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Rural Mechanics Course 3: Repair and Maintenance of Stationary Diesel Engines

By: John van Winden

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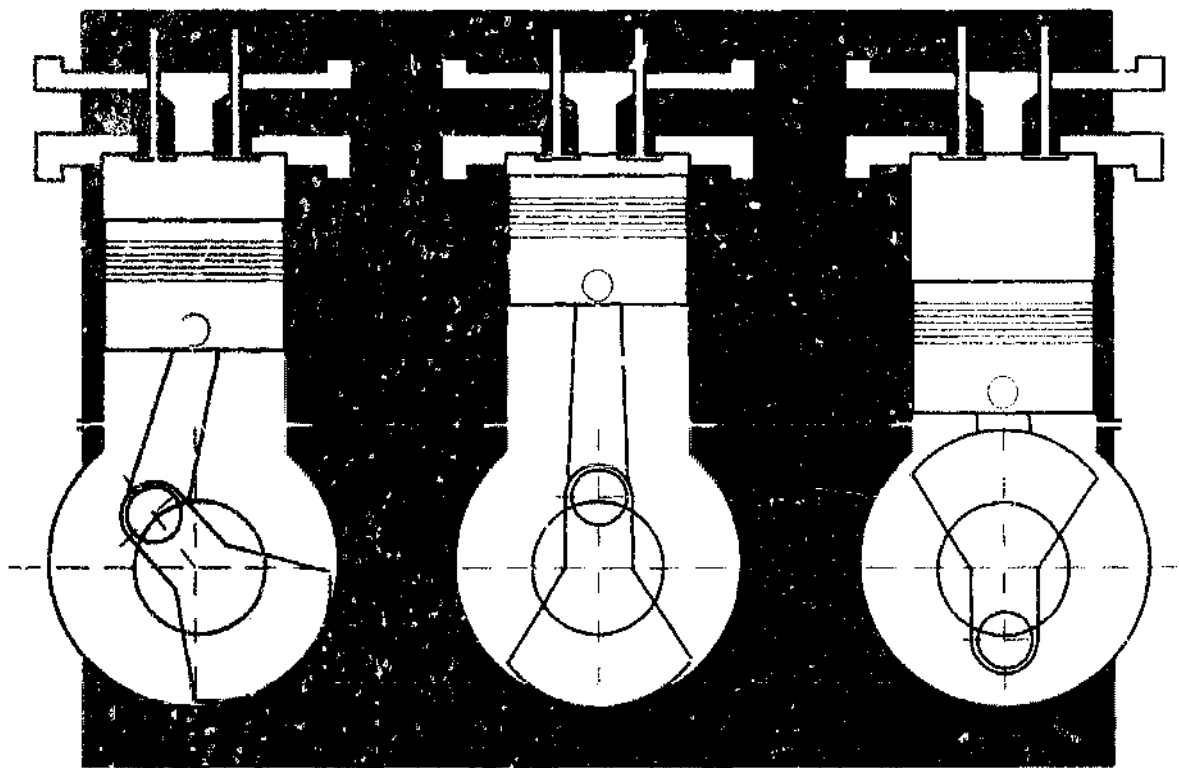1018 AV Amsterdam
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REPAIR AND MAINTENANCE OF STATIONARY DIESEL ENGINES

RURAL MECHANICS COURSE 3

TOOL

John van Winden

Maintenance and Repair of Stationary Diesel Engines

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Preface

We have decided to publish this edition of the Rural Mechanics Course in response to the many requests from people involved in training for technical vocations and in general development work.

The main aim of this set of books is to provide technical training information in understandable language and with illustrations suited to the understanding of those involved.

The contents of these books reflect the rural development taking place in the agricultural sector in particular, where many urgent needs have to be looked after and solved in order to achieve sound development at all levels.

This Rural Mechanics Course has been compiled for teaching in Technical Vocation Centres in addition to a Rural Building Course, which deals with skills such as carpentry and masonry.

We are grateful to the Stichting Brothers F.I.C., Stichting TOOL for their technical assistance, Stichting Cebemo for their financial support and the German Volunteer Service for so many volunteers who have contributed in no small way to the compilation of these books.

It is our sincere wish that the contents of these books may be of assistance in stimulating the use of appropriate techniques to aid agriculture and general development.

Bro John van Winden F.I.C.

Introduction

In many situations radical and urgent changes are taking place in rural areas in order to restore land to agriculture, to bring about better living conditions and secure health and educational facilities - the basis for a healthy economy.

Needs arising from these changes are not always dealt with because many technical institutions do not provide appropriate technical training geared to solving problems which have gone unnoticed in the past.

It can also be noted that small co-operative workshops are being started these days in the interests of agriculture and these too may develop as they deal with the upkeep of small mechanized farm implements and diesel engines used for water supply or with making ploughs, handcarts, gardening tools, etc.

Integrated and relevant technical training and grouping young people together into co-operative movements should be emphasized to ensure sound agricultural and general development. That is why an attempt has been made to achieve appropriate technical training for rural mechanics, who will contribute in no small way towards the necessary development.

Since the technical needs in rural areas are many but do not on the whole need highly specialised technicians to solve them, the rural mechanic - because his training covers a broad basis - will often be solving problems arising from the introduction of new implements or tools.

The course lasts four years, almost two years of which are set aside for so-called 'on-the-job training'. This is practical training provided in various workshops under the guidance of qualified technicians as well as a centre instructor who visits the workshop at intervals to see for himself how the trainees are progressing. During 'on-the-job training' the trainee is rewarded for his work which may help him later to buy the set of tools he has used during his training, so he can start working immediately after completing the course successfully.

Rural mechanics course

A set of four books has been compiled to accompany the four-year course for rural mechanics:

1 - General metal work, sheetmetal work and handpump maintenance
2 - Blacksmithing, welding and soldering
3 - Maintenance and repair of stationary diesel engines
4 - Technical drawing

While each of these books covers the full material of one course, a lot of additional information needed besides the contents of one particular book will be found in another book. So it is difficult to use just one of these books without consulting the others. The text on the properties of metals, for example, is to be found in the general metal work book. But this information is also needed when you are dealing with other subjects, such as diesel engines, blacksmithing etc.

As mentioned above, this course is made up in such a way that most of the practicals can be carried out with a limited set of tools. You will however notice that ... equipment or tools are needed sometimes and these must be available in the Vocational Centre s workshop.

It is believed and hoped that with the formation of co-operatives these additional tools and equipment will be available in the workshops because, though they are more expensive, they can be owned by the group.

The main aim of this course is that the trainee, besides acquiring a good formative background, will learn to master such skills as:

- working with and maintaining all the tools explained
- blacksmithing to such a degree that he will be able to shape different metals to the required implements, tools, etc.
- repairing, maintaining and installing hand waterpumps
- dismantling, repairing and assembling stationary diesel engines
- sketching or drawing simple items in orthographic, oblique and isometric form; reading engine or machine manuals.

This set of books can be used partly in the classroom but must also be used during workshop practice, where the reality of what can be seen will add greatly to the text and

illustrations in the books. Practical exercises recommended in the books can be varied since the practical nature of this course calls for articles to be made which can be used directly by people who may order them. But care should be taken that, though production may be necessary for one reason or another, all the skills which must be mastered are incorporated in each practical, so as to ensure sound training.

It is very important to study the proposed timetable given in each book to ensure that all skills are given the necessary attention. Apart from the progress made by each trainee, the time recommended for each skill may vary as well. Some skills take more time to master than others.

You will note the absence in this course of the science which may be important in explaining the diesel engine in particular. Providing this background theory is however beyond the scope of the course. But if the need arises, the relevant science should be included during part of the related subject time.

This Rural Mechanics Course is the result of many years' observation and experimentation with different techniques. The contents have frequently been revised to serve all those interested in rural development, and it is hoped this course will be used in many technical vocation centres and communities. It is also the sincere wish of the founders of this course that the trainees should feel on completion of their training that they are able to contribute personally to the development of the rural areas, which is of such importance to any general development.

Rural mechanics course lay-out and timetable

Four year training course
a - Full Centre training: workshop practicals, trade theory, technical drawing and related subjects. Two years = 80 weeks
b - Partly Centre training: trade theory, technical drawing, related subjects. Practicals take place outside the Vocational Centre. One year = 40 weeks
c - On-the-job training: practicals take place outside the Vocational Centre. (Practicals are however controlled by Centre staff and marks are awarded for any progress made.) One year = 40 weeks

Total vocational training time
Four years = 160 weeks

Weekly timetable for related subjects and practicals
a - Trade theory	4	hours
b - Technical drawing	1½	hours
c - Mathematics	2	hours
d - Language	2	hours
e - Other related subjects	2½	hours
Total related subjects	12	hours
Total hours workshop practice	28	hours
Total training time in centre	40	hours

Four-year timetable, workshop practicals
One full year reserved for Centre workshop practice:
a - General metal work
b - Blacksmithing
c - Welding and Soldering
d - Sheetmetal work 1120 hours

One full year reserved for Centre workshop practice:
a - Stationary diesel engines
b - Agricultural machinery 1000 hours
c - Water pumps and water supply 120 hours

Two full years reserved for on-the-job training:
a - One year partly practicals 1120 hours
b - One year full on-the-job training outside the Centre. (Care should be taken that the time is evenly divided for practical training in all skills.) 1760 hours

Three-year Centre timetable for trade theory
a - General metal work		
b - Welding and soldering		240 hours
c - Blacksmithing		
d - Sheetmetal work		
e - Stationary diesel engines		220 hours
f - Waterpumps and supply		20 hours
Total theory time:		480 hours

General

Stationary diesel engines

With the introduction of mechanically driven water pumps, small agricultural machinery and electric plants for all kinds of purposes in modern agriculture and general development, an urgent need has grown up for skilled people able to look after diesel engines – the main power source for these machines.

That is why a widely trained mechanic who owns certain tools and equipment should be able to carry out most of the common repairs and maintain these engines used in rural areas. This part of the Rural Mechanics Course provides the necessary information for technical training on water and air cooled 1, 2, 3 and 4 cylinder stationary diesel engines, including:

- reading engine manuals,
- installing stationary diesel engines,
- dismantling an engine,
- checking parts,
- repairing certain items,
- knowing how to order engine parts,
- assembly of the engine,
- ensuring sound running of the engine,
- keeping up the maintenance of the engine.

Diesel engine theory

This diesel engine theory book can be used in the classroom as well as in the workshop, where text and illustrations will help the instruction on the operation of the diesel engine and ensuring sound running of the engine.

During workshop or classroom theory lessons, making use of large technical aids is very much encouraged. The aids may be real parts cut in sections or self-made parts from all kinds of material made and coloured, to show the trainee clearly the function(s) of that particular part.

It is advisable to start instruction on diesel engines only when the trainee has finished the major part of the whole Rural Mechanics Course, technical drawing and general metal work, which can be seen as preparatory to this part of the course.

Although some science is needed for the instruction on diesel engines, it is left to the instructor to find the time and the suitable materials to teach this science.
Going through this book you will rightly note that no very detailed explanations are given on the construction of the diesel engine. This is because the course is only meant to teach the trainee the principles behind the working of the stationary diesel engine and not the composition of special metals or materials used in these engines, or the repair of very complicated parts.

During theory lessons in the classroom or workshop, ample time should be given the trainee to make the necessary notes and any question should be correctly formulated before explanations are asked for.

Diesel engine workshop practice

During workshop practice where several trainees are working on one engine, it is advisable to appoint one trainee supervisor of the group. He should be responsible for organizing the work to be done, recording all technical data, final checking of all parts, for assembly and smooth running of the engine. The engine may only run with permission from the instructor and in his presence. Each trainee should be appointed to the position of supervisor by rota.

Enough time should be set aside for instruction on how to install diesel engines and, if required, to the attachment of equipment. Special attention should be paid to ventilation in an engine room, because high temperatures reduce the life of diesel engines considerably. The storage of fuel should be given the necessary attention because in rural areas fuel is mostly bought and stored in bulk, which must be done under the correct conditions.

During workshop practice trainees should be encouraged to carry out many jobs on the engine with a limited set of tools or equipment. But, however the limited set of tools, the trainee should learn to use the correct ones. Too often spanners or tools are used which do not fit correctly, resulting in damage to nuts and bolts in parts of vital importance.

Correct teaching of this course makes it necessary to have additional tools and equipment in the workshop and to instruct trainees in how to work with them. This is necessary, because the trainee himself may not be able to buy this equipment but he may be able to use them at a later stage when working in a co-operative workshop where the group owns these tools or equipment.

It is left to the discretion of the instructor to use his creativity to teach trainees how to make and construct additional equipment which they can make by themselves during other workshop practicals.
Working with limited equipment also means that trainees must learn to judge when to go to more specialized workshops where more complicated engine parts, such as fuel pumps and injectors, can be checked and repaired.

As a lot of time in this course is set aside for practical training, especially during on-the-job training, not much time will be available for repairing all kinds of diesel engines which may need repairs.
Instruction on cleaning and systematic working is very important. During the practicals in the workshop, parts should be handled with care, recorded and stored in a box and locked in a storeroom after the lessons.
The progress made by trainees in the workshop and also during on-the-job training should be recorded. In general, marks should be given for constructional skills and other marks for the way in which the work is carried out. These marks will differ in value when a final mark is calculated.

Stationary diesel engines

Following the technical development in rural areas you will notice that, besides newly developed tools and equipment, the diesel engine has also been introduced to ensure extra power supply where this is necessary.
Small electric plants used in hospitals, schools and co-operative workshops, grinding mills for flour, bore-hole water supply etc. demand power that can be supplied by diesel engines.
The need for more power supplied by diesel engines is accompanied by the urgent question of how to install and maintain these engines. Since the power requirements are mostly moderate, this book explains installation, maintenance and smooth running of only stationary diesel engines.

When you look at a stationary diesel engine, you may be confused at first to see so many external parts mounted on the engine and you may also wonder about their purpose. But basically there are only a few real differences, such as the number of cylinders, the actual fuel supply to the cylinders and the cooling which can be either water or air cooling. Many other parts are installed to ensure high engine performance.

A typical air cooled stationary diesel engine is shown on page 13 and all external parts are named. This kind of engine is used widely and is either air or water cooled, depending on requirements. As you rightly note, this engine has one cylinder and one fuel pump which is located behind the fuel pump cover. When more power is needed, a similar engine is possible with a longer crankcase onto which more cylinders are mounted. For each injector a separate fuel pump may be installed or a common fuel pump from which all injectors are supplied with fuel.
Whatever the difference may be, you should first understand that during performance, maintenance and testing the engine should be mounted ridgidly to a firm base.

Installation of stationary diesel engines

During maintenance in the workshop and operation in the engine room a stationary diesel engine should be bolted to a firm base in such a way that it cannot vibrate excessively during operation. You must make sure that all points of the crankcase with holes for the bolts are resting correctly on the base, to avoid stress when the nuts are being fastened.

In dusty places, such as rooms where flour is ground or woodwork is done, a water cooled diesel engine is recommended, because dust in the air may jam the fan blades and also block the fins around the cylinders, reducing the essential optimum flow of fresh air.

Especially in tropical areas, diesel engines should be installed in such a way that a generous supply of fresh air is ensured and precautions are taken against dust. It is very important to keep in mind that clean air is very important for correct performance by a diesel engine.

When working on a diesel engine it is essential to have the manufacturer's manual in addition to this book to ensure correct settings and dimensions of parts.

Let us take a look at the next page where you will see figures of the external parts of a typical air cooled one-cylinder diesel engine.

Typical air cooled diesel engine

Front view:
- Fuel tank 1-A
- Fuel pump cover 1-B
- Stop/start handle 1-C
- Crankcase cover 1-D
- Starting shaft 1-E
- Flywheel 1-F
- Fan cover 1-G
- Cylinder head cover 1-H
- Valve lifter 1-I
- Fuel overflow 1-J

Back view:
- Fuel tank cover 2-A
- Air filter 2-B
- Exhaust 2-C
- Fuel filter 2-D
- Lubrication oil dip stick 2-E
- Speed adjustment 2-F
- Fuel pipe 2-G
- Camshaft extension 2-H
- Gear cover 2-I
- Fuel tank cover 2-J
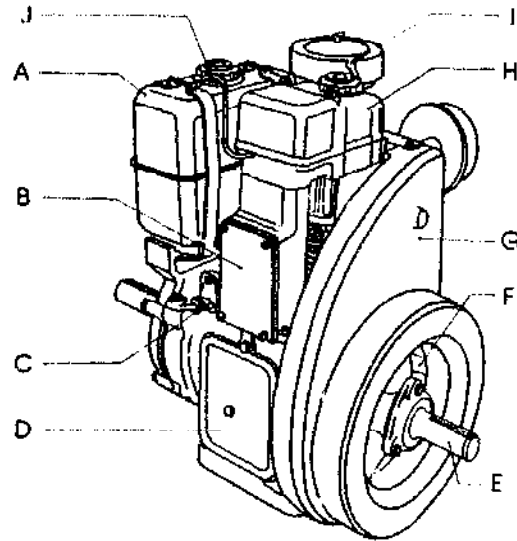
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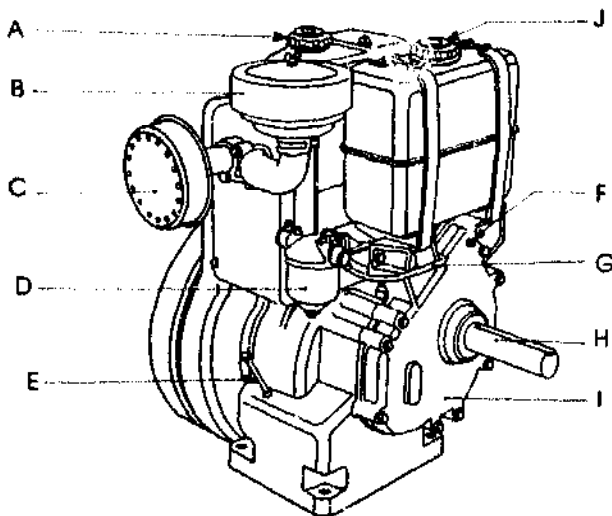
2

Water cooled one-cylinder diesel engine
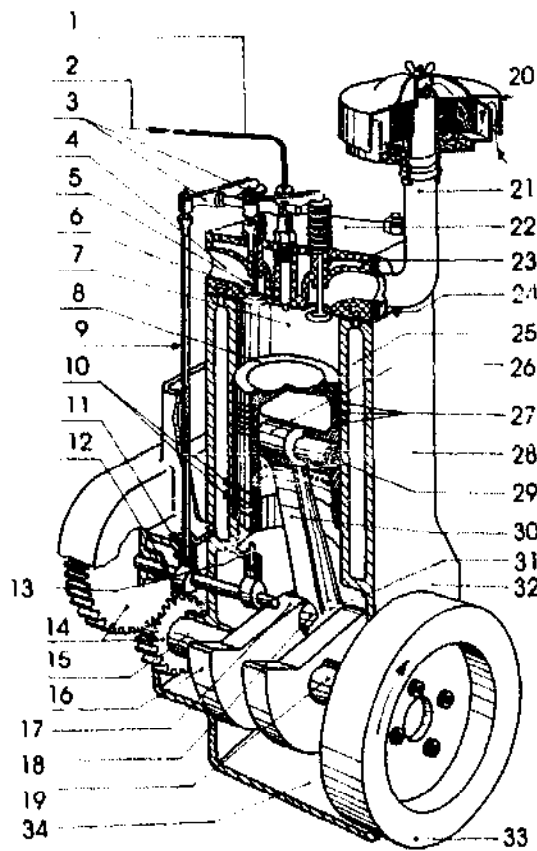
Figure 1 shows a section of a one-cylinder water cooled diesel engine. From the previous page you have learned the most important external parts. Now you have to learn the most important internal parts of the diesel engine.

1 – Fuel pipe
2 – Fuel from fuel pump
3 – Rocker arms
4 – Exhaust
5 – Exhaust valve
6 – Injector
7 – Cylinder
8 – Piston
9 – Push rod
10 – Oil scraper rings
11 – Tappet
12 – Camshaft
13 – Push rod
14 – Timing transmission
15 – Crankshaft
16 – Counterweight
17 – Throw
18 – Big end
19 – Journals
20 – Air filter
21 – Manifold (inlet)
22 – Cylinder head
23 – Inlet valve
24 – Cylinder head gasket
25 – Cooling compartment
26 – Small end (connecting rod)
27 – Piston rings
28 – Gudgeon pin
29 – Cylinder block
30 – Connecting rod
31 – Big end (connecting rod)
32 – Crankcase
33 – Flywheel
34 – Sump

1

Water cooled one-cylinder diesel engine

Figure 1 shows a cross-section of a one-cylinder, water cooled diesel engine. The most important parts connected to the functioning of the diesel engine are shown.

1 – Valves
2 – Combustion chamber
3 – Top Dead Centre (T.D.C.)
4 – Full stroke
5 – Bottom Dead Centre (B.D.C.)
6 – Entrance coolant
7 – T.D.C. crankshaft
8 – Throw
9 – Journal
10 – Counterweight
11 – B.D.C. crankshaft
12 – Sump
13 – Injector
14 – Cylinder head
15 – Cylinder head gasket
16 – Cylinder bore
17 – Top, piston
18 – Piston rings
19 – Piston
20 – Gudgeon pin
21 – Engine block
22 – Cooling compartment
23 – Connecting rod
24 – Crank case
25 – Big end (connecting rod)
26 – Crankshaft
27 – Distance half stroke
28 – Distance full stroke
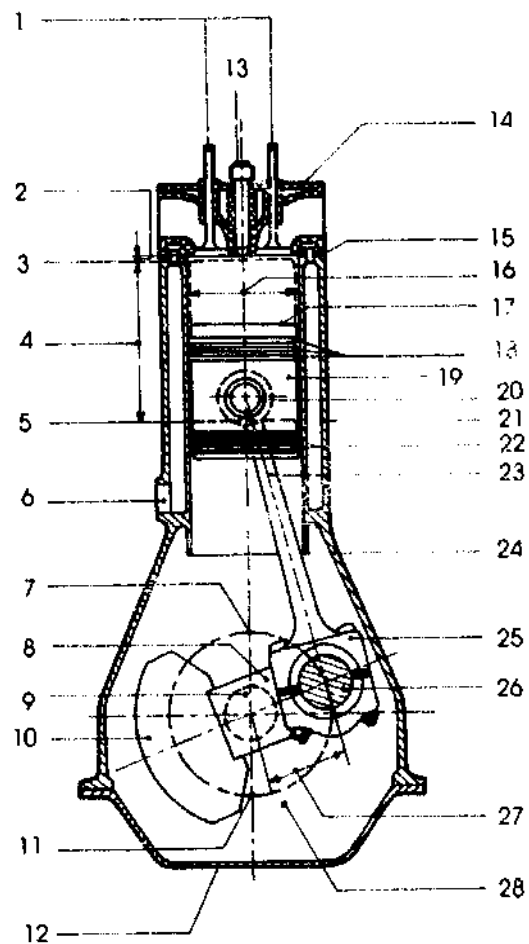
1

How the diesel engine operates

Internal combustion engine
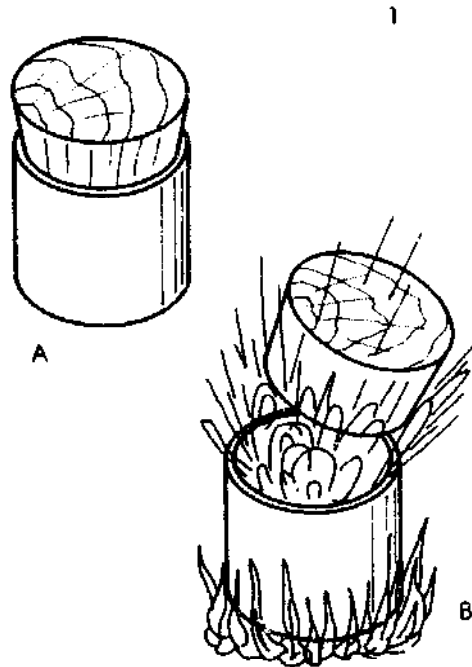
An internal combustion engine is an engine which burns fuel *internally*. This engine is basically a container, see Fig. 1, into which *fuel* and *air* can be fed and made to burn. Figure 1-A shows just such a container, closed with a stopper, in which there is a mixture of *fuel* and *air*. The mixture of fuel and air is highly flammable. If by any means the mixture is ignited, the container explodes, throwing the stopper out of the container with force, as shown in Fig. 1-B.

Air has two properties which affect the engine:
- Air can be compressed.
- Air gets hot when it is compressed.

Fuel should mix readily with air and ignite easily by vaporizing. Vaporizing helps each particle of the fuel to contact enough hot air to burn fully.

Combustion is the actual igniting and burning of the fuel/air mixture. It is the oxygen in the air which combines with fuel to cause combustion.
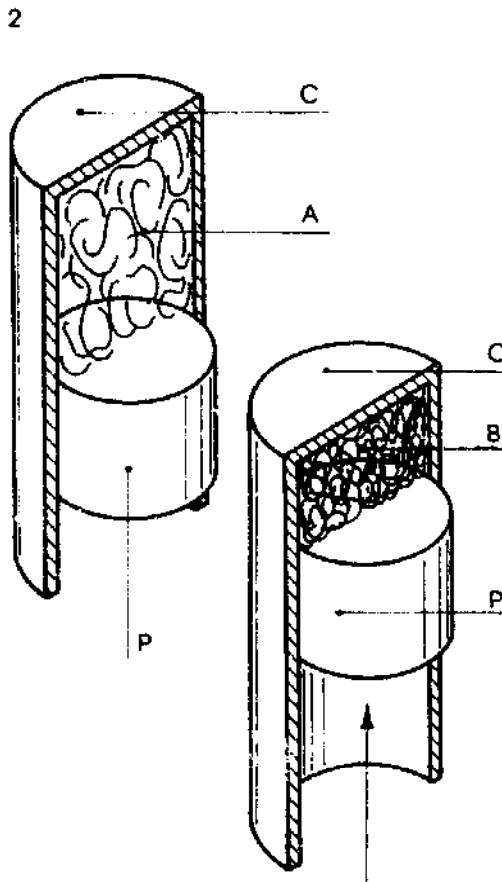
Fast burning fuel

If a container with diesel fuel is ignited in calm outside air, it burns rather lazily, because the air contacts only the surface of the fuel. To make it burn faster we have to:
- heat the fuel,
- vaporize the fuel.

But too powerful an explosion damages an engine, so we have to control the rate of burning. The rate of burning depends on:
- how much the air is compressed and thus heated,
- how much fuel is used,
- how volatile the fuel is.

Figure 2 shows the fuel/air mixture 2-A trapped in a strong cylinder which is closed at one end. A piston 2-P is fitted into the cylinder in such a way that it can move up and down inside the cylinder, but while moving, it keeps the gases tightly locked inside the cylinder.

When the piston is moved upwards the fuel/air mixture is compressed in chamber 2-B. When the compressed fuel/air mixture is ignited it explodes, creating a high pressure in the cylinder 2-C above the piston 2-P. The pressure then pushes the piston down in the cylinder and this produces mechanical energy.

