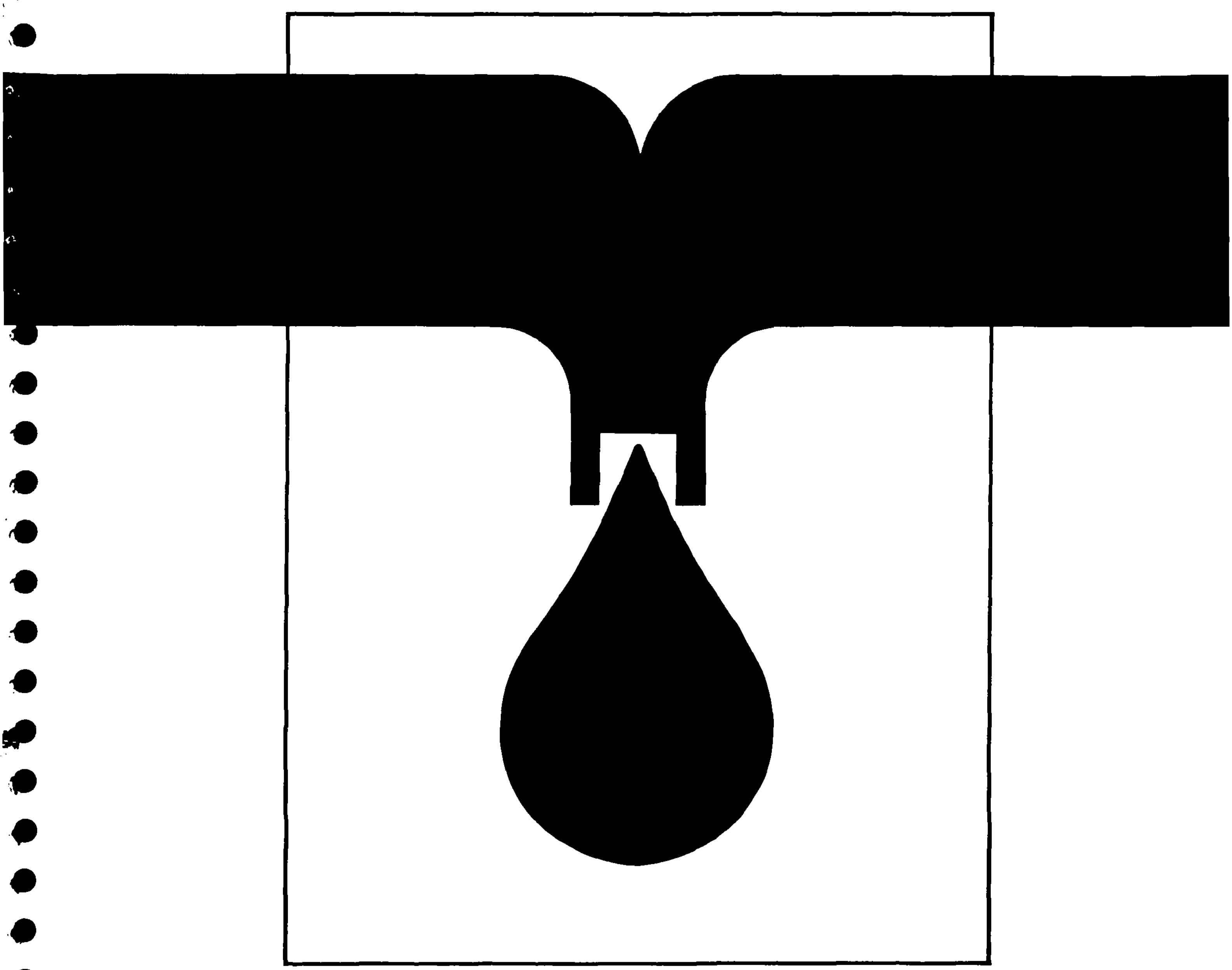
# TRAINING MODULES FOR WATERWORKS PERSONNEL



## Special Knowledge

## 2.3 a

Maintenance and repair
of diesel engines and petrol engines

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## Foreword

Even the greatest optimists are no longer sure that the goals of the UN "International Drinking Water Supply and Sanitation Decade", set in 1977 in Mar del Plata, can be achieved by 1990. High population growth in the Third World combined with stagnating financial and personnel resources have led to modifications to the strategies in cooperation with developing countries. A reorientation process has commenced which can be characterized by the following catchwords:

- use of appropriate, simple and – if possible – low-cost technologies,
- lowering of excessively high water-supply and disposal standards,
- priority to optimal operation and maintenance, rather than new investments,
- emphasis on institution-building and human resources development.

Our training modules are an effort to translate the last two strategies into practice. Experience has shown that a standardized training system for waterworks personnel in developing countries does not meet our partners' varying individual needs. But to prepare specific documents for each new project or compile them anew from existing materials on hand cannot be justified from the economic viewpoint. We have therefore opted for a flexible system of training modules which can be combined to suit the situation and needs of the target group in each case, and thus put existing personnel in a position to optimally maintain and operate the plant.

The modules will primarily be used as guidelines and basic training aids by GTZ staff and GTZ consultants in institution-building and operation and maintenance projects. In the medium term, however, they could be used by local instructors, trainers, plant managers and operating personnel in their daily work, as check lists and working instructions.

45 modules are presently available, each covering subject-specific knowledge and skills required in individual areas of waterworks operations, preventive maintenance and repair. Different combinations of modules will be required for classroom work, exercises, and practical application, to suit in each case the type of project, size of plant and the previous qualifications and practical experience of potential users.

Practical day-to-day use will of course generate hints on how to supplement or modify the texts. In other words: this edition is by no means a finalized version. We hope to receive your critical comments on the modules so that they can be optimized over the course of time.

Our grateful thanks are due to

Prof. Dr.-Ing. H. P. Haug
and
Ing.-Grad. H. Hack

for their committed coordination work and also to the following co-authors for preparing the modules:

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It is my sincere wish that these training modules will be put to successful use and will thus support world-wide efforts in improving water supply and raising living standards.

Dr. Ing. Klaus Erbel
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Hydraulic Engineering,
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Eschborn, May 1987

Title: Diesel engine, petrol engine

Table of contents:

## 0. Introduction

Diesel and petrol engines are internal-combustion engines which are used for directly driving machines or for generating electrical energy.

The primary energy required to drive the engine is contained in the fuel. Conversion into thermal energy takes place in the engine by way of the combustion process once fuel and atmospheric oxygen have been supplied. The gases which expand in the course of this process drive the crankgear via the piston, so that mechanical energy is available at the engine output point (clutch).

Chemical energy (Fuel) —Combustion→ Thermal energy

—Crankgear→ Mechanical energy → Conversion into electrical energy / Driving of machines

## 1. General overview of internal-combustion engines

### 1.1 Classification

Almost all internal-combustion engines used are reciprocating engines, in which the up-and-down motion of the pistons is converted via crankgear into a rotary motion; this is the most common form of drive.

The various internal-combustion engine designs are subdivided according to the following features:

- Type of fuel and mixture preparation, with the following categories:
  1. petrol engine (Otto or spark-ignition engine)
  2. diesel engine
- Type of working cycle, with the following categories:
  1. two-stroke engine
  2. four-stroke engine

All four possible versions are used:

- Petrol engine
  - Four-stroke
  - Two-stroke
- Diesel engine
  - Four-stroke
  - Two-stroke

## 1.2 Basic terms

Fig. 1 aims to help explain the following basic terms:

TDC = Top dead centre: Upper limit point of piston travel.

BDC = Bottom dead centre: Lower limit point of piston travel.

$V_c$ = Clearance volume: Volume contained in the cylinder above the piston when the latter is at TDC.

$V_h$ = Swept volume: Volume displaced by the piston during its travel between TDC and BDC.

$V_H$ = Engine swept volume: Total swept volume of all cylinders (number of cylinders z), with $V_H = V_h \times z$.

$\varepsilon$ = Compression ratio: Ratio of cylinder volume with piston at BDC to cylinder volume with piston at TDC.

P = Power, measured in kW

1 kW = 1.36 PS (German horsepower) = 1.34 BHP

$\eta_e$ = Efficiency: Ratio of work delivered at the clutch to thermal energy contained in the fuel supplied.

$b_e$ = Specific consumption: Ratio of fuel used (B) to power (P)

$$b_e = \frac{B}{P} \text{ (g/kWh)}$$

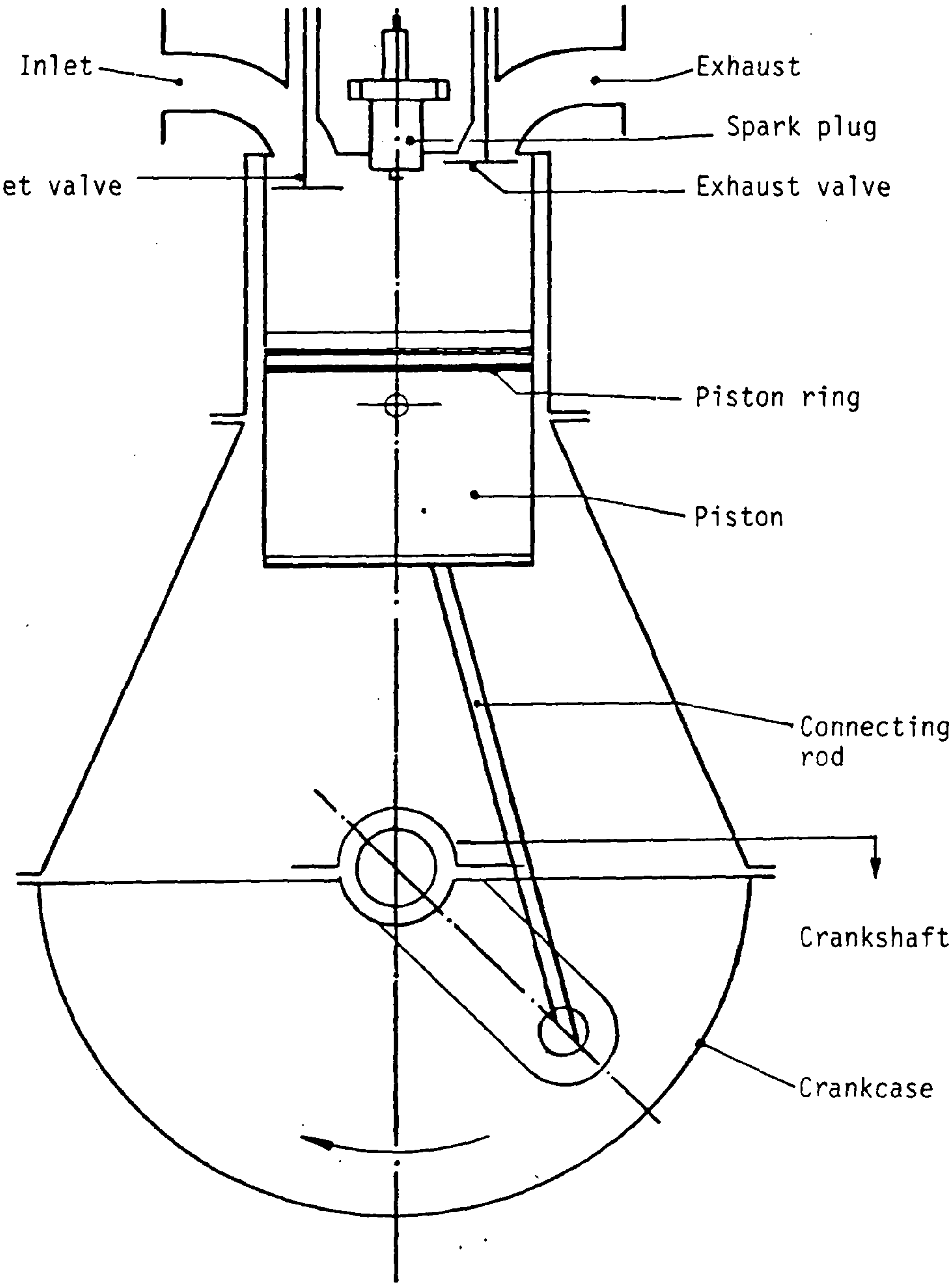
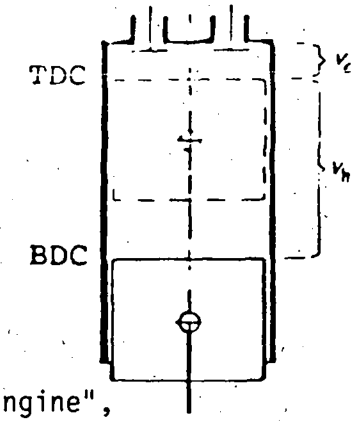



Fig: 1: Schematic diagram of an internal-combustion engine

Fig. 1a: Diagram explaining the geometrical definitions in the compression ratio




$$\varepsilon = \frac{V_h + V_c}{V_c}$$

## 2. Petrol engine

This engine, which is the most commonly used engine in motor vehicles, is also sometimes known as the "Otto engine", being named after its inventor.

The combustion of the compressed fuel/air mixture is initiated by timed external spark ignition: Mixture formation can take place outside the working cylinder in the carburettor in the case of the carburettor engine or by means of injection of the fuel into the air flow in the case of the fuel-injection engine.

