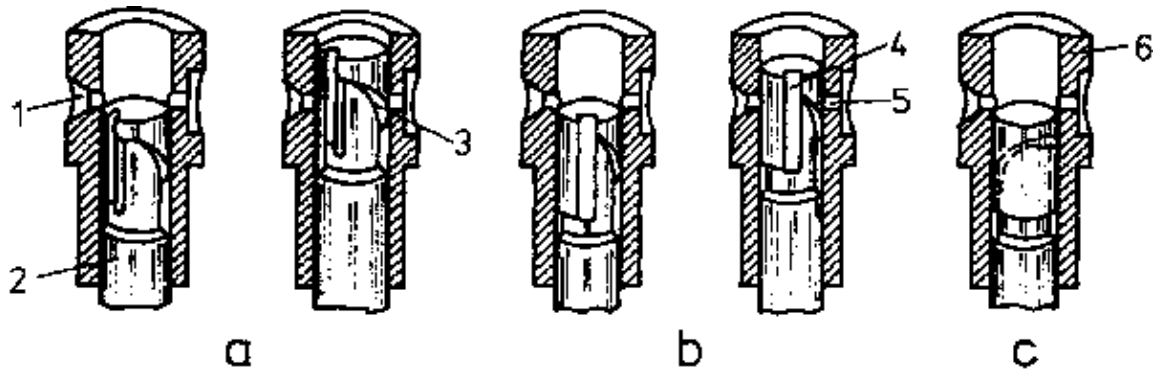


Figure 4/5 Changing the rate of delivery of the injection pump

A Maximum delivery; 3 Half–delivery; C Zero delivery 1 Suction port; 2 Piston; 3 Helix; 4 Longitudinal groove; 5 Return port; 6 Cylinder

Mechanical speed governors are mounted to the injection pump. They can either be mounted upstream of the injection pump or be integrated with it. They are designed as mechanical governors and limit the maximum speed and the idle run of the engine. They consists mainly of two flyweights which are spring loaded. They cause the control rod to be pushed towards stop direction when the speed limit is exceeded. If the speed in idle run falls too much, the control rod is moved towards full load. In the speed range between idle run and maximum speed the governor does not work because the volume injected is controlled here by the accelerator pedal. However, if the maximum speed is exceeded, the governor begins to function again.

The injection pump is driven by the crankshaft, either by timing gears or a toothed belt. Here the power can be transmitted either by a flange or a cross–head coupling. The coupling has a device for setting early or late injection. This corresponds with the ignition control in Otto engines.

## 4.3. The injection nozzle

The fuel is supplied to the injection nozzles by the pumping elements. Their function is to inject the fuel under high pressure in atomized state into the combustion chamber. The nozzle consists of the nozzle body and the nozzle needle. The nozzle needle is pressed onto the valve seat of the nozzle body by a strong spring. On the nozzle needle there is a conical section which fits into the ring–groove. The fuel flows through the bore in the nozzle holder into the ring–groove. When the pressure is high enough to overcome the spring tension, the nozzle needle is lifted and the fuel is fed into the combustion chamber in atomized state. When the delivery stroke is finished, the nozzle needle is pressed into the valve seat by the spring tension. The injection pressure is between 100 and 180 kg/cm$^2$. Various types of injection nozzles are used in diesel engines. The most important ones are shown in Fig. 4/6.
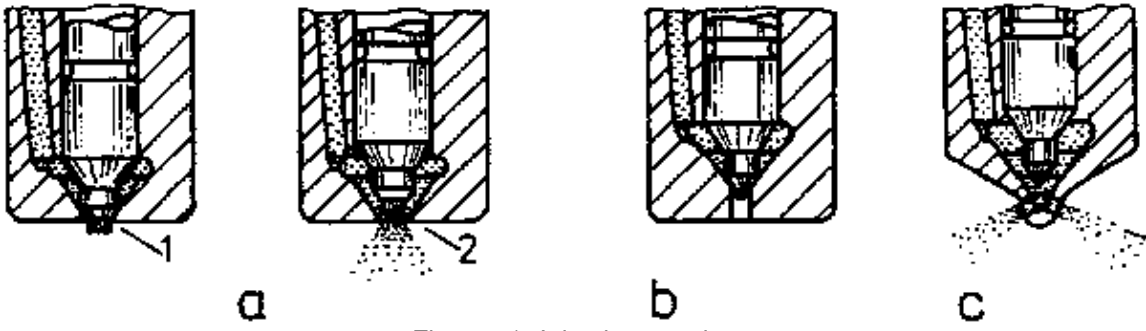
Figure 4/6 Injection nozzles

A Pintle nozzle; 1 opened; 2 closed
B Single−orifice nozzle closed,
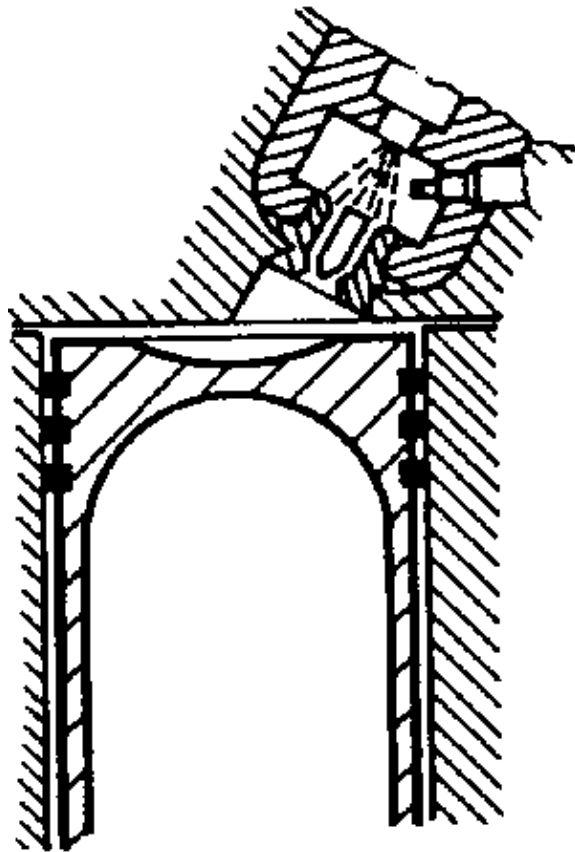C Multi−orifice nozzle opened