Reciprocating and rotary motion

The up-and-down motion occurring in the cylinder is called *reciprocating motion*, see Fig. 1-R. In the engine the reciprocal motion of the piston must be converted into *rotary motion*, to be able to drive any gears. Four basic parts are needed to make the engine work this way:
- cylinder
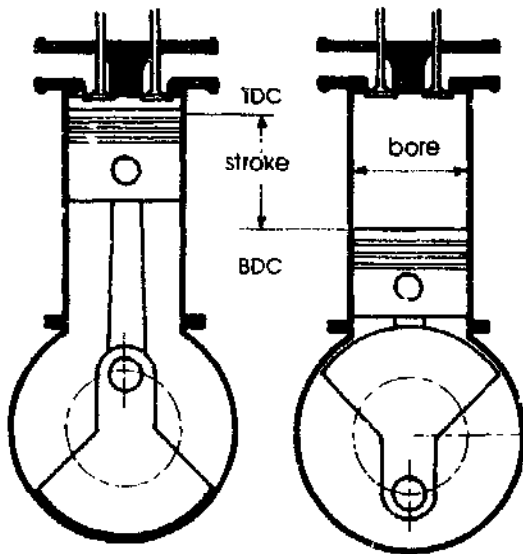- piston
- connecting rod
- crankshaft

As explained before, the piston and the cylinder are mated parts. They are fitted so closely that no gases can escape, but with a little clearance at the sides to ensure a smooth reciprocating motion. See Fig. 2.

The link transmitting the reciprocating motion of the piston to the crankshaft is called the connecting rod, 2-A. The crankshaft 2-B has a section off the centre line of the shaft so that it 'cranks' when the shaft is turned. This rotary motion is basically the same as pedalling a bicycle. Your leg is like the connecting rod, while the pedal crank and the sprocket are like the crankshaft.

The whole combination shown in Fig. 2 makes it possible to convert the reciprocating motion 2-C into a rotary motion 2-D.
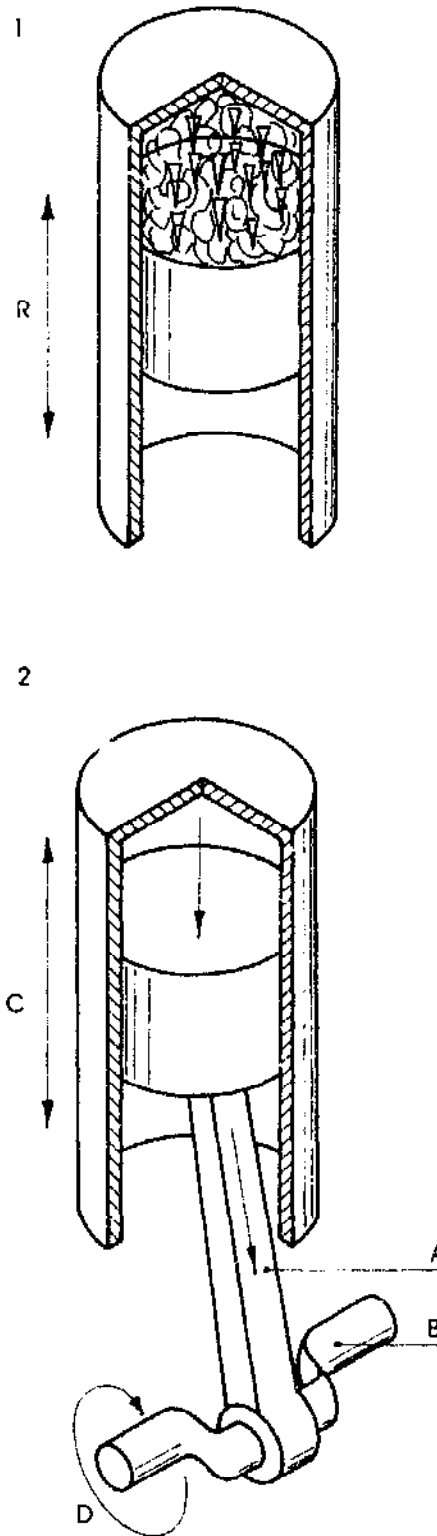
T.D.C., B.D.C., stroke, bore, volume throw and compression ratio

Top dead centre
When the piston is at its highest position, the piston is at *top dead centre* (T.D.C.), see Fig. 1

Bottom dead centre
When the piston is at its lowest position, the piston is at *bottom dead centre* (B.D.C.), see Fig. 1.

Stroke
The distance between T.D.C. and B.D.C. is called *stroke* (S), see Fig. 1. The stroke is measured in mm.

Bore
The inside diameter of the cylinder is called *bore* (B), see Fig. 1. The bore is measured in mm.

Throw
The distance between the centres of the crankshaft and connected rod journals is called *throw* (T). The throw is half the distance of a stroke, see Fig. 2.
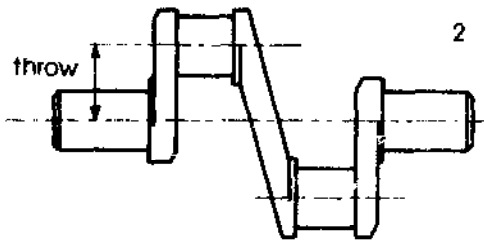
Compression ratio
Compression ratio is the total volume of air in a cylinder when the piston is at B.D.C. compared to the volume in the combustion chamber when the piston is at T.D.C. – for example 16 to 1 in a diesel engine. Refer to Fig. 3:

Compression ration =

in principle:

(Stroke (A) + Combustion Chamber (B)) / Combustion chamber =

$$= \text{Stroke volume} = \pi/4 \times D^2 \times \text{Stroke length (A)}$$

$$\text{Comb volume} = \pi/4 \times D^2 \times \text{Comb chamber height (B)}$$

$$\text{Compression ratio} = (A + B)/B$$

Described, for example, as 16:1.
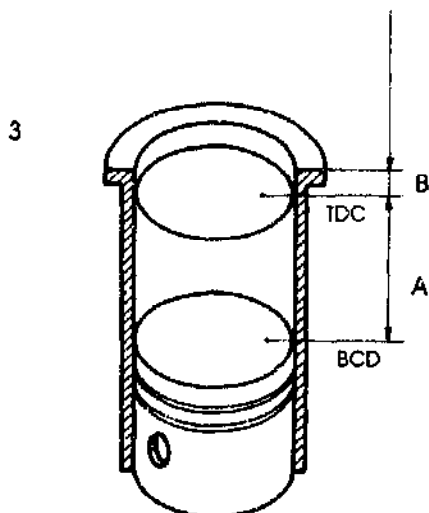
The four-stroke cycle engine

For the operation of this engine, a series of events must take place in sequence:
- *Induction stroke* 1-A
  Clean air is drawn through an air filter into the cylinder. The air enters through the open *inlet* 1-I valve as the piston moves down on the induction stroke.
- *Compression stroke* 1-B
  The inlet valve closes and, as the piston *rises*, the trapped air is compressed to the required pressure. Fig. 1-X shows the moment the air is compressed and the fuel is injected.
- *Power stroke* 1-C
  At second the fuel is sprayed, particles vaporise almost instantaneously and start to burn. The heat needed to ignite the particles comes from the very high pressure of the compressed air charge combustion continues, the pressure the cylinder rises very rapidly and the is forced down to give the power stroke
- *Exhaust stroke* 1-
  Towards the end power stroke, the exhaust valve opens to allow the waste products of combustion to escape. With the exhaust v -E fully open, the cylinder is completely emptied of the waste products as the piston rises for the second time.
  Figure 1-Y shows the moment the exhaust valve closes and the inlet valve opens again.
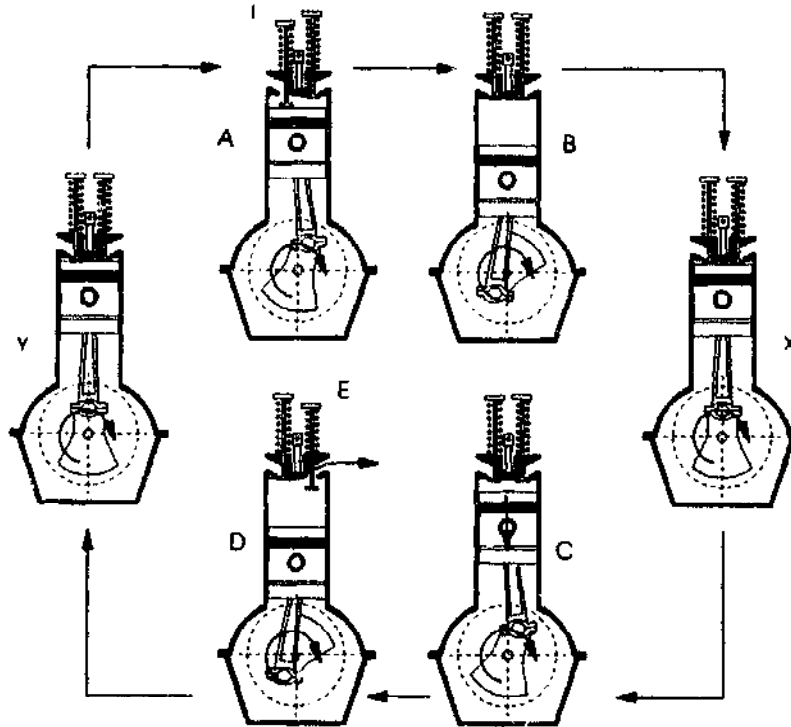
Multiple cylinder engines

So far we have seen the operation of one cylinder in an engine, but since this cylinder gives only one power stroke every two revolutions of the crankshaft, it produces power only one quarter of the time.
For more continuous power, extra cylinders are added to the engine and each one delivers one power stroke during the two revolutions of the crankshaft.
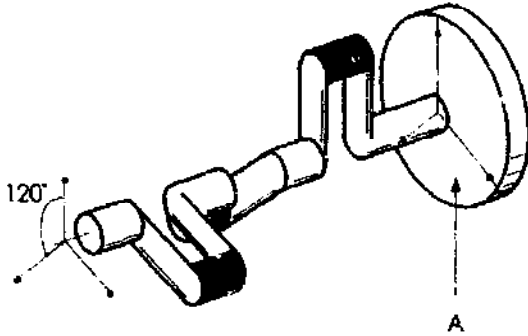
The power strokes thus follow each other more closely, resulting in a fairly continuous delivery of power to the crankshaft. For example, in a typical four-stroke cycle engine with three cylinders, the cranks are set 120° apart on the crankshaft, see Fig. 1.

The cylinders normally fire and deliver their power strokes in the following order: 1 – 3 – 2. The power strokes follow each other closely, thus ensuring continuous and smooth delivery of power to the crankshaft.
The heavy flywheel 1-A attached to the crankshaft at the rear gives it momentum to return the pistons to the tops of the cylinders after each power stroke. Counterweights on the crankshaft are used to help balance the forces created in the engine by the fast moving parts.

Different types of engines

Besides the *in-line engine* shown in Fig. 2-A, you may see some other types of engines, such as an engine with the pistons lined up in a 'V'. So Fig. 2-B shows an engine called a *V-engine*. Another arrangement of pistons is shown in the engine in Fig. 2-C. This is called a *boxer engine*. It has the pistons situated opposite to each other on the side of the engine.
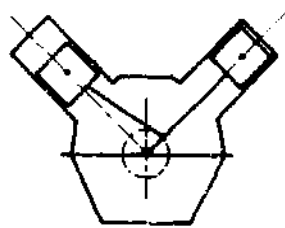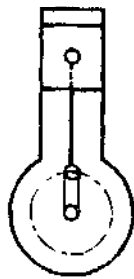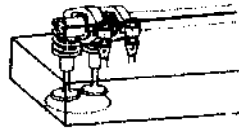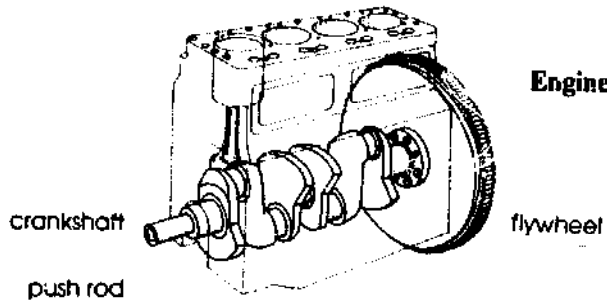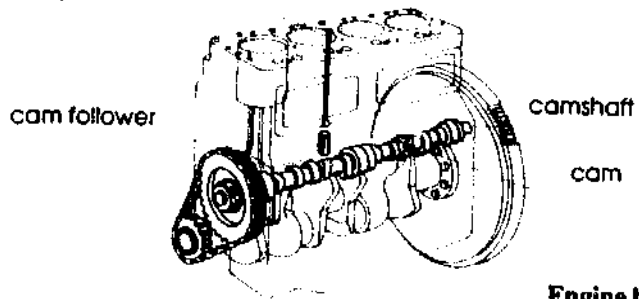
Components of the engine

gasket

Cylinderhead cover

Cylinderhead

gasket

Cylinderblock

Crankcase
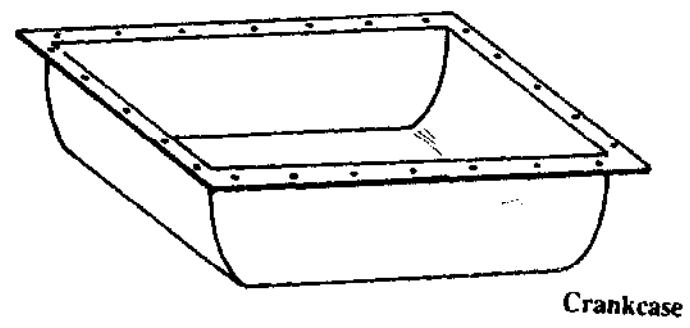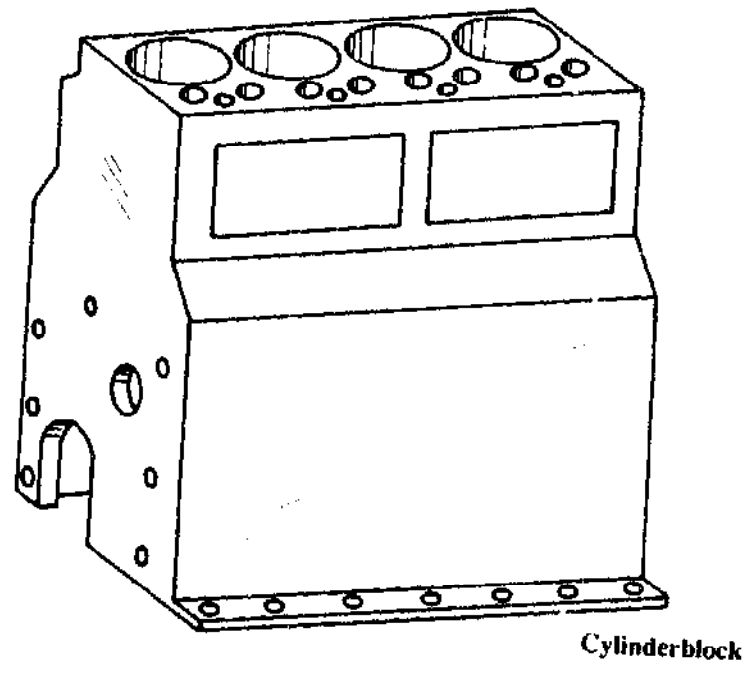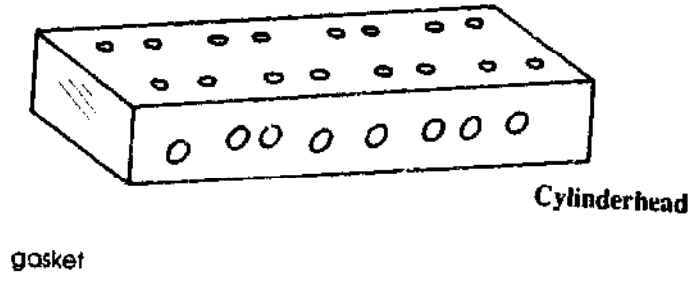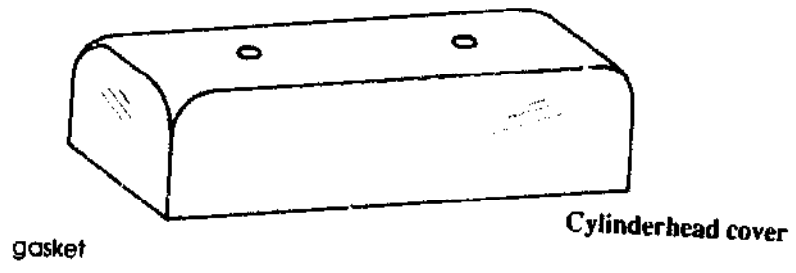
Components of the engine

Cylinderhead: valve assembly

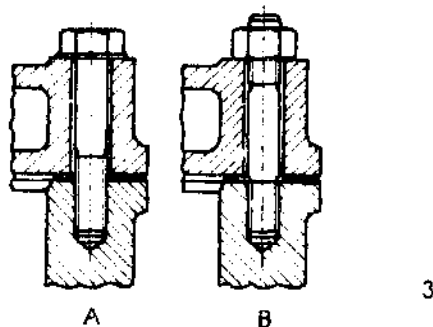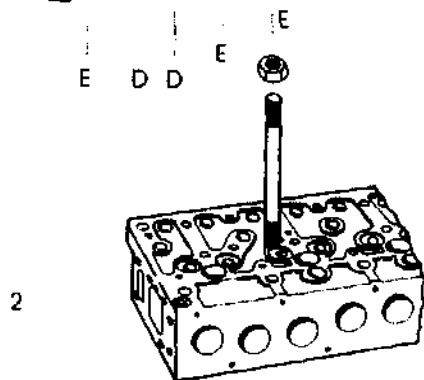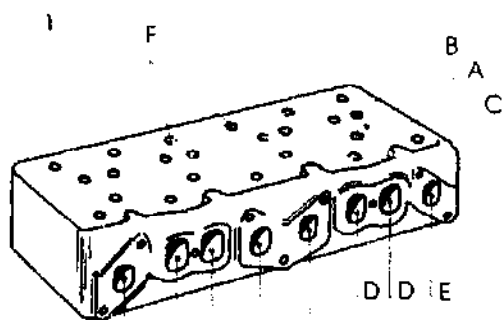Engine block: flywheel and crankshaft

crankshaft

push rod

flywheel

cam follower

camshaft

cam

Engine block: camshaft

Cylinder head and valves

Cylinder head
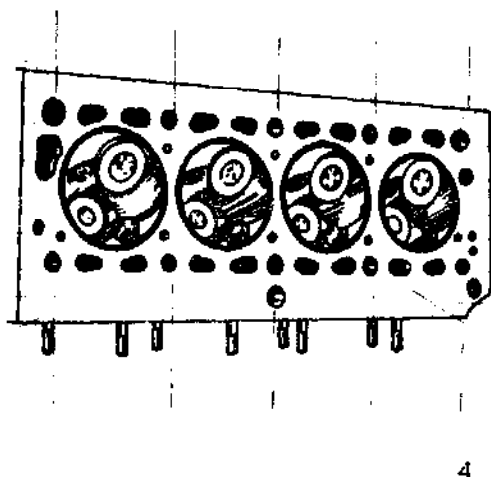
The cylinder head is fitted at the top end of the cylinder block and secured with studs or bolts passing through the head to the cylinder block. Most cylinder heads are cast from an alloy of iron and copper or aluminium. The intake and exhaust passages are cast or bored into the cylinder head as shown in Fig. 1:
- Cylinder head 1-A
- Holes for valves 1-B
- Holes for pushrods 1-C
- Holes for air inlet 1-D
- Holes for exhaust 1-E
- Holes for bolts or studs 1-F

Part of a typical cylinder head is shown in Fig. 2 with an exploded view of the stud with a nut. Figure 3 shows an enlarged detail of a cylinder head bolt 3-A and nut 3-B.

Servicing the cylinder head

First remove the rocker arm assembly before taking off the cylinder head. Then carefully loosen the cylinder head nuts and bolts. Leave the injectors in the cylinder head, because as the crankshaft turned pressure built up in the cylinders and this helps loosen the cylinder head. Light tapping with a soft hammer may make the cylinder head come off more easily. Never use a screwdriver or cold chisel between the head and the cylinder block, since this will damage the edges of the cylinder head and the engine block. After removal, check the surface of the cylinder head for damage. Clean all carbon deposits from the head by scraping or brushing with a wire brush. Also check the water passages for lime deposits.

After a long period of service or overheating, the heat may have caused the head to warp. So check the surface as follows, see Fig. 4.
- Use a heavy accurate straight edge and feeler gauge to check for warp at each end and between the cylinders.
- Check too for end-to-end warp in at least six places.
- Decide whether the cylinder head must be re-installed or re-faced. Re-facing is done in a specially equipped shop.
- Also check the head for any cracks.

Cylinder head gasket

A typical cylinder head gasket is shown in
Fig. 1-A and an enlarged detail in Fig. 1-B.
This gasket is placed between the cylinder
head and the cylinder block and is used to
make the connection between these two; it is
gas and water-tight.

Gaskets are made up from different materials.
For example, the one shown is composed of
one layer of copper 1-C and three layers of soft
iron 1-D. When installing the cylinder head,
mind the top and front of the gasket.

Installing the cylinder head

After checking the valve seats, which will be
explained at a later stage, the cylinder head can
be installed again. First check the surface of
the cylinder block. Install a new cylinder head
gasket, following the manufacturer's
recommendations about application of a
sealing compound on one or two sides of the
head gasket. Carefully set the cylinder head on
the cylinder block, without disturbing the head
gasket.
Make sure the ends of the bolts or studs are
clean and lightly oiled.
Press down the cylinder head gradually and
evenly. This is very important to ensure a good
seal between the cylinder head and the cylinder
block.

Tighten the nuts or bolts fingertight. Use the
sequence shown in Fig. 2 for tightening the
head bolts or nuts, turning them one by one
about one-half turn until the torque specified
by the manufacturer is reached. Sometimes
nuts or bolts are tightened in a way discribed
by the engine manufacturer.

*Cylinder head nuts or bolts should usually be
re-tightened to the specified torque after a
warming-up period!*
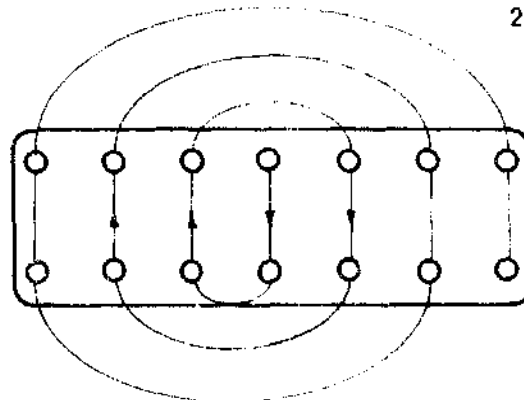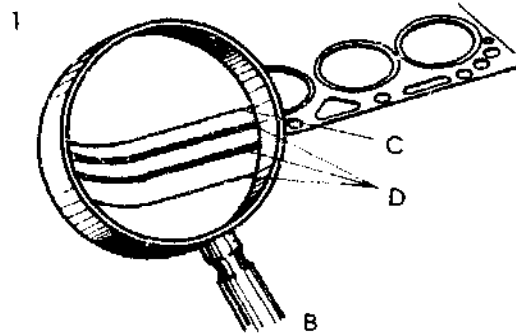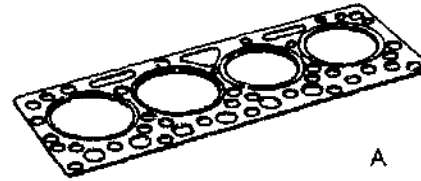
Valve mechanism
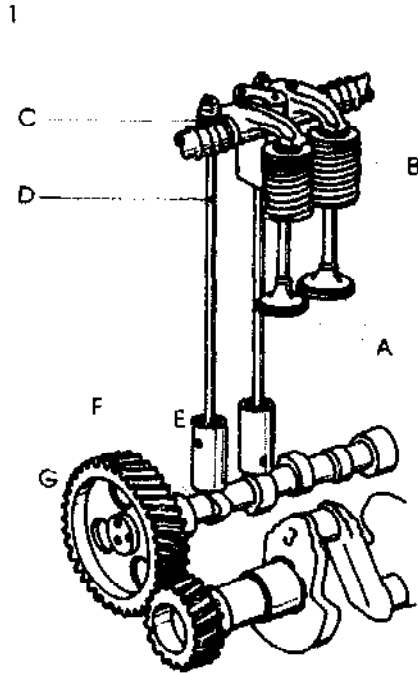
As you know, an engine must take in fuel/air and exhaust burned gases. Intake and exhaust must occur at precise intervals. Valves as shown in Fig. 1-A are used to do this job. The whole valve operating system is called the *valve train*:

- Valves (inlet small, exhaust large) 1-A
- Valve springs 1-B
- Valve rocker arm 1-C
- Push rod 1-D
- Valve lifter 1-E
- Camshaft 1-F
- Gear transmission 1-G

The position in which the valves operate here is called *overhead valve mechanism*.

Sequence of valve operation

Figure 2 shows once again the sequence of the valve operation in a typical four-cycle engine. Each cylinder has one intake and one exhaust valve in this case.