### 2.1 Four-stroke spark-ignition engine

Two crankshaft revolutions are required for one power stroke!

The sequence of the strokes, with one crankshaft revolution being required for the first two and a second revolution for the other two, is as follows:

Induction - Compression - Power - Exhaust

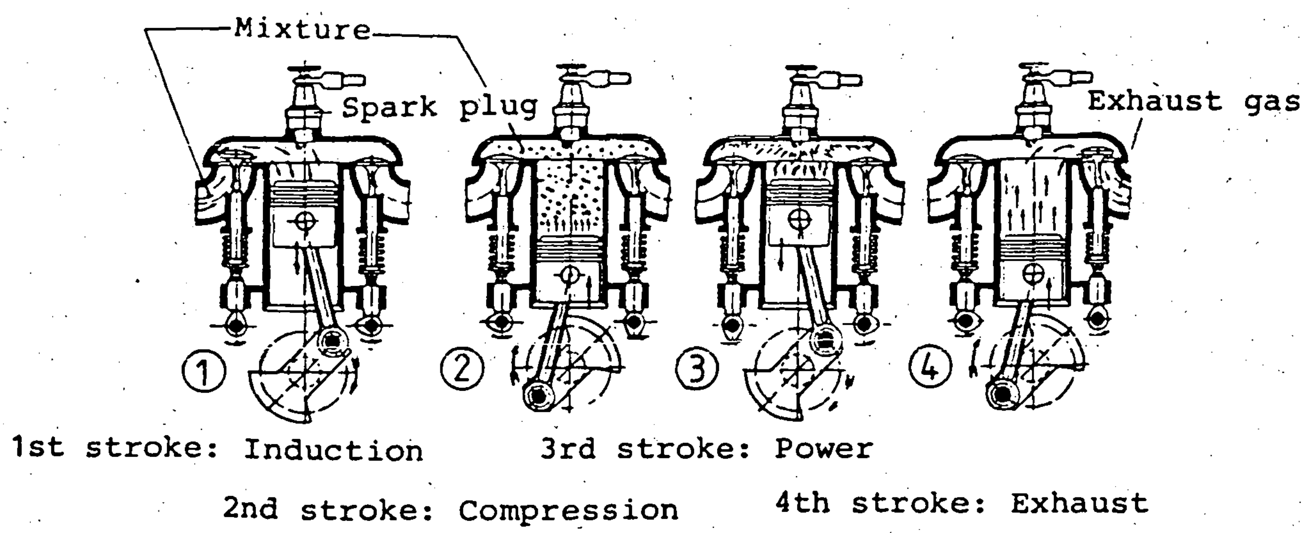



Fig. 2: Sequence of strokes in the petrol engine

Compression pressure $P_c$: 10 to 16 bar

Compression temperature $T_c$: 250 to 550° C

Maximum pressure (firing pressure) $P_z$: 30 to 60 bar

Combustion temperature $T_z$: approx. 2700°C

2.1.1 Explanation of the strokes

1st stroke = Induction: The descending piston generates a partial vacuum in the cylinder. The pressure difference causes the fuel/air mixture to flow rapidly into the cylinder. The mixture heats up in the cylinder; the last fuel particles evaporate and are intimately mixed with the air. In order to achieve a good cylinder charge the inlet valve is opened very early and closed as late as possible.

2nd stroke = Compression: The ascending piston compresses the fuel/air mixture in the combustion chamber, with the valves closed, until the compression pressure is attained. The temperature rises considerably and the gas particles are subjected to intensive swirling.

3rd stroke = Power: The mixture is ignited by an electric spark shortly before the piston reaches top dead centre. The combustion gases expand very rapidly and a high pressure is generated. The pressure wave acts on the piston and forces it downwards. The piston performs work.

4th stroke = Exhaust: The exhaust valve is opened before the piston reaches bottom dead centre. The subsequently ascending piston forces the exhaust gases out of the cylinder into the exhaust pipe. When the piston reaches top dead centre, both valves are briefly opened. The inflowing fresh gases force the remaining exhaust gases out of the cylinder (the exhaust gases have a temperature of 300 - 400°C).

2.1.2 Control of the charge cycle

As can be seen in Fig. 3, the crankshaft drives the valve-timing gear. A small proportion of the engine power is required for this purpose and is therefore lost. The charge cycle, and thus the efficiency of the engine, however, are dependent on the valve layout, the size of the valves and the operation of the valvegear.

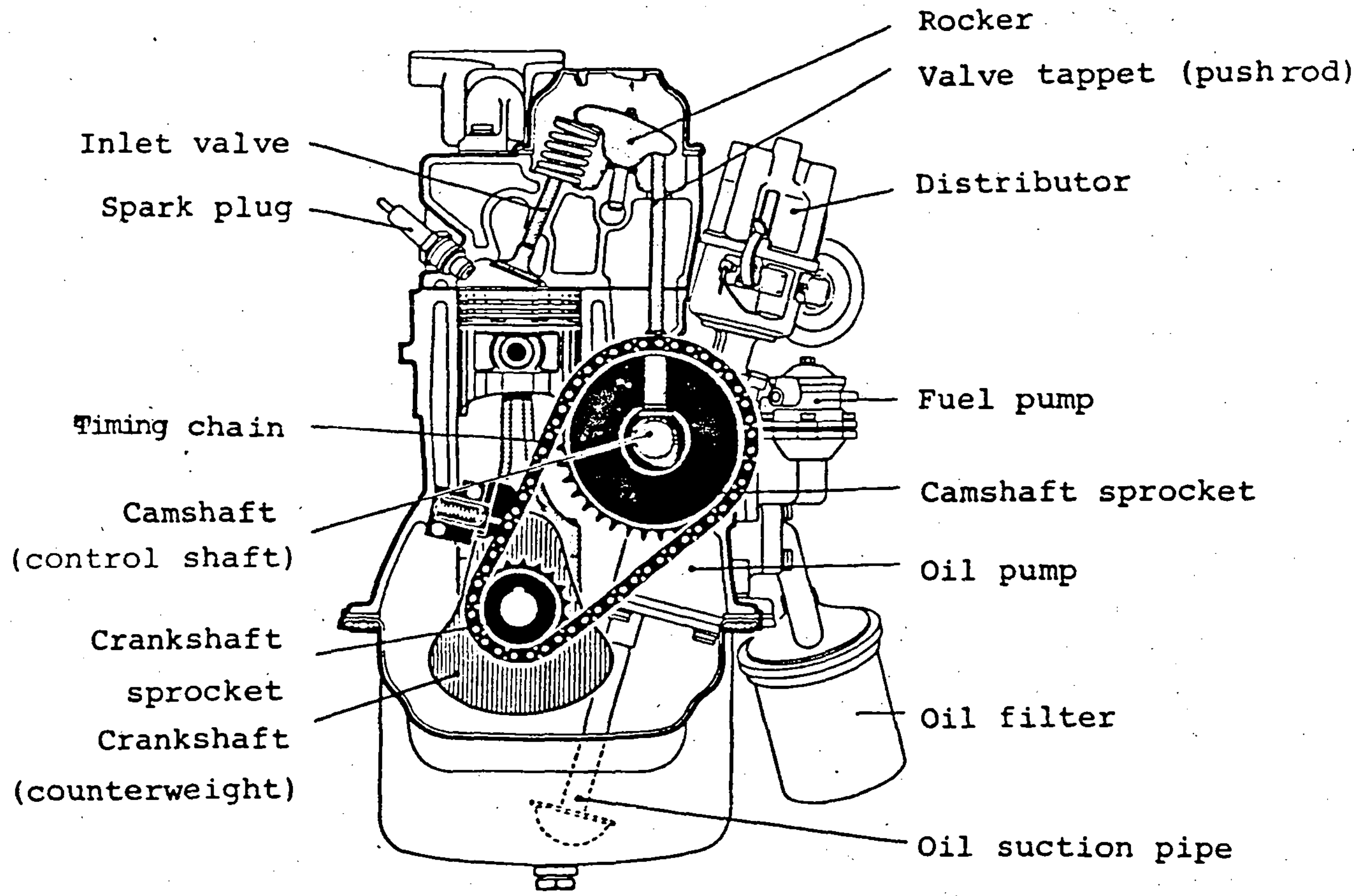



Fig. 3: Cross-section through a four-stroke spark-ignition engine

The individual components of the valvegear are as follows:

Crankshaft sprocket - Drive chain - Camshaft sprocket - Camshaft - Pushrod - Rocker - Valve with valve spring.

If the engine is to operate perfectly, the valve-timing gear must open and close the valves at precisely stipulated times and with the pistons in the appropriate positions.

The camshaft, which is driven from the crankshaft, determines the timing. The cam lift, however, can be transmitted to the valves in a wide variety of ways (Fig. 4). The determining features are the valve layout and the position of the camshaft.

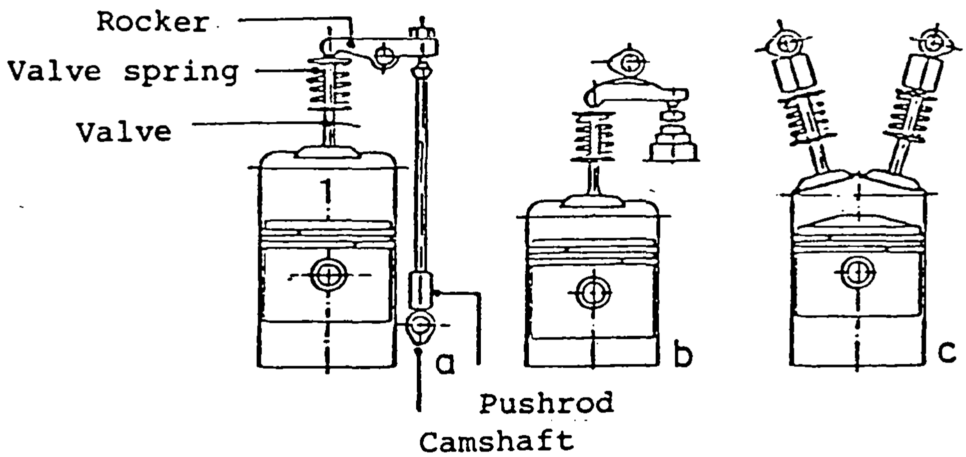


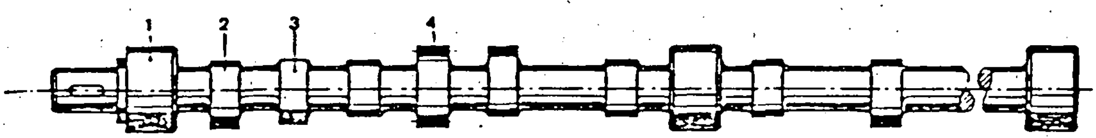

Fig. 4: Various forms of valvegear

a) Camshaft with power transmission via pushrods

b + c) Overhead camshafts with power transmission via rockers or bucket tappets

Older-style engines often have a pushrod-type camshaft and overhead valves (Fig. 4a); this is known as an OHV (overhead valve) engine. Pushrods and rockers are required for the purpose of power transmission. The heavy transmission components are relatively inert and at high engine speeds do not remain in contact with the cams. The camshaft is therefore often located above the valves to transmit the rocker movement to the valves (Fig. 4b).

Fig. 4c shows another type of overhead camshaft: in conjunction with the hemispherical combustion chamber the inclined valves, which are operated via short, light-weight bucket tappets, permit a high power output at high engine speeds. This design is relatively complex because two camshafts are necessary where the valves are opposite each other.




1 = Bearing 2 = Cam 3 = Eccentric disc 4 = Gear

Fig. 5: Camshaft components

Valves:

The valves have a calibrated stem and a head located centrically with respect to the stem. On the head is a bevelled face which fits tightly onto the valve seat and simultaneously centres the valve (Fig. 7). The valve stem carries the valve spring and provides the valve with the necessary guidance (Fig. 8). When the valve is open, a groove diverts the inflowing and outflowing gases, thereby improving the cylinder charge. The inlet valve therefore also has a larger head diameter than the exhaust valve.