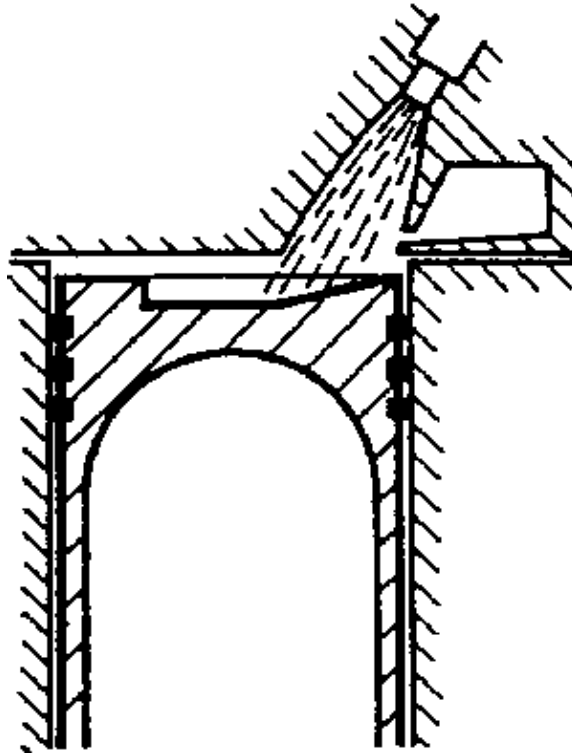Figure 4/7 Pre−chamber process (182/3)
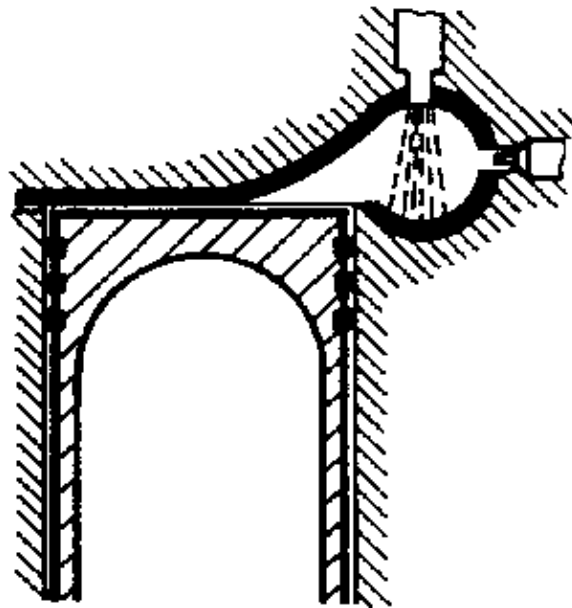
Figure 4/8 Air–chamber process (182/4)



Figure 4/9 Whirl–chamber process (182/2)

The pintle nozzle and the single hole nozzle are used in combustion engines for the pre–chamber procedure (Fig. 4/7), the air–chamber procedure (Fig. 4/8) and the whirl–chamber procedure (Fig. 4/9) as they produce a good turbulence effect. For combustion engines in which the turbulence effect is not so good, multi–hole nozzles are used in order to improve it.

Direct–injection, a special type of fuel injection, has lead to the development of new methods of mixing. A spiral–type intake duct forces the incoming charge to rotate around the cylinder axis. This turbulence flow is continued by the spherical piston recess. In the case of this process, the fuel is injected at top dead centre. Approximately 95 % of the volume injected is deposited as a film at the wall of the combustion chamber and only 5 % is atomized in the air thus starting combustion. Due to the effect of the combustion heat and the turbulence in the combustion chamber, the fuel is evaporated.
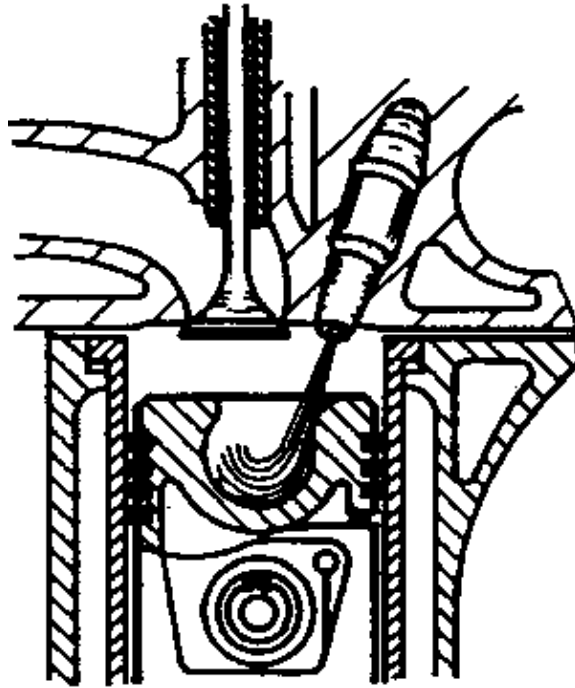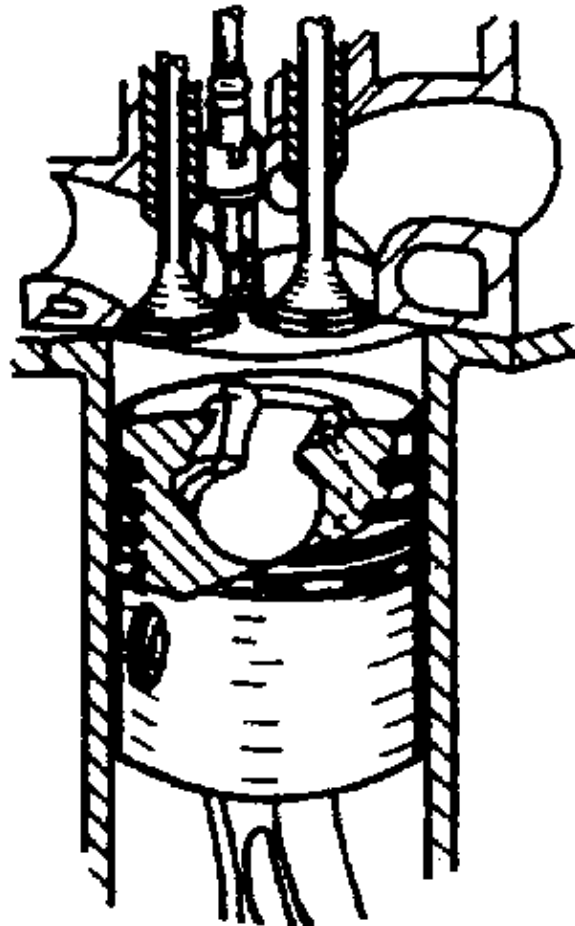
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Figure 4/10 Direct injection process, (182/5)



Figure 4/11 Direct injection process with externally supplied ignition (182/6)

Thus a homogeneous mixture is formed which, controlled by the charging current, is supplied to the flame front (Fig. 4/10). A further development is shown in Fig. 4/11. It meets the requirements of multi−fuel engine. The mixing process is the same as above. However, ignition is not caused by the great compression heat, but by a spark plug which protrudes into the combustion chamber. This engine combines the advantages of both Otto and diesel engines. Due to the use of external ignition, the compression can be kept within the range of self−ignition. Further merits include:

– All types of petrol can be burnt at high compression without causing knocking.

– Efficient operation of the diesel engine is ensured.

– In comparison to the Otto engine, the exhaust gases contain only small amounts of carbon monoxide throughout the entire service range.