- *Intake*
  During the intake stroke, the inlet valve opens as shown in Fig. 2-A. The fuel/air mixture is drawn into the cylinder through the open inlet valve while the piston moves down.
- *Compression*
  Both valves are closed, see Fig. 2-B, when compression takes place during the upward movement of the piston.
- *Power*
  Both valves remain closed while the compressed fuel/air mixture is ignited and expanded gases force the piston down, see Fig. 2-C.
- *Exhaust*
  The exhaust valve opens when the piston is moving upwards and thus forces the burned gases through the open exhaust valve, see Fig. 2-D.
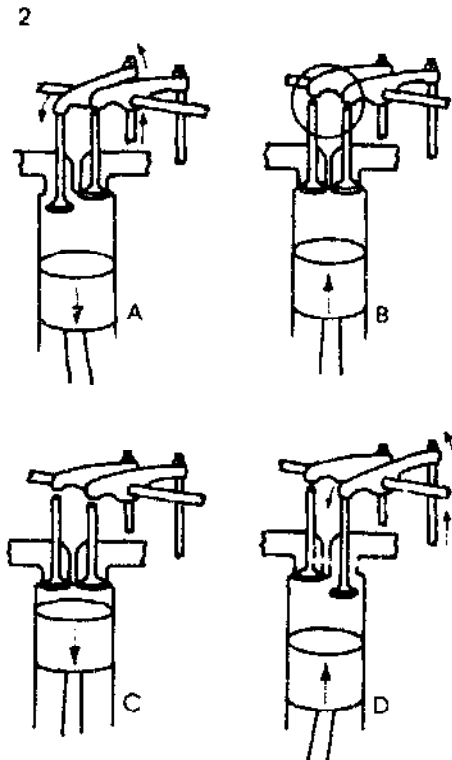
Valve lifting system

A typical valve lifting system is shown in Fig. 1. It consists of:
- Combustion chamber 1-A
- Valve seat 1-B
- Port 1-C
- Valve guide 1-D
- Valve stem 1-E
- Valve springs 1-F
- Valve spring retainer 1-G
- Valve key 1-H
- Rocker arm 1-I
- Valve clearance adjusting screw 1-J
- Push rod 1-K
- Valve lifter 1-L
- Camshaft 1-M

Valve detail
- Valve head 2-A
- Margin 2-B
- Face 2-C
- Seat 2-D
- Stem 2-E
- Guide 2-F

Poppet valve detail
- Inner valve spring 3-A
- Outer valve spring 3-B; note that the inner and outer springs are winded in opposite directions
- Valve spring retainer 3-C
- Valve stem 3-D
- Valve key (in two halves) 3-E
- Valve cap 3-F allows the valves to rotate during operation

Cooling the valves
Valves have to be cooled while the engine is hot due to operation. See Fig. 4. The valve heat is transferred to the head 4-B and from there to the water passages 4-C, which are cooled with coolant (see arrows). At all times the heat of the valve is transferred to the valve guide 4-A and from there to the cylinder head.
The cylinder head is cooled with coolant. You must ensure that all passages in the cylinder head are clean and wide open so the coolant can pass freely during engine operation.
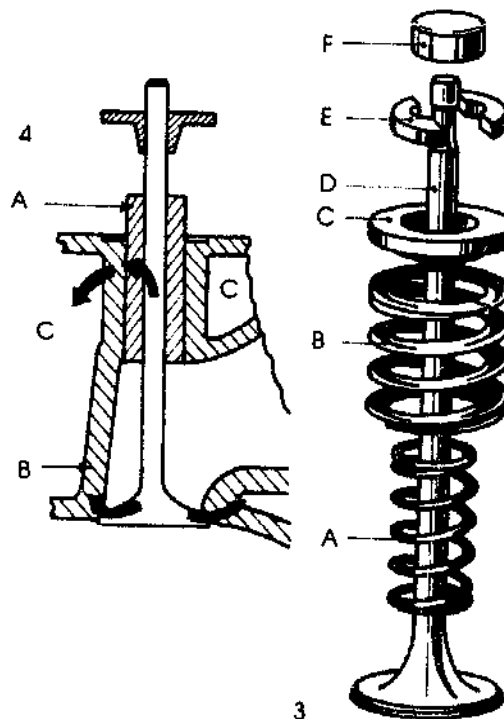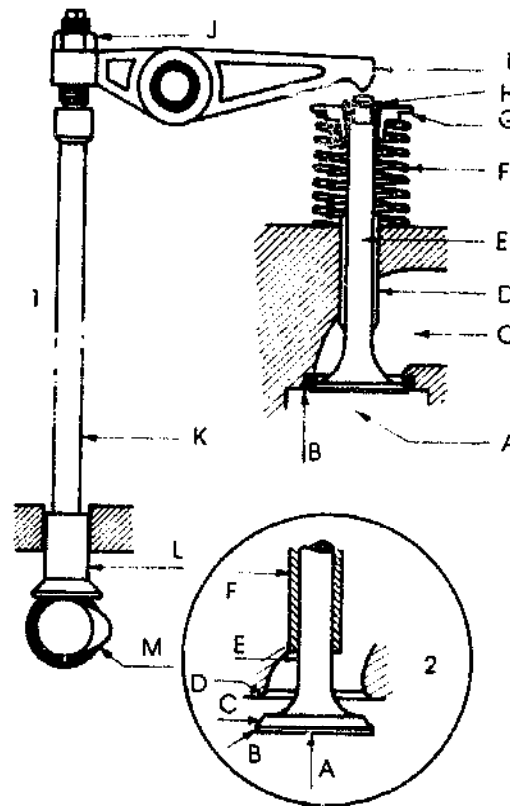
Removal of valves

Follow this procedure when removing the valves from the cylinder head:
- Using a valve spring compressor, compress the valve springs, Fig. 1.
- Place the valve spring compressor absolutely straight on the valve head and at the other side on the valve spring retainer, see Fig. 2.
- When you turn the handle of the spring compressor, the valve spring retainer 2-B should move down and release the two halves of valve key 2-A. Place the two halves for easy replacement in their original position.
- Remove the valve spring retainer 2-B and the two springs 2-C. Place them in order.
- Before pushing out the valve, check whether the rotation of the valve has produced a burr on the tip of the valve stem 2-D. If so, remove the burr as it might otherwise damage the valve guide bore 2-E.
- Push the valve out of the valve guide and place it carefully in order.

Checking valves
Check all valves for:
- distortion and deposits on the valve face and valve stem,
- burned and broken valve heads,
- erosion under the valve heads,
- fatigue and broken valves,
- worn valve guides,
- the thickness of the margin on the valve head. If it is less than 1 mm, the valve must be replaced, see Fig. 3.

Correct shape of valves
A correctly shaped valve is shown in Fig. 3-A. The margin 3-X is the same on all sides and the face is perfectly round. Fig. 3-B shows a valve with a knife head. This valve cannot be used any more. A warped and knife-edged valve head is shown in Fig. 3-C.
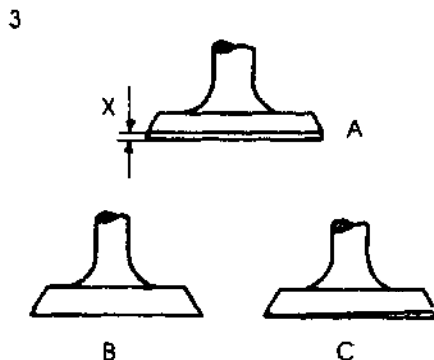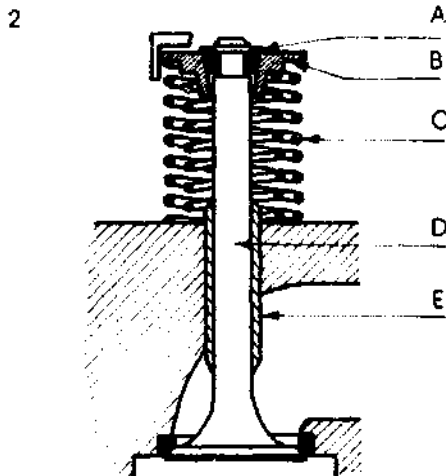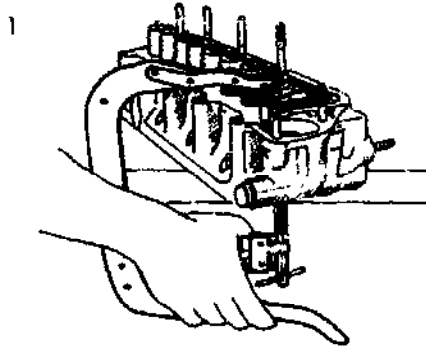
Setting the valve clearance in a four-stroke diesel engine

- Depending on the type of engine, the valves should be set on a cold or a warm engine. Consult the manufacturer's manual.
- Remove the valve cover from the cylinder on which the valve clearance is to be set. Sometimes there is only one valve cover for all the cylinders.
- Find (by looking at the manifolds, for instance) the intake and exhaust valves of the cylinder you are working on.
- Rotate the crankshaft in the correct direction until the exhaust valve is completely opened (seen from above it is pressed).
- Now rotate the crankshaft slowly until the exhaust valve is almost closed and the intake valve starts to open. At this moment the cylinder concerned is between the exhaust stroke and the inlet stroke, with the piston in approximately TDC.
- Mark the position of the crankshaft pulley and make one complete revolution (360°).
- Now you can set both intake and exhaust valves on this cylinder. You should always use a feeler gauge of the correct size. To ensure correct setting you also need the feeler gauge of the next size up, which is 0.05 mm thicker. The correct feeler gauge should just fit between the rocker and the valve stem. The next larger feeler gauge should not fit.
- Repeat this procedure for the other cylinder.
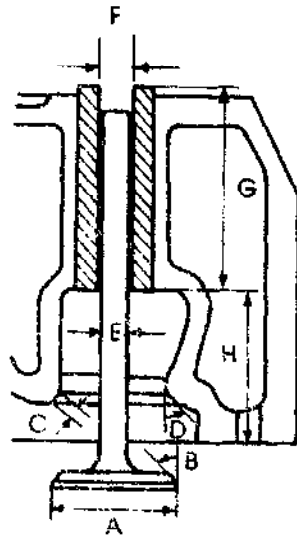
1

Reconditioning valves

The correct technical data on valves is essential when they have to be ordered or reconditioned. Take care that you know the following measurements:
- Diameter, valve head 1-A
- Angle, valve face 1-B
- Width, valve seat 1-C
- Angle, valve face 1-D
- Diameter, valve stem 1-E
- Diameter, valve guide 1-F
- Length, valve guide 1-G
- Distance, guide from head 1-H

Note that inlet and exhaust valves are different.

Intake valve seat inserts

If the engine has valve seat inserts fitted, the maximum amount that can be removed from the valve seat insert during re-shaping is such that a 45° cutter makes contact with point 2-B. To provide sufficient clearance between the head and the piston crown, the intake valve seats are machined approximately 1 mm below the cylinder head joint face.
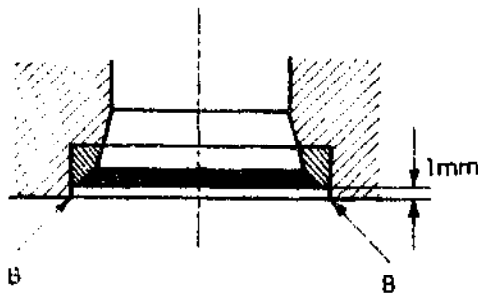
Exhaust valve seat inserts

If a 45° cutter makes contact with point 2-A, the valve seat insert must be removed and exchanged for a new one. The valve seat should be 1.5 to 2 mm wide.

Intake valve seats

If an engine has valve seats cut directly into the cylinder head casting, the maximum amount that can be removed from the seat is such that a step remains at 3-A. The width of the valve seat should be about 1.5 to 2 mm.

2

3
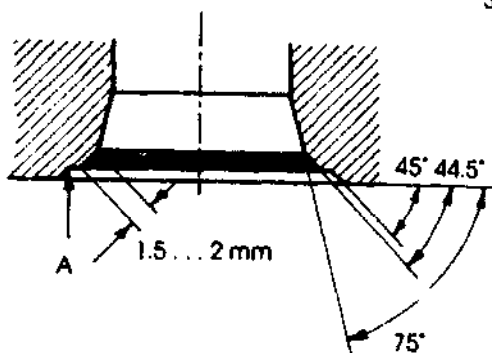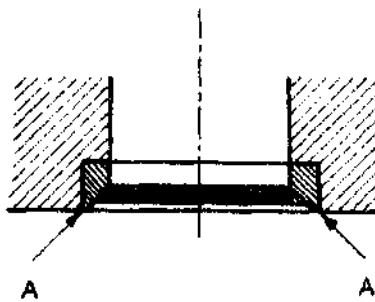
Grinding precautions

- Do not grind too long.
- Do not use too much pressure.
- Keep the work area clean.
- Check the seat width and contact with blueing.

Grinding-in the valve seats

When removing valves from the cylinder head, remember to place them in a numbered rack or mark them, to ensure that all valves return to their own valve guides. If all valves, valve guides and valve seats are in good condition, each valve should be ground in.

It is important to know that the distance between the valve head and the cylinder head joint face must not exceed 2.5 mm.

Procedure

- Place the cylinder head on the work bench with the cylinder head joint faced up.
- Coat one valve face lightly with grinding paste. The grain size of the paste depends on the condition of the valve seat.
- Insert the valve into its guide and rotate the valve clockwise and counterclockwise using a rubber suction type of grinding tool as shown in Fig. 1.
- While grinding in the valve seat, lift the valve several times and press it down again, allowing the paste to enter the gap.
- Examine the valve seat at intervals, until a smooth dull ring is formed around the seating face.
- Carefully remove all grinding paste from the valve and the valve seat.
- Place the valve in its guide again and drop diesel fuel onto the valve head. If the valve seals through its own weight, the valve seat is sufficiently ground in.
- Repeat this procedure for the remaining valves.

Valve guides

The valve guide ensures that the valve is exactly centered, which in turn ensures a proper valve seating. The wear of the valve guide should also be checked when valve seats are reconditioned.

To check the wear of the valve guide, raise the valve with a piece of distance pipe to about 10 mm above the cylinder head, see Figs. 2-A, and 2-B. Place a piece of steel on top of the cylinder head and against the margin of the valve head. Move the valve left and right. If the allowance is more than 1.5 mm the valve guide must be renewed.
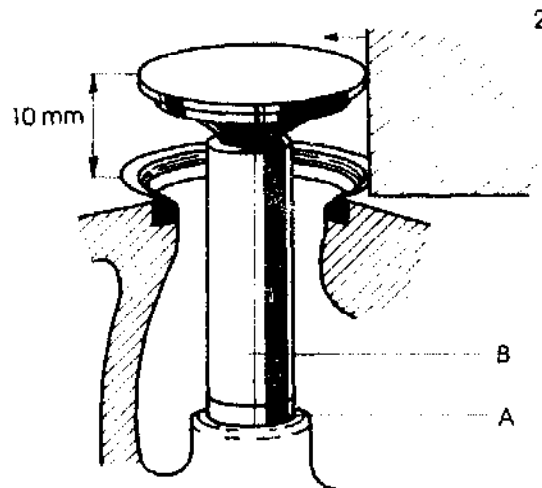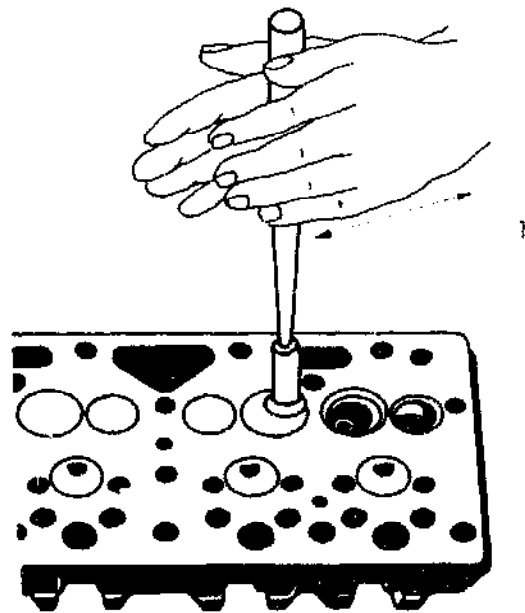
Camshaft and timing mechanism
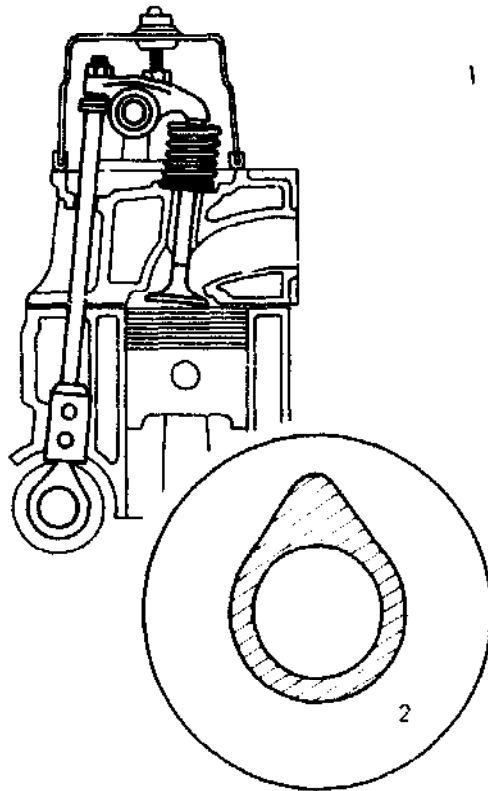
The camshaft is fitted into the engine block on the lefthand side, above the crankshaft, see Fig. 1. In small and medium sized engines it is generally made of a one-piece casting or forging and is supported by three bearings. Most camshafts are made of low-carbon alloy steel. The cam and journal surfaces are carburized before grinding them to their final shape.

The intake and exhaust cams on the camshaft are fitted in pairs for each cylinder. The arrangement of the cams on the shaft determines the firing order of the engine. The contour of the cam, see Fig. 2, decides the time and the opening rate of each valve.

Camshafts may also drive oil pumps and fuel pumps using extra lobs or a gear on the shaft.

The timing transmission
The camshaft, that is running at half the speed of the crankshaft, can be driven by different kinds of transmission, the most common are:
- *Gearwheel transmission*
  The gearwheel transmission uses a steel gearwheel on the crankshaft, driving the camshaft. See Fig. 3. To obtain a quiet drive, this gear can also be made of other material, such as pressed fibre or a light alloy. Both gears have timing marks. When these are aligned, the crankshaft movement and valve timing will always be in correct relation to each other, see Fig. 3-A.
- *Chain transmission*
  This transmission is used when the camshaft is a long way from the crankshaft. See Fig. 4. The timing sprockets on both crankshaft 4-A and camshaft 4-B also have timing marks 4-C. Both marks should be in line with the centre line of the sprockets for correct timing of the engine.
The timing chain is designed so that it will not stretch during operation. But to improve transmission efficiency and reduce noise, a chain tensioner is placed on the non-pulling side of the chain to maintain the proper tension in the chain.
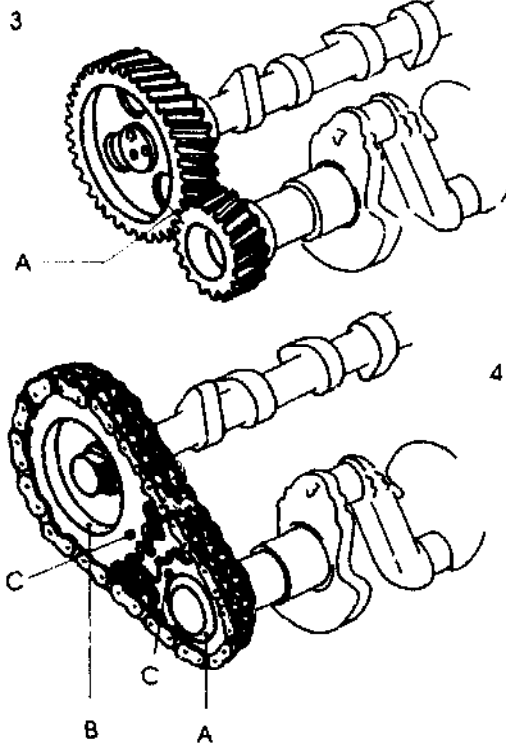
Valve timing

Valve timing is very important in obtaining the best combination of:
- power – efficiency
- economy – long engine life

A key factor in achieving these objectives is correct filling of the cylinder with fuel/air mixture.

Valve timing diagram

Figure 1 shows a section of the inlet and outlet port, the inlet valve 1-I, the exhaust valve 1-E, the piston, the connecting rod and a revolution of the crankshaft, shown as a circle.

The inlet valve opens when the piston is just about to reach the Top Dead Centre (TDC) during its exhaust stroke. The valve remains open during the inlet stroke and closes after the piston has passed the Bottom Dead Centre (BDC), see Fig 2.

This period when the valve is open (shown as a dotted area) is given as degrees of the revolution of the crankshaft in relation to the position of the piston.

Valve timing degrees

Figure 3 shows a diagram with degrees, shown as A, B and C. In this case the inlet valve opens when the position of the crankshaft is 20° before the piston reaches TDC, see 3-A. It closes when the position of the crankshaft is 60° after the piston has passed BDC, see 3-C.

The total time the valve remains open is therefore 20 + 180 + 60 = 260°.
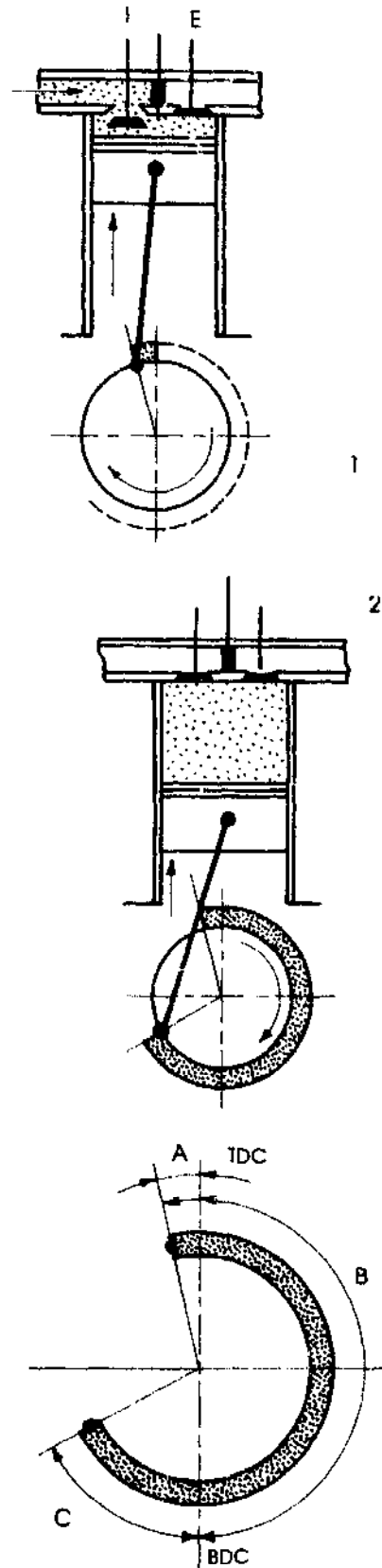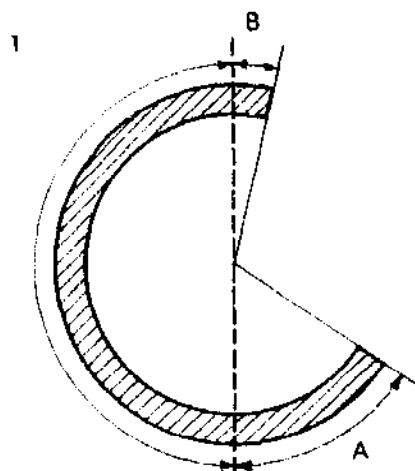
Valve timing degrees (exhaust)

Figure 1 shows the diagram with degrees for the exhaust valve timing, where 1-A = 65° and 1-B = 20°. The exhaust valve opens at 65° before BDC (BBDC). The exhaust valve closes at 20° after TDC (ATDC).

The total time the valve remains open is therefore 20 + 180 + 65 = 265°.

Valve timing diagram

If we combine the inlet diagram and the exhaust diagram in one drawing, we have a valve timing diagram as shown in Fig 2. Valve timing diagrams are supplied with each engine according to the manufacturer's recommendations.
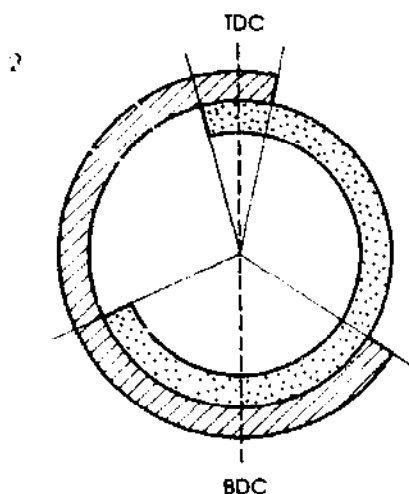
Typical engine valve timing

Sometimes a whole work cycle diagram is supplied, as shown in Fig 3, where:

A = 20°
B = 65°
C = 60°
D = 19°

The intake valve opens: 20 + 180 + 65 = 265°. Both valves are closed during the compression and power stroke:

180 - 65 = 115°
180 - 60 = 120°
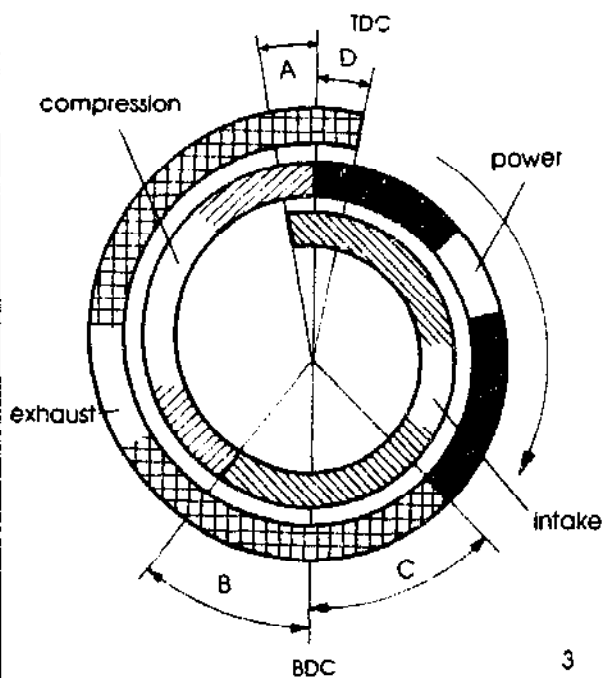Total time 235°

The exhaust valve opens:
60 + 180 + 19 = 259°

This means the crankshaft rotates 265 + 235 + 259 = 759° to complete the work circle.
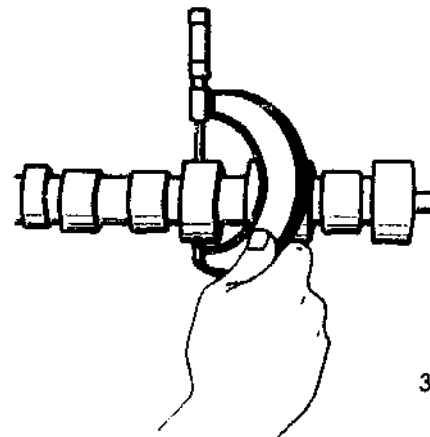
Servicing the camshaft

A cam profile as shown in Fig. 1 includes the *nose* 1-A which holds the valve open, and the *back* 1-B which allows the valve to close.
If you look at the shape of the cam you will see that it has curved faces. The right curved face 1-C causes the valve to open gradually until it reaches the top of the nose. Face 1-D allows the valve to close gradually.
Figure 2 shows how tappet 2-B rests on a face of the cam prior to being pushed open by the nose of cam 2-A following the direction of the arrow.
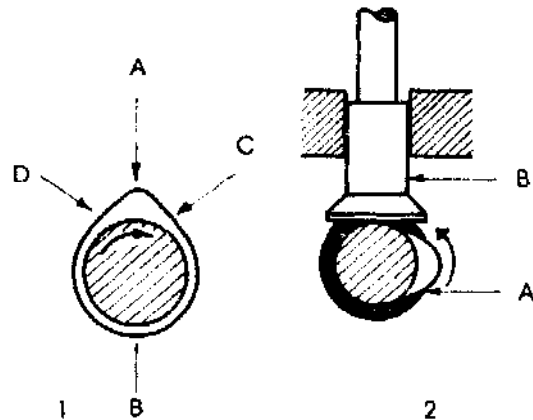
Dismantling the camshaft
- Clamp the camshaft in a soft-jaw vice.
- Bend back the tab of the lock washer at the front of the camshaft.
- Loosen the lock nut, remove the lock washer, take off the drive gear and collect the Woodruff key.
- Take off the front end of the camshaft bearing.
- Take out the camshaft from the front of the engine; be careful not to damage the cams while removing the shaft.
- Clean the camshaft and the camshaft bores with clean diesel fuel.