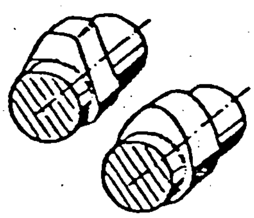


Fig. 6: Design of cams

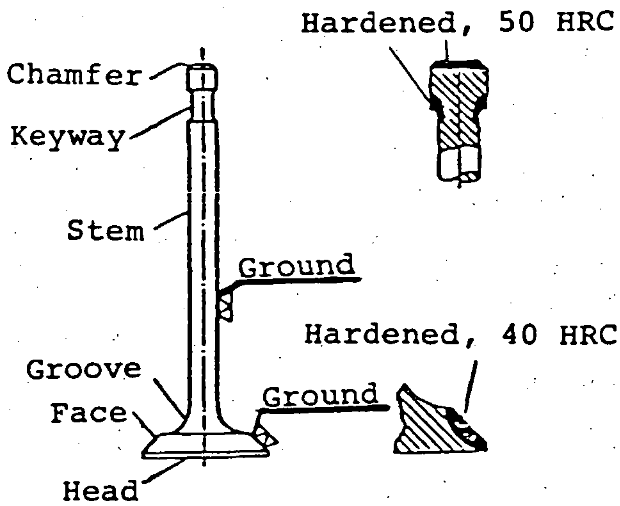


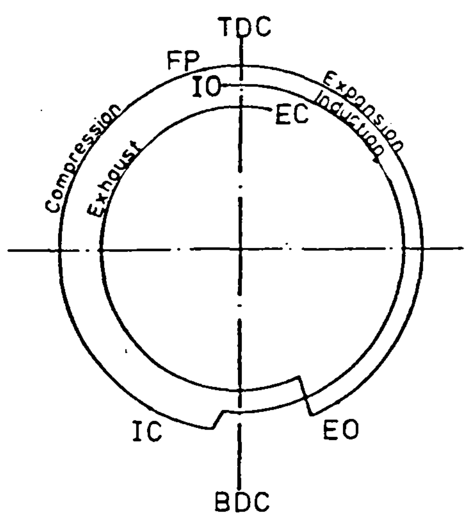

Fig. 7: Valve features

On account of the severe stresses imposed on them, valves are made of alloy steel and are drop-forged. The alloy components chromium, silicon and nickel increase above all the material's high-temperature strength and resistance to wear. The contact points are also hardened.

The resistance of the edge of the head can also be improved by hard-facing it with cobalt/chromium/tungsten alloys.

Valve timing:

As already mentioned, the valves open and close at specific times which are determined by the position of the crankshaft and thus by that of the piston. The camshaft rotates at precisely half the speed of the crankshaft..
The timing diagram (Fig. 8) therefore illustrates the valve movements and other important points, such as the firing point, or the start of injection in the diesel engine, in correlation with the continuing rotation of the crankshaft. The firing point is accordingly marked on the flywheel and there are timing marks on the camshaft timing gears.




FP: Firing point
IO: Inlet opens
EC: Exhaust closes
IC: Inlet closes
EO: Exhaust opens

Fig. 8: Timing diagram of a four-stroke petrol engine

## 2.2 Two-stroke spark-ignition engine

This port-controlled engine, which operates on the spark-ignition principle, is interesting on account of its simple design. There is no valvegear at all; the function of the valvegear is assumed by ports in the cylinder wall, together with the piston acting as a timing element and the crankcase as a charge pump.

As the charge cycle is condensed into one crankshaft revolution, each revolution yields a power stroke.

This type of engine is used in motorcycles and, on account of its simple, easy-to-repair design, in small machines for construction work and other purposes.

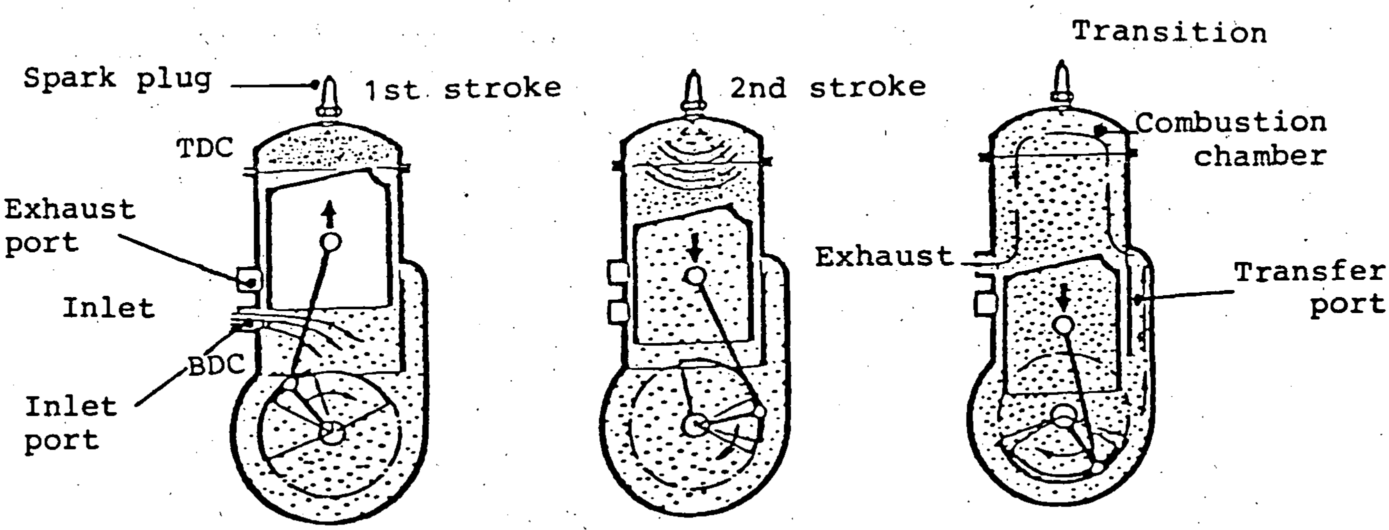



Fig. 9: Charge cycle in the two-stroke engine

Once it has been uncovered by the piston, the transfer port links the crankcase, which contains the compressed fuel/air mixture, with the combustion chamber.

The charge cycle is as follows (Fig. 9):

1st stroke = Compression and induction:
The ascending piston compresses the fuel/air mixture in the cylinder and simultaneously generates a partial vacuum in the crankcase. After a specific time the lower edge of the piston uncovers the inlet port. The fresh gas now flows into the crankcase and balances the pressure difference.

2nd stroke = Power and crankcase compression:

The mixture is ignited shortly before top dead centre. The hot combustion gases force the piston downwards and drive the crankshaft. The descending piston now blocks off the inlet port again and simultaneously compresses the gases in the crankcase somewhat. This generates a slight overpressure (0.3 bar), which subsequently forces the gases into the cylinder and thereby accelerates the charge cycle.

Transition:

The upper edge of the piston finally uncovers the exhaust port. The gases, which are still under pressure, flow out rapidly into the atmosphere. The transfer port, however, opens somewhat later and admits the fresh gases to the cylinder. A small deflector on the piston causes the gases to be routed to the spark plug and to scavenge the remaining combustion gases out of the cylinder head.

As the opening times of the ports overlap, the old and new gases can easily intermingle and then escape prematurely into the atmosphere without performing any work. The cylinders therefore usually have two or three transfer ports which route the gas flow tangentially against the cylinder wall and only then diagonally upwards (Fig. 10). The combined gas flows are then diverted in the cylinder head thereby ensuring better scavenging of the cylinder. It is thus sufficient to have a simple flat piston, which is not only easier to manufacture, but which also withstands higher temperatures and can be subjected to more even loading.

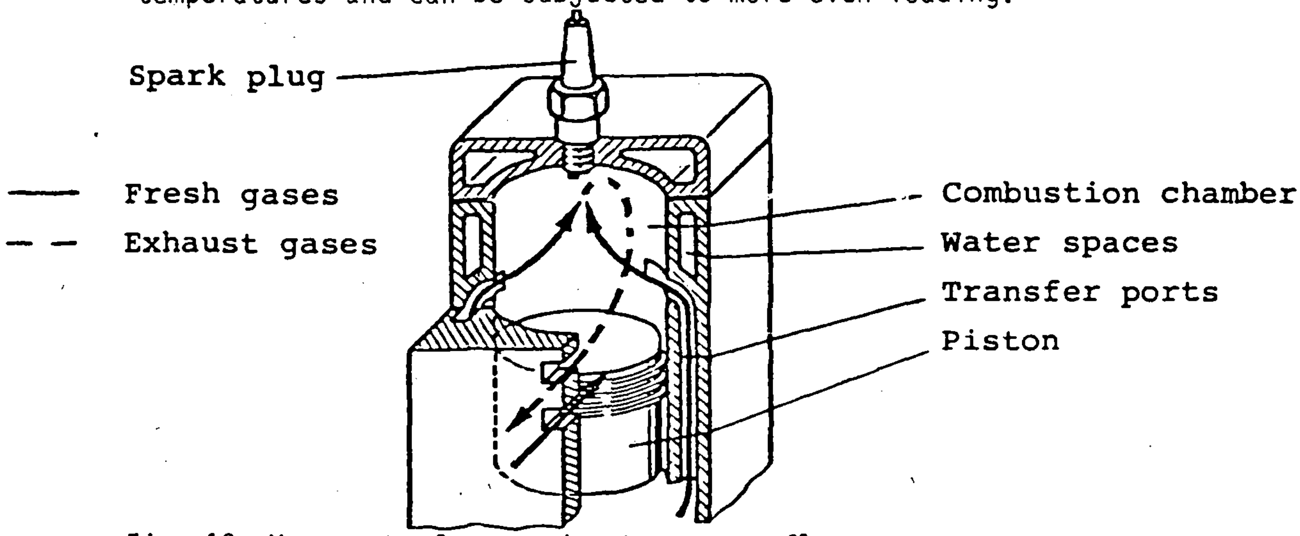



Fig. 10: Movement of gases in the counterflow process

Two-stroke engines have a power output which is 30 - 40 % higher than that of the four-stroke engine on account of the double number of working cycles. The extremely rapid and therefore incomplete charge cycle prevents a further increase in output and leads to relatively high fuel consumption.

In order to condense the operations of induction, compression, combustion and exhaust into only two piston movements or only one crankshaft revolution, the space below the piston is incorporated in the charge cycle. In contrast to the four-stroke cycle, where the lowest part of the crankcase serves as an oil reservoir, a different lubrication system must be chosen.

## 2.3 Formation and ignition of the fuel/air mixture

Spark-ignition engines generally have external mixture formation. The fuel and air are mixed before they reach the cylinder, either in the carburettor or by means of injection of the fuel into the inlet port.

However, only a volatile fuel can mix properly with the air in the carburettor or in the inlet port. Carburettor engines are therefore operated on regular or premium petrol.

Depending on the desired engine output, the carburettor is regulated such that a greater or smaller amount of mixture is supplied to the combustion chamber (quantitative regulation). The ratio of the weight of the petrol to that of the air, however, must always be around 1 : 14.5, as otherwise ignition in the combustion chamber by the spark plug may not take place or the mixture will only be partially burned.

This would lead to unnecessarily high fuel consumption and a high pollutant content in the exhaust emissions.

The route taken by the fuel and by the air is shown in Fig. 11:

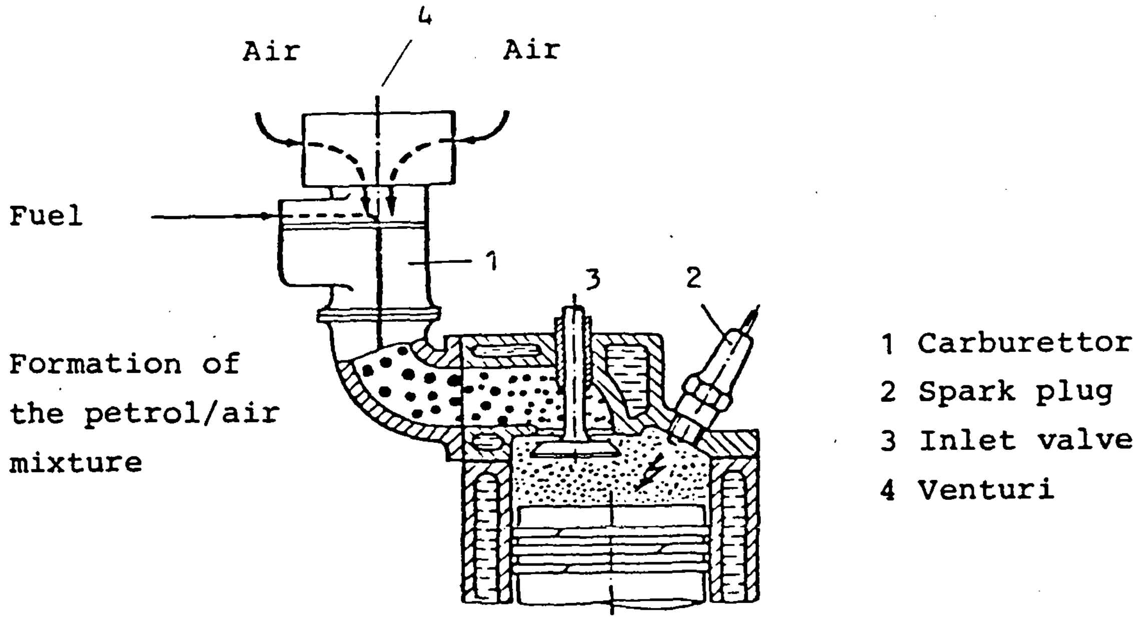



Fig. 11: Route taken by fuel and air in a spark-ignition engine

Mixture preparation by injection pumps and injectors is becoming increasingly important in motor vehicles. The petrol is injected into the intake manifold and not directly into the cylinder as is the case in diesel engines.

Optimum matching to power requirements improves the engine's reliability, fuel economy and exhaust-gas composition. The disadvantage of modern injection systems is their complicated design.

## 3. Diesel engines

The diesel engine, named after its inventor, is more widespread than the petrol engine in almost all fields of application. This can be attributed to its minimal need for repairs, combined with a long service life, high efficiency and fuel economy and use of less expensive fuels representing a smaller fire hazard.