The injection nozzles are inserted into a nozzle holder and can be replaced. The thrust spring required to produce the injection pressure is also located in the nozzle holder. The thrust spring can be adjusted. The nozzle holder is connected with the injection pump by a pressure line. The ends of the pressure lines are sealed with sealing cones. There are two ducts in the nozzle holder. One is used to supply the fuel to the nozzle, the other is coupled with the flowback line, and returns excess fuel.

Test questions

4.1. Explain the differences between diesel engine and Otto engine.

4.2. Describe the fuel system of the diesel engine.

4.3. Describe design and function of the fuel pump.

4.4. Explain function and structure of the injection pump.

4.5. Describe the mode of operation of a rotary injection pump.

4.6. What is the function of the centrifugal governor of an injection pump?

4.7. Describe the design and the function of injection nozzles.

4.8. What types of injection procedures do you know? Give some examples.

4.9. What are the merits of the MAN – M – process in comparison with other injection processes?


# 5. Engine lubrication

The combustion engine has a great number of metal surfaces sliding on one another. If metal surfaces slide directly on one another, strong friction occurs, causing excessive heating and high wear. In order to prevent friction a lubricant is used. The lubricant is to form a film on the sliding metal surfaces, thus preventing friction between them (since liquid friction is lower than dry friction) and reducing metal abrasion. The lubricant used in the combustion engine is engine oil which can be of various viscosities. However, the engine oil not only lubricates it also cools and seals the sliding surfaces, e.g. sealing of combustion chamber (piston rings – cylinder wall).

High demands are made of the engine oil. It must always maintain its properties whatever the conditions prevailing in the engine. In the case of high pressures and temperatures, the oil must cool, seal and lubricate. In addition to constant supervision, it is imperative to observe the periodical oil changes specified by the engine manufacturer in order to prevent damage to the engine. Always use the oil specified. In order to. ensure that all moving parts of the combustion engine are constantly supplied with oil it is circulated, and having been cooled and filtered, is supplied to the individual lubricating points. There are three main types of engine lubrication:

– Forced feed lubrication
– Dry sump lubrication
– Petrol lubrication.

Forces feed lubrication

The forced feed lubrication (see Fig. 5/1) is the type of lubrication used most frequently in modern motor vehicle engineering, and is mainly used in four–stroke engines. The oil pump (see Fig. 5/2) which is mainly designed as a gear pump and driven by the crankshaft, supplies the oil through lubricating channels to the

individual lube points of the engine. The oil pan forms the lower end of the engine block. There is a recess in the oil pan which is called the oil sump. The oil screen which is connected to the oil pump extends into the oil sump. The oil passes through the screen to a rotating filter in which, due to its great speed, all floating and abrasive particles are thrown out and deposited on the filter walls. Therefore, the filter must be cleaned at regular intervals.
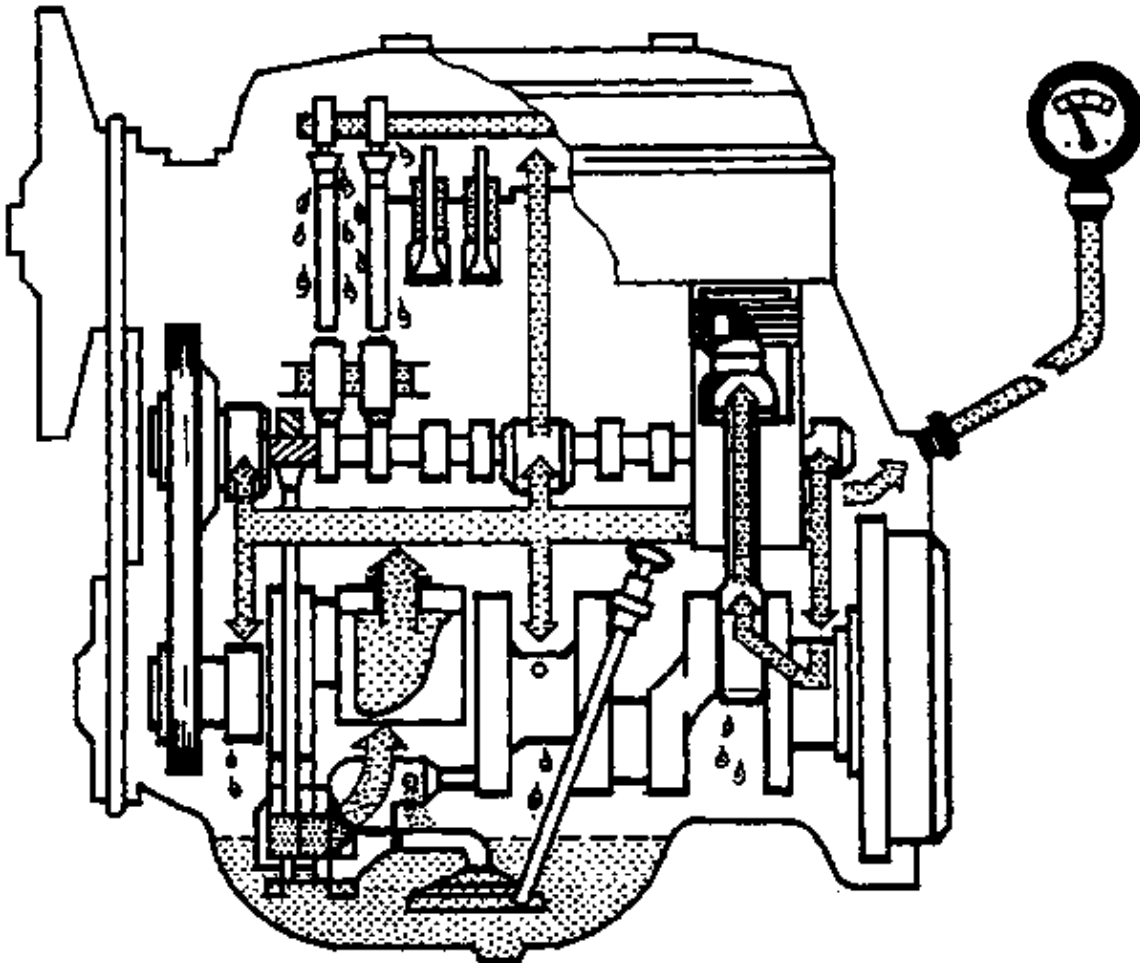