Checking the camshaft
A micrometer is needed to measure the cams and journals of the camshaft and to check the camshaft bores.
- First measure the camshaft journals for signs of wear or out-of-round condition, see Fig. 3. This is done with an outside micrometer.
- Measure the camshaft bores with an inside micrometer, see Fig. 4.
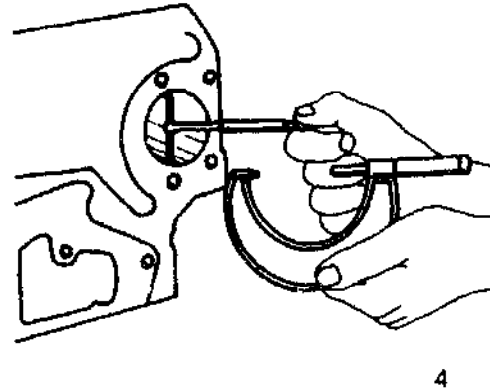
Compare the results with the technical data provided with the engine.
- Check for wear and scratches on the cam lobes. Use the micrometer to check the height and width of each cam lobe, see Fig 5.
- Compare the intake valve cam lobes with each other. Compare the exhaust valve cam lobes with each other as well.
- Check the wear of the injection drive gear.
- Check whether the faces of the cams are polished and examine the surface for fatigue. The nose of the cams should be polished and flat.
- The end float, see Fig. 5, can be adjusted by adding shims if it is too big or removing material from the bearing bush if it is too small. Carefully rub the bearing bush on emery cloth until the correct end float is obtained. Measure with a feeler gauge.
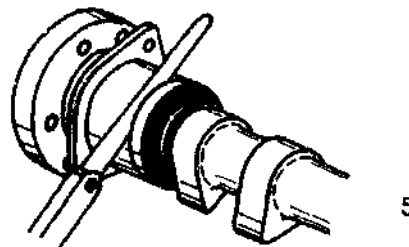
Tappets
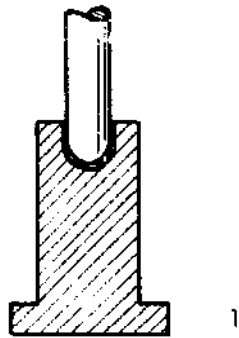
The movement of the cam is transferred by the tappet first, see Fig. 1. When the tappet is raised by the cam, some pressure is applied to one side of it, see Fig. 2. To enable the lifter to take this side pressure it is designed with a rather large diameter, see Figs. 1 and 2.

As you see in Fig. 3, the tappet is slightly offset from the centre of the cam 3-C. This is done so that the contact friction c' ites rotary movement of the tappet. The result is that wear is distributed evenly over the contact surface of the tappet and lubrication is improved.

Figure 4 shows tappet 4-A which has been turning satisfactorily and the wear is spread evenly over the whole surface. Tappet 4-B has not been turning and the wear is concentrated in one place.
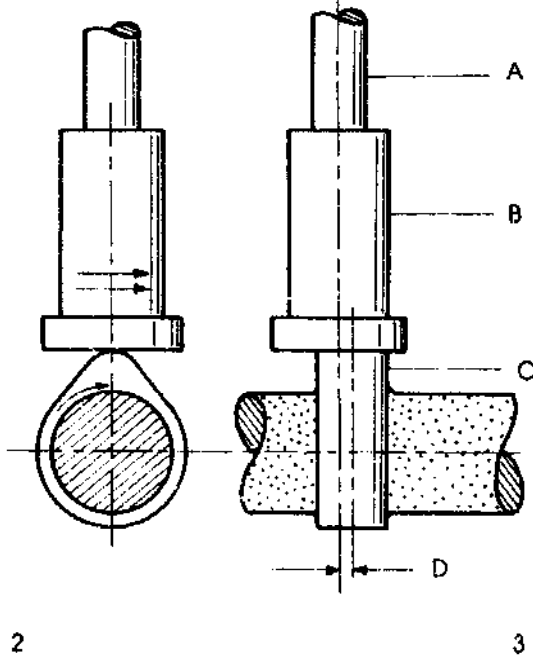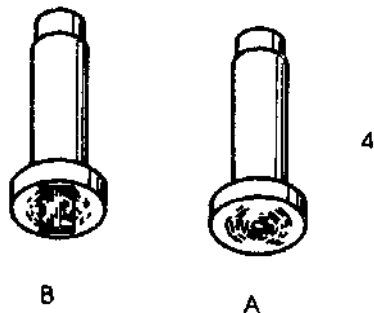
Check tappets
- Examine each tappet for wear and scratches
- Examine the tappets to see whether they have been turning in their bores
- Check the seating of the push rods

Names of tappet related parts
- Push rod 3-A
- Tappet 3-B
- Camshaft cam 3-C
- Distance off-centre 3-D

Push rods

The push rod in Fig. 1-A transfers the motion
from the tappet to the rocker arm 1-B. It is
usually made of hollow steel pipe with solid
steel ends, see Fig. 2. The upper end is
sometimes cup-shaped to fit the ball-shaped
end of the adjusting screw. The other end is
slightly ball-shaped to fit the tappet. When
removing the pushrods, mark each rod so it can
be re-assembled with the same mating parts.

Check whether the push rods have become
bent. Place the rods on a flat steel plate and roll
them over. They must be replaced if they are
bent more than the tolerance specified by the
manufacturer.

Valve springs
The main function of the valve springs is to
close the valve and keep it closed until it is
forced open again by the camshaft. Cylindrical
springs as shown in Fig. 3 are installed in most
engines:
- Valve stem 3-A
- Spring cap 3-B
- Outer spring 3-C
- Inner spring 3-D

Inspecting valve springs
- After taking off the springs, check the
  casting on the cylinder block where the
  springs rotate.
- Check that spring caps are of the correct
  thickness, see Fig. 3-E.
- Check the end of the springs.
- Also check the springs by placing them on a
  flat surface, using the tee square.
- Check the force of the springs with the
  spring tester, see specifications.
- Do not worry if the springs are of different
  lengths. Lengths may differ, yet the springs
  will be the same length and have the same
  force when they are in the compressed
  position.
- Note that after valves and valve seats have
  been re-ground there may be less spring
  tension than before, because as the ground
  valve seat is deeper the spring operating
  height is longer. This can be remedied with
  a few washers.
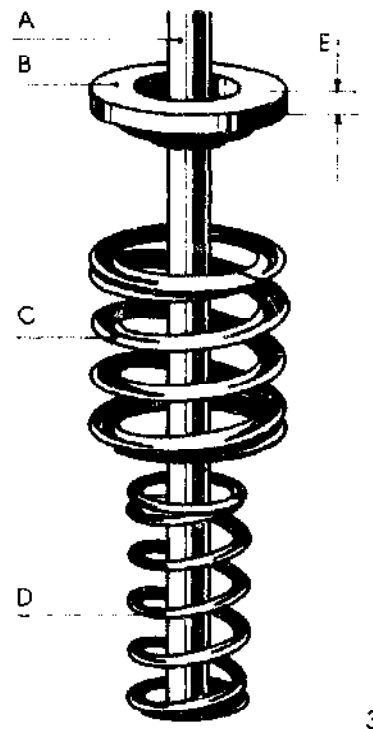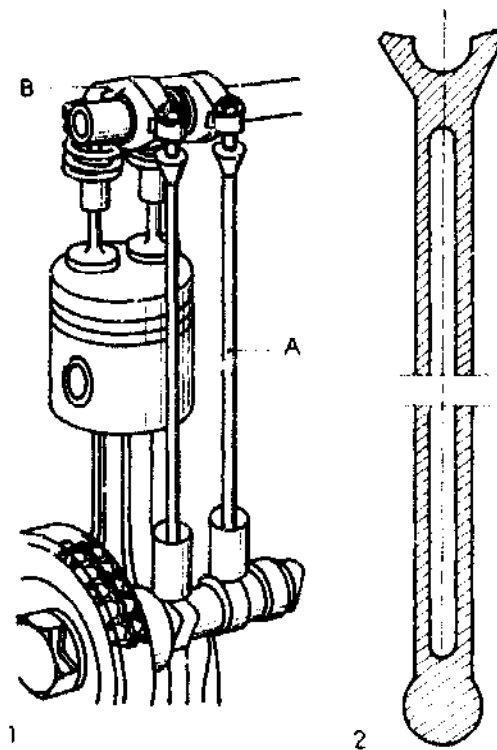
Rocker arm
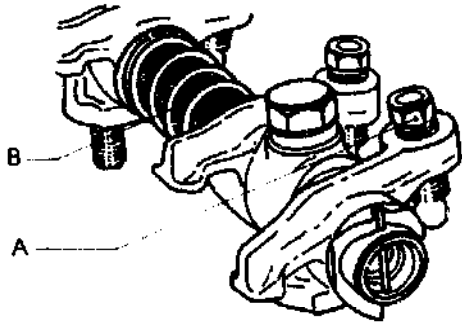
The rocker arm transmits the camshaft motion to the valves. The rocker arms shown in Fig. 1 are mounted on a hollow shaft 1-B which is secured with brackets and bolted to the cylinder head. Lubricating oil is pumped through the hollow shaft to lubricate all rocker arms. Springs are positioned between the rocker arms to keep them in place. A valve adjusting screw is shown at 1-A.

### Rocker arm tip
A rocker arm tip is shown in Figs. 2-A and 2-B. This tip 2-C, which comes into contact with the valve cap 2-D, may exhibit concave wear after some time and this will affect the correct valve clearance. Sometimes a special screw may be fixed in the rocker arm tip to allow easy replacement of worn parts and extra adjustment. When installing rocker arms, make sure you install the arms and springs in the same sequence as they were removed.
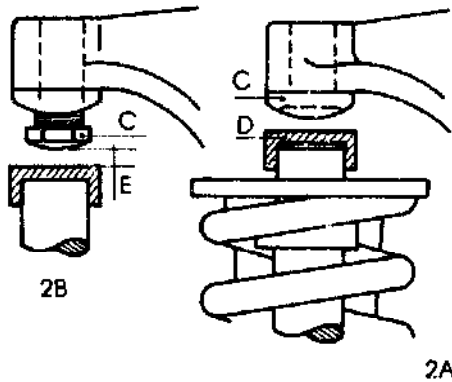
Valve clearance
When valves are properly adjusted, there is a small clearance between the valve tip and the valve cap. see 2-E. This clearance is called *valve lash* or *valve clearance*. Valve clearance is essential to allow for heat expansion in all the parts involved. Without clearance, expansion of the heated parts means the valve stays partly open during operation.

According to the manufacturer's specifications, the valve clearance may depend on whether the engine is hot or cold.

Too little valve clearance
Too little valve clearance affects the timing of the engine. It may make the valve to open too early and close too late. Additional it may cause bending of the push rods, because they expand in length due to the heat. Too little valve clearance can also make the valves burn, because hot combustion gases passing round the valve can cause overheating. This is because the valve has not been in contact with the valve seat long enough and therefore cannot cool down. See Fig. 3.
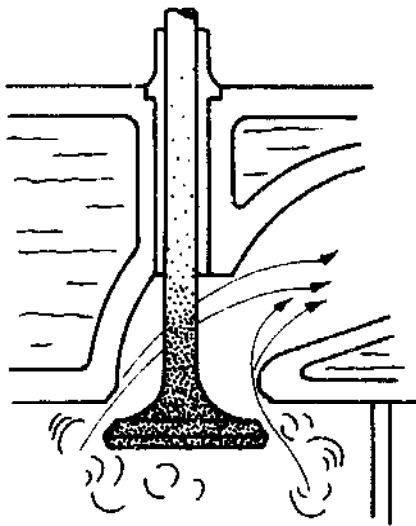
Too much valve clearance

Too much valve clearance may cause the
situation shown in Fig. 1. Contrary to the
situation shown in Fig. 3 on the previous page,
the combustion heat is transferred to the cooled
cylinder head, but the exhaust gases are sealed
into the cylinder and cannot escape because the
exhaust valve closes too early and the fuel/air
mixture is late entering the cylinder during the
intake stroke.

The valve itself may also be damaged, because
in a normal situation the shape of the cam
means the camshaft slows the speed of the
valve movement as it closes. With too much
valve clearance, the valves close with great
impact, cracking or breaking the valve and
damaging the cam and the tappets as well.
Refer to Fig. 2:
- Valve clearance 2-A
- Rocker arm 2-B
- Valve head 2-C
- Screw 2-D
- Valve 2-E

*Follow the manufacturer's specifications when
adjusting the valve clearance!*

- Make sure the engine is at the recommended
  temperature.
- Check which are the *intake* and which are
  the *exhaust* valves, because the clearance is
  usually different for both.
- Most engines have timing marks on the
  flywheel. Turn the flywheel until the first
  cylinder is at Top Dead Centre (TDC) of its
  compression stroke.
- A method of finding out whether the piston
  is exactly at TDC is to remove the injector
  and close the hole with your finger. On the
  compression stroke, air is then forced out
  through the hole against your finger until the
  piston reaches exactly the TDC point. Never
  try to feel where the piston is with your little
  finger through the injector hole – this is very
  dangerous.
- Check the valve clearance when the piston
  is at TDC. If necessary, adjust the valve
  clearance with a feeler gauge as shown in
  Fig. 3, turning adjusting screw 2-D up or
  down until the correct valve clearance
  according to the specifications is obtained.
- Rotate the flywheel in its firing order and
  adjust all valve clearances when each piston
  reaches the TDC on its compression stroke.
- Check again after running in.
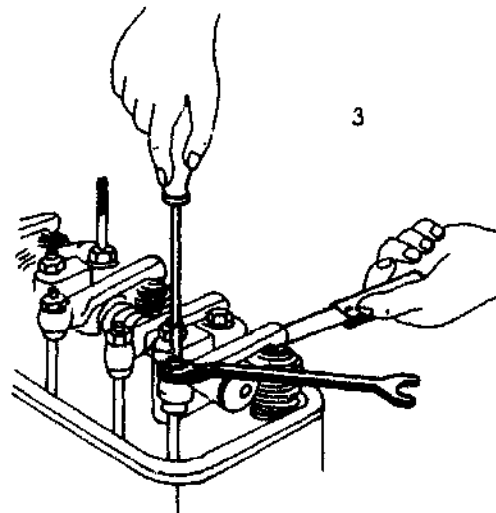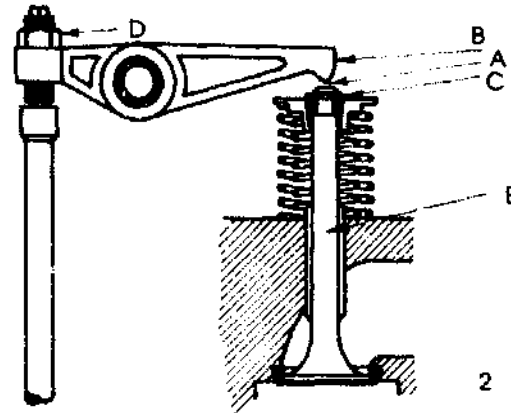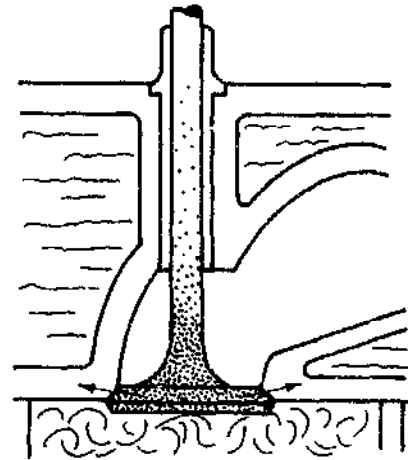
Cylinder block and cylinders

Cylinder blocks

Figure 1 shows a typical cylinder block. This block is made of grey cast iron as a one-piece casting. Cylinder blocks are cast with centre webs to support the crank and camshaft. They have enlargements in their walls for coolant and oil passages.

The cylinders in the cylinder block are sometimes cast into the block or bored in the block at a later stage to lodge replaceable cylinder liners.

Cleaning cylinder blocks

After stripping, scrape all gasket material from the surface of the block. Remove all oil gallery and core hole plugs to facilitate cleaning inside. Cleaning can be done with hot water or any other recommended solution. A special solution should be used in particular when the water passages are heavily scaled. It is very important to clean the passages well to avoid overheating of the cylinder block.

Inspecting the cylinder block

Cracks and leaks can be checked with water and air pressure. Check the cylinder block top surface as shown in Fig. 2. The surface is checked in all directions with a straight edge and a feeler gauge, see Fig. 3. This checking must be very accurate, because the surface must seal off the area to water, oil and compression.

Inspect all studs, dowels, pins, pipe plugs etc. for looseness, damage or wear and replace parts as necessary. Inspect the cylinder bores carefully. After cleaning and inspection, spray the whole cylinder block with thin engine oil.
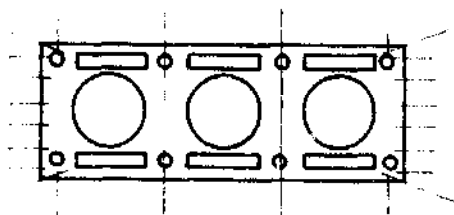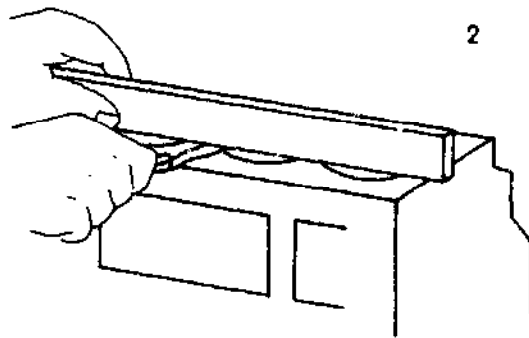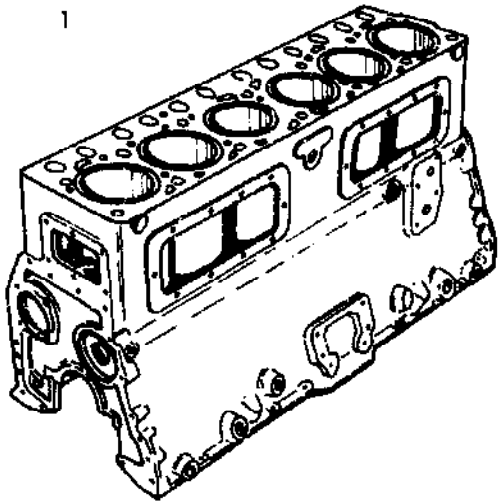
The cylinder

A cylinder is basically a hollow tube which guides the piston and forms the combustion chamber together with the cylinder head and the piston. There are two basic types of cylinders:
– Cast-in-block
– Individual castings

Cast-in-block
In a cast-in-block engine design, the cylinders are cast and polished into the cylinder block, thus forming a single unit.

Individual castings
In this type of casting the cylinder is made together with the cooling fans and bolted separately to a base. The main advantage of such a system is that it is possible to build up an engine with any number of cylinders. Another advantage is that, if failure occurs in one of the cyclinders, it can be replaced individually.

Dry and wet liners
Another type of cylinder casting is one in which the cylinder is made and shaped like a hollow tube which fits into the cylinder block. There are two types:
– Dry liners, see Fig. 1
– Wet liners, see Fig. 2

Dry liners
Dry liners are sleeves which fit inside an already completed cylinder casting in the cylinder block, see Fig. 1-C. The liner is in fact a wearing surface for the piston, because the material the cylinder block is made of is not able to withstand forces applied during operation. As shown in Fig. 1 this liner is not exposed to the engine coolant in 1-A and 1-B, so it is called a *dry liner*.

Wet liners
An engine with a wet liner is shown in Fig. 2. You note that this liner 2-C has two functions: it is the actual cylinder and it also forms the inside of the water jacket 2-A and 2-B.

Two sections of wet liners are shown in Fig. 3. As you see, both liners have flanges at the top to seat in a mating counter-bore at the top of the cylinder block. The bottom of the liner is sealed with two rubber rings 3-A or with a copper ring 3-B.

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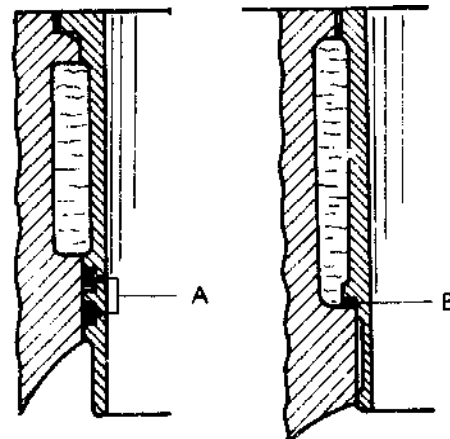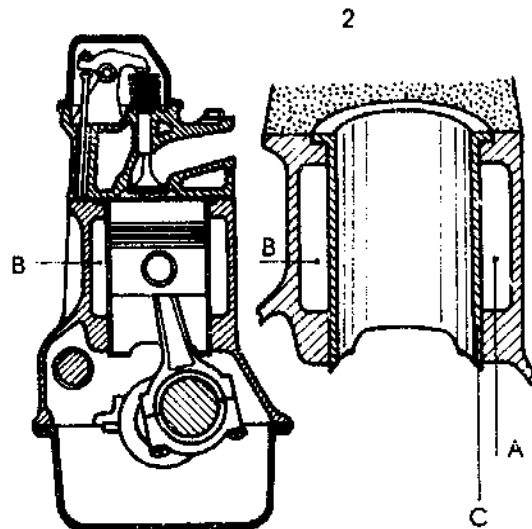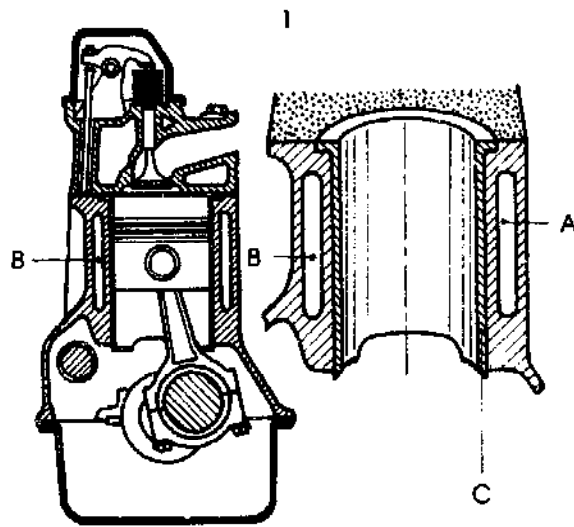
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Servicing cylinders
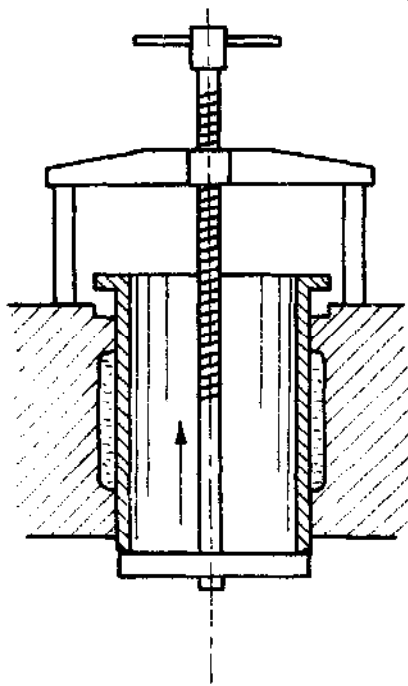
A cylinder is removed with a cylinder puller as shown in Fig. 1. After removing the cylinder the rubber or copper seals can be taken off. Then clean the counter-bores on top of the cylinder block and remove the scale from the water jackets with a wire brush. Also clean the lower sealing surface in the cylinder block where the rubber or copper seals are positioned.

When removing the cylinders, mark them and place them in the same sequence as you take them out of the cylinder block.

Checking cylinders

Measure the cylinders for taper shape and out-of-roundness. This means measuring the top and bottom parallel to the crankshaft. Measure too the top and bottom parallel and at right angles to the crankshaft. Then compare the differences.

The tolerances depend on the manufacturer's specifications for exact wear limits, which should generally not exceed 0.127 mm. After measuring decide what should be done:
- replace the cylinder,
- re-bore the cylinder,
- hone the cylinder,
- de-glaze the cylinder.

Replace the cylinder when the wear is beyond the tolerance. The piston is usually replaced as well.

Cylinder liners for larger engines are re-bored when necessary to the smallest oversize diameter. Oversized pistons should then be fitted to provide the correct piston-to-liner clearance. Re-boring is done with special machinery complying with the manufacturer's specifications.

Honing

Honing is done to smooth the cylinder and produce a special finish which must be neither too rough nor too smooth. A finish which is too smooth can retard piston ring seatings and a rough finish may wear out the rings too quickly.

A typical honing tool is shown in Fig. 1. Insert the hone in the cylinder bore and adjust stones 1-A to the narrowest section. When it is adjusted correctly, move the hone up and down at low speed with a stroke overlapping by about 2.5 mm. Concentrate first on the high spots. When they are removed, the drag of the hone becomes lighter. When honing, use a mix of 50% diesel fuel and 50% engine oil to ensure the honing stones are cooled and to avoid excessive wear.

Remove the hone and measure the bore. It should be clear that moving the hone from top to bottom inside the cylinder will not take away the out-of-round shape. Make sure that you do not remain in one place too long while honing, because the bore will become irregular. Thoroughly clean the cylinder, and if necessary the cylinder block, to remove all particles caused by the honing.
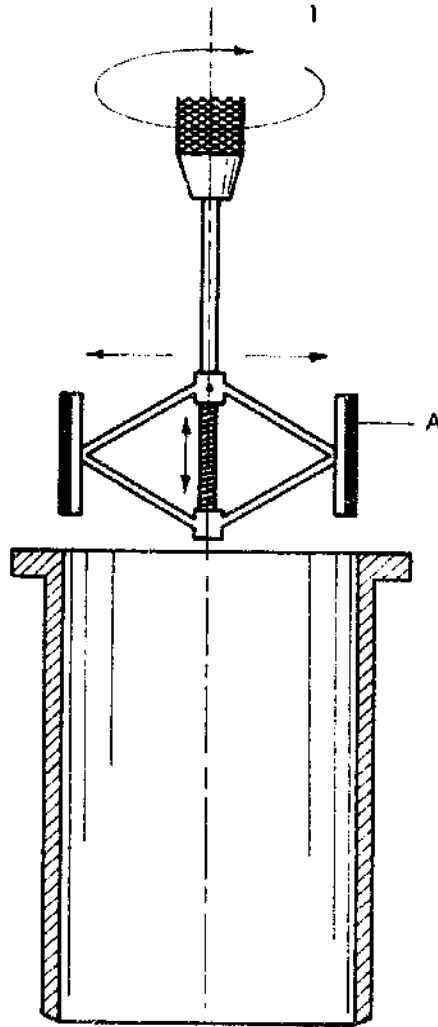
De-glazing

De-glazing is done with a special de-glazing tool as shown in Fig. 1. This tool is brush-like with coated tips. Move the tool at low speed for at least 10 complete strokes. Move it at such a speed that the result is a cross-hatch pattern as shown in Fig. 1.

Installing dry cylinder liners

First read the manufacturer's recommendations on installing the dry liners. Clean all parts correctly and insert the liner carefully, placing each liner in the bore from which it came before.

Installing wet cylinder liners

Clean the cylinder flange and the lower sealing surface. Also clean the cylinder block bore and the lower sealing surface inside the cylinder block.

Install the liner first without a seal and check its height in relation to the top of the cylinder block. See Fig. 2. Check whether the liner is seated squarely. All cylinder liners should be of the same height to avoid cylinder head gasket leaks. Take out the liners and place the new seals. If necessary, lubricate the seals and the mating surfaces in the cylinder block. At the same time make sure the seals are not twisted. Press the liner as far into position as possible by hand. Finish the job by placing a hard wooden block over the liner and tapping it lightly with a hammer, moving it into position, see 2-A. The liner may protrude above the cylinder block 2-C, see 2-B. The cylinder head 2-D will finish the rest and press the bottom seal together. The top of the liner is sealed off with the cylinder head gasket 2-E.