Designs range from miniature engines up to large 35,000 kW diesel engines. The differences lie primarily in application-related features influenced by engine speed, and in particular in volume and weight.

The following categories exist:

1. Low-speed engines up to 250 rpm, two-stroke operation, crosshead design, with piston diameters of approx. 1 m, cylinder output up to 3000 kW with 5 to 12 cylinders.

Their major area of application is in ships.

2. Medium-speed engines from 350 to 1000 rpm, piston diameter approx. 350 - 650 mm, cylinder outputs up to 1200 kW. Used in ships and in electricity generating plants in the Third World.

3. High-speed engines with speeds in excess of 1000 rpm, total output generally less than 220 kW.

The essential feature in which the diesel engine differs from the petrol engine is the way in which the fuel is ignited. The pure air is compressed to such an extent that the resultant temperature is far higher than the ignition temperature of the fuel. Diesel fuel is injected into this hot air in the combustion chamber shortly before the piston reaches top dead centre and ignites there of its own accord; the design of the combustion chamber has a major influence on the engine's operating behaviour. Combustion chambers with a prechamber into which the fuel is injected ensure smooth running. If, in the absence of a prechamber, the fuel is injected directly into the main combustion chamber, particularly low fuel consumption is achieved.

The resultant working pressures on the one hand have the disadvantage that the power unit is subjected to considerable stresses; on the other hand, high pressures have an advantage in that they guarantee high efficiency and thus good fuel utilization.

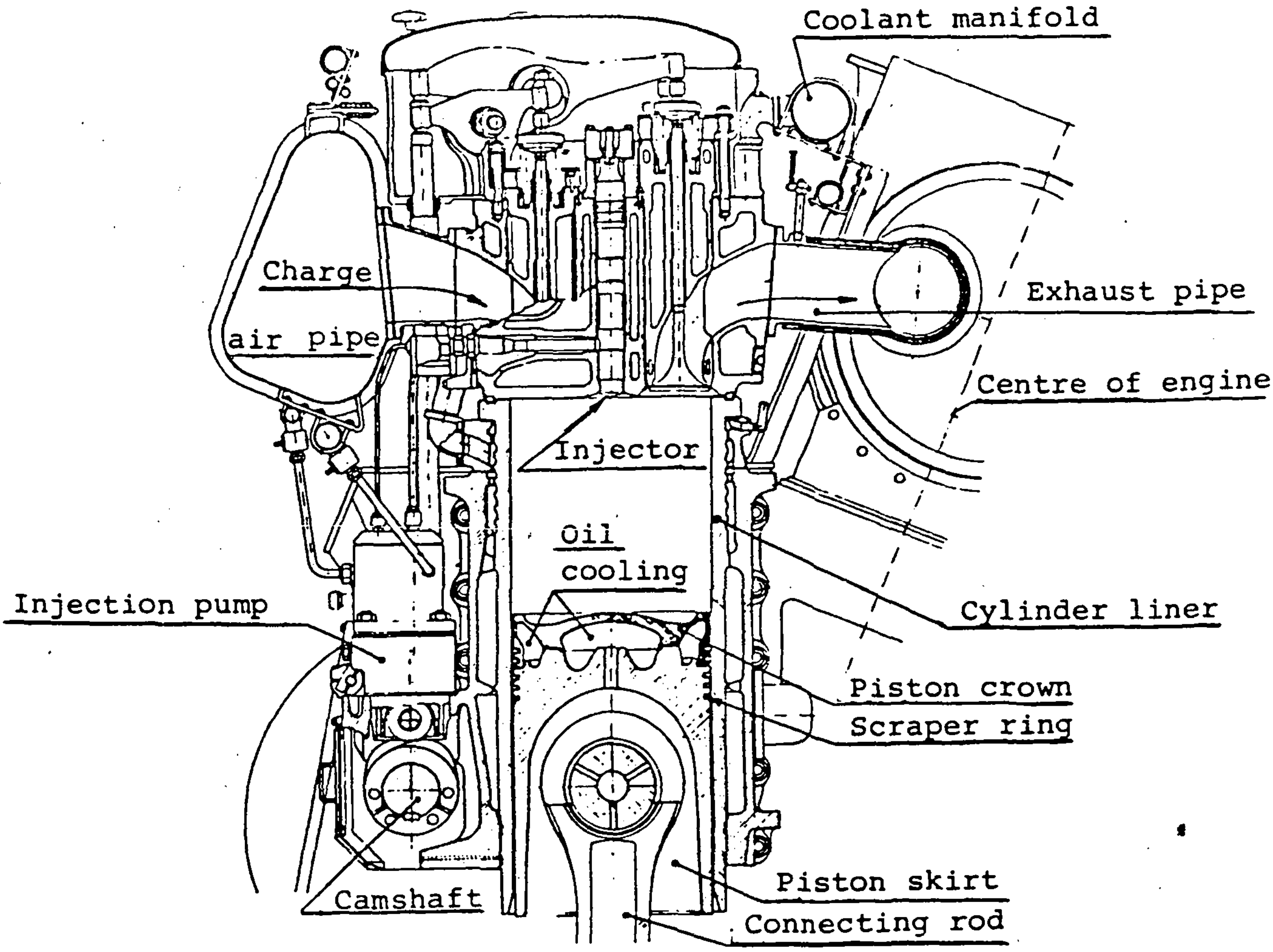



Fig. 12.: A four-stroke diesel engine in V-configuration with direct injection.
Cylinder diameter: 520 mm
Stroke= 550 mm
The piston skirt and piston crown have a screwed connection.

3.1 Four-stroke cycle in the diesel engine

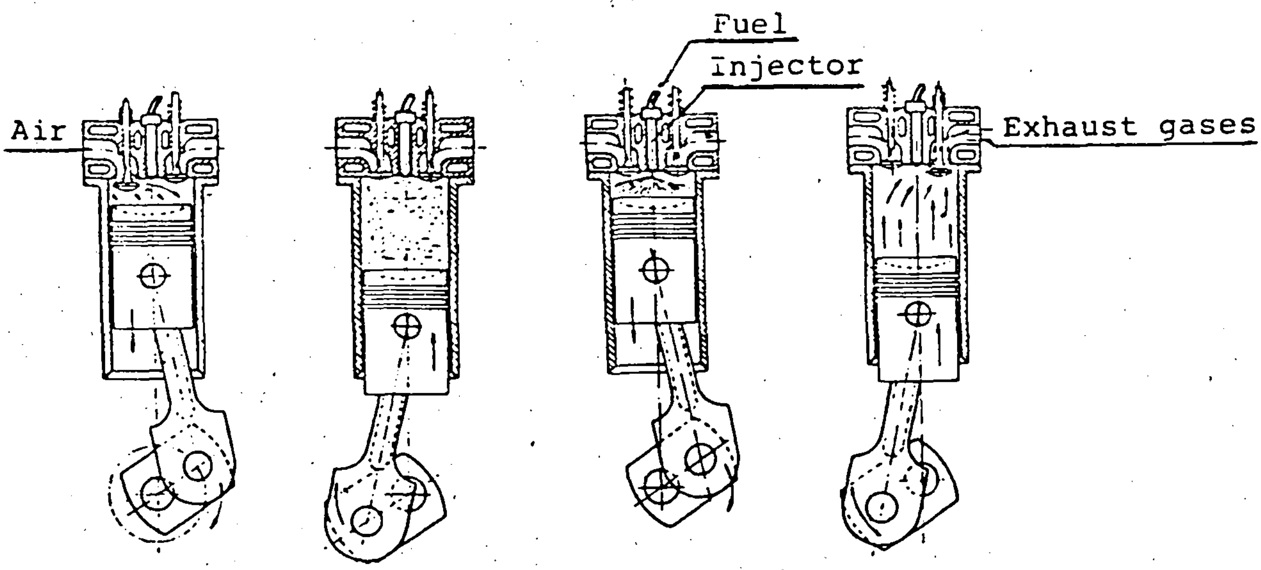



Fig. 13: Sequence of strokes in the four-stroke diesel engine

1. Induction : The descending piston draws in fresh air via the open inlet valve.

2. Compression : The air drawn in is compressed by the ascending piston to between 1/12 and 1/20 of its volume upon intake (= 12:1 to 20:1).
Compression pressure: 30 to 60 bar
Compression temperature: 400 to 700°C.

3. Power : At the end of the compression stroke the fuel is injected into the combustion chamber via the injector at high pressure and in a finely atomized form. The fuel evaporates, exceeds the self-ignition temperature and burns, resulting in peak pressures of between 45 and 80 bar. The expansive force of the combustion gases causes the piston to move downwards.

4. Exhaust : With the exhaust valve already having opened before BDC and the gases having expanded, the ascending piston expels the exhaust gases.

### 3.2 Design and principal components

The high compression and combustion pressures mean that the components must be strongly built. Cast iron is generally used for all engine casing components and steel forgings for connecting rods and crankshafts. Only pistons are made of light metal. These measures mean that a diesel engine is comparatively heavy.

The cylinders in diesel engines are either cast in one piece with the water jacket or liners are fitted in the cylinder block. Liners must be able to expand longitudinally downwards. The seal with respect to the water spaces is generally created by means of copper or soft iron rings at the top and by means of rubber gaskets fitted in ring grooves at the bottom.

With the exception of very large units, crankshafts are forged in one piece from carbon steels or alloy steels. They are mounted in the main bearings in the crankcase. These bearings consist of steel shells coated with a layer of lead bronze and with an additional lead-tin overlay (running-in layer).

A flywheel is mounted at the main power end on the crankshaft flange using body-fit bolts. The size of the flywheel is such that critical torsional vibrations are avoided. A ring gear on the flywheel allows it to engage with an electric starter and makes it possible to rotate the engine during assembly and inspection work.

Connecting rods, which are forged from high-grade steel, may have either a round or a T-shaped cross-section.
Connecting rods generally have a linked head, known as the small end. This accommodates the small-end bearing, which is made of lead bronze. The lower part of the connecting rod and the connecting-rod cap are joined by means of anti-fatigue stud bolts and together form the big end, which accommodates the big-end bearing. The small-end bearings are supplied with oil via spray nozzles or bores in the connecting rod.

The pistons in a diesel engine are subjected to severe stresses in both mechanical and thermal terms. They are made of light alloys, except in the case of large engines. The floating gudgeon pins are prevented from moving in the axial direction by means of caps and circlips.

Pistons may have no cooling or may be cooled by means of splash oil or pressure oil.

The long skirt of the piston serves to provide better guidance in the cylinder liner, since very high lateral forces can occur as a result of the tilting, thereby causing the lubrication to suffer.

In large diesel engines, therefore, the force acting on the piston is transmitted via the piston rod firstly to the crosshead and the connecting rod and only then to the crankshaft. There is thus no tilting motion on the part of the piston, but the loading in the journal bearing is extremely severe as a result of one-sided pressure exerted by the journal on the lower bearing shell, since no lubricating oil wedge can form. The numerous components make this design particularly heavy and on account of the high inertia forces it is suitable only for engine speeds below 1000 rpm.

As the piston crown expands to a greater extent than the rest of the piston on account of the combustion heat, the upper part of the piston must be fitted with sufficient clearance. On account of the good thermal conductivity of light metal pistons the heat is better dissipated via the cylinder walls to the cooling water and to the splash oil on the underside of the piston.

A corresponding number of self-tensioning piston rings are fitted in three to six ring grooves on the piston; these rings seal the combustion chamber between piston and cylinder liner. The lower rings act as scraper rings, which are intended to prevent lubricating oil from entering the combustion chamber.

Piston rings are made of tough, fine-grained cast iron.