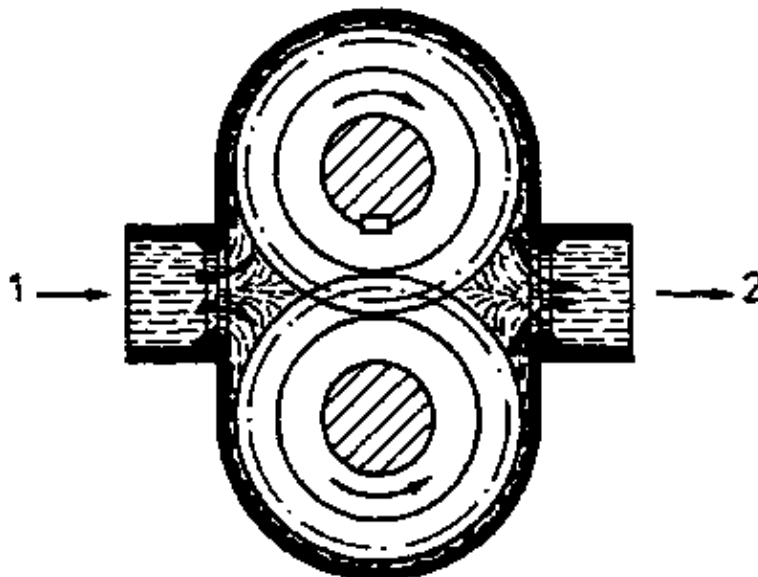Figure 5/1 Force−feed circulation oiling (183)



Figure 5/2 Oil pump

1 Oil coming from oil screen 2 Oil to lubricating points

When the oil has passed through the filter, the pressure carries it to the individual lubricating points through channel systems and oil bores. Modern types of combustion engines have oil coolers in which the oil is cooled

by the air stream and then returned into the oil pan. The oil is cooled so that it maintains its lubricating properties even if temperatures are high.

There is an oil level dipstick at the engine. When the engine is at standstill, it can be used to check the oil level in the oil pan. The oil level dipstick has a minimum and a maximum level mark. If the oil level falls below the minimum mark, it could result in excessive wear and seizure. If the oil level exceeds the maximum mark, however, there will either be severe carbon deposits or the oil will be pressed out of the engine. Therefore, in order to prevent such damage, the checking of the oil level in the engine should be a routine before starting the vehicle. Inside the motor vehicle there are instruments which indicate the oil pressure when the engine is running. These instruments can be either an oil pressure gauge or an oil pressure light.

Dry sump lubrication

Dry sump lubrication (see Fig. 5/3) is another type of forced feed lubrication. Here two oil pumps are used, one of which constantly empties the oil sump and supplies oil to the oil reservoir. The oil reservoir is connected to a second pump which pumps the oil to the individual lubricating points as described above. Both pumps can be accommodated in the same housing and driven by the same shaft. Even if the motor is in a tilted position, dry sump lubrication ensures good oil supply because the oil is not only present in the oil pan. The oil pan can have cooling fins to give better dissipation of heat.
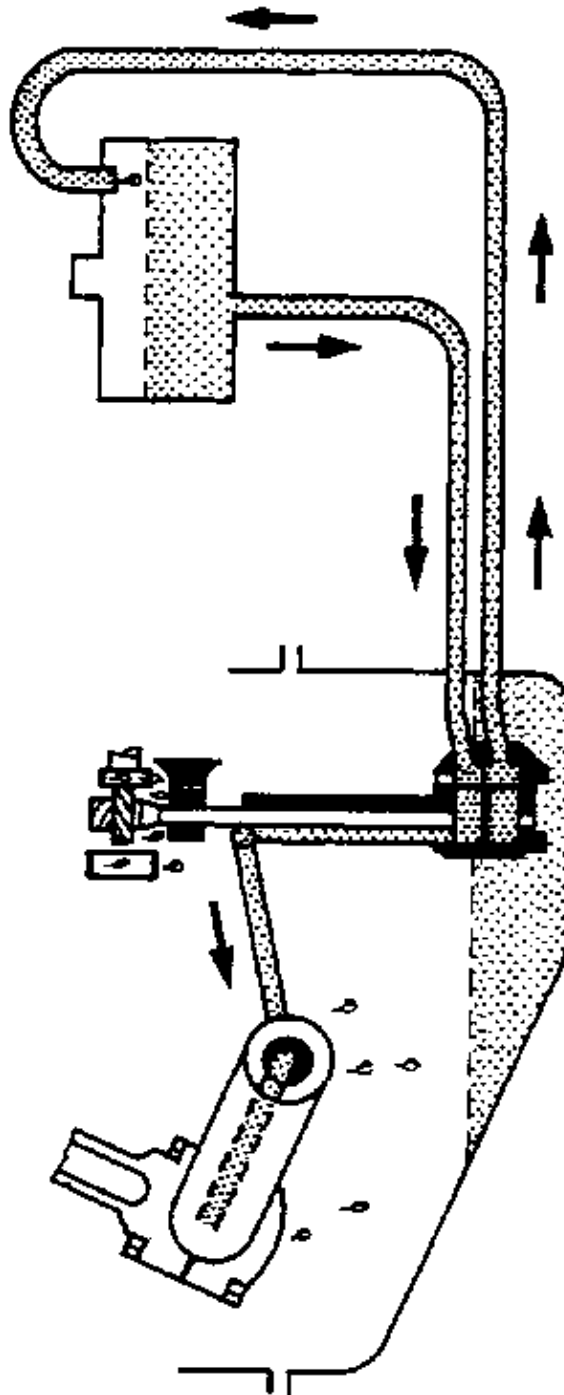
Figure 5/3 Dry sump lubrication (184)

Petrol lubrication

Petrol lubrication (see Fig. 5/4) is the simplest type of engine lubrication. It is only used in two−stroke Otto engines. In this kind of engine lubrication oil and petrol are mixed in a particular ratio. Modern two− stroke engines work with a mixing ratio of 1: 33 or 1: 50.
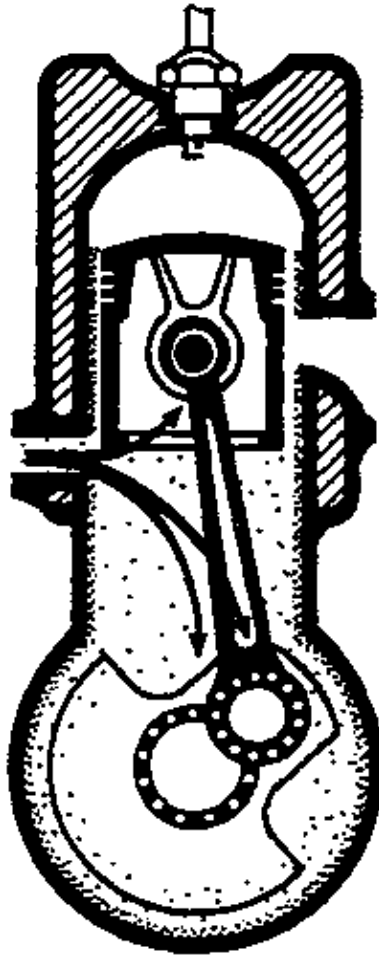
Figure 5/4 Petrol lubrication

1 litre of oil is mixed with 33 litres of petrol. Here, once again, only one particular grade of oil should be used. The oil enters the crank−case with the fuel air mixture, during pre−compression, it is forced out and carried to the individual bearing points such as crankshaft, piston and cylinder liners.