1
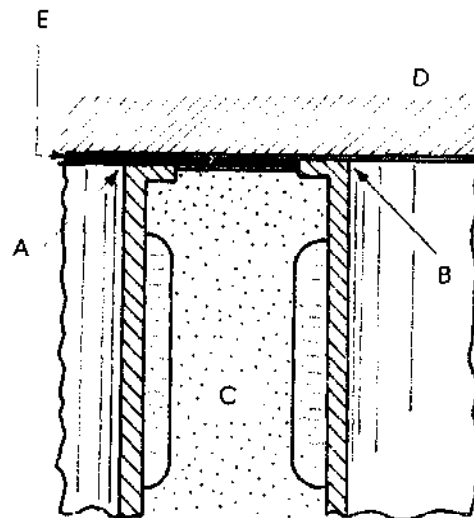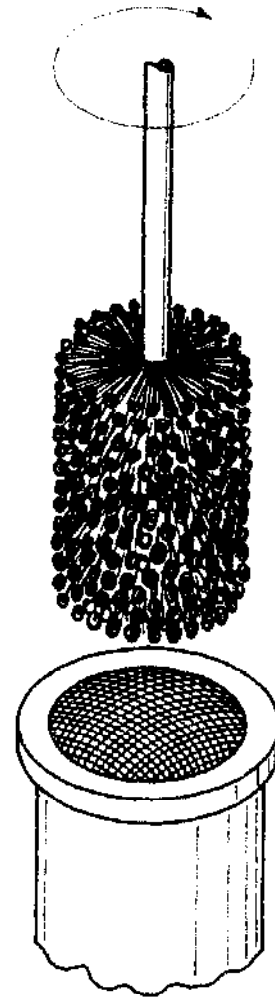
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Pistons and
piston rings

Pistons
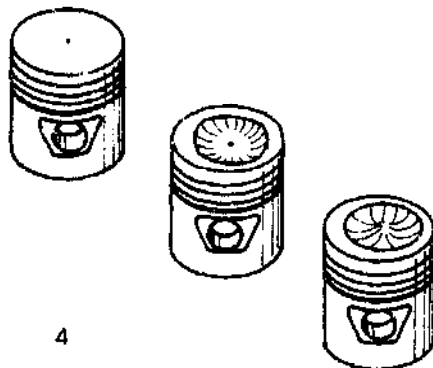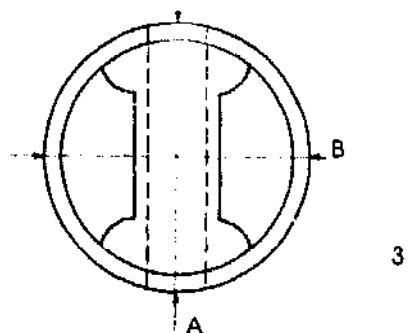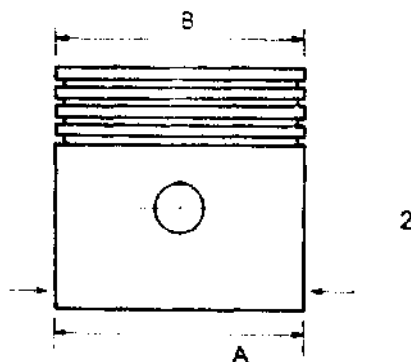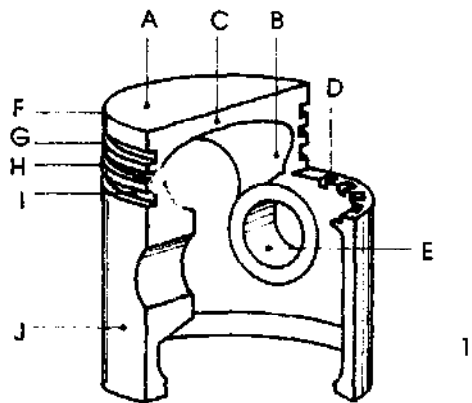
The piston is basically a plunger which moves up and down inside the cylinder. It seals off the crank case from the combustion chamber. Its main functions are:
- Sealing off the crank case from the combustion chamber.
- Providing vacuum during the intake stroke.
- Receiving the force of the expanding gases and passing it on to the connecting rod etc.
- Pushing out the exhaust gases.
- Compressing air prior to ignition.

Pistons are made of:
- cast iron,
- aluminium alloy.

Parts of the piston are (see Fig. 1):
- Piston head 1-A
- Reinforcement 1-B
- Head rib 1-C
- Lubrication holes 1-D
- Piston pin boss 1-E
- Top land 1-F
- 2nd land 1-G
- 3rd land 1-H
- Ring groove 1-I
- Skirt 1-J

Piston construction

Ribs inside the piston reinforce it and at the same time transfer the heat from the head to the piston rings. The skirt, see Fig. 2, keeps the piston in alignment. It is usually tapered, so the diameter of the skirt 2-A is slightly larger than the diameter 2-B at the piston head. The elliptical shape shown in Fig. 3 should be slightly more across the thrust face in diameter 3-B than diameter 3-A.

Types of heads
- Flat head
- Irregular head
- Concave head

The different shapes of the piston faces are shown in Fig. 4. They allow for more or less compression and swirling. Remember that diesel engines sometimes have swirling chambers in the cylinder head, which will be explained at a later stage.

Piston rings

Ring grooves are cut round the piston to accommodate the piston rings. A typical piston ring is shown in Fig. 1. Piston rings have three functions:
- They form a gas-tight seal between the piston and the cylinder.
- They transfer the heat from the combustion, affecting the piston to the cylinder.
- They control the lubrication between the piston and the cylinder wall.

Compression rings

Compression rings can have various shapes as shown in Fig. 2, where you see:
- Rectangular type 2-A
- Taper-faced type 2-B
- Key-stone type 2-C
- Barrel-face type 2-D
- Other types are available

Compression rings can have different joints, see Fig. 1. Three types are shown:
- Step joint 1-A
- Angle joint 1-B
- Straight joint 1-C

Oil rings can also have different shapes. The ring shown in Fig. 3 has an expander spring inside the ring. A detail of the function of the oil ring is shown in Fig. 4. The oil control ring is marked 4-A. The piston section is marked 4-C. The oil return holes are marked 3-A and 4-B.

Oil consumption must be controlled to avoid waste and a smokey exhaust. So the oil ring must wipe any excess oil from the cylinder wall and allow it to return through the oil return holes in the oil rings and in the piston. From there it returns to the crank case.
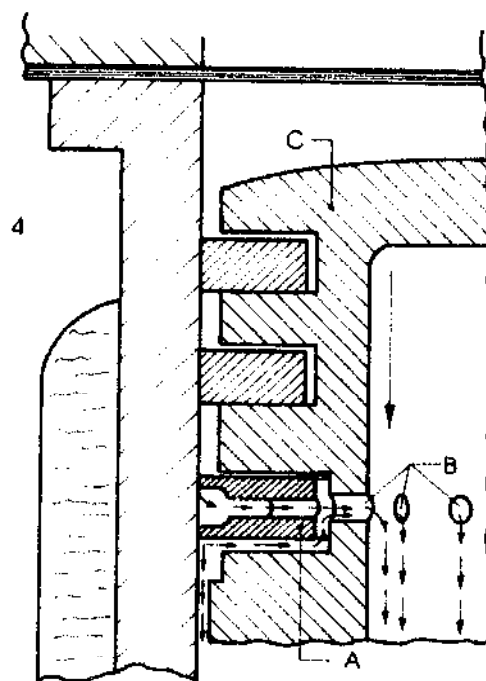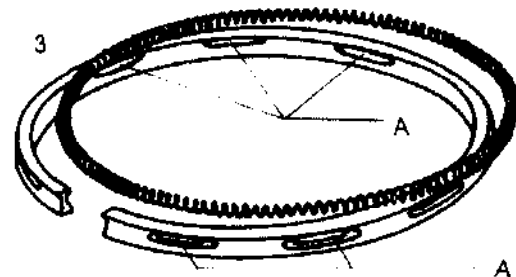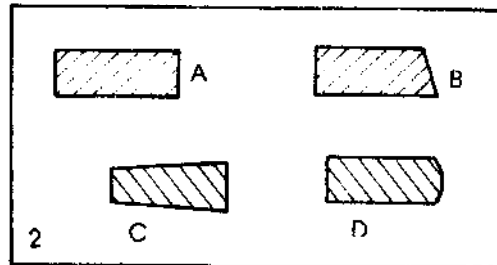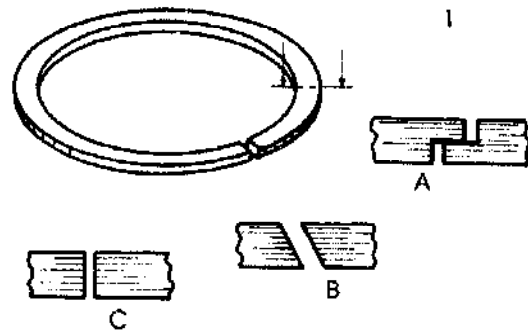
Piston and piston rings
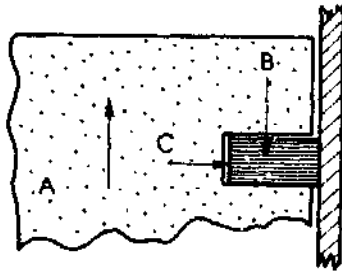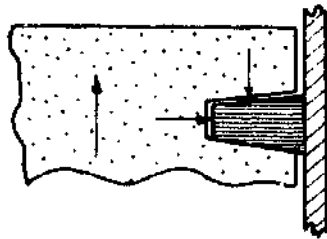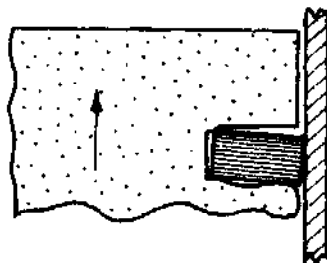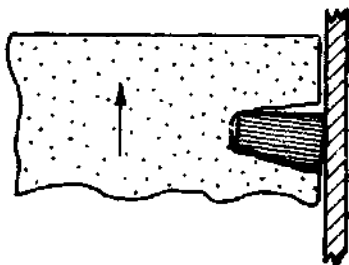
To obtain a good seal between cylinder wall and piston, the piston rings should have the correct shape and tension and be installed in the specified sequence. If piston rings are installed in the wrong sequence, are of the wrong type or size or are overstretched, oil and gases may pass and cause overheating and other problems.

Overheating, unburned fuel or an excess of lubrication oil collected by the rings during operation may cause them to *stick* or become *plugged* into their grooves. Rings often break when they are stuck or plugged.

If you look at the power stroke 1-A illustrated in Figs. 1 and 2, you see that combustion forces the ring down against the lower side of the groove 1-B. The gases which pass behind the ring force it out against the cylinder wall, resulting in a tight seal, see 1-C.

A new rectangular or tapered ring installed in an old groove is shown in Figs. 3 and 4. The worn sides of the old groove do not permit the new ring to mate correctly, giving a bad seal between both the face and the side of the ring. The result will be broken rings and damaged pistons.

The top piston ring is very important because it acts as a compression ring and at the same time as the final oil control ring. The top ring and its groove wear a lot because they are exposed to most of the heat, pressure and dirt and get the least lubrication. Rings must fit correctly in their grooves and have the correct side clearance. The grooves must be smooth and parallel.

Lubrication oil consumption

As explained before, the function of the piston
and the piston rings is to seal off the
combustion chamber from the rest of the
engine and prevent from:
- excessive lubrication oil consumption,
- gases passing to the crankcase.

Excessive oil consumption can occur due to
the pumping action of a piston with worn
piston rings. The more the cylinder and piston
rings are worn, the greater the oil consumption.
Piston rings must however let a small amount
of oil pass for correct lubrication, thus leaving
a film of oil on the cylinder wall to avoid
wearing out too fast.

Correct oil consumption is shown in the
illustrations, where you will see:
- Cylinder wall 1-A to 4-A
- Piston and rings 1-B to 4-B
- Lubrication oil (shaded areas) 1-C to 4-C
- Blow-by gases 4-D

As the piston moves down, oil is forced into
the ring grooves by the scraping action of the
rings on the cylinder wall, see shaded area 1-C.
This happens during the *intake stroke*.

During the *compression stroke*, see Fig. 2, the
piston rings are forced to the bottom of the ring
grooves, with the result that the oil is trapped
above the rings in the grooves 2-C.

The *power stroke* makes the piston move down
and the oil is then transferred to the cylinder
wall. The piston rings are held down against
the ring land by the force of expansion, see
Fig. 3.

During the *exhaust stroke* the oil is forced from
the cylinder wall into the combustion chamber,
where it is burned. See Fig. 4.

When cylinders or piston rings are worn, gases
can pass by between the cylinder wall and the
rings. This is called *blow-by*. A small amount
of gas always passes between the cylinder and
the rings. The crank case must therefore be
well ventilated, see Fig. 4-D. Blow-by can
cause the pistons to overheat and expand, thus
scoring both piston and cylinder wall. The
lubrication oil is then contaminated and causes
wear. Compression is lost, leading to loss of
power.
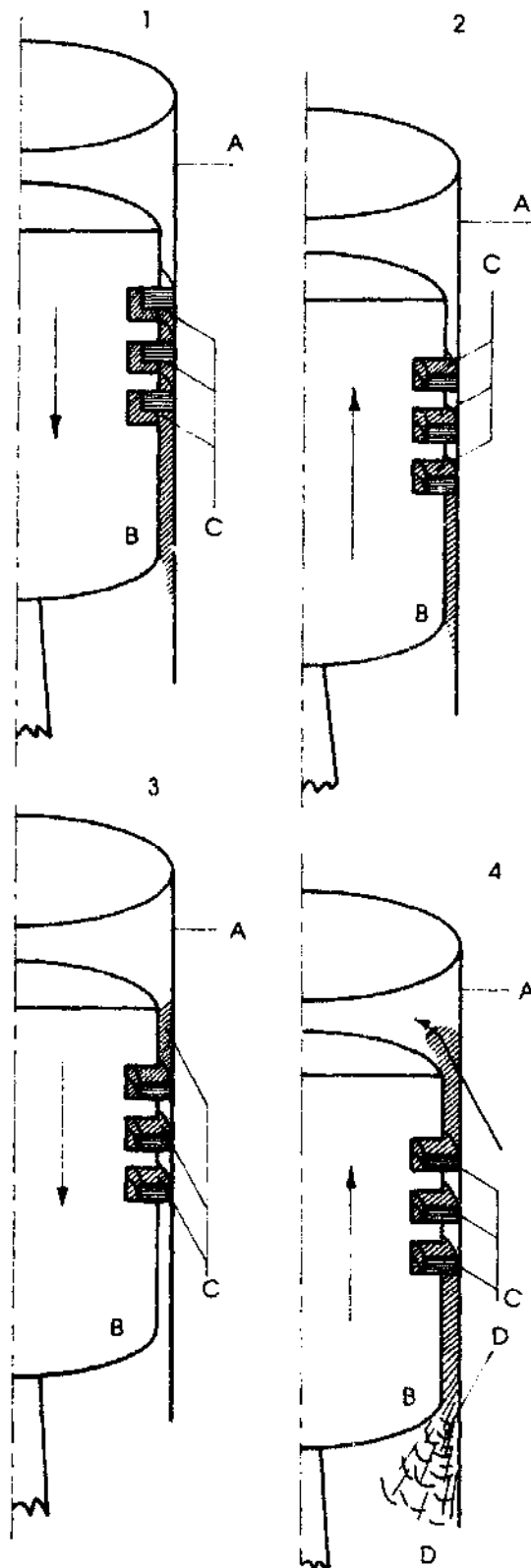
Wear of piston and piston rings
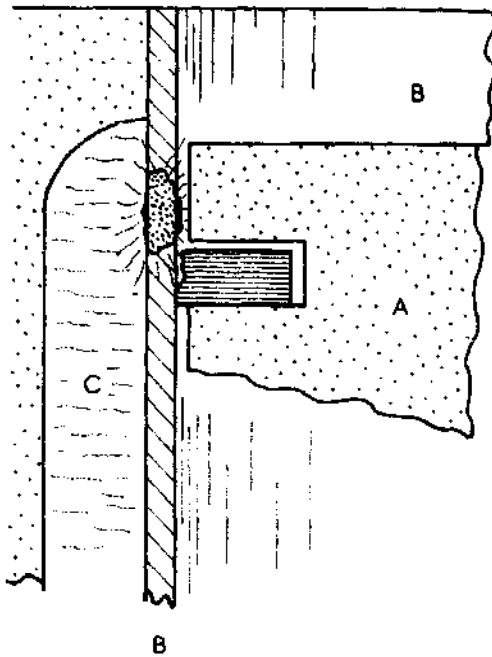
Wear of piston and piston rings may be caused by dirty lubrication oil, wrong air intake and dirty fuel. Another cause of wear is *scuffing*, what happens when two metal parts rub together. Heat builds up to the melting point due to the friction, after which some of the melted metal is pulled out and deposited on the cooler surface, as shown in Fig. 1. The coolest part is of course the cylinder 1-B, which is cooled with water 1-C. If no coolant is present the piston 1-A may be the hottest part. Scuffing is difficult to identify. If it develops to the extent of becoming noticeable, it is called *scoring*.

Another cause of piston and cylinder wear is corrosion. Leaking coolant, the wrong lubrication oils or cold engine operation can cause this problem. Corrosion will leave a mottled, grayish pitted surface on the pistons and cylinder walls.

Burning the piston and breaking or sticking rings may occur due to *knocking*. This is the result of fuel in the cylinder combusting too early, too fast or unevenly. Another cause of knocking may be:
- wrong fuel,
- ignition timing advanced too much,
- over-fuelling,
- cooling system not working.

Piston damage
A piston may be damaged if:
- The piston is handled carelessly before installation.
- The ring grooves are damaged while cleaning out the carbon deposits.
- The gudgeon pin locks are faulty or wrongly installed.
- The cylinder bore is out of alignment.
- The crankshaft has too much float or the journal has too much taper.

Cleaning the piston
Do not use a wire brush to clean the piston. Avoid scratching the sides of the piston ring grooves.

Inspecting the piston

After taking the piston out of the cylinder, take off the piston rings with a ring expander and place the rings on the workbench in the correct order, see Fig 1.

After cleaning, check the piston for cracks in the head and skirt and for bent or broken lands. Check the whole piston for score marks, signs of overheating and finally for damaged ring grooves.

Piston to cylinder clearance

To find the clearance between the cylinder and the piston you must:
- measure the inside cylinder diameter with a micrometer at rightangles to the crankshaft in the lower area of the cylinder,
- measure the diameter of the piston with a micrometer across the thrust face, see Fig. 2.

The difference between these measurements is the clearance. Always compare the results with the technical data in your engine manual.

Checking the ring grooves

A ring groove must be checked as shown in Fig. 3. Place a corresponding ring 3-B into the groove. Insert a feeler gauge 3-A between the upper face of the new ring and the piston land. The clearance is now found by reading the result on the feeler gauge blade. Check the groove at several points.

Grooves of different designs can be checked with special wear gauges supplied by the manufacturer, see Fig. 4. Donnot forget to check at the same time whether the oil ring holes are open.

Damaged pistons can be re-conditioned in special workshops. Always replace damaged pistons to avoid further damage.

Checking piston rings

Piston rings can be checked by comparing the old ring with a new one, see Fig. 5. First measure the radial wall 5-A of the new ring with a micrometer. Compare the reading with the radial wall dimensions of the old ring 5-B and 5-C.

1

2

3

No 10

4

5
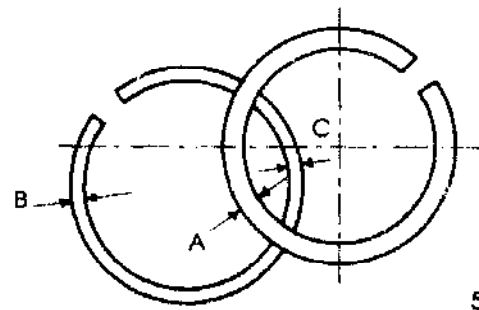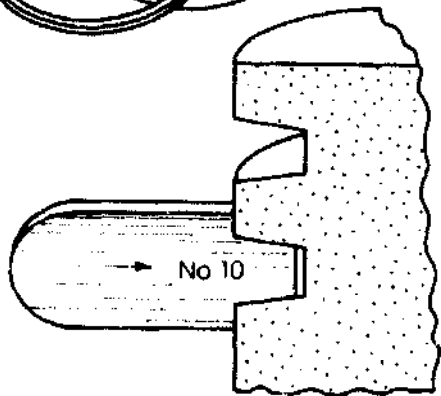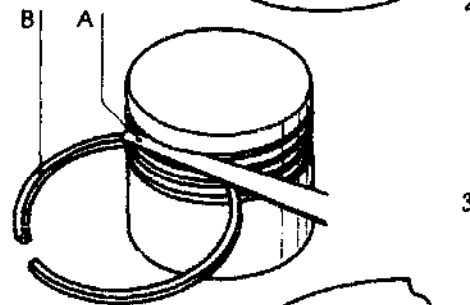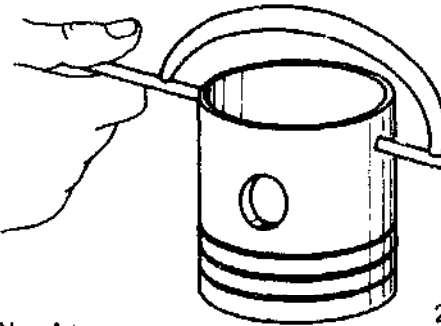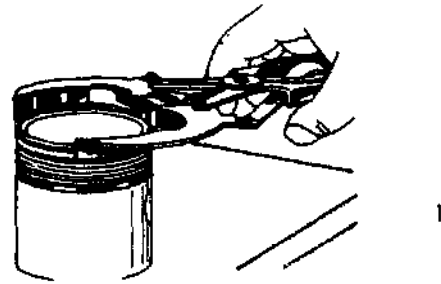
Ring gap measurement

The ring gap is measured as illustrated in Fig. 1. Insert the ring into the cylinder and find the clearance of the gap with a feeler gauge 1-A.
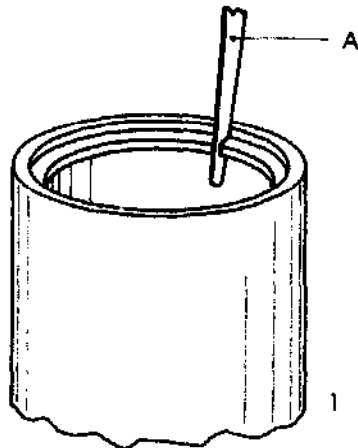
Installing piston rings

After ensuring that the piston grooves and oil return holes are clean, the rings can be placed according to the manufacturer's specifications. See Fig. 2. Rings are marked with a T, which means Top side.

Use a ring expander to prevent the rings twisting or stretching during installation. If you twist or expand the rings too much, you distort them permanently and thus reduce their performance. Place the rings in such a way that the ring ends are staggered round the piston.

Installing the piston

Before installation, lubricate each piston thoroughly with engine oil. This is necessary because of engine cranking during the installation until the *oil throw-off* from the connecting rod journals is sufficient. Note that several hundred revolutions are needed before the engine lubrication system is working adequately.

Different types of ring compressors can be used for installation. Sometimes a special compressor is recommended by the manufacturer. Press the rings, together with the compressor, into their grooves. Place the piston with the compressor in the cylinder, applying gentle pressure on the piston as shown in Fig. 3, where 3-A is the piston and 3-B the compressor. The piston may be tapped lightly on the edge – never tap the piston head, because this will damage the head. The whole piston assembly should move into place during light tapping. If the piston sticks, compress the rings again and check the cylinder for any obstruction.
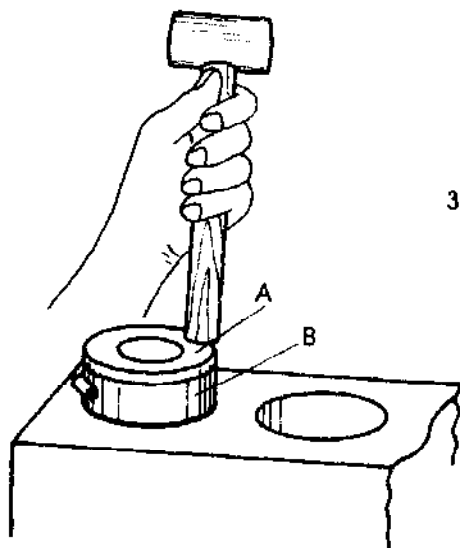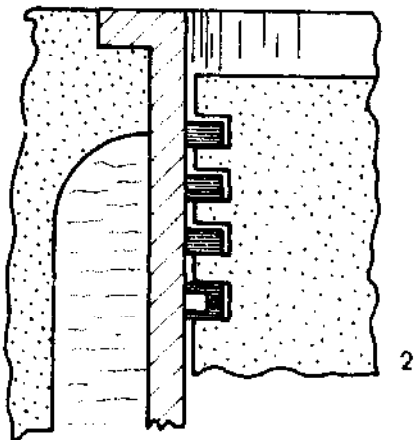
Prior to installation, the gudgeon pin and connecting rod must be assembled.

Piston-connecting rod assembly

Figure 1 shows a piston-connecting rod assembly, consisting of:
- Shank 1-A
- Shank 1-B
- Head 1-C
- Cap 1-D
- Bolt 1-E
- Gudgeon pin 1-F
- Circlip 1-G
- Small end bush 1-H
- Piston 1-I
- Crankshaft 1-J
- Bearing 1-K

Before the piston assembly can be placed in proper position, the connecting rod with the gudgeon pin assembly must be checked and maintained.
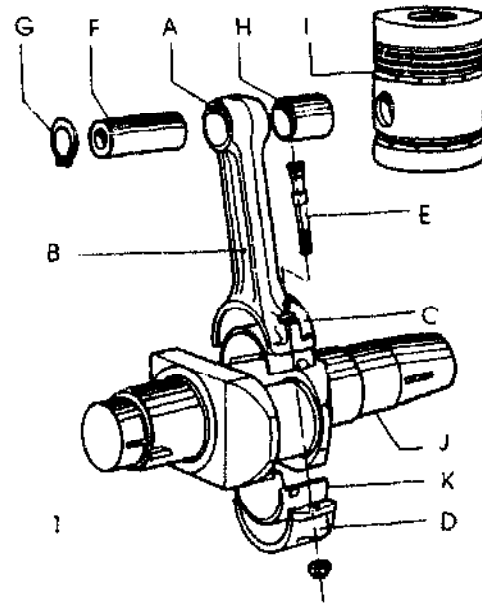
Removing the gudeon pin

The gudeon pin may be removed from the piston, see Fig. 2, with a tool 2-A or with the help of a special shaped wooden block 2-B. Before removing the gudeon pin, heat the piston to 50 °C and then remove the pin in a gentle way and with moderate force.
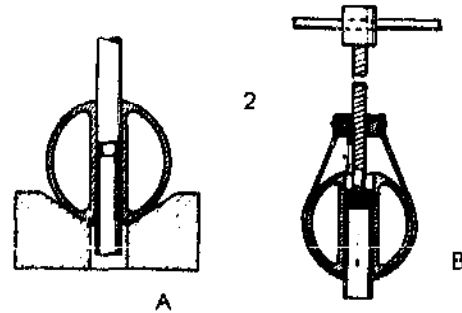
Gudgeon pins

The gudgeon pin connects the piston to the connecting rod. The gudgeon pin can be fastened in three ways:
- Most pistons are *full floating*. This is shown in Fig. 3. The gudgeon pin can turn in the cylinder bore and the connecting rod small end round the gudgeon pin. The pin must therefore be locked in the piston bore with two circlips as shown.
- A *fixed gudeon pin* is shown in Fig. 4. The pin is fixed in the cylinder bore with screw 4-A. The gudgeon pin cannot move anymore and the small end of the connecting rod moves around the pin.
- Sometimes the gudgeon pin is fastened in the small end of the connecting rod with a bolt. This is shown in Fig. 5. The assembly is called *semi-floating* because it turns only in the piston. A bushing 5-A prevents wear of the piston bore.