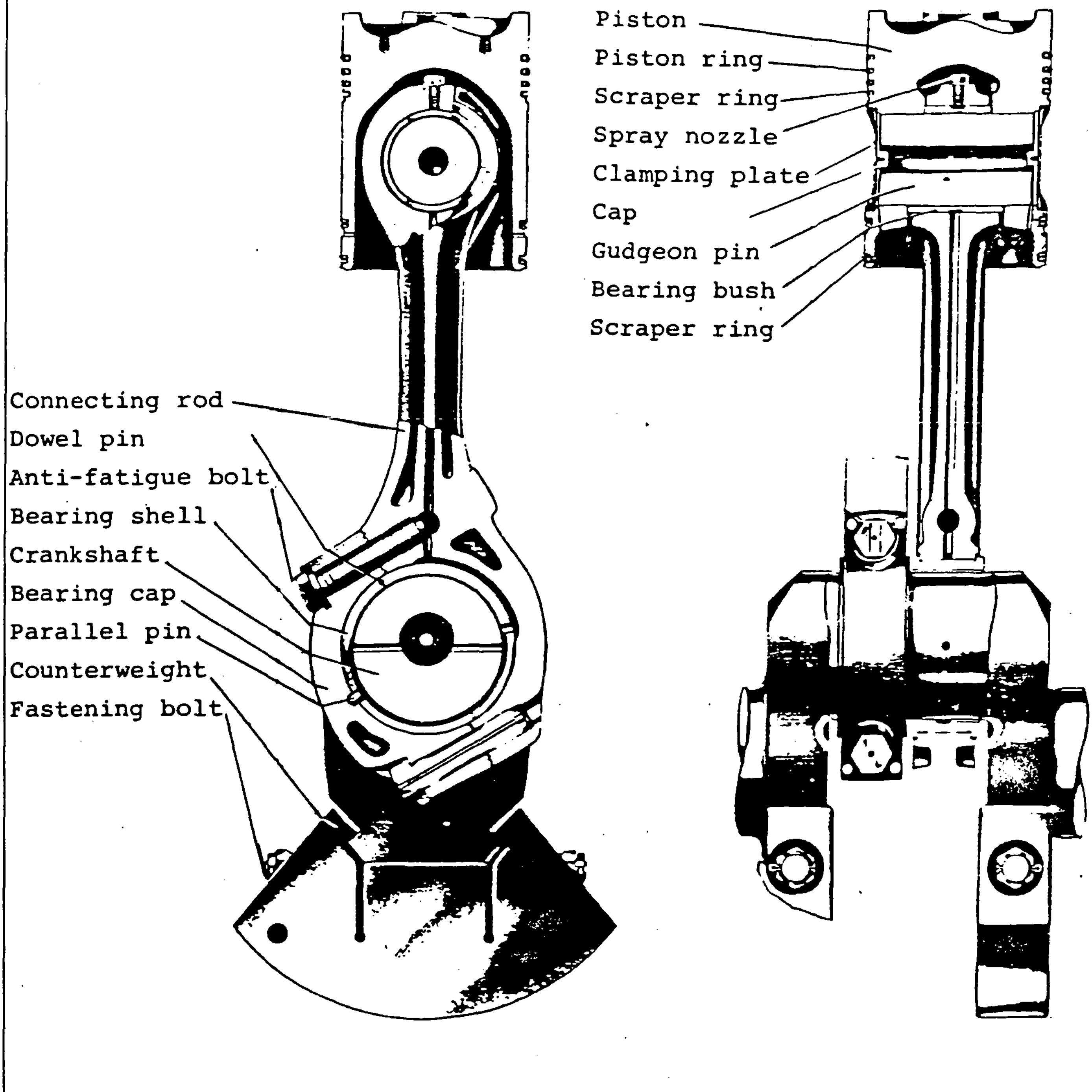



Fig. 14: The engine components piston/connecting rod/crankshaft showing individual parts in a simple design.

The carburettor and ignition system of the petrol engine are replaced in the diesel engine by the fuel-injection pump and its control elements, the high-pressure delivery lines and the injectors. As the power output can be varied by altering the amount of fuel injected, there is no need for a throttle element in the intake air passage.

Small engines have electric glow plugs to facilitate starting when the engine is cold. These glow until the air temperature in the combustion chamber is high enough to ignite the diesel fuel.

### 3.3 Mixture formation and combustion process

The fuel is injected into the combustion chamber at high pressure by the injection pump via injectors. In the combustion chamber it must be combined with the compressed hot air to form a mixture and must be burned as totally as possible in a very short time with the maximum possible power output. In order for this to be achieved, the following conditions must be fulfilled:

1. Non-throttled supply of air so that the fuel's self-ignition temperature is exceeded as a result of a high degree of compression and excess air ensures that sufficient oxygen is available everywhere for combustion.
2. Appropriate control of mixture formation by means of suitable combustion chamber design and high combustion temperature.
3. The time elapsing between the start of injection and the start of ignition - the ignition delay - must be as short as possible, otherwise a sizeable quantity of as yet unburned fuel will accumulate in the combustion chamber. When ignition starts, this will burn suddenly, accompanied by a substantial rise in pressure, and will cause engine roughness and severe stressing of the power unit components.

A number of systems have been developed with a view to fulfilling these requirements:

Direct injection (Fig. 12): The fuel is injected, in a well-distributed form, into the hot air at pressures in excess of 150 bar by a multi hole nozzle. A high pressure and a small hole diameter result in extremely fine atomization.
Spherical combustion chambers machined in the piston, together with a fuel spray accurately directed by means of wall-distributed or wall-parallel injection, improve swirl and permit complete combustion, low fuel consumption and low thermal loading. These further developments mean that direct injection is now also possible in small high-speed engines.

Indirect injection has been used in almost all smaller engines up to the present day.
The combustion chamber is divided into a main combustion chamber and a preceding secondary combustion chamber. With the secondary combustion chamber it is possible to achieve brief fuel injection via a pintle nozzle - Fig. 15 - (the small holes in the multi-hole nozzle would coke); low injection pressures between 80 and 120 bar, good mixture formation and combustion in all operating ranges, low peak pressures and quiet engine running. The principal disadvantage to be set against these advantages is higher fuel consumption, which is caused by the transfer losses between the secondary combustion chamber and the main combustion chamber as well as by the heat losses resulting from the larger surface of the combustion-chamber wall.
Only two types of secondary combustion chambers are used today: The prechamber and the swirl chamber.

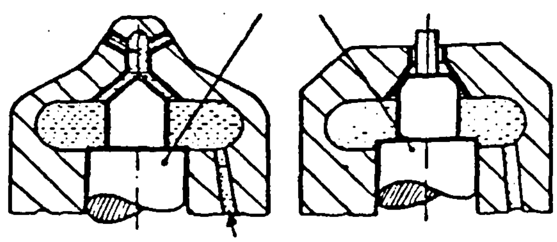



Fig. 15: The two most important types of injection nozzle

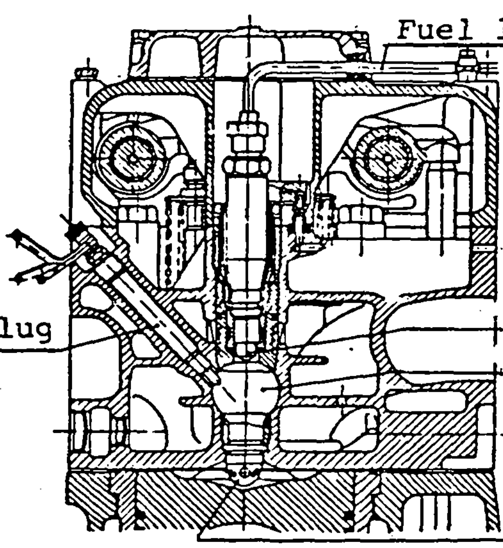



Fig. 16: Section through the cylinder head of an engine, showing

both the prechamber as well as the upper part of the cylinder with the main combustion chamber.

The two parts of the combustion chamber are linked by a heat-resistant burner insert. The positive combustion pressure blows the burning mixture through this insert into the main combustion chamber, where it is swirled about with the air and is completely burned.

### 3.4 The fuel system

The finely atomized fuel is injected into the cylinder at a pressure of 80 - 350 bar. Prechamber engines require lower injection pressures, while engines with direct injection call for higher pressures.

The injection system (Figs. 17 and 18) consists of the following principal components: supply pump, fuel filter, injection pump and injector. The supply pump draws the fuel out of the tank and forces it into the suction gallery of the fuel-injection pump via the filter at approximately 1 bar gauge pressure. This ensures that (after bleeding) all chambers are filled with fuel and no compressible gases enter the high-pressure delivery line. Any excess fuel supplied is routed back to the tank via the overflow valve and overflow line. During injection each cylinder is supplied with a precisely metered amount of fuel by the injection pump, the fuel being pumped to the injector via the high-pressure delivery line and entering the cylinder in finely atomized form.

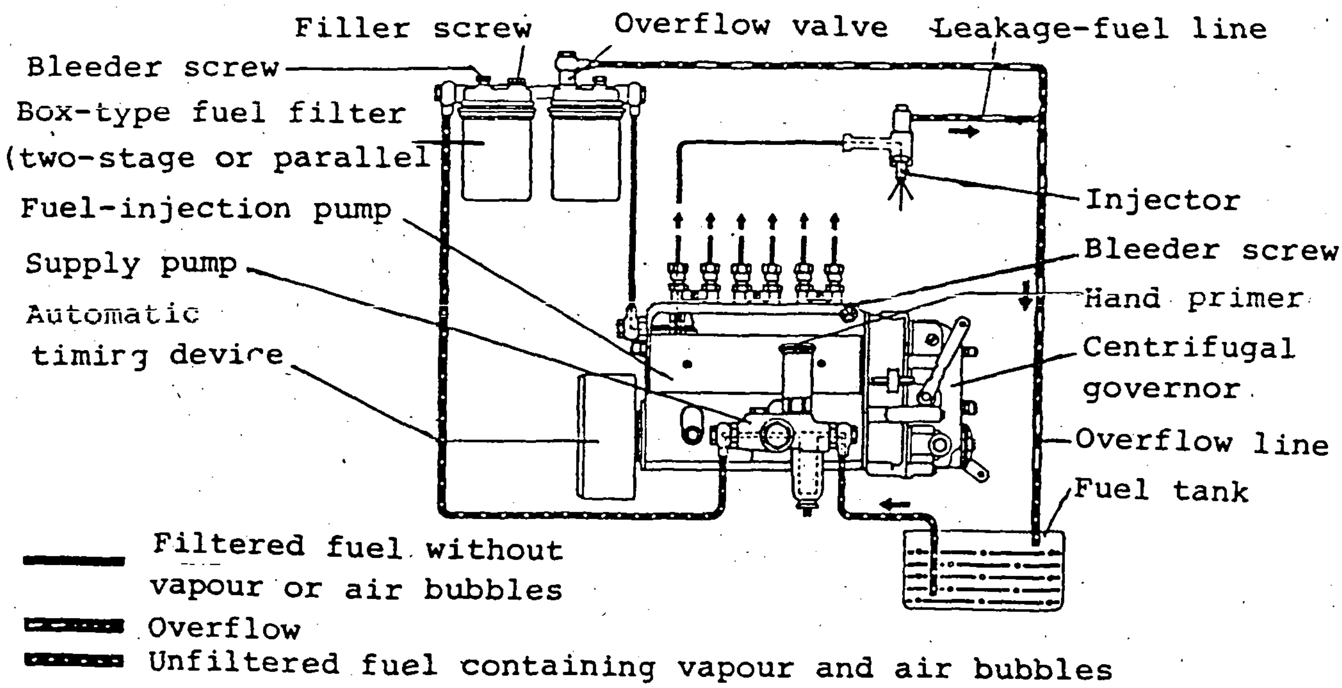



Fig. 17: Fuel circulation in the injection system

The fuel which escapes between the nozzle needle and nozzle body flows back to the tank via the leakage-fuel line. There is one injection-pump plunger-and-barrel assembly for each engine cylinder. In small and medium-sized engines these assemblies are combined in a single housing to form a multi-barrel pump. Large engines have a single-plunger pump on each cylinder so that the fuel lines to the injectors are not too long. This is because the high pumping pressures cause the high-pressure delivery lines (steel) to expand. The start of injection is delayed if the lines are long and at the end of injection pressure relief in the line takes place more slowly, with the result that the injection nozzle drips.

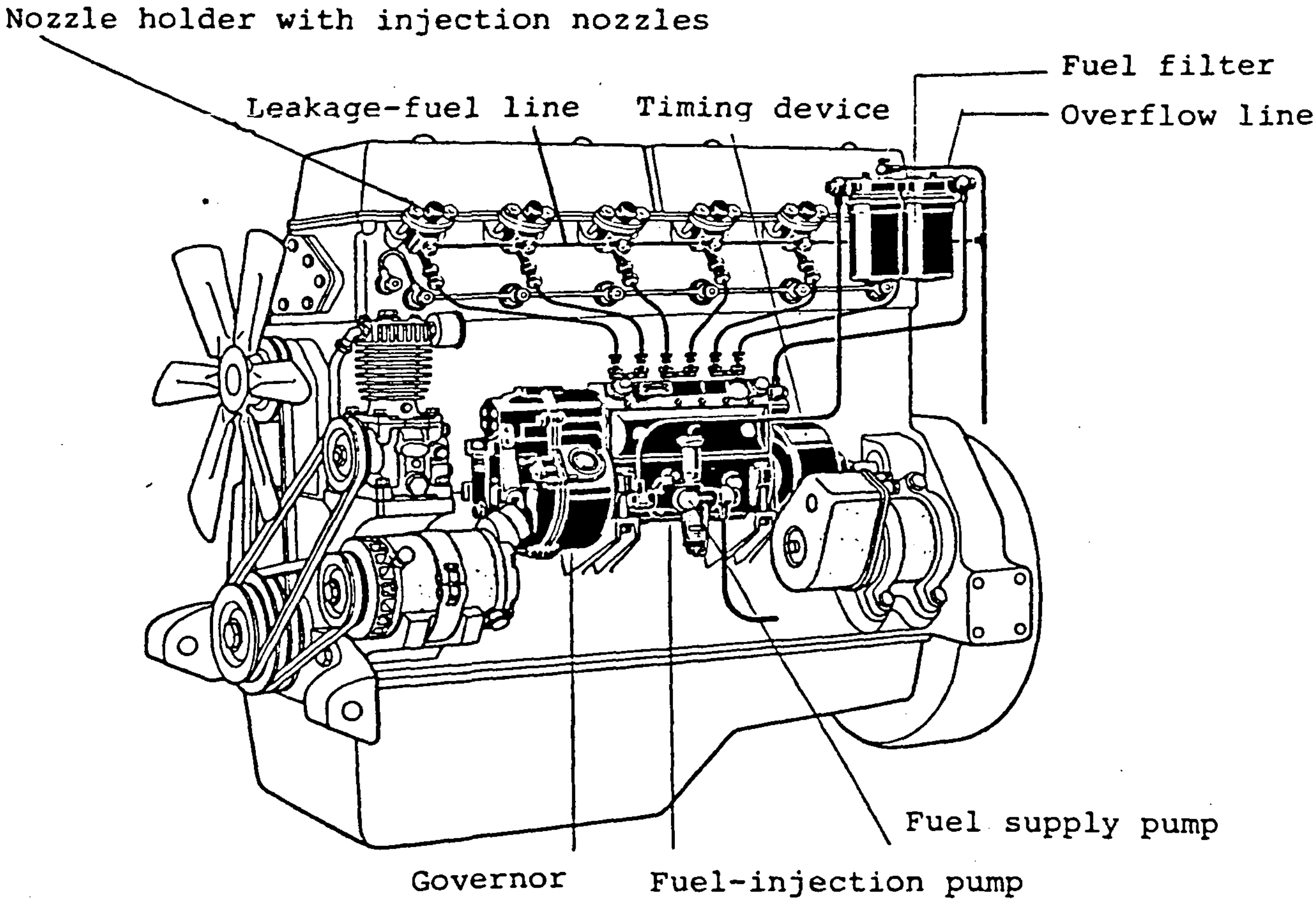



Fig. 18: Injection system on a vehicle engine.