Fresh oil lubrication

Another form of lubrication of two−stroke engines in the fresh oil lubrication. Here the oil is stored in a separate reservoir. The volume of oil is dependent on the speed and the throttle valve position of the carburettor. The volume, which can be varied, is added to the fuel through a feeding point behind the compensating jet in the carburettor.

Test questions

5.1. What is the function of the engine lubrication system?

5.2. Describe forced feed lubrication.

5.3. Explain the mode of operation of dry sump lubrication.

5.4. Explain the petrol lubrication principle.


# 6. The cooling system

In the combustion engine heat is generated during operation and must be dissipated. This requires intensive cooling. If an engine is not cool enough, the components could be overloaded. If the fuel−air mixture is heated excessively, performance will drop, the oil film will evaporate, and dry friction will occur, causing damage to the sliding surfaces.

There are two types of cooling used in motor vehicles:

   – Water cooling
   – Air cooling.

## 6.1. Water–cooling system

A water–cooling system is designed to dissipate the combustion heat generated by an engine. Every combustion engine must have a certain service temperature so that components of performance agree. There are two important types of liquid cooling:

   – Thermosiphon cooling
   – Pump circulated cooling.

The principle of liquid cooling is based on the fact that the cylinder is surrounded by cooling water. Since the temperature of the coolant is lower than the service temperature, the heat is transferred to the coolant. This process is utilized in thermosiphon cooling as the heated water rises because it is lighter than the cold water. The engine block is connected with a heat exchanger, called a radiator. The radiator dissipates much of the ' heat of the cooling water into the atmosphere. The water cooled down in this way sinks to the bottom again. Then the circulation starts again. However, since not all of the heat has been dissipated, the engine reaches its service temperature once more. Fig. 6/1 shows the diagram of the thermosiphon cooling system. It is based on the simple physical principle that the specific weight of the heated water is relatively lighter than that of cold water. To ensure better cooling in warm conditions, a fan is located behind the radiator which is driven from the crankshaft by a vee–belt to accelerate the air flow. When this type of cooling system is used it is necessary to ensure that there is always sufficient coolant in the cooling system to protect the circuit from interruption. The cooling surface required here is normally larger than that required for pump cooling.
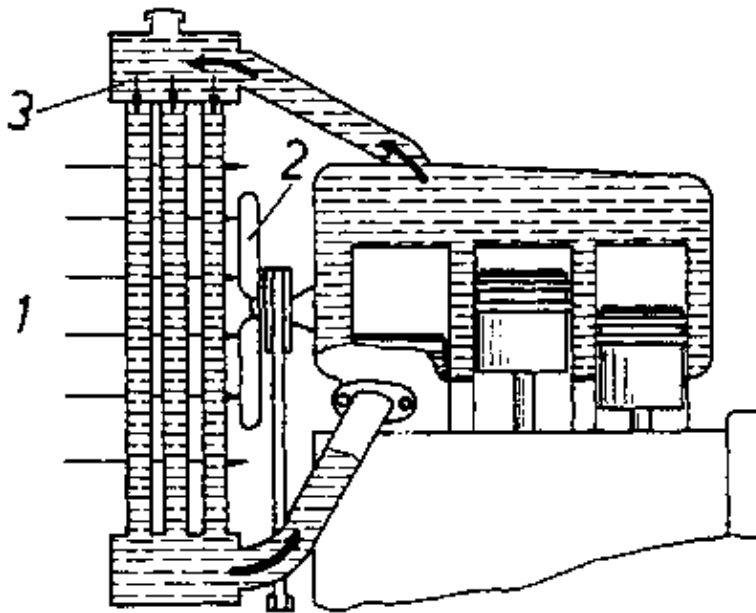

Figure 6/1 Thermosyphon cooling

   1 Air;
   2 Fan;
   3 Radiator

Another type of liquid cooling is pump circulated cooling. In principle it is the same as the thermosiphon cooling, the only difference is that there is an additional pump to circulate the coolant (see Fig. 6/2).
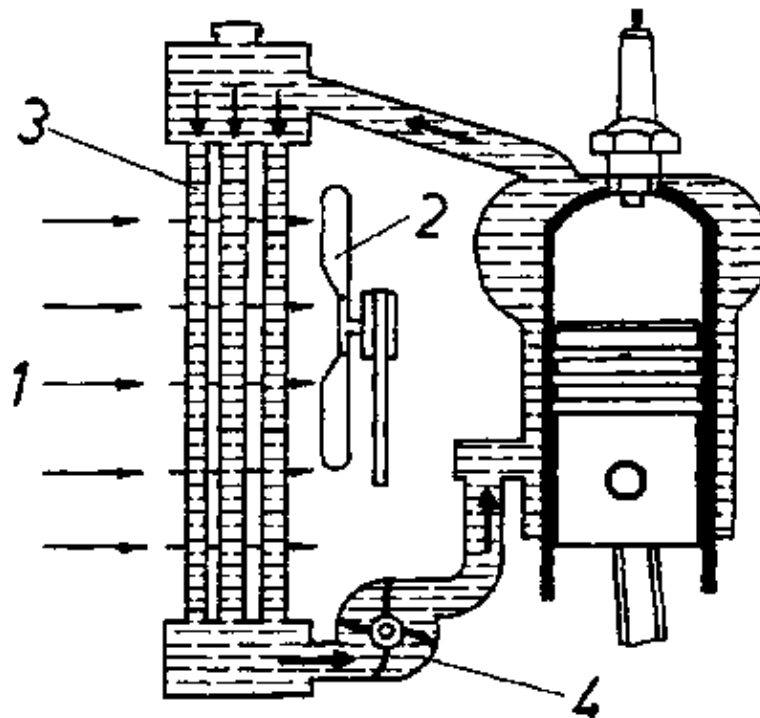
Figure 6/2 Pump circulation cooling

1 Air; 2 Fan; 3 Radiator; 4 Water pump

In comparison with thermosiphon cooling, this type of liquid cooling is much more effective, The volume of water required for this type of cooling is smaller, and the general dimensions of the radiator can be smaller. Due to the relatively high water flow rates, the pipe cross sections can be smaller. The speed of the water pump is 1 to 1.5 times that of the crankshaft. In the case of pump cooling, a fan is also provided.

In most engines the water pump is flanged to the front face and is driven by the Vee–belt. In the pump bowl there is an impeller which causes the water to circulate. The pump shaft is sealed in the pump housing by radial sealing rings or stuffing boxes. Water pump grease is used for lubrication because it is not sensitive to water.

The radiator serves to decrease the water temperature by means of the air passed through it. It is used as a heat exchanger in which the largest possible exchange area is accommodated in the smallest possible space. These radiators are made of a metal which is light weight but ensures good conductivity. It consists of the upper and the lower header tank with intermediate small tubes. The filler stud with safety valve and the supply pipe are mounted to the upper header tank. The radiator mounting, drain plug and drain pipe are mounted to the lower header tank.