In high-speed engines, floating pins bear directly on the piston material.
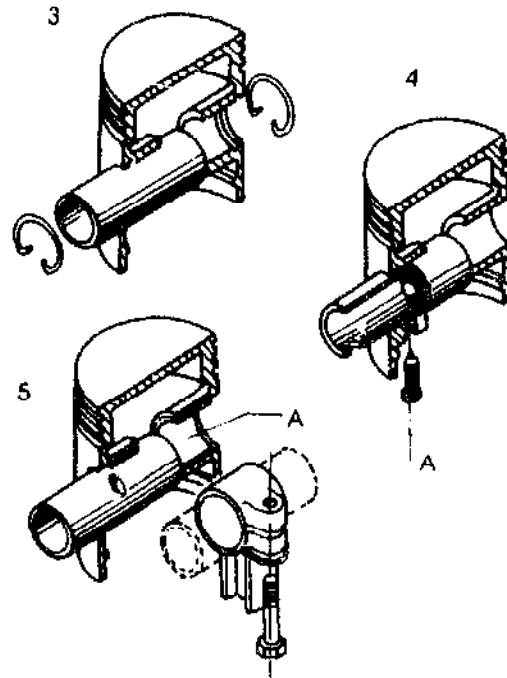
Checking the piston bore and rod bearing
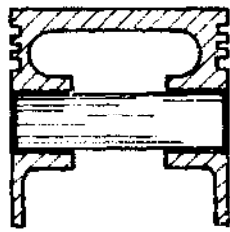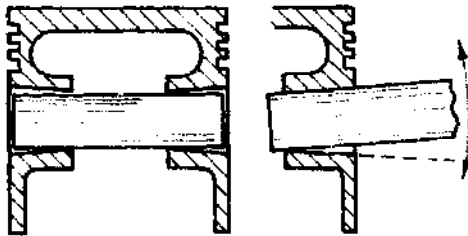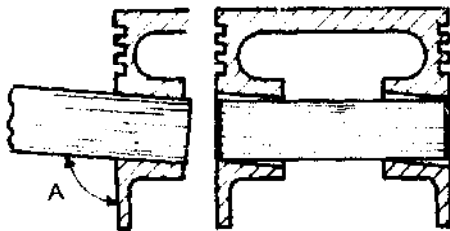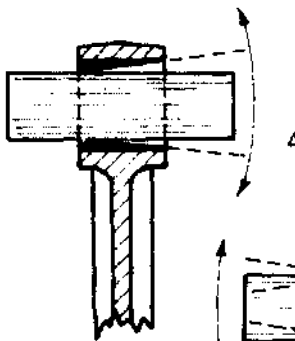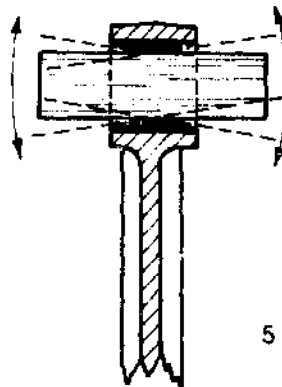
Before the piston is assembled in the cylinder, the gudgeon pin bearing in the piston and the connecting rod must be checked for tapered or misaligned holes.

To check for taper or misalignment between the holes, check each hole in the piston separately with the gudgeon pin. Both holes must be straight and of equal size. The pin must enter and be positioned square to the skirt of the piston without any side play.

If the hole is not tapered, push the pin through towards the second piston bore. The pin must enter this bore without any force or binding and also without a 'click'. A good gudgeon pin bearing should have equal *drag* (resistance) through both holes, see Fig. 1.

Figure 2 shows a piston with tapered gudgeon pin holes. The taper can be checked by inserting the gudgeon pin in one side. If the pin moves up and down, the hole is tapered. Misaligned holes can be checked as shown in Fig. 3. Insert the pin in one side. If the pin is not positioned square to the skirt of the piston, the hole is misaligned. See 3-A.

A method of checking the gudgeon pin fit in the small end bush of the connecting rod is shown in Figs. 4 and 5. To check the bushing for out-of-roundness or looseness, clamp the pin carefully in the bench vice and move the connecting rod a small end back and forth over the gudgeon pin several times. After removing the rod, examine the bushing for shiny contact points. A good pin should show contact over the entire surface of the bushing in the small end.

While holding the gudgeon pin in the vice, move the connecting rod left and right and note the allowance in the bushing.

Figure 4 shows a tapered hole in the small end bushing. Figure 5 shows a bell-mouthed hole in the small end bushing.

Check in the manual the exact clearance between the gudgeon pin and the bearing to sustain and support an adequate oil film.

Connecting rod and crankshaft

Connecting rods
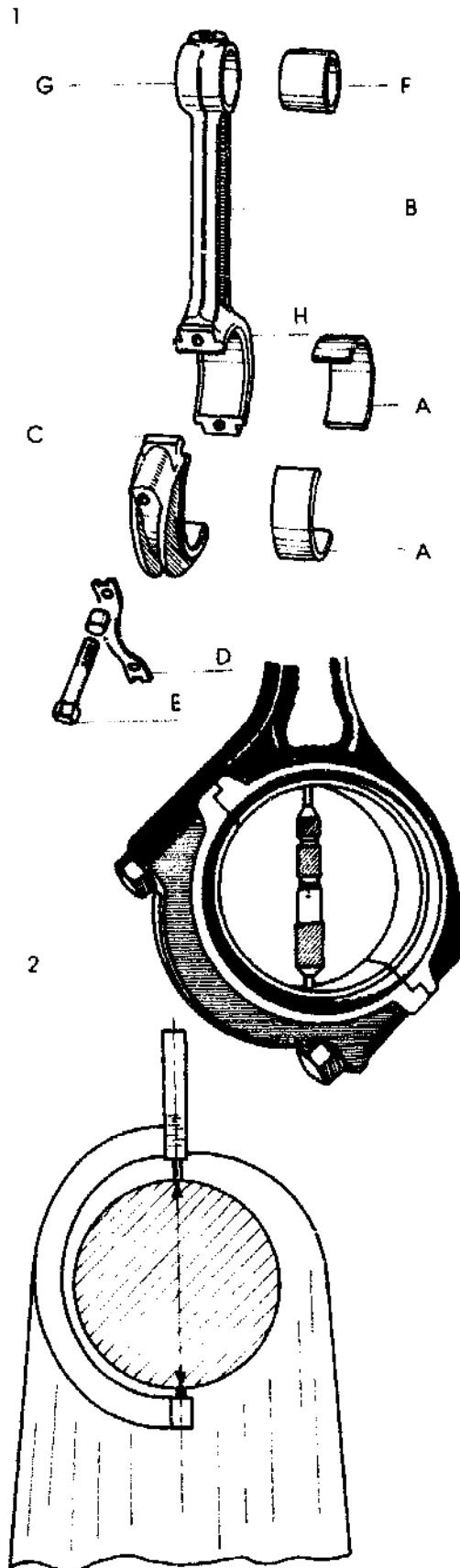
The function of a connecting rod is to transmit the thrust of the piston to the crankshaft, see Fig. 1. It is shaped in such a way that less material is needed and a maximum of strength is obtained. Parts are:
- Bearing 1-A
- Shank 1-B
- Cap 1-C
- Lock plate 1-D
- Locking bolt 1-E
- Bushing 1-F
- Small end 1-G
- Big end 1-H

Most connecting rods are forged from one piece of metal and the cap is cut off at a later stage. Two split *bearing halves* are inserted into the head and the cap.

Connecting rods must be aligned with close limits. If this is not so, the piston cannot work squarely in the cylinder which causes oil consumption and blow-by. Big loads are imposed on rod bearings, pistons and cylinder walls if the connecting rod is not correctly aligned.

Corrections can be made to connecting rods. But heavy rods may return to their distorted shape and it is therefore better to replace them with a new rod

Replacing a bushing
The old bushing can be removed from the small end of the connecting rod with a recessed pin. Be careful not to damage the edges of the bore which have to receive the new bushing. The new bushing must be pressed into place exactly in line with the bore. Tap the bushing into place on all sides with light taps. Never use force because you may damage the bore and the bushing will be loose in its bore.

Bearing clearance
Fix the cap back on the head with the old bearings in place. Measure the inside diameter as shown in Fig. 2. Measure at several points. Measure the crankshaft connecting rod journals as shown in Fig. 3. Measure at several points and compare the results to find the bearing clearance.

The crankshaft

A one-piece drop-forged crankshaft is shown in Figs. 1 and 2. This crankshaft is for a four-piston engine and can be mounted in three main bearing housings.
- Main bearing journals 1-A
- Connecting rod bearing journals 1-B
- Counterweights 1-C
- Crankshaft throws 1-D
- Flywheel 1-E
- Lubrication oil passage 1-F

An engine block with main bearing bores is shown in Fig. 3, where the bearing half inserts are also shown, see 3-A. Five main bearings are located in this engine block. This is not the case with all engines. Sometimes a four cylinder engine may have three main bearings. The cross-section in Fig. 4 shows how the main bearing caps are secured with bolts to the bearing bores.
- Crankshaft 4-A
- Engine block 4-B
- Top bearing insert 4-C
- Bottom bearing insert 4-D
- Main bearing cap 4-E

Crankshaft throws
Crankshaft throws as shown in Fig. 1 are placed in such a way that they counterbalance each other when the crankshaft rotates at high speed. They are designed to:
- balance the engine and reduce vibration during performance.
- affect the loads on the main bearings.

Counterweights
To balance the force of the pistons and connecting rods on the crankshaft, counterweights are placed opposite the connecting rod journals. This also helps to control the vibration affecting the crankshaft.

Flywheel
The weight of the flywheel also helps to stabilize the rotating crankshaft.
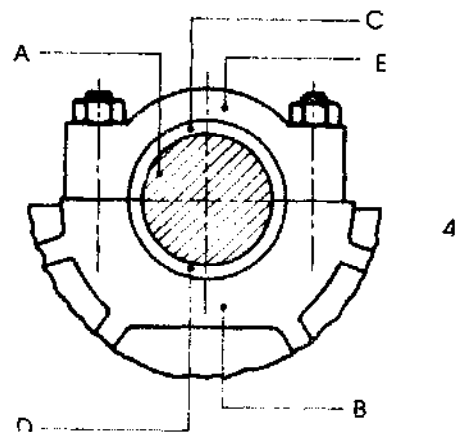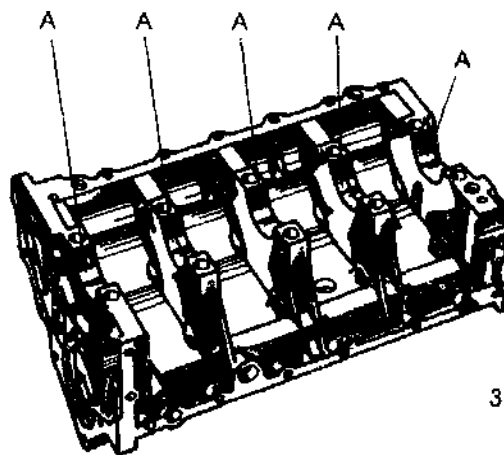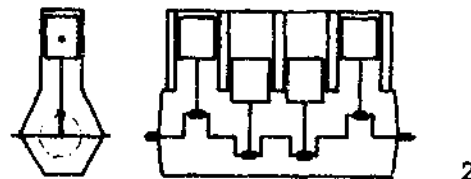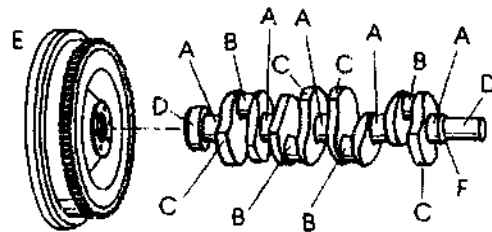
Inspecting the crankshaft
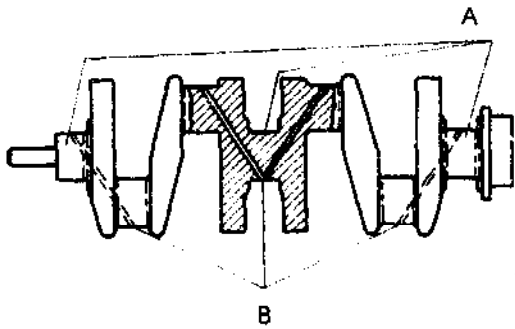
After the crankshaft has been removed it should be washed with fuel oil. Special care must be taken to ensure the oil passages are clean and open.

Figure 1 shows a crankshaft with a part section of the oil passages:
- Main bearings 1-A
- Oil passages 1-B

Almost all engines have pressurized oil lubricating the crankshaft. See Fig. 2. Holes leading in from the engine block via the main bearings provide a path for the lubrication oil 2-A to reach the connecting rod journals, see 2-B. As the oil is under pressure, the excess oil will spray out via 2-C to help lubricate the piston and the cylinders.
- Measure all the connecting rod bearing journals. As instructed in previous lessons, measure at several points and also round the journal to find the smallest diameter.
- Then measure the main bearing journals in the same way as the connecting rod journals.
- Install the main bearing caps again and tighten the bolts to the correct torque. Use an inside micrometer to measure the main bearing inserts.
- Compare all the readings and calculate the difference between the two.
- Check in the manual for the correct specifications.
- Inspect the journals for ridges and the whole crankshaft for cracks due to fatigue.
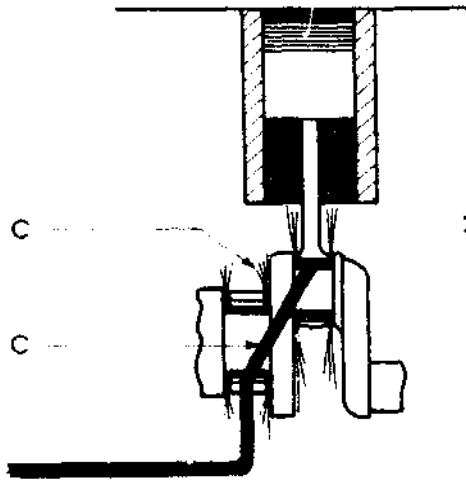
A ridged journal is shown in Fig. 3. Ridge 3-A is caused by the oil groove in the bearing shell shown at 3-B.
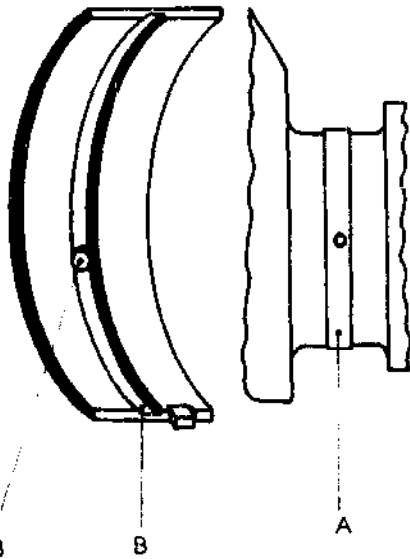
Crankshaft float

A crankshaft must have a certain amount of float. Separate thrust washers on both sides of the main bearing or bearing inserts with two thrust flanges on it are used to keep the crankshaft in place.
- Measure the thrust and compare the result with the manufacturer's specifications.

Bushings and bearings

Bushings and bearings are used on rotating load bearing points in an engine to reduce friction. Bearings are used in the engine for the camshaft, connecting rod journals and main bearing journals where heavy loads and high speeds are imposed. See Fig. 1-A.
Bushings are used round the gudgeon pin, rocker arms, oil pump and other places where speed is not high and the load imposed is rather light. See Fig. 2.
Bushings are pressed into place. This must be done gently, with great care. They must be inserted exactly straight, the pressure being applied on all sides simultaneously.

Bearing inserts are placed in their housings and bearing locks prevent rotation of the bearing. One lug 1-B on the insert prevents from rotation of the insert in one direction and the other lug 1-C prevents from rotation in the opposite direction.

The connecting rod bearing is slightly larger than the housing, to keep it tightly in place. The difference in diameter is called the *crush fit*. Refer to Fig. 3. When tightening cap 3-A over bearing 3-B, the crush height shown at 3-C makes the bearing fit tightly.

Bearing oil grooves
As you have already learned, lubrication oil for the bearing is supplied from the engine block via the crankshaft to the bearings. Inserts have an oil groove as shown in Fig. 1-D to spread oil over the bearing journals. Sometimes other shapes of oil grooves are used, depending on the function.

Thrust bearings
Thrust washers and thrust flanges on bearings have already been mentioned in the explanation of the crankshaft float. Figure 4 shows a section of a bearing with thrust washers (4-A) and a bearing with thrust flanges (4-B). These bearings are used near the flywheel and must be on both halves of the bearing.
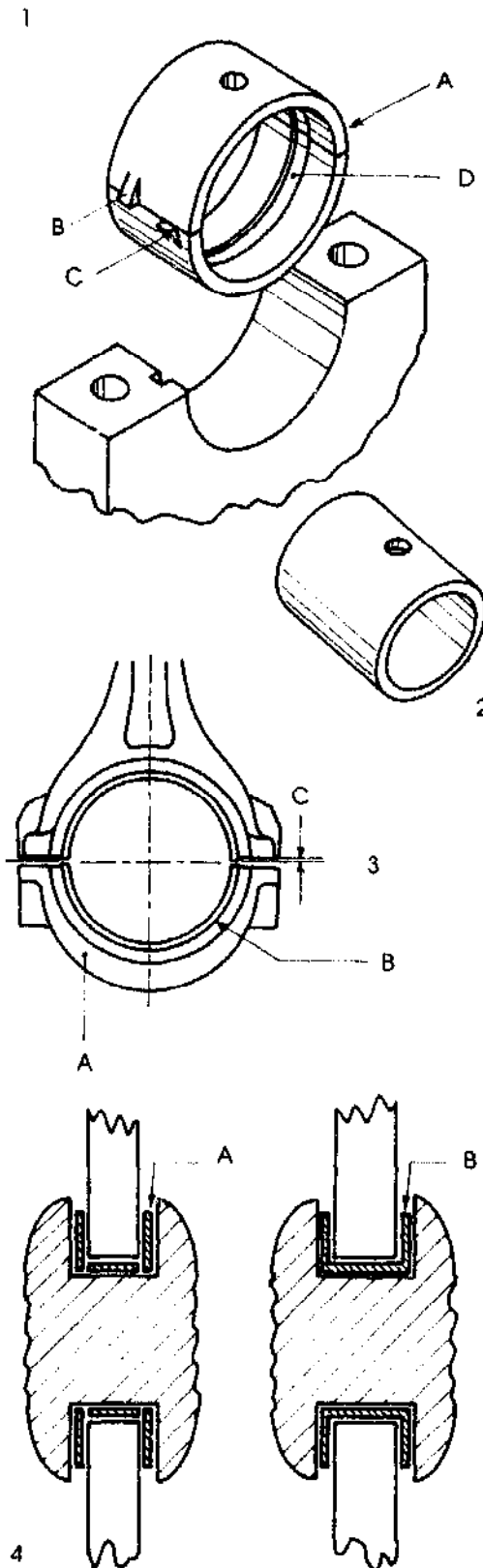
Bearing metal alloys
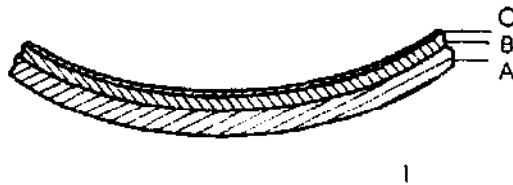
In general a bearing (see Fig. 1) has a body made of steel 1-A with some linings of different material 1-B and 1-C. The bearing material depends on the expected stresses. Lining on bearings may be:
- copper or aluminium alloys and silver combinations,
- copper or aluminium alloys,
- tin or lead-base babbitt,
- special alloys.

Bearing inspection

Before taking out the bearings, clean the top of the workbench so that all bearings can be placed in the same sequence as they are removed, see Fig. 2. Use one line for the gudgeon pin bushings 2-A, one line for the connecting rod bearings 2-B and one line for the main bearings 2-C.
- After cleaning the bearings, mark them with a soft pencil to remember their position, see Fig. 3.
- Check whether all the bearings fit correctly into their housings.
- Fix the connecting rod and main bearings back into their housings and measure with a micrometer for wear.
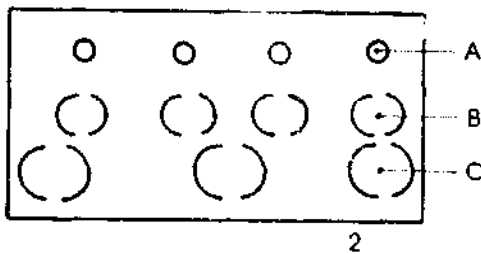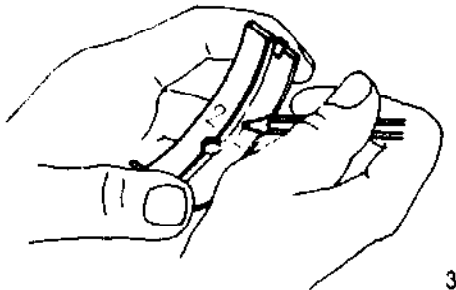
Remember that a bent connecting rod can damage bearings. So you must pay special attention to the connecting rod.

If the supply of lubrication oil is not adequate, bearings show score marks. If fuel oil drips into the crankcase, it dilutes the lubrication oil and causes the same problem.

A finely pitted surface exhibits corrosion due to acid formation in the lubrication oil, excessive blow-by or the oil temperature exceeding 150 °C. It may also be due to stop-and-go operation which causes condensation in the crankcase.

Other damage can be caused by tapered journals and dirt.

Do not just replace the bearings; first find the cause of the damage and repair it. Then replace the bearings.

Measuring practice

Once you have worked through the chapters on pistons, cylinders etc., it is good practice to measure the diameters of;
- Cylinders
- Pistons
- Connecting rod bearings
- Crankshaft journals
- Crankshaft bearings

To do this you need an inside and outside micrometer, the use of which has already been explained in volume 1 of the Rural Mechanics Course: *General metal work, sheet metal work and handpump maintenance*.

Copy the tables as shown on this and the next two pages and fill in the correct diameters you measure. After each practical, consult your instructor.

Find the difference between the nominal size and the actual size of the cylinder at positions 1-A and 1-B at levels I, II and III.
Enter the sizes in the table below.
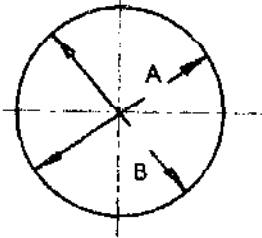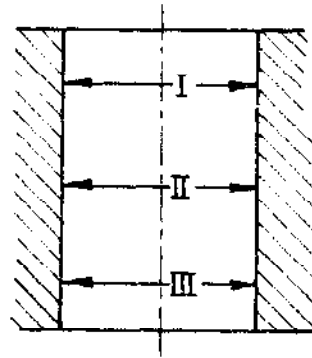
Manufacturer and engine no.:								
Nominal diameter of cylinder:								
Cylinder	1		2		3		4	
Position	A	B	A	B	A	B	A	B
I								
II								
III								

Measuring practice

Check the diameter of the pistons in positions
1-A and 1-B at levels I, II and III.
Enter the sizes in the table below
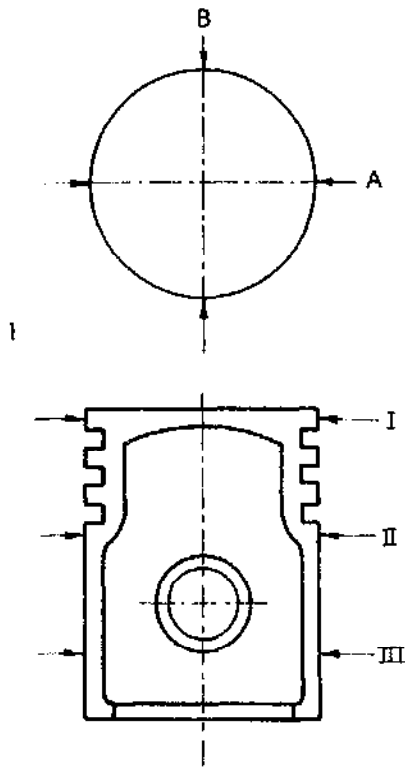
Manufacturer and engine no.:								
Nominal diameter of pistons:								
Piston no.:	1		2		3		4	
Position	A	B	A	B	A	B	A	B
I								
II								
III								

Clean the bearings thoroughly and tighten
them again with the torque wrench. Use the
micrometer to measure the bearings at the
positions 2-A1, 2-A2, 2-B1, 2-B2.
Enter the sizes in the table below.
Find the difference between the nominal size
and the actual size.

Nominal diameter of bearing:				
Bearing no.:	A1	A2	B1	B2
A				
B				
C				
D				
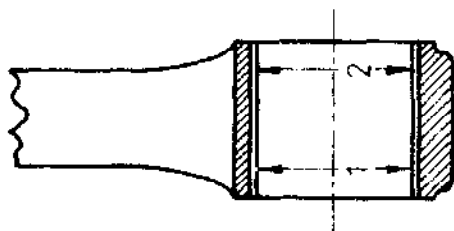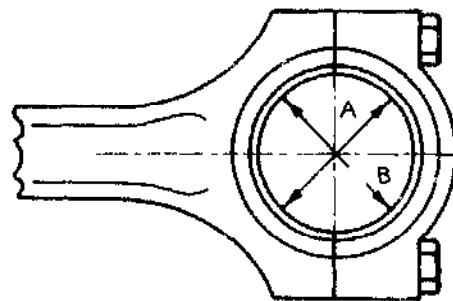
Measuring practice

Check the crank journals at the points 1-A1, 1-A2, 1-A3, 1-B1, 1-B2 and 1-B3.
Enter the results in the following tables.

1
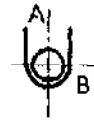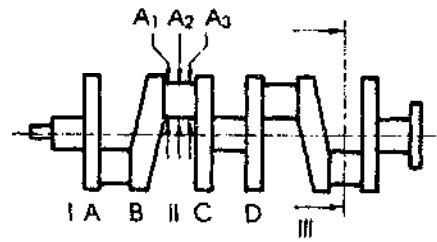
Manufacturer and engine no.:												
Crank journal	A			B			C			D		
Position	1	2	3	1	2	3	1	2	3	1	2	3
A												
B												

Main journal	I			II			III		
Position	1	2	3	1	2	3	1	2	3
A									
B									

2

Clean the bearings thoroughly and tighten them with the torque wrench.
Use the micrometer to measure the bearings at positions 2-A1, 2-A2, 2-B1 and 2-B2.
Enter the sizes in the table. Find the difference between the nominal size and the actual size.
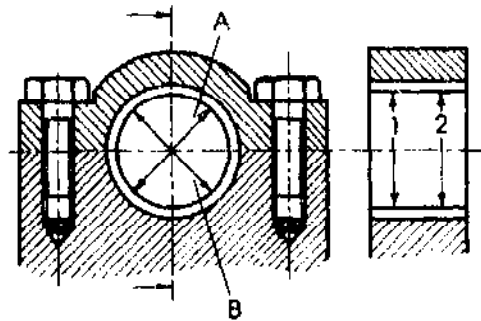
Manufacturer and engine no.:				
Nominal diameter of bearing:				
Bearing no.:	A1	A2	B1	B2
I				
II				
III				
IV				

The flywheel

A flywheel is heavy in weight and construction. It is usually made of steel or cast iron, see Fig. 1-A. The flywheel is mounted on the crankshaft at the rear of the engine and its purpose is to stabilize the engine. A flywheel is used to:
- store energy for dead moments between the power strokes,
- ensure a regular crankshaft rotation,
- transmit power via a clutch or pulley to any machinery attached,
- start the engine, if fitted with a ring gear.