## 3.5 The two-stroke diesel engine

Whereas the two-stroke cycle is viable only for small power outputs in the case of spark-ignition engines, two-stroke diesel operation has proved particularly effective for high power outputs. It achieves the high efficiency of four-stroke engines because it uses pure air for scavenging, thereby making it possible to expel the exhaust gases in full by means of a high rate of air flow.

The scavenging and charge air is generated by the underside of the piston and cylinder, by piston compressors mounted on the end of the engine, by mechanically operated centrifugal superchargers or by exhaust turbochargers. Cylinder evacuation and recharging is effected by way of loop scavenging or uniflow scavenging.

Loop scavenging (Fig. 19):
The exhaust ports are located above the scavenging ports on the same side of the cylinder. The descending piston ends its power stroke when its upper edge uncovers the exhaust ports. The gases escape through the exhaust pipe and expand; the piston then uncovers the scavenging ports. The incoming scavenging and charge air removes the remaining exhaust gases in the direction of flow shown. The ascending piston starts the compression process once its upper edge has covered the exhaust ports. The schematic diagram also shows the way in which the underside of the piston and cylinder acts as a charge pump.

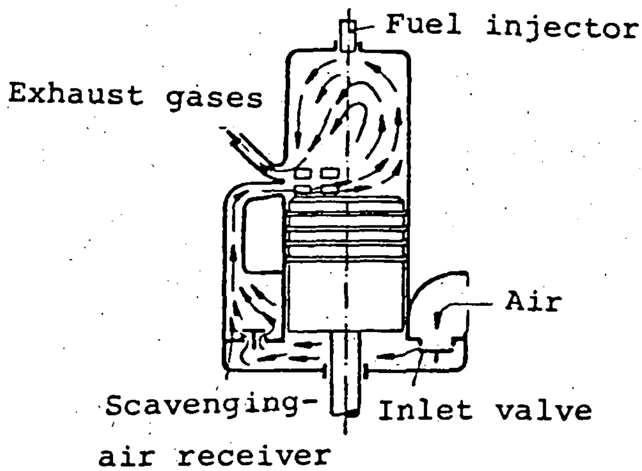



Fig. 19: Loop scavenging

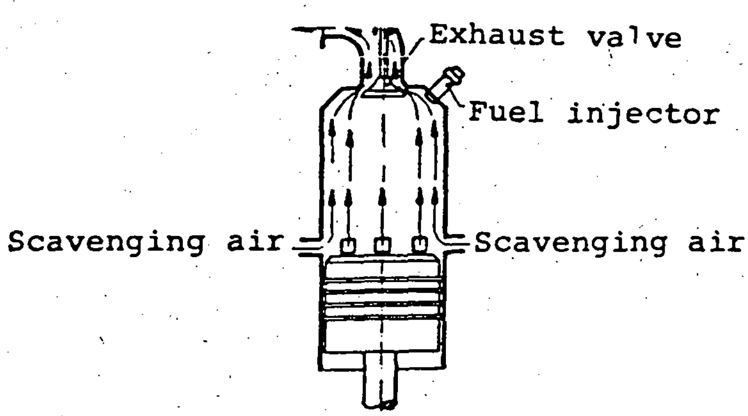



Fig. 20: Uniflow scavenging

Uniflow scavenging (Fig. 20):
The cylinder head contains between one and four timed exhaust valves. The scavenging ports generally route the scavenging air into the cylinder at an angle, so that it flows upwards with a slightly circling motion. The advantage of uniflow scavenging is the reduction of scavenging losses. Moreover, the opening and closing times of the exhaust valves are independent of piston position. They can thus be asymmetrical with respect to BDC and, for example, can be adapted as required to the operating conditions of supercharged engines with exhaust turbochargers.

## 3.6 Supercharging

Large diesel engines - including, more recently, vehicle engines as well - are today supercharged almost solely by means of exhaust turbochargers. In the supercharging process the air is drawn in by a compressor and supplied to the cylinder at a pressure above atmospheric. In accordance with the greater quantity of charge air, more fuel can be burned per power stroke and the specific power output thereby increased. The resultant advantages are reduced weight and smaller space requirements for an engine with a given power output as well as improved energy utilization (degree of efficiency: 40 - 45 %).

The increases in both pressure and temperature resulting from supercharging and increased energy conversion are limited by the thermal loading capacity of the engine. The thermal load can be reduced by making the inlet and exhaust ports remain open for longer, allowing the high rate of air flow to cool the cylinder and valves. This simultaneously reduces the temperature of the exhaust gases (approx. 400°C) such that they can be directed onto the vanes of the turbine of the exhaust turbocharger without any further measures being taken.

Supercharging and the greater energy throughput would also lead to an undesirable rise in the firing pressure, a factor which determines the load imposed on the power unit components. This pressure is limited by means of an appropriate injection characteristic with combustion which starts later and is extended.

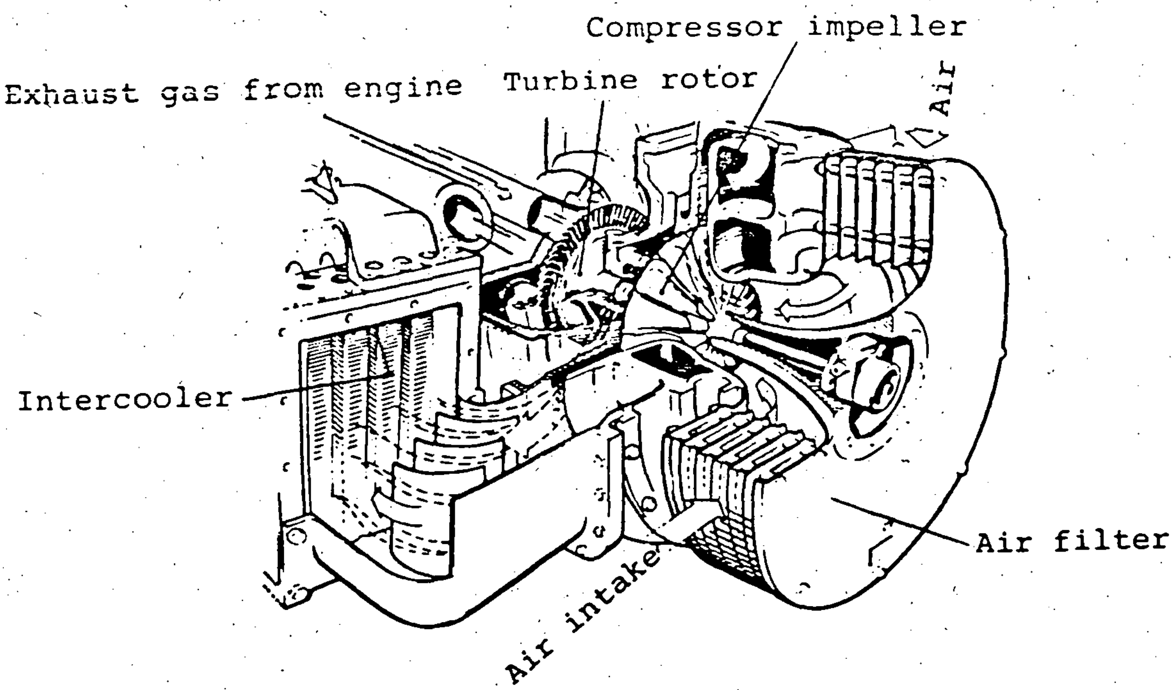



Fig. 21: Exhaust turbocharger

The exhaust turbocharger (Fig. 21) consists of a generally single-stage exhaust-driven turbine with a turbocharger compressor rigidly coupled to it. In the turbine, part of the exhaust energy, which is otherwise lost, is used to drive the compressor.
The turbine largely adapts to the engine's supercharging requirements in that the exhaust energy causes it to run more quickly or more slowly as power output changes.

The precompression increases the temperature of the air and accordingly reduces the mass of the charge air. In the case of high boost pressures, therefore, an intercooler is connected between the compressor and the engine inlet. Exhaust turbochargers are built as standard for a positive boost pressure of 1.6 bar.
The pulse method and the constant-pressure method are used to drive the turbines (see Fig. 22).

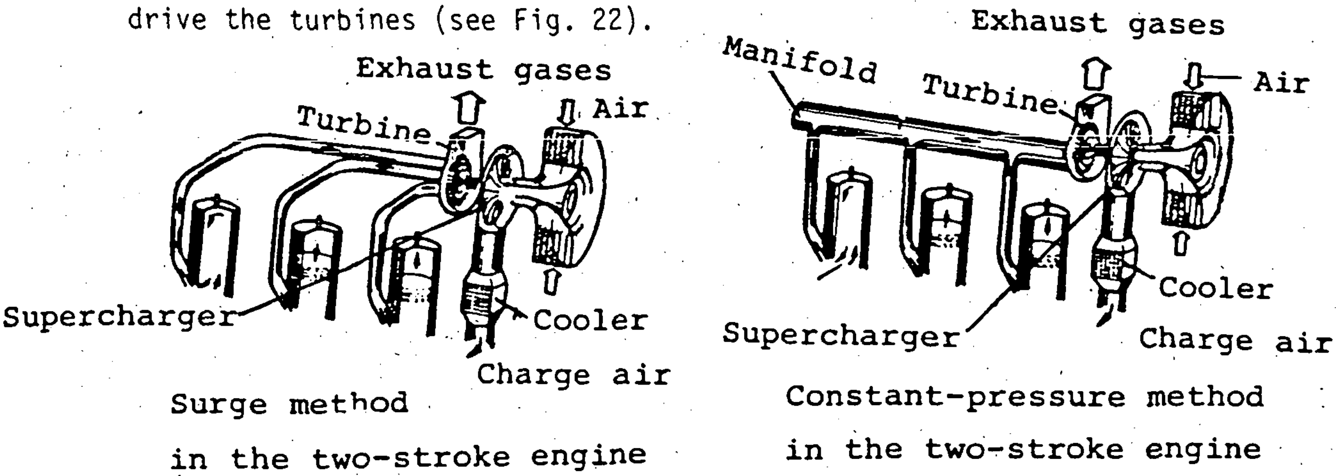



Fig. 22: Surge method and constant-pressure method

3.7 Comparison between diesel engine and petrol engine

| Features | Diesel | Petrol |
|---|---|---|
| Fuel | Diesel oil, gas oil | Petrol |
| Ignition | Self ignition | Spark ignition |
| Mixture formation | Internal | External |
| Engine speed | Up to 4500 rpm | Higher |
| Efficiency | Approx. 40 % | Approx. 30 % |
| Proportion of toxic substances in exhaust emissions | Smaller | Larger |
| Specific fuel consumption * | Lower | Higher |
| Noise generation | Greater | Smaller |
| Engine weight | Heavy | Light |
| Firing pressures | 50 - 80 bar | 35 - 45 bar |

* Fuel consumption in relation to unit of power, measured in $\frac{g}{kWh}$

4. Fuels

These are without exception hydrocarbon compounds and are obtained primarily from crude oils by means of fractional distillation. This means that the crude oil is broken down according to boiling ranges as follows: Straight-run petrol up to 200°C, paraffin between 180 and 280°C, gas oil or diesel oil between 280 and 360°C and lubricating oils over 360°C. Gaseous fuels occur in the form of natural gases or are produced in the course of petrol synthesis, e.g. propane or butane.