The radiator is connected with the water circulation system by flexible connections (e.g. rubber hoses). It is also mounted on flexible shims in the motor vehicle. In modern motor vehicle engineering closed cooling systems are also still in use. In these systems the coolant which consists of distilled water and anti–freeze is circulated in a closed circuit which is connected to the compensating tank.

The merit of the system is that no coolant is lost as it is always collected by the compensating tank and returned into the circuit. To ensure that the combustion engine reaches service temperature as quickly as possible, the cooling circuit is divided into a large and a small circuit by a thermostat. The large circuit includes the radiator. When the service temperature, which ranges between 80 and 85 C depending on the type of engine, is reached, the large circuit is opened by the thermostat and when the temperature falls again, it is closed.

The fan can be directly connected with the water pump, or alternatively it may be coupled with an electromagnetic coupling. If it is directly connected, it is runs constantly. To further increases the effect of the thermostat the fan is integrated into the cooling system by means of an electromagnetic coupling. Until the service temperature is reached the fan is at a standstill and only when this temperature is exceeded is it started by a thermostat. Another merit is that the service temperature is reached earlier and so the engine is preserved because wear is essentially greater when the engine is cold.

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## 6.2. Air–cooling system

There are some external features which make it easy to distinguish the air–cooling system from the water–cooling system; the air–cooling system does not require a radiator or a water pump and it has a different cylinder form. In the case of air–cooling, the surface of the cylinder block must be greatly extended in order to dissipate excessive heat.
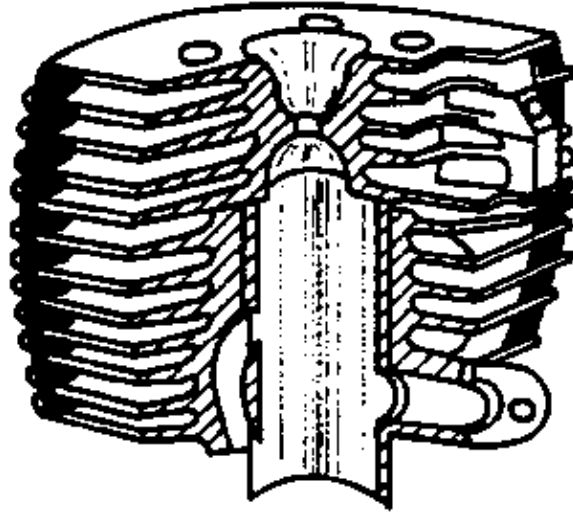


Figure 5/3 Air–stream cooling

This extension is achieved by additional radiating fins (see Fig. 6/3 and 6/4) which are arranged parallel to the air stream. In general, they are made of a light metal which is a good heat conductor. There are two types of air cooling: air stream cooling and fan–type air cooling. Air stream cooling is used in motorcycles, and uses air taken from the air stream. Cylinders with large radiating fins are required. In order to protect these large fins against excessive vibrations, rubber stabilizers are used for damping. The radiating fins must have a rough top surface in order to trap the air stream or the fan air stream and to dissipate the heat.
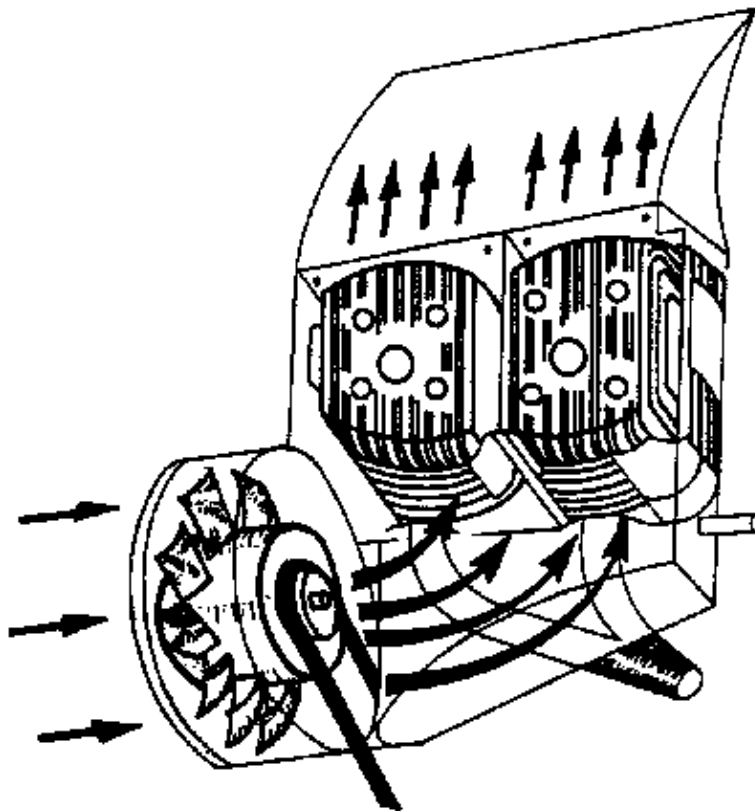


Figure 6/4 Fan cooling

Fig. 6/4 shows the fan–type air–cooling system. The impeller, which is driven directly by the crankshaft via a vee–belt, intensifies the air stream still further. However, this means that the engine must be clead with air guide plates. Air cooling is noisier because of the air turbine.

Test questions

6.1. What is the function of the engine cooling system?

6.2. Describe the thermosiphon cooling system.

6.3. Explain the principle of pump circulation cooling system.

6.4. Describe the design and the function of the water pump.

6.5. What is the function of the cooler? Describe its design.

6.6. What do you understand by air cooling, and what types of air cooling do you know?


## 7. The air filter

The air required by the engine for combustion in the fuel–air mixture must be cleaned before it reaches the combustion chamber. To do this an air filter is required to remove any airborne dust particles from the air, which would otherwise act like abrasive powder in the engine components and cause excessive wear. There are two types of filter: wet–type air filters and dry filters.

The wet–type filters have a metal fabric insert which is oilwetted in order to bind the dust. Another type is the turbulence oil filter. Here a certain amount of oil is circulated by the air stream and binds over which it passes.

The dry air filter is equipped with a filter cartridge made of filter paper which is similar to the oil filter. It is inserted into an intake silencer which is made of steel sheet and can be mounted directly to the carburettor or the intake pipe. All air filters also serve as intake silencers.

Air filters must be cleaned at regular intervals. This means that the filter cartridge must either be replaced or the oil must be changed in order to ensure correct operation.

The lifetime of an air filter is specified by the manufacturer. Lifetime is specified either as mileage, or in the case of marine engines, number of service hours. If the air filters are clogged with dust, engine output will be impaired as insufficient air can pass through them.