Parts of the flywheel
Figure 2 shows an illustration of a flywheel, where you will see:
- Holes to balance the flywheel 2-A
- Possible bearing hole 2-B
- Holes for bolting the crankshaft to the flywheel 2-C
- Dowel hole 2-D
- Flywheel body 2-E
- Starter ring gear 2-F
- Locking plates 2-G
- Bolts 2-H

Starter ring gear
The starter ring gear may be integrated in the flywheel body or may be separated and shrunk into place on the flywheel rim.

If the teeth are damaged the ring must be replaced. To make it easier to remove the ring, it is best to drill an 8 mm hole (Fig. 3-A) as near as possible to the inside edge of the ring and then cut off the remaining part with a hacksaw (3-B). Immerse the new ring in boiling water. Do not heat it more, because the material may lose its hardness.
Place the flywheel on a solid base. With the ring in place, fix clamps and with light turns and taps drive it into place squarely against its flange. Make sure the ring is correctly fixed with the tapered edge of the teeth facing away from the flywheel.

Fixing the flywheel
When re-fitting the flywheel, make sure it is mounted in the same position as it was taken off. The dowel pin must return in exactly the same hole and the bolt and locking plates must be fixed securely.
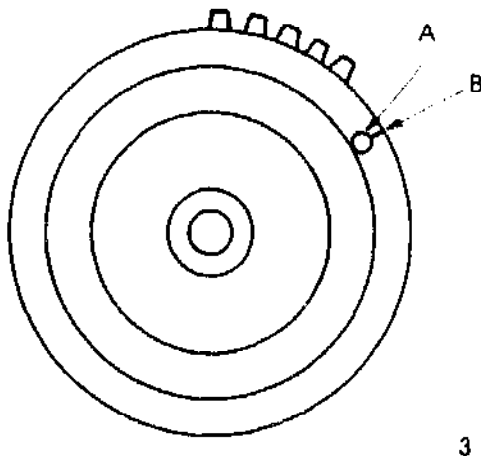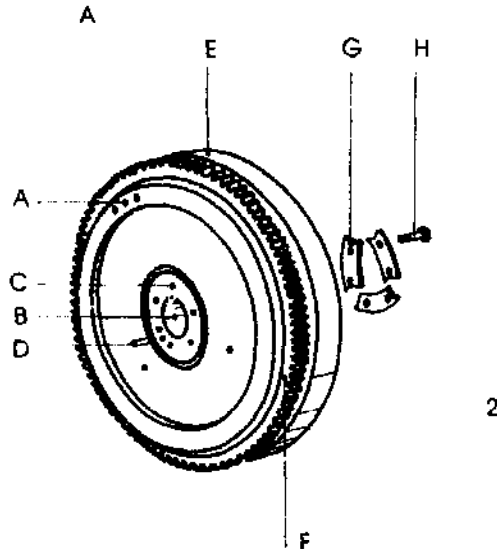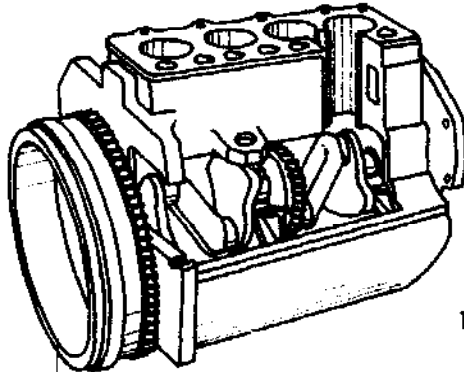
Timing transmission

Transmission from the crankshaft to the camshaft is via gearwheels, as shown in Fig. 1 The crankshaft gear wheel 1-A has straight teeth, square to the shaft. The camshaft gear wheel 1-B runs with a reduction of only half the speed and in the opposite direction. Wheels 1-C and 1-D have helical teeth, which reduces the noise when the engine is running at full speed.

The timing gear train
The timing gear train is made up of two or more gear wheels to drive the camshaft or other engine parts, such as the lubrication oil pump, fuel pump etc., see Fig. 2.

The power transmission can be realised by:
- a gearwheel transmission as shown in Fig. 3,
- a chain transmission as shown in Fig. 4,
- a toothed belt transmission, used mostly in car engines.

Timing the gear train
Many gears in the engine's gear train must be synchronized to ensure correct engine operation. The camshaft operating the valves must be synchronized with the pistons and the crankshaft.
To make it easier to set the gears correctly after overhauling, mark the gearwheels with either a short line or a punch dot. Figure 3 shows a short line made on the camshaft gearwheel (3-A) and a punched dot (3-B) on the crankshaft gearwheel. Figure 4-B shows a punch dot made on both wheels.
In some cases the two marks must match each other exactly, see Fig. 3. In other cases the punch dot on one of the teeth must match the other punch dot between the gearwheel teeth of the other wheel, see Fig. 4.
Other timing marks may be used. Check in the engine operating manual on how to synchronize the engine.

Gear train backlash
Teeth of the gearwheels may be slightly worn. The clearance between the teeth is called *backlash* and the allowance for backlash is given in the engine's specifications. Chain tension 4-A reduces the backlash.

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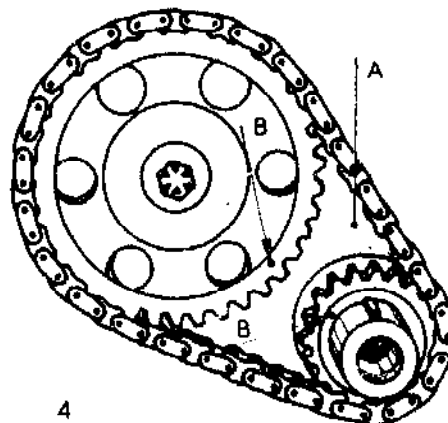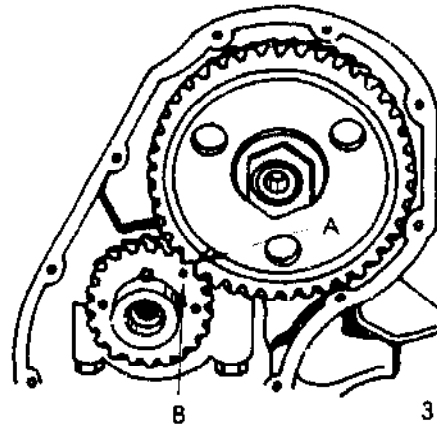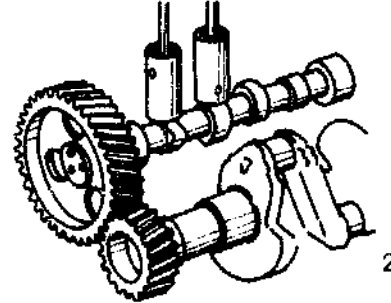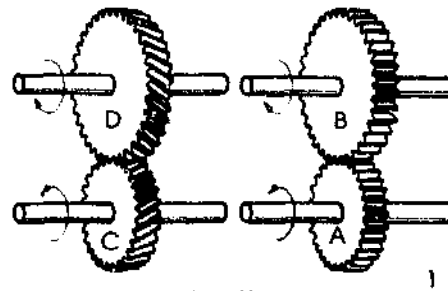
Fuel systems
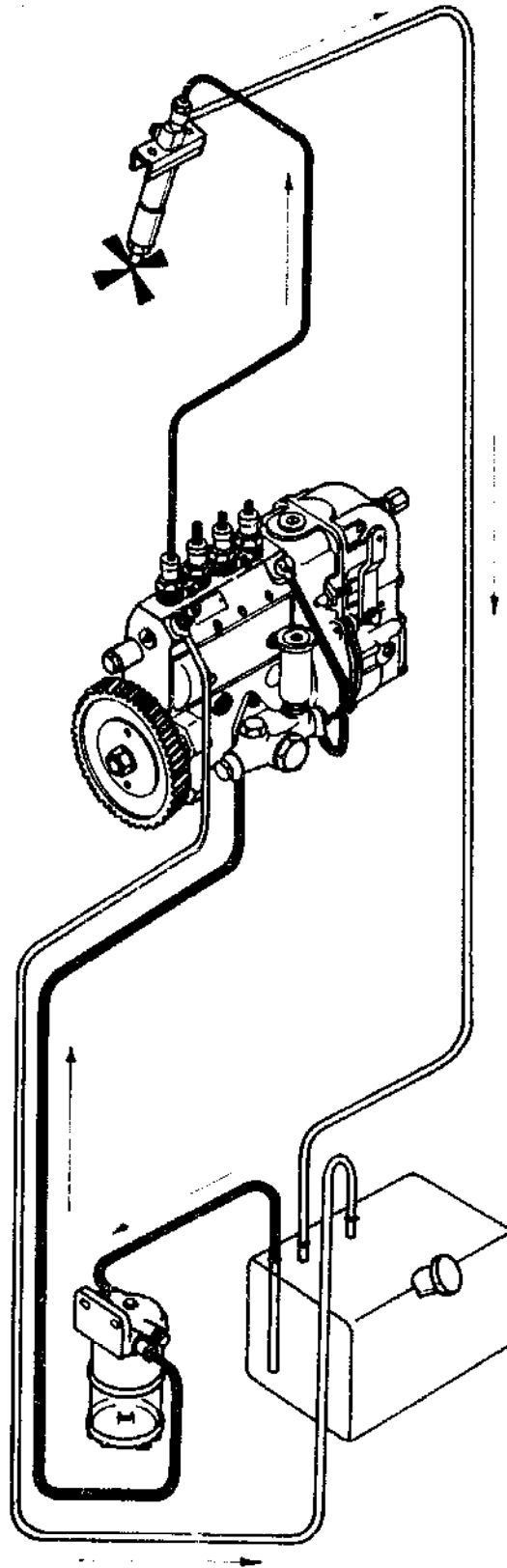
Fuel and fuel storage
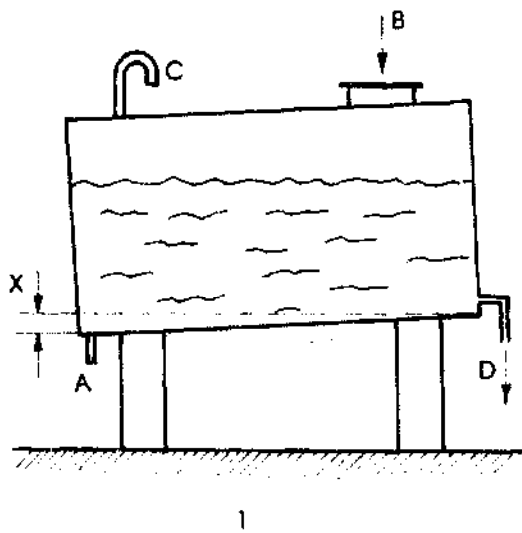
Fuel as received from the supplier is usually stored in a bulk tank, which should be situated outside the engine room. The main storage tank is normally made of steel and it is essential to make sure the steel is *not* galvanised internally, because all fuels are to a certain extent acid. Acid dissolves zinc plating, producing a gas that is highly explosive. It also leaves a sludge deposit in the bottom of the tank that could enter the fuel system, causing much damage.

The storage tank should be installed with a sloping bottom, see Fig. 1. The slope 1-X may be between 100 to 150 mm and there must be a drain plug 1-A at the lowest point, so that water and sludge can be drained at regular intervals. A filler opening with a filter must be positioned at the top of tank 1-B and a vent pipe in the shade shown in 1-C should allow air to enter. As mentioned before, the supply outlet 1-D should be some 120 mm above the drainpipe.

Fuel is taken from the main supply tank to the daily fuel tank. This tank must contain sufficient fuel for the required operating hours. Use a funnel with filter. If a drum is used as a fuel tank, leave the drum for at least 12 hours to ensure that dirt and water have been able to settle.
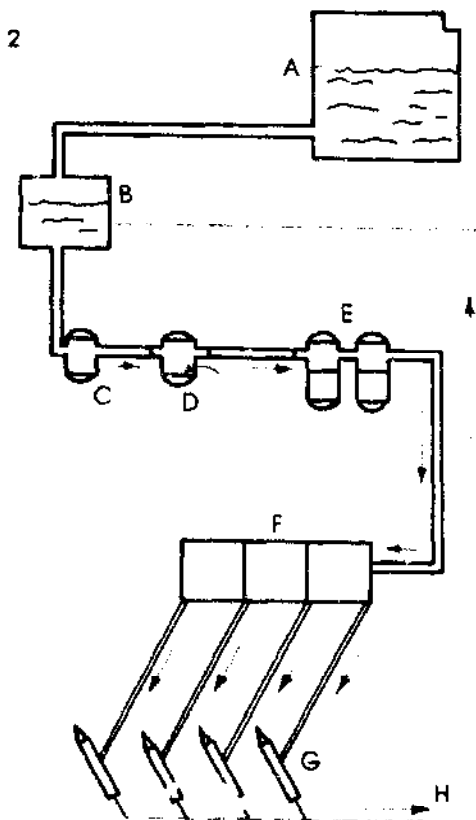
Diesel fuel systems

No matter what diesel fuel equipment is fitted, you must realize that the main function of the system is to supply an exact amount of atomized and pressurized fuel to a cylinder at a precise moment. As you have already learned, combustion occurs in a diesel engine when a charge of fuel is mixed with hot compressed air.

As shown in Fig. 2, the main parts of a diesel fuel system are:
- Fuel storage tank 2-A
- Daily fuel storage tank 2-B
- Sediment bowl 2-C
- Fuel transfer pump 2-D
- Fuel filter(s) 2-E
- Injection pump(s) 2-F
- Injection nozzle(s) 2-G
- Spalway 2-H

Sediment bowl

A sediment bowl is used to let any dirt settle down into a bowl made of glass. Through this glass you can see how much dirt has settled and when it must be taken out. As shown in Fig. 1, a fuel valve assembly 1-A is fixed to a glass bowl 1-B. A retainer 1-C and a knurled nut 1-D attach the sediment bowl to the valve assembly. A rubber gasket 1-E and a filter gauze 1-F are placed between the sediment bowl and the valve assembly. A fuel valve 1-G is located in the valve assembly.

When installing the bowl, fill it with fuel prior to tightening, making sure no air is trapped in the bowl.

Fuel feed pump

Fuel is pumped from the sediment bowl by a mechanically operated diaphragm fuel supply pump, see Fig. 2. This pump is mounted on the side of the cylinder block and is operated by the engine's camshaft 2-A and cam lob 2-B. The fuel feed pump has a hand priming lever 2-C for bleeding the fuel system after it has been drained or when air has entered the system. The main parts of the pump are given on the next page.

One of the most important parts of the fuel supply pump is the diaphragm 2-D. This diaphragm can be made of different materials and carries out the pumping action in the pump. After removing the diaphragm, check it thoroughly for wear and cracks. Also check the length of the pin 2-E and the strength of the spring 2-F.
When checking the pump, pay special attention to the operation of the valves 2-G and 2-H, they are of vital importance.

When assembling the diaphragm, tighten all screws lightly at first, then gradually tighten them further. If you tighten the screws too much on one side at first, it is difficult to achieve a leak-proof connection.

Handle valves with the greatest care because they are made of a very light material and distort easily.

Cleaning the fuel filter 2-I prior to assembly is essential.

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top view

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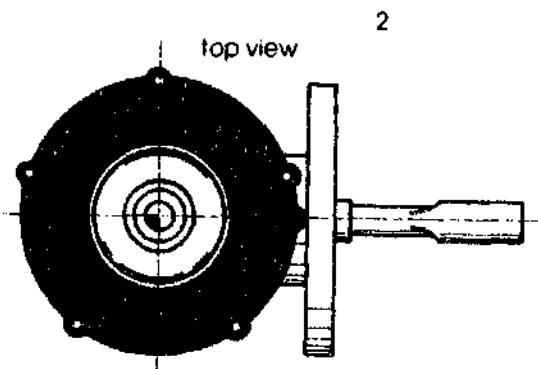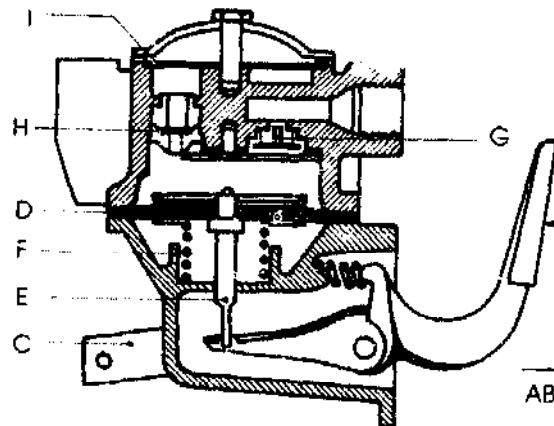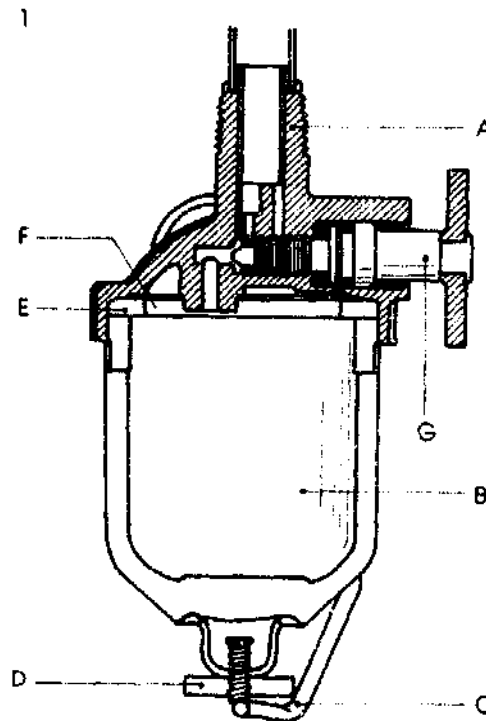
Typical fuel supply pump assembly
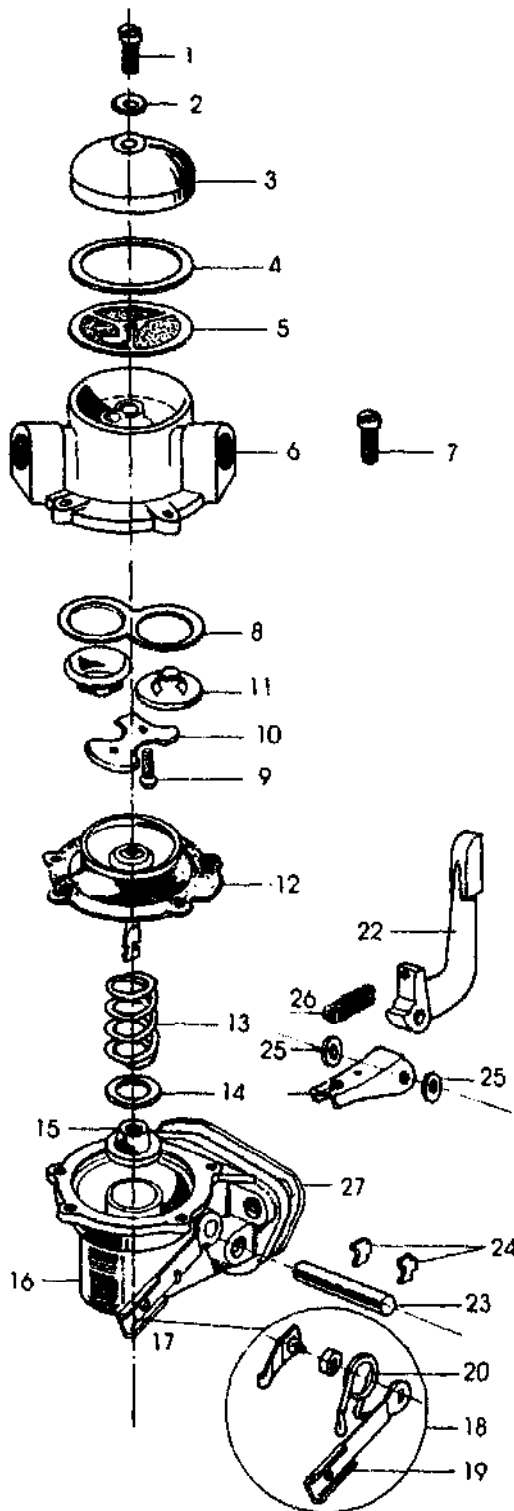
1   – Filter cover screw
2   – Screw gasket
3   – Cover
4   – Cover gasket
5   – Filter gauze
6   – Upper housing
7   – Upper housing screw
8   – Gasket valve plate
9   – Valve retainer screw
10 – Valve retainer
11 – Valve assembly
12 – Diaphragm assembly
13 – Diaphragm spring
14 – Diaphragm spindle seal
15 – Retainer seal
16 – Body
17 – Hand primer assembly
18 – Hand primer parts set
19 – Hand primer
20 – Primer lever spring
21 – Rocker arm lever
22 – Rocker arm
23 – Rocker arm pin
24 – Rocker arm pin retainer
25 – Plain washer
26 – Rocker arm return spring
27 – Joint

Assembling the pump

- Flush the valves in diesel fuel; this improves the seal between the valves and the seats.
- Fit the outlet valve spring in the centre on the four cast webs in the upper housing and place the outlet valve on the spring.
- Place the inlet valve on the valve seat in the upper housing and the valve spring on the centre of the inlet valve.
- Place the valve plate gasket and the valve retainer in position and secure them with three screws.
- Use a piece of wire to test whether the valves are moving freely.
- Place the filter screen, cork gasket, cover and fibre washer in position and fix them with the retaining screw.
- Assemble the connecting rod link, the two washers and the rocker arm spring inside the lower housing, then spring the retaining clips into their grooves.
- Insert the fabric washer first, then the metal washer and position the diaphragm spring in the lower housing.
- Fix the upper and lower housings together with screws.

Fuel filters

Fuel filters can be installed singly or in pairs to prevent harmful dirt and abrasive substances finding their way into the delicate parts of the injection pump and injectors.

Dual filters connected in cascade are shown in Fig 1. Fuel enters the first filter through inlet 1-A. After the large particles are filtered, the fuel moves to filter 1-B, from where it runs to the fuel pump through 1-C. Excess of fuel is returned via 1-D.

Typical fuel filter parts
- Filter bowl 2-A
- Drain plug 2-B
- Drain plug washer 2-C
- Dished plate 2-D
- Dished plate steel 2-E
- Centre bolt 2-F
- Circlip 2-G
- Spring 2-H
- Plain washer 2-I
- Washer, centre bolt sealing 2-J
- Plate 2-K
- Sealing ring 2-L
- Filter element 2-M
- Sealing ring 2-N
- Sealing head to bowl 2-O
- Filter head 2-P
- Bleeding plug 2-Q
- Bleeding plug washer 2-R

Assembling the fuel filter
- Replace filter head assembly
  Replace all fuel pipes, make all unions finger tight and check whether the connections are centred correctly. Tighten the connections correctly, do not over-tighten them.
- Refit the filter bowl with the new filter element and O-ring. Engage the head assembly with the centre stud and screw firmly. Again, do not over-tighten.
- Close the drain plug.
- Open the fuel supply valve at the tank and bleed the fuel system.
- Check all connections for leaks.

Note: some fuel filters can not be washed.
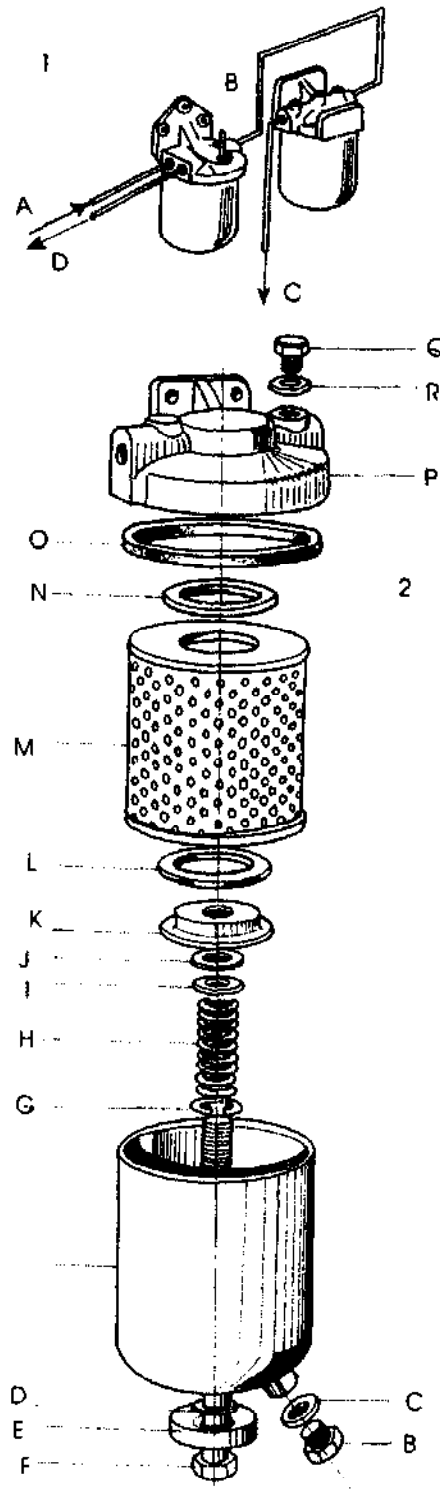
Injection and combustion

Spontaneous combustion through high compression in a diesel engine may be difficult to understand, since it is by no means an uncontrolled explosion. Though the charge of fuel may be injected into the cylinder in a hundredth of a second, the resultant combustion is a general process which occurs in stages. These stages can be controlled to ensure optimum performance.

First stage of combustion

The first stage of combustion is a *warming up* stage during which the fuel, as it is sprayed into the combustion chamber under high pressure, is raised from its normal temperature almost to that of the compressed air in the combustion chamber.

The compression temperature is higher than the ignition temperature of the fuel. So obviously, after a certain delay, the fuel must actually burn.

The delay between injection and the beginning of combustion is known as the *Ignition Delay Period* and sometimes takes as much as one third of the total injection time. It is important to reduce this delay period as much as possible, especially in diesel engines which run at high speed.

The Ignition Delay Period is influenced by several factors:

- the ignition quality of the fuel,
- the fineness of the fuel atomization,
- the difference between the air and fuel temperatures.

For these reasons it is important to use the best quality fuel available, because the fineness of the atomized fuel during injection determines the time taken for the fuel to mix with the air charge. The temperature difference between the injected fuel and the compressed air in the combustion chamber is directly related to the temperature of compression and hence to the compression ratio of the engine.