Properties of some liquid fuels:

| Type of fuel | Density $\rho$ in kg/l | Calorific value in kJ/kg | Theoretical air requirement in $m^3$/kg of fuel |
|---|---|---|---|
| Petrol (on average) | 0.74 | 43 000 | 12.5 |
| Benzene | 0.87 | 40 000 | 10.6 |
| Ethyl alcohol | 0.8 | 27 000 | 7.4 |
| Methyl alcohol | 0.8 | 20 000 | 5.3 |
| Diesel fuel | 0.85 | 42 000 | 11.0 |

The fuels to be used in petrol and diesel engines are totally different from each other in terms of their most important properties:
The mixture supplied to the petrol engine must not ignite of its own accord at "hot spots" in the combustion chamber, since it is supposed to be ignited at the correct moment by the spark plug. Explosive igniton which starts at the wrong moment is generally referred to as "knocking" and can in the long run lead to severe engine damage.
It is therefore essential to have "knock-resistant" fuels; knock resistance can be achieved through the addition of benzene, lead compounds etc. The octane number, which is determined in test engines, indicates the anti-knock quality of fuels for petrol engines.
In the diesel engine, combustion must be initiated by way of self ignition. Ignition quality, expressed by the cetane number, is therefore extremely important. Here again, the cause of the knocking typical of diesel engines is the rapid rise in pressure caused by explosive combustion. The evaporation of the initially injected fuel particles causes an ignition delay, which is quickly followed by sudden combustion. Diesel fuels with a good ignition quality reduce the ignition delay and permit smoother running. A cold engine, insufficient compression as a result of old piston rings and part-load operation, however, increase the loud running noise.

## 5. Lubrication

The lubricating oil obtained from crude oil is essentially required to perform the following functions in the internal-combustion engine:

- To reduce the friction on the part of all moving components by means of lubrication (pistons, cylinders, crankgear, valvegear etc.)
- To cool the engine
- To seal the engine (engine block, piston/cylinder, bearing points)
- To prevent dirt particles in the engine from settling; this achieves a cleaning effect
- To protect the engine against corrosion (in the case of long periods of disuse)
- To suppress noise

The following types of lubrication are most commonly used:

- Pressure lubrication
- Petroil lubrication (only in two-stroke spark-ignition engines)

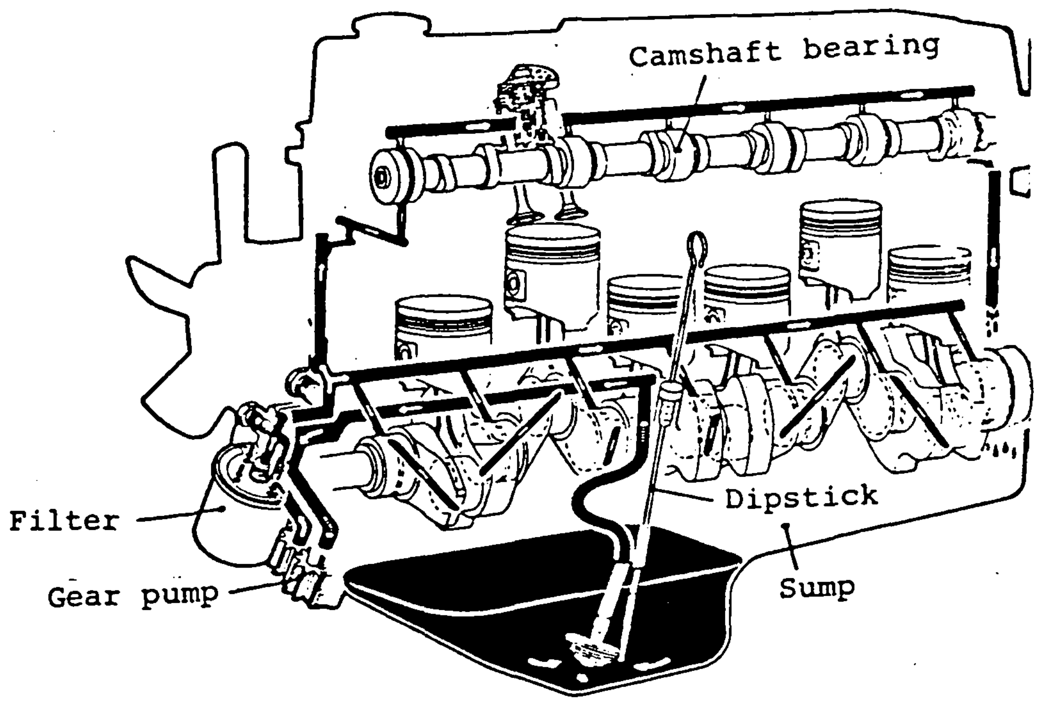



Fig. 23: Pressure lubrication in a spark-ignition engine

Pressure lubrication is the lubrication system generally used today. The larger the engine, the greater the number of parts, lubrication points and feed lines to be suppllied.

Parts subjected to considerable thermal stressing (cylinder walls, piston crowns) are cooled via special oil feed lines. The oil is recooled in an oil cooler.

Fig. 23 illustrates the lubricating-oil circulation system usual in standard vehicle engines. A gear pump (shown on its own in Fig. 24) draws the oil out of the sump and delivers it to the lubrication points at a pressure of approx. 2 - 5 bar. Parallel to this, part of the oil flows through the filter. Each of the individual crankshaft bearings has an oil passage; through holes in the crankshaft the oil reaches the big-end bearings, where it is partly flung out and lubricates and cools the cylinder walls, pistons and gudgeon pins.

Two-stroke spark-ignition engines require a special lubrication system, as the crankcase is required for the charge cycle. The lubricating oil is added to the fuel with a fuel/oil mixture ratio of around 30 : 1 to 40 : 1 and reaches the parts to be lubricated together with the fuel.

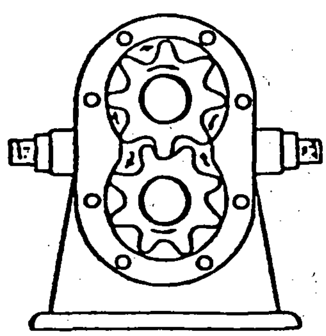
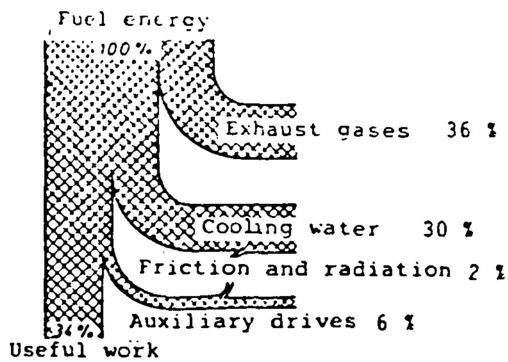


Fig. 24: Gear pump for supplying oil

## 6. Engine cooling

The hot combustion gases cause temperatures of over 2000°C for brief periods in the engine. However, the material of the engine components can only withstand these temperatures up to a certain limit without sacrificing any of its strength. A considerable proportion of the heat produced must therefore be dissipated, as shown in Fig. 25; the engine needs a cooling system.



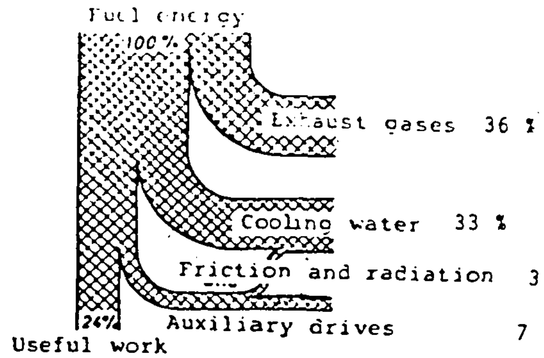




Fig. 25: Energy flow diagrams for a diesel engine (left) and a petrol engine (right)

The primary coolant is the oil used for lubrication, with water or air providing secondary cooling.

In the case of water cooling, several cylinders form an engine block surrounded by a water jacket. A pump supplies the water - which circulates from bottom to top - to the cylinder block; the water is then routed to the heat exchanger, where it is cooled again with air or water.

The aim should be to quickly achieve operating temperatures around 80°C in order to prevent the fuel from forming harmful condensates (risk of corrosion). A thermostat helps to ensure this during the engine warm-up phase.

In the case of air cooling, the heat-dissipating surface of the cylinder and cylinder head is enlarged by means of cooling fins, the air flow being forced through between these fins with the aid of fans. Only motorcycle engines - by virtue of the head wind - do not require a fan. Its simple maintenance makes air cooling a particularly attractive proposition for small, highly stressed engines in the construction industry.

1 = Thermostat
2 = Hose connection
3 = Radiator cap
4 = Subsidiary coolant pipe
5 = Radiator
6 = Radiator drain tap
7 = Cooling water pump
8 = Cylinder
9 = Engine drain tap
10 = Cylinder head
11 = Remote thermometer

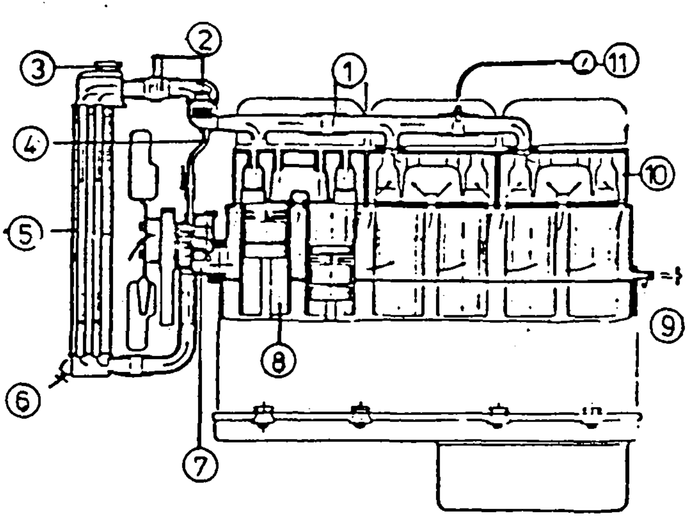



Fig. 26: Water-cooled vehicle engine

7. <u>Electrical systems on the engine:</u>

1. Ignition system
2. Generator/alternator
3. Starter motor
4. Battery

7.1 Ignition system:

In all spark-ignition engines the fuel/air mixture in the cylinder is ignited by an electric spark. This spark, however, can be produced and triggered in various ways. The individual ignition systems therefore differ in terms of their design and mode of operation.

<u>Ignition systems:</u>

The most commonly used system is coil ignition. A battery or generator supplies the electric current which flows through an ignition coil. An extremely high ignition voltage is generated in the coil if the circuit is broken. The contact breaker in the distributor is actuated by a camshaft. A rotating distributor arm feeds the ignition current to the appropriate spark plugs, where the current generates the desired ignition spark and then flows back to the power source via earth.

The individual components are located at various points in the engine and are connected to one another by means of insulated leads. The current flow can be easily seen from a circuit diagram. There are two different circuits: a voltage of 6 or 12 V is generated in the primary circuit and a voltage of 10 000 - 25 000 V in the secondary circuit. The leads of the secondary circuit are well insulated with respect to earth on account of the high voltage.

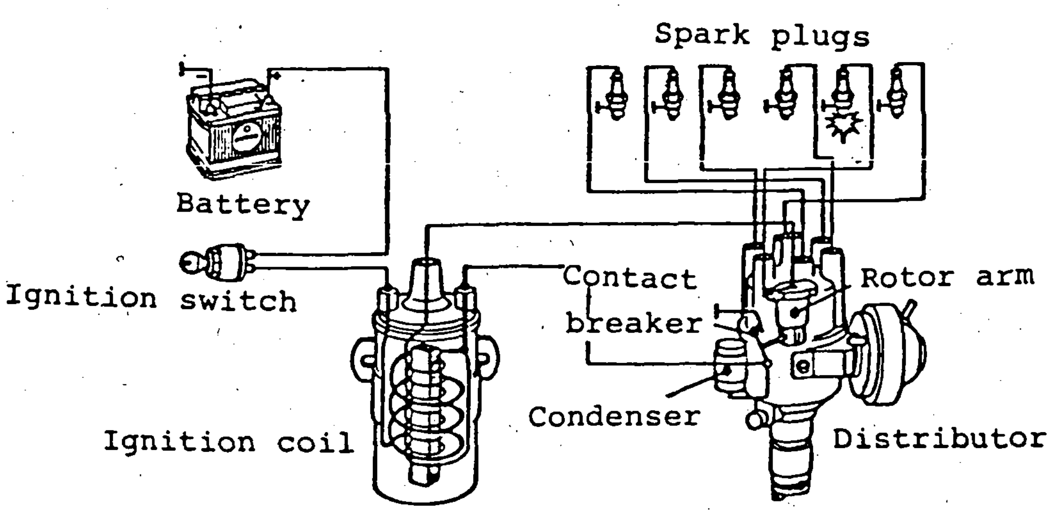



Fig. 27: Ignition system of a six-cylinder petrol engine

Ignition coil:

The current has to overcome a considerable resistance in the spark plug and therefore requires a very high voltage (10 000 to 25 000 V). This ignition voltage is generated in the ignition coil (Fig. 28).