## 8. Mode of operation of the gas turbine

Apart from the combustion engines described above there are other types of engines used in modern vehicle engineering, for example the gas turbine and the rotary piston engine, also called the Wankel engine after its inventor Felix Wankel. Fig. 8/1 compares the sizes of a diesel engine and a gas turbine of the same output. Since the output of today's combustion engine can only be slightly improved, new methods of powering motor vehicles must be found. Combustion engine speeds cannot be constantly increased because the forces which are generated by the moving masses increase as the square of the speeds and therefore can only be controlled up to a certain value. This however is not the case with the gas turbine.
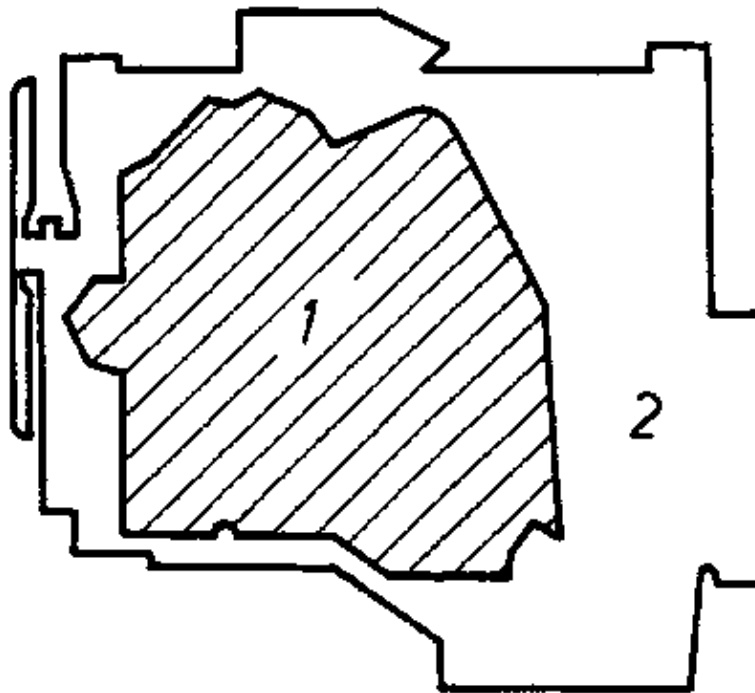
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Figure 8/1 Difference in size between a gas turbine and a diesel engine

1 Outline of a gas turbine
2 Outline of a diesel engine (of same performance)

Gas turbines are thermal engines. The rotational movement is produced by gases flowing against the turbine blades. Like the combustion engines, gas turbines are started by a starter which must produce very high speeds in order to start the turbine. Gas turbines have a large amount of excess air and therefore their exhaust gases are free of carbon monoxide and not dangerous. There are four types of gas turbines: single–shaft gas turbines, twin–shaft gas turbines, tripple–shaft gas turbines and free–piston gas turbines.

In the single–shaft gas turbine, all the thermal energy is converted in the turbine by extension, i.e. some of the power generated is used for driving the compressor and only the remainder of the effective output can be used for driving the engine. This type of gas turbine is not suitable for driving motor vehicles because the output rapidly decreases as speed falls.

In the twin–shaft gas turbine, however, a completely different torque characteristic is produced. Extension takes place in two turbines which are mechanically separated.

A compressor is driven by a high–pressure valve while the effective output is generated through a low–pressure valve. This type of turbine is very useful for powering motor vehicles because its torque characteristic is more favourable than that of the reciprocating piston engine. Moreover, it ensures a good starting torque, and the effective power turbine can be matched to the speed at any time, independent of the gas producer, the compressor and its driving turbine, by changing the amount of fuel injected. Fig. 3/2 shows the diagram of a triple–shaft gas turbine. This turbine has three shafts and two combustion chambers.
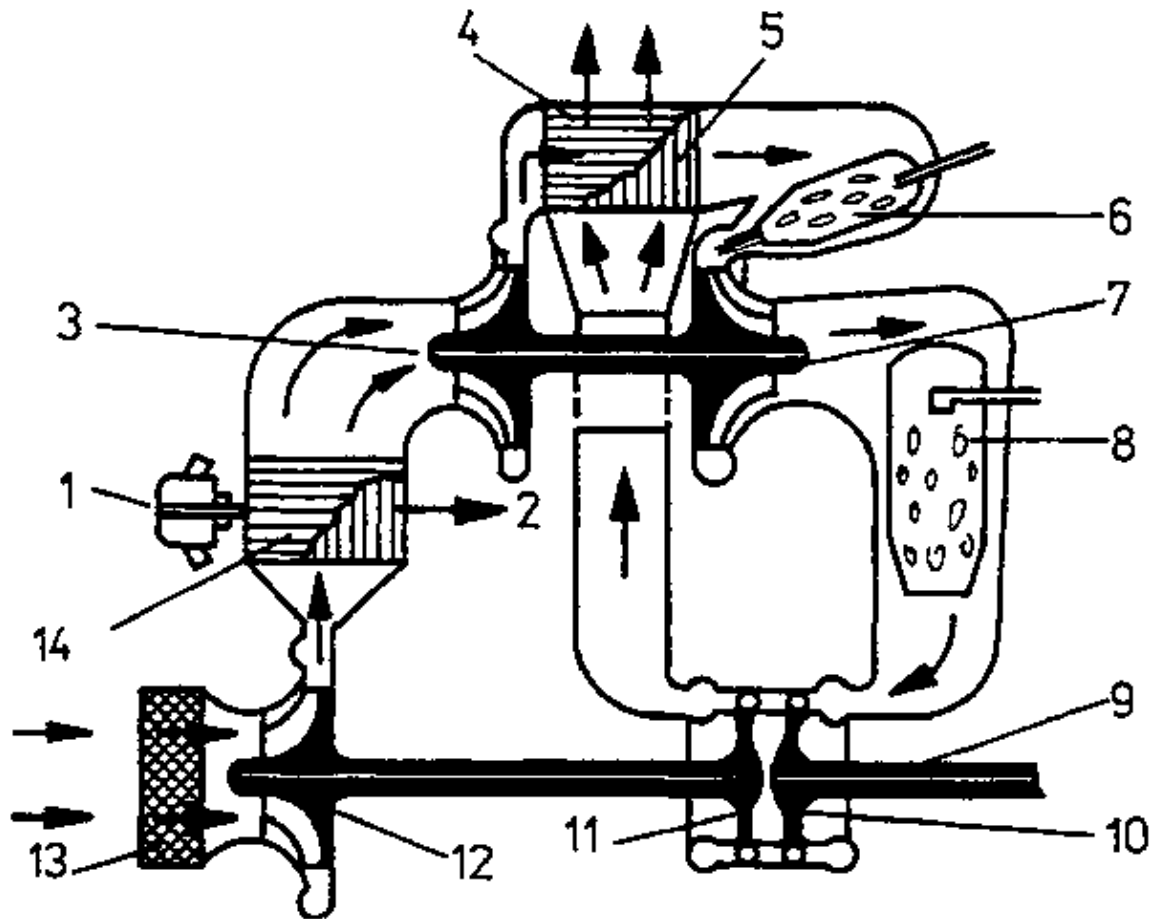
Figure 3/2 Three–shaft gas turbine

1 Cooling fan; 2 Fan air; 3 High–pressure compressor; 4 Exhaust; 5 Recuperator; 6 First combustion chamber; 7 High–pressure turbine; 8 Second combustion chamber; 9 Drive shaft; 10 Operating turbine; 11 Low–pressure turbine; 12 Low–pressure compressor; 13 Air filter; 14 Intermediate cooler

## 9. Mode of operation of the rotary piston engine

Another type of engine is the rotary piston engine. In the case of this engine, the compression pressure is not transferred to a cylindrical, piston, as is the case with the reciprocating piston engine, but to a triangular rotor which is directly connected to the drive shaft. Fig. 9/1 shows the main components of the Wankel engine, the drive shaft with the flywheel mass, the rotor shaft with external toothing and compensating mass and the rotor with internal toothing. While the engine is working, all these components are moving. In contrast to the reciprocating piston engine, they only describe a circle. The rotor and the housing always form three different chambers the volume of which changes constantly. This is necessary in order to allow gas exchange and compression.
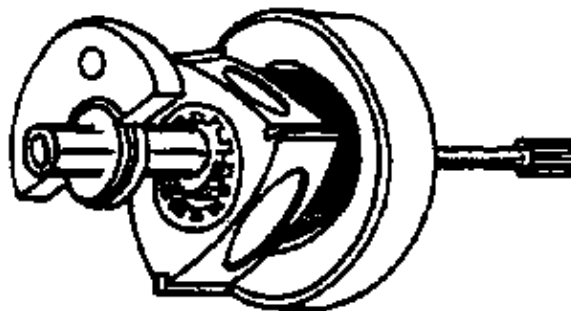


Figure 9/1 Shaft and piston of a rotary piston engine

As in the reciprocating piston engine, ignition occurs at maximum compression. This engine requires a fuel–air mixture and has external ignition. The mode of operation of the rotary piston engine is shown in Fig. 9/2. The combustion pressure causes the piston area to be rotated in clockwise direction and due to the geometry of the rotor, this operation continues of its own accord. In order to seal the rotor from the housing, it revolves both around the drive shaft and on its own axis. The mode of operation of the rotary piston engine can be compared with that of the four–stroke engine, although it has no valves. In the case of this engine, sealing the rotor from the housing is of particular importance as not only the edges must be sealed, but also the surfaces.
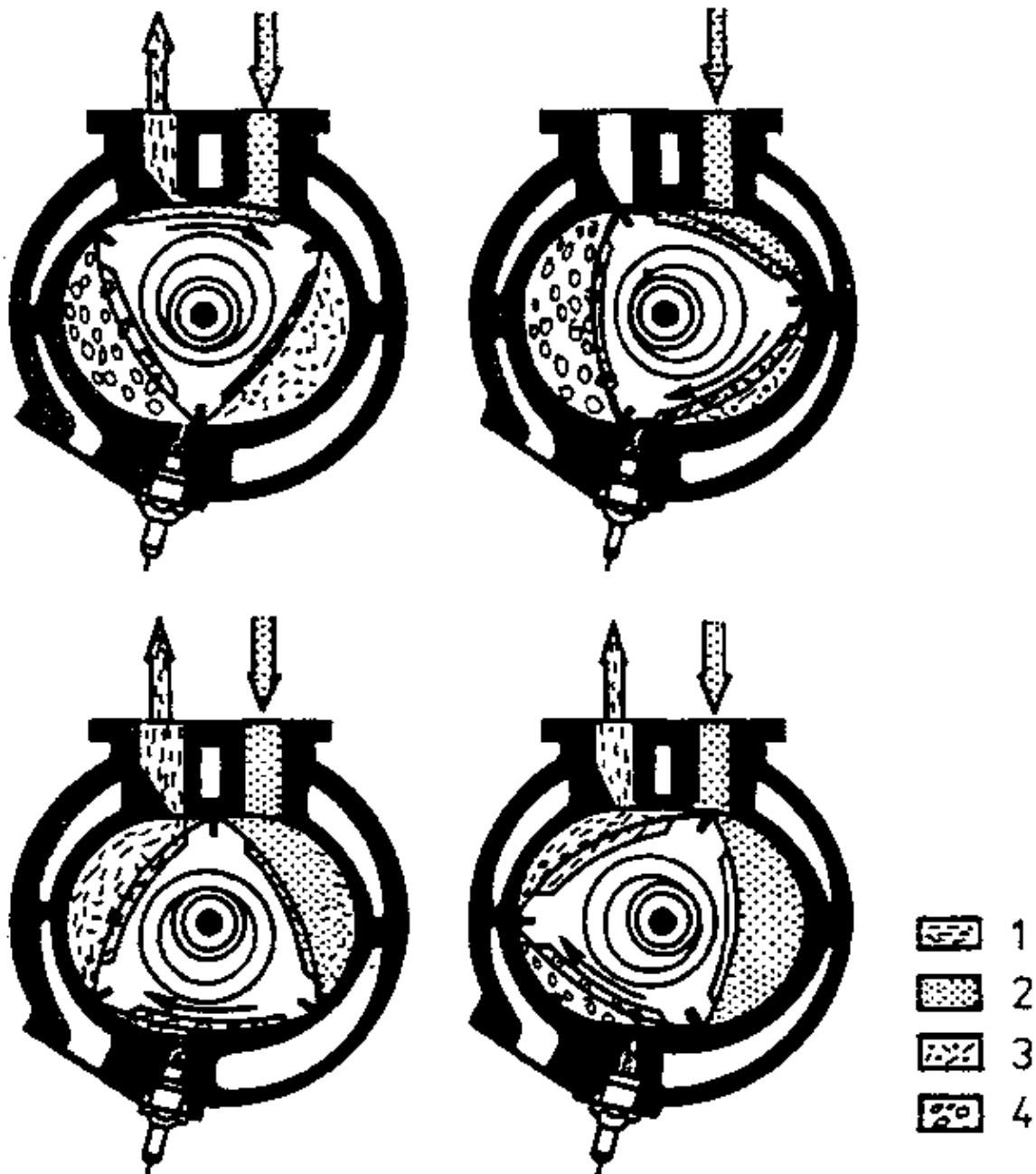


Figure 9/2 Node of operation of a rotary piston engine

1 Exhaust; 2 Intake; 3 Compression (ignition); 4 Power stroke (combustion)

Another problem is the spark plug. To ensure proper sealing, it must not extend into the combustion chamber. Hitherto rotary piston engines have been used exclusively in cars, marine engines and as stationary engines.