The ignition coil has a primary winding made of thick copper wire and a secondary winding made of thin copper wire. The two windings are wrapped one over the other and in the centre of them is an iron core, which is made up of individual laminations, each of which has paper on one side. All the parts are contained in a metal casing and are well insulated with respect to one another. The casing is filled with a sealing compound and a cap provides an air-tight seal. This cap is made of moulded material and carries the terminals. When the primary circuit is closed, a magnetic field is set up in the coil. This field collapses again, however, if the circuit is broken and the magnetic lines of force then generate a high induced voltage in the secondary winding. The battery is subjected to a very heavy load during starting and often delivers an insufficient ignition current. Many ignition coils therefore have a second primary winding which is then connected and reinforces the magnetic flux.

The same effect can also be achieved by means of a series-connected resistor. This is short-circuited upon starting, so that the coil once again receives its full voltage and can generate an adequate spark. The resistor also limits the current inflow and thus prevents winding burn-out.

The operation of an ignition coil can be checked in a simple manner. For this purpose the centre ignition lead is detached from the distributor and held against the engine block. The spark must jump the considerably larger air gap when the circuit is broken.

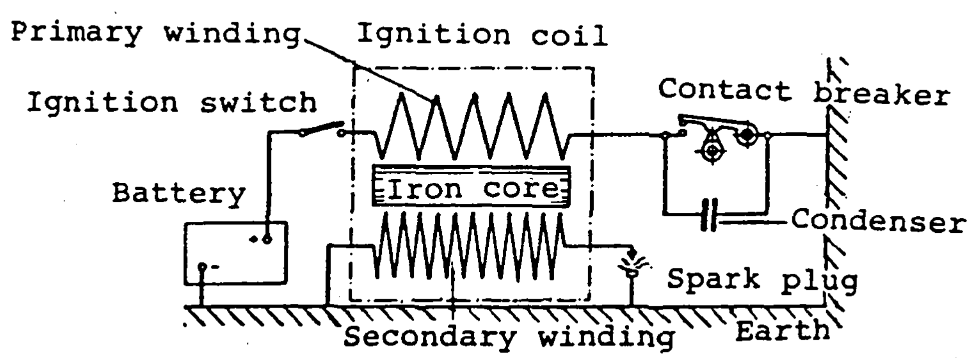
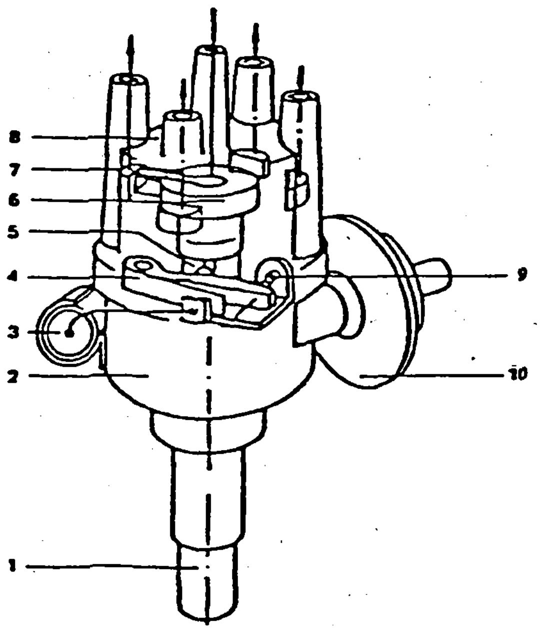



Fig. 28: Operating principle of a coil ignition system

Distributor:

The distributor regulates the timing and distribution of the ignition sparks. This is done by the distributor shaft and by the rotor arm (Fig. 29). The distributor shaft is driven either by the camshaft (four-stroke engines) or by the crankshaft (two-stroke engines) of the engine and actuates the contact-breaker arm. This arm is insulated with respect to earth and is pushed against the distributor shaft by a leaf spring. The contacts open each time the arm is actuated by the cam and thus automatically trigger the ignition pulse.




1 = Distributor shaft
2 = Distributor body
3 = Condenser
4 = Contact-breaker arm
5 = Camshaft
6 = Rotor arm
7 = Electrode
8 = Distributor cap
9 = Contacts
10 = Vacuum unit

Fig. 29: Prinicipal components of a distributor

The rotor arm routes the high-tension ignition current to the individual ignition contacts, which are located in the distributor cap and are separated by a small gap from the metal electrode of the rotor arm. The ignition current is therefore always of a specific strength. The firing sequence is determined by the engine's mode of operation. The connection for the first cylinder is indicated on the rim of the distributor by means of a small notch.

The magnitude of the ignition voltage depends upon the generation of the magnetic field in the ignition coil, a process for which a certain amount of time is required. The decisive factor, therefore, is the time for which the contacts are closed (dwell period); this in turn is determined by the dwell angle and the engine speed.

The dwell angle and thus the ignition voltage can, however, be varied within certain limits by means of the gap between the contact-breaker points. A large breaker-point gap yields a small dwell angle and a small gap a large dwell angle. The specified breaker-point gap and dwell angle must therefore be precisely observed.

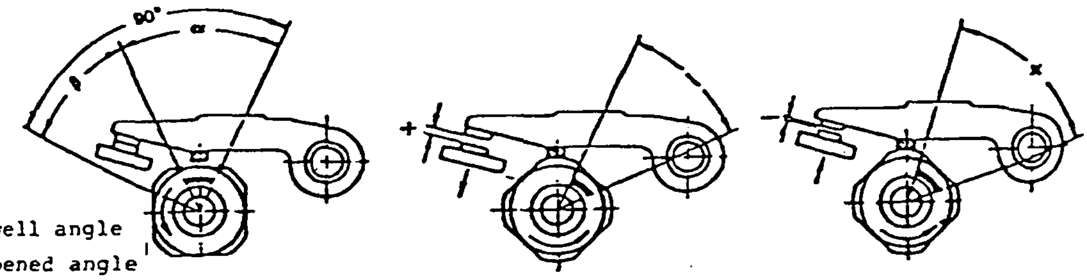



Fig. 30: Breaker-point gap and dwell angle

Spark plug:

The function of the spark plug is to feed the high-tension ignition current to the combustion chamber and produce a spark there. The spark plug is made of several parts and generally cannot be dis-assembled.

The centre electrode with the terminal nut for the ignition lead is embedded in an insulator made of ceramic material (Pyranit) such that there is a gas-tight seal. The insulator is secured in a steel housing by means of a crimping ring and a seal ring; the housing has a fine thread so that it can be screwed into the cylinder head.

Spark plugs generally have an M 14 x 1.25 thread, although M 18 x 1.5 threads are also used for two-stroke engines. The earth electrodes are located on the bottom of the housing.

1 = Terminal stud
2 = Pyranit insulator
3 = Crimping ring
4 = Housing
5 = Shrinkage zone
6 = Fused mass
7 = Gasket
8 = Seal ring
9 = Centre electrode
10 = Earth electrode
11 = M 14 x 1.25
M 18 x 1.5

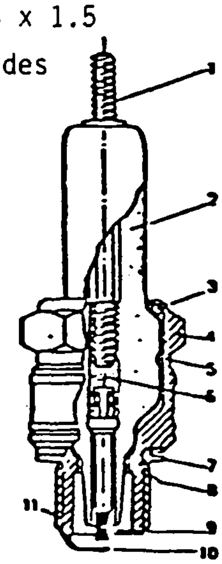


Fig. 31:
Principal components
of a spark plug

Heat rating:

The spark plugs are subjected to severe loading in the cylinder as a result of the changing temperatures (60 - 2000°C) and gas pressures (1-50 bar). The temperature of the spark plug, however, must not exceed 800°C, since otherwise the inflowing gases will ignite prematurely on the glowing of the spark plugs and neutralize the effect of the spark.

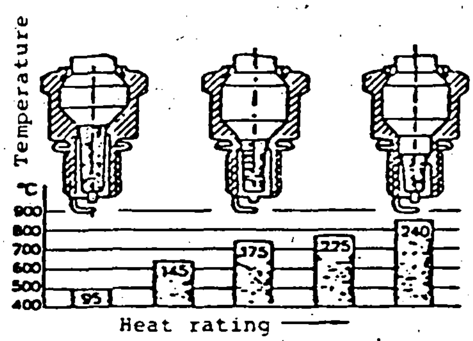



Fig. 32: Heat rating table for spark plugs

Moreover, the operating temperature must not drop below 500°C, as otherwise the combustion residues will contaminate the firing end of the spark plug and divert the ignition current to earth. As the spark plugs absorb only a specific amount of heat, plugs with various heat ratings have been designed. The higher the heat rating, the longer the insulator nose. The heat rating gives information on the thermal stress capacity of spark plugs.

7.2 Generator/alternator

Engine generators and alternators have to meet the following demands:
- Supply of the power required by the electrical loads.
- Sufficiently large power reserve for charging the battery, even with permanent loads switched on.
- Battery charging even at low engine speed (idling).
- Constant voltage under all operating and load conditions.
- Insensitivity to vibration, temperature variations, moisture, dirt, petrol, oil.
- Large speed range.
- Operation without servicing.
- Dimensions requiring little installation space, low weight.

These requirements are best met by the alternator with rectifier, which has largely superseded the DC generator.

## 7.3 Starter motor

Unlike electric motors and steams engines, internal-combustion engines are not capable of self starting, so they must be started by a special device. In most cases, use is made of a battery-supplied electric motor with a pinion capable of axial displacement and which during starting engages a ring gear fitted to the inertia flywheel or to a transmission component of the engine.

The size of the starter motor and battery (starting system) is determined by the torque required for cranking the engine at the starting limit temperature (maximum viscosity of lubricating oil) and the required cranking speed.

## 7.4 Battery

The battery supplies the stationary engine with electric current. When a specific engine speed is reached the generator takes over this function. The battery is simultaneously recharged; this process is indicated by a red lamp going out.

The battery consists of an acid-proof case, which is subdivided into several cells and tightly sealed with respect to the atmosphere by means of a cover.

Each cell contains several grid-like plates made of hard lead. The individual spaces are filled with a lead-containing paste. When in a charged condition, the positive plates are dark brown and the negative plates bluish-grey. The plates are divided from one another by means of separators.

The cells are filled with dilute sulphuric acid and, when in a charged condition, deliver an electric voltage of around 2 V. As a motor vehicle requires 6, 12 or 24 V, however, three, six or twelve cells are always connected in series. The terminal posts have different diameters; the leads are subsequently connected to these posts with the aid of special terminals. The positive lead (+) is connected first when the battery is installed and the negative lead (-) detached first when the battery is removed.

1 = Battery case
2 = Cell partition
3 = Cell connector
4 = Terminal post
5 = One-piece cover
6 = Vent plug
7 = Plate connector
8 = Negative plate
9 = Separator
10 = Positive plate

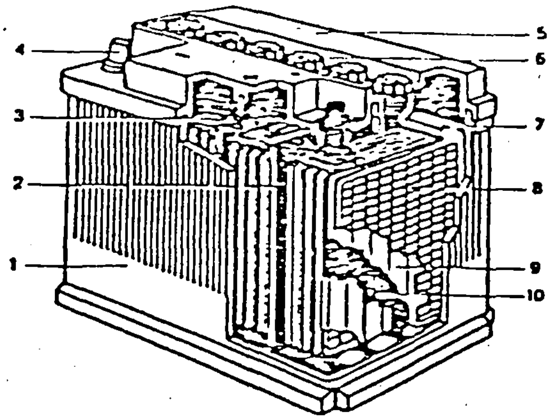



Fig. 33: Structure of a battery

The battery can absorb only a certain amount of current. Its capacity is essentially determined by the number and size of the plates. The so-called "ampere-hour capacity" is determined by the current and the discharge time. The nominal value applies to a discharge time of 20 hours and an electrolyte temperature of 27°C.

Ampere-hour capacity = current · discharge time or $Q = I \cdot t$

or in other words $I = \frac{Q}{t}$ and $t = \frac{Q}{I}$

The respective battery voltage then yields the available working capacity.

Working capacity = battery voltage · battery ampere-hour capacity or $W = U \cdot Q$

<u>Example</u>:

A 12 V battery has an ampere-hour capacity of 45 Ah. How much power can be taken from the battery?

$W = U \cdot Q = 12 \cdot 45 = 540$ Wh.

If a large amount of current is consumed, only the molecules at the surface of the plates are converted. The battery will then soon deliver a reduced current and will, moreover, soon become discharged. The starter motor, which has a high current consumption, must therefore not be operated for too long a time.

Self-discharge:

Batteries lose their charge even when not in use. This self-discharge, which is greatly accelerated by even the slightest trace of impurities in the electrolyte and which increases at high temperatures, amounts to 0.2 - 1 % of the ampere-hour capacity daily, depending on the age of the battery.

Electrolyte:

Acid values of dilute sulphuric acid.

| State of charge | Battery type | Electrolyte density 1) kg/l | Freezing point °C |
|---|---|---|---|
| Charged | Standard | 1.28 | - 68 |
| | For tropics | 1.23 | - 40 |
| Half-charged | Standard | 1.20 | - 27 |
| | For tropics | 1.16 | - 17 |
| Discharged | Standard | 1.12 | - 11 |
| | For tropics | 1.08 | - 8 |

If a battery has been properly cared for (plates not sulphated), the electrolyte density provides a measure of the state of charge.

1) At 20°C.

The electrolyte density is inversely proportional to the temperature with approx. 0.01 kg/l corresponding to a 14°C change in temperature.

8. Bibliography

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