Second stage of combustion

After combustion has taken place, the temperature inside the cylinder rises very gradually since heat is still absorbed by most of the fuel particles created by atomization. The delay period is thus prolonged until the heat caused by the burning fuel is more than sufficient to offset the heat required to prepare for further fuel combustion. Following the delay period there is a stage of uncontrolled combustion as the flame spreads to the entire charge of fuel which has been injected throughout the delay period. This naturally causes a very high cylinder temperature and along with it a high cylinder pressure.

Third stage of combustion

The final stage of the combustion process is a direct burning phase when the fuel already in the combustion chamber continues to burn and the fuel still being injected ignites almost instantaneously on entry. The pressure attained during this period depends almost entirely on the rate of fuel injection. That is why combustion can be partly controlled by the design of the camshaft-fuel cam profile. When fuel injection is completed, combustion continues until the fuel charge has expanded, which is accompanied by expansion of the gases being produced as a direct result of combustion and displacement of the piston on its power stroke.

Combustion conditions

Two essential conditions for complete combustion are:

- The fuel must be injected into the cylinder in a highly atomized condition.
- An adequate supply of air must be available so the fuel can mix with it intimately.

To make sure the fuel is in a highly atomized condition, various fuel pumps and injectors are used which are explained in detail in the following lessons.

An adequate supply of clean fresh air is also explained at a later stage.

Fuel injection pumps

Each cylinder in a diesel engine has its own
injector and each injector has its own fuel
supply through a fuel pump.
Only a single-element fuel pump is installed in
a one-cylinder diesel engine. This fuel pump is
powered by the engine's camshaft. See Fig. 1.
Single-element pumps are sometimes installed
in a multi-cylinder diesel engine. These pumps
are powered by the camshaft. They are joined
together with a fuel control bar, so that all
pumps work correctly at the same time.

In-line pump

The in-line pump provides for each cylinder a
different fuel pump. Basically the in-line pump
is similar to the single-element pump. The
difference is that this pump is not powered by
the engine's camshaft, but by the timing gear
via a small camshaft located inside the in-line
pump housing, from where each injector is
supplied via a built-in pump. See Fig. 2.

Distributor fuel pump

Multi-cylinder engines may also have a
distributor type of fuel pump. See Fig. 3. This
pump is also connected to the timing gear 3-A
but the fuel supply to the different injectors is
different from that of the in-line pump, as we
will see at a later stage.
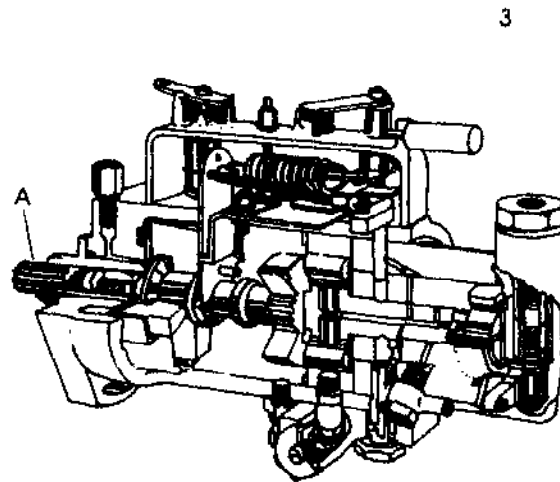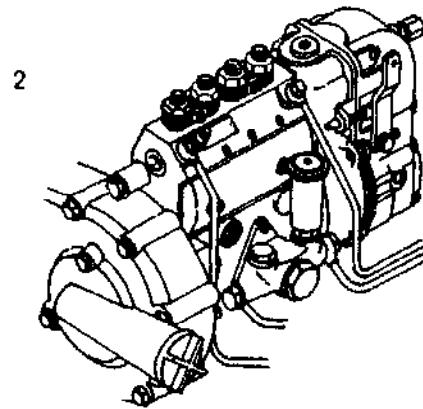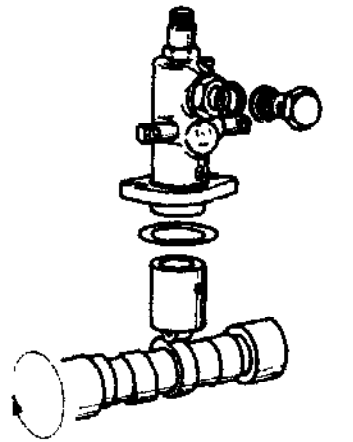
Single-element fuel injection pump

Figure 1 shows a cross-section of a single-element fuel injection pump. A pump element consists of a highly ground steel plunger operating in a barrel which is also precision ground. The fitting clearance for these components is so precise that the plunger and barrel are matched as pairs by the manufacturer. It is important to note that, if a new element must be fitted, both the barrel and the plunger must be replaced.

If for any reason the elements of several pumps are removed at the same time, care must be taken to ensure that plungers are re-assembled in their correct barrels. The delivery valve fitted at the upper end of each barrel is mitre-fitted and has a cylinder body with an angular groove cut into it. The lower part of the valve has four longitudinal grooves communicating with the annular groove. The upper part forms a small piston, which fits very accurately in the valve guide. In Fig. 1 you will see the following parts:

- Opening to fuel pipe 1-A
- Pipe connection 1-B
- Delivery valve spring 1-C
- Delivery valve 1-D
- Element locking screw 1-E
- Pump barrel 1-F
- Pump plunger 1-G
- Control sleeve 1-H
- Plunger part 1-I
- Plunger return spring 1-J
- Fuel control bar 1-K
- Fuel supply inlet 1-L
- Bleed screw 1-M

Pump action

The fuel injection pump plunger is moved with power from the camshaft. If you study Fig. 2, you will see how the plunger in the fuel injection pumps is moved via a roller in a tappet from the fuel cam on the camshaft:

- Single fuel pump element 2-A
- Shim 2-B
- Tappet 2-C
- Camshaft 2-D
- Pushrod tappet 2-E
- Fuel cam on camshaft 2-F
- Guide, fuel pump element 3-A
- Cap 3-B
- Tappet 3-C
- Roller pin 3-D
- Retaining pin 3-E
- Bushing 3-F
- Roller 3-G

- Washer 3-H
- Locating pin 3-I
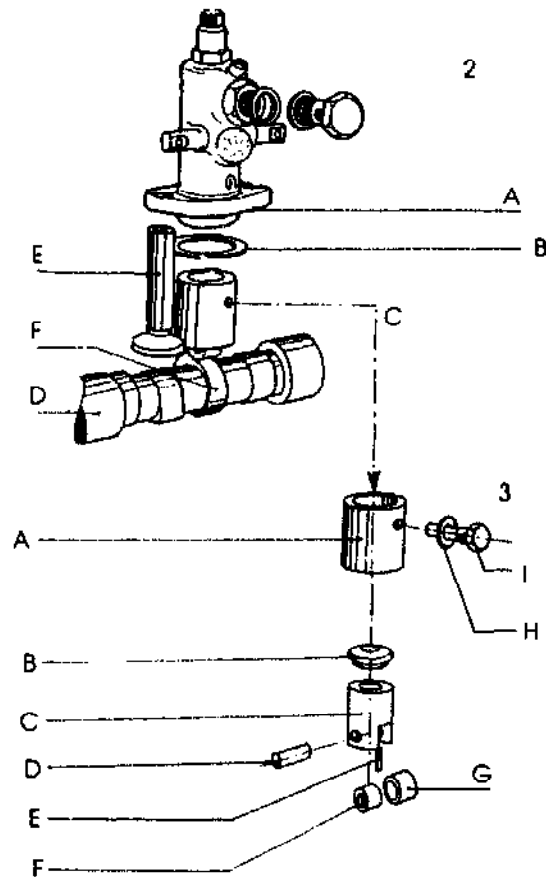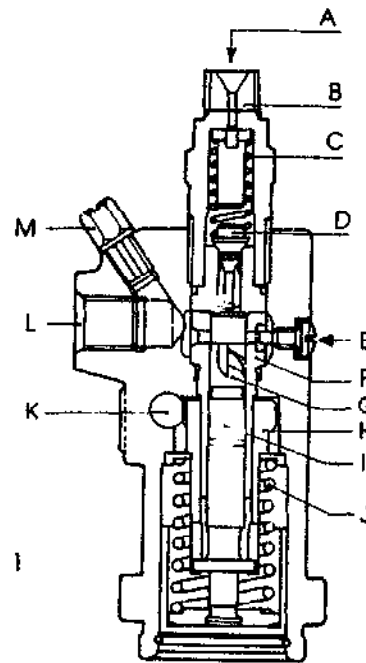
Operation of the fuel pump element

When the plunger is at its lowest point as shown in Fig. 1, the fuel is free to flow into the barrel through the fuel port. The injection pump is constantly flooded by a supply of fuel from a fuel booster pump or by gravity feed. The different parts are called:
- Delivery valve spring 1-A
- Delivery valve 1-B
- Fuel inlet port 1-C
- Vertical slot in plunger 1-D
- Helical land in plunger 1-E
- Fuel spill port 1-F

As the plunger rises to the position shown in Fig. 2, the top of the plunger closes the inlet and spill ports to the barrel. Further movement of the plunger causes the pressure to rise on the fuel trapped in the pump barrel. The only outlet for the fuel is through the delivery valve into the pipe leading to the injector.

Make sure the delivery pipe is flooded during operation, then the pressure rise is transmitted to the fuel injector valve, causing it to open and the nozzle to spray fuel into the cylinder combustion chamber.

Injection continues in this way until the pump plunger has risen to the position shown in Fig. 3, where the helical land on the bottom of the plunger has uncovered the ports in the pump barrel, thus allowing the pressurised fuel to flow back to the suction side of the pump via the vertical slot in the plunger. This causes an immediate pressure drop in the delivery line, so the delivery valve at the top of the pump closes under the action of its spring. The pressure drop also causes the injector nozzle valve to snap-shut on its seat.

To vary the fuel supply the control rod 4-A on the pump element can rotate the plunger 4-B as shown in Figs. 4, 5, 6 and 7. The plunger stroke is always constant, but that part of it which is actually effective can be varied by rotating the plunger in its barrel. This rotation alters the position of the bottom of the plunger helix in relation to the ports in the barrel, so the point of cut-off can be made to occur earlier or later in the stroke.

The effective stroke shown in Figs. 4 and 5 is long and corresponds to almost maximum load, where – as in Fig. 6 – the plunger has been rotated in such a way that the helix opens the barrel ports earlier in the stroke, corresponding to a very light load. In the stop position, Fig. 7, the vertical slot actually registers with the suction port over the entire

plunger stroke. The result is a total absence of pressure build-up and the fuel simply circulates from the delivery side to the suction side of the pump in a continious cycle.
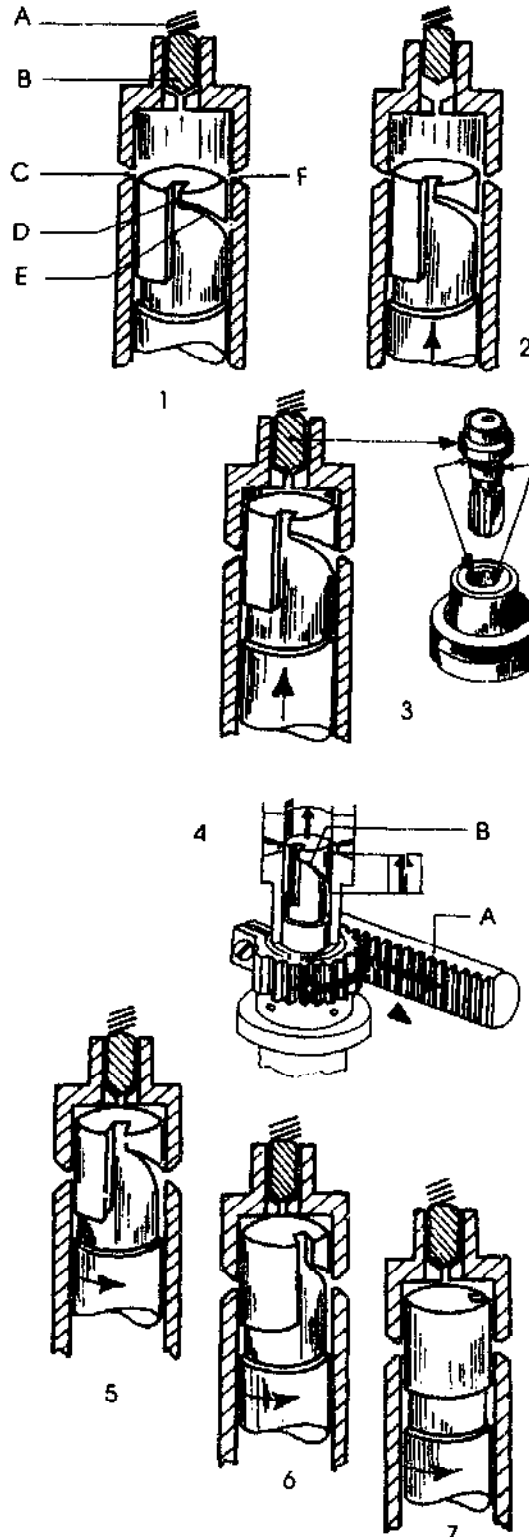
Typical fuel injection pump

In Fig. 1 you will see the parts of a typical fuel injection pump:
- Governor weights 1-A
- Drive hub screw 1-B
- Drive shaft 1-C
- Drive hub 1-D
- Back leak connection 1-E
- Shut-off lever 1-F
- Governor spring 1-G
- Idling stop 1-H
- Control lever 1-I
- Maximum speed stop 1-J
- Metering valve 1-K
- Fuel inlet 1-L
- Pressure regulating valve 1-M
- Hydraulic head 1-N
- Rotor 1-O
- Fuel filter 1-P
- Regulating piston 1-R
- Priming spring 1-S
- Transfer pump 1-T
- To injector 1-U
- Advance device 1-V
- Cam ring 1-W
- Plungers 1-X

Typical rotary (D.P.A.) Fuel pump

The distributor type of fuel pump, an example of which is shown in Fig. 1, is very compact. It is flange-mounted to the side of the crankcase. The pump is driven by a shaft through a gear attached to the camshaft and is self-lubricated by fuel.

Fuel entering the pump through the main inlet connection 1-L is pressurised by a sliding vane transfer pump 1-T carried on the rotor inside the hydraulic head 1-N. The pressure rise is controlled by a regulating valve assembly 1-M located in the pump end plates. The fuel then passes from the regulating valve to the pumping elements 1-X.

The internal cam ring, mounted in the pump housing, normally has as many lobes as there are engine cylinders, see 1-W, and operates the opposed pump plungers 1-X via cam rollers. The plungers are forced inwards simultaneously as the rollers contact the diametrically opposed cam lobes. This is the injection stroke. The plungers are returned by pressure of the in-flowing fuel. This is the charging stroke.

Figures 2 and 3 show that, as the rotor turns, the inlet port 2-A is cut off and the single distributor port in the rotor registers with an outlet port 3-A in the hydraulic head. At the same time the plungers 3-B are forced inwards

and fuel under injection pressure passes up the central bore of the rotor through the aligned ports to one of the injectors.

The rotor normally has as many inlet ports as the engine has cylinders and a simular number of outlet ports in the hydraulic head of the pump.

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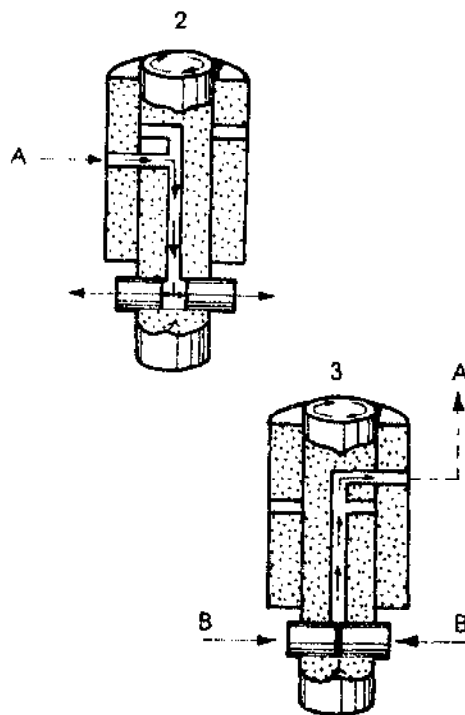
Governor systems

To understand the working principle of the governor, study carefully Figs. 1 and 2. Two pieces of rope with weights at the end are attached to the disk in Fig. 1. If you rotate the disk at a certain speed as in Fig. 2, the weight swings outwards due to centrifugal force. If you decrease the speed, the weight moves inwards again. Both weights must be exactly the same to avoid vibration during rotation.

The governor
The governor is a method of regulating the amount of fuel delivered by the fuel pump so that a specific engine speed can be maintained during operation.
In the multi-cylinder pump the governor is inside the housing of the fuel pump and is an integral part of the pump.
Single element pumps have a common governor, a typical lay-out of which is shown in Figs. 3, 4 and 5.

Figure 3 shows at 3-D the last part of the fuel pump rack. This rack is moved by a governor sleeve 3-C, which in turn is moved up and down by forces produced by the governor's weights 3-A and 3-B. When the speed increases, the weights of the governor move outwards and the fuel pump rack is then moved in such a way that it closes off the fuel supply and so reduces the speed.
When the speed decreases, the weights move inwards and the fuel pump rack is then moved in such a way that engine speed increases again. See Fig. 4.
The type of governor shown is called a variable speed governor. The speed is finally controlled with a lever or cable, operating between set limits.

Figure 5 shows a constant speed governor. The special spring 5-A allows the governor weight to return to a position as required. You must understand that not just any spring may be used – this spring is made precisely for that particular governor and that particular speed. Always check the manufacturer's technical data when working on the governor.
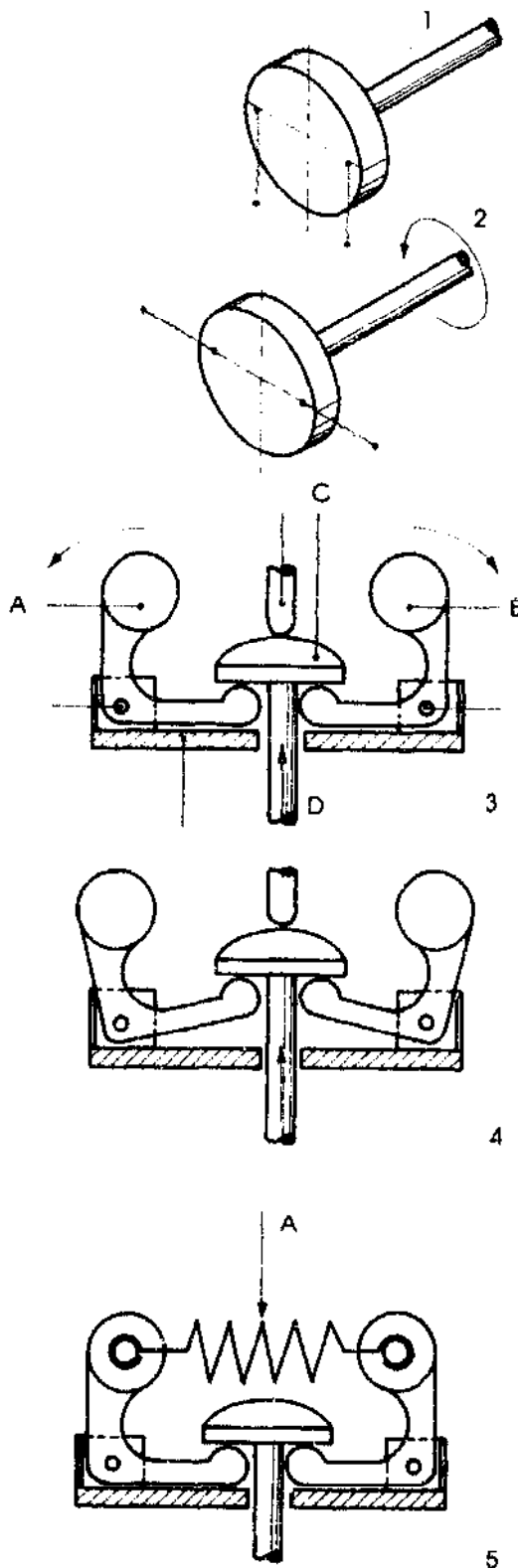
Fuel and governor setting
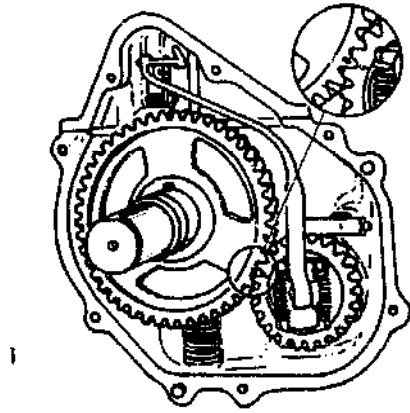
Since the fuel pump pumps with the action of the camshaft, make sure that the mark on the pin coincides with the gearwheel mark, see Fig. 1.

Typical governor setting for a one-cylinder diesel engine

Figure 2 shows a typical fuel pump setting assembly. Study this lay-out carefully and name all the parts. To set the fuel pump and governor for a single fuel injection pump you have to set the control on the *run* position 2-R. Then adjust the linkage 2-A in such a way that the calibration mark 2-B coincides with the side of the fuel pump, see Fig. 2.

Adjust the linkage with the nut 2-C in such a way that the calibration mark 2-B coincides with the side of the fuel pump within a tolerance given by the manufacturer. However, the fuel pump rack must move freely after this adjustment.
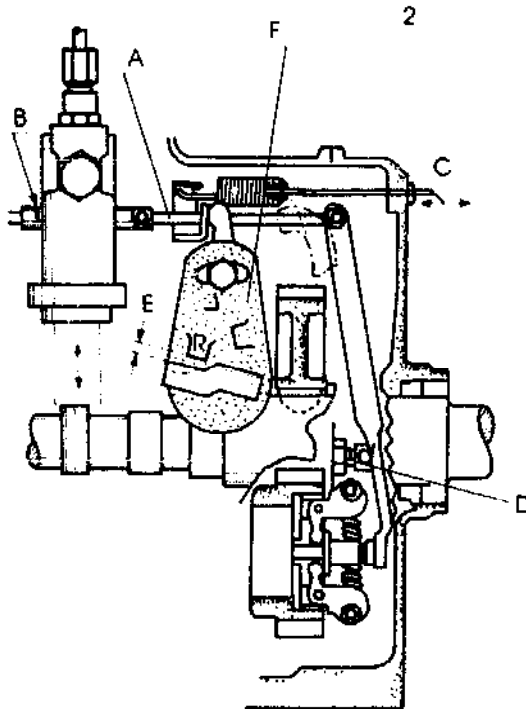
Adjust the governor lever fulcrum 2-D so that, when the calibration mark 2-B is against the outside of the fuel pump, the distance between the inside of the governor sleeve and the outside of the governor weight carrier complies with the manufacturer's technical data.

Set the clearance 2-E to the correct figure for the application and speed of the engine; check these in the technical data. Maintain the correct clearance and rotate the locating plate 2-F until the calibration mark 2-B coincides with the side of the fuel pump. The full width of the calibration mark must be visible. When the marks coincide and the clearance is correct, secure the locating plate with the screw. After making adjustments, check that the fuel pump rack and the linkage move freely.

Firing point

For an engine to operate efficiently the fuel must be injected into the cylinder combustion chamber at the correct time. This is known as the *firing point* and it occurs at a very precise time marked in degrees before TDC on the flywheel, see Fig. 1.
The firing point for each cylinder is usually marked as FP on the flywheel. The letters FP occur when this mark coincides with a fixed mark or pointer attached to the engine.

Timing the fuel injection pump

There are several methods of checking fuel pump timing, such as Spill Timing, Air Timing and Pump Drive Shaft Timing. Each manufacturer has developed his own fuel system and it is therefore essential to study the manufacturer's instructions and follow them precisely.

The timing is said to be *advanced* if the fuel is injected too early, see Fig. 2. The timing is said to be *retarded* if injection takes place after the flywheel has passed the fixed mark.
On single element pumps the firing point position can be adjusted by changing the vertical distance between the fuel pump and the camshaft, either by adding or removing thin metal shims under the pump body or by moving the pump vertically by a fixed adjuster. See Fig. 3-A.

In multi-cylinder pumps the fuel pump drive shaft is rotated after spill timing in line pumps. For rotary pumps a specially designed tool is used to show the angular degrees.
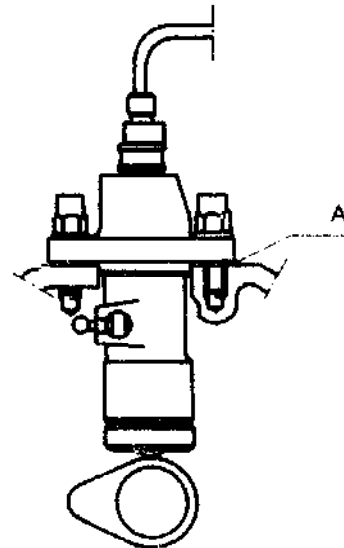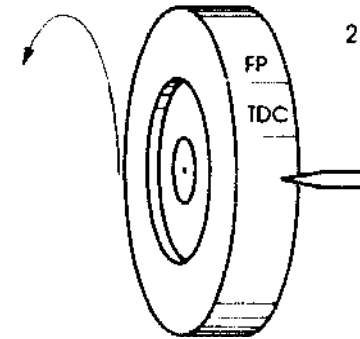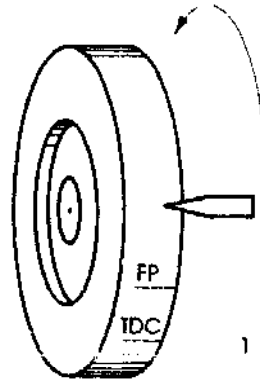
Fuel injection

The way the fuel is injected into the air charge is very important, as you have seen before. There are two main methods of injection:
- Direct injection
- Indirect injection
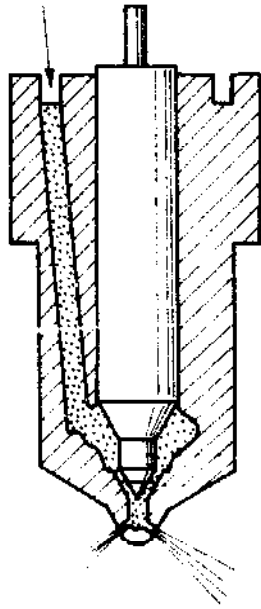
Direct injection
When the piston rises during its compression stroke, a swirling motion of air is produced at the top of the stroke. This swirling motion takes the form of a ring of air revolving at high speed, like a ring of smoke blown from a pipe. It is into this rotating ring of air that the fuel charge is sprayed from many fine holes at the tip of the injector nozzle, see Fig. 1.

Direct injection by means of multi-hole injectors is widely used because, with this method of injection, the fuel is highly atomized before it mixes with the swirling air. But one disadvantage of direct injection is that, to produce a very fine spray, the fuel is injected through several very fine holes which may become blocked by carbon.

Indirect injection
Contrary to multi-hole injectors, the indirect injection nozzles have large holes through which the fuel is sprayed into the combustion chamber. Indirect injection nozzles are usually of the single or twin hole type with larger holes. So atomizing is not as satisfactory unless additional means are provided to ensure good mixing of the fuel and air, see Fig. 2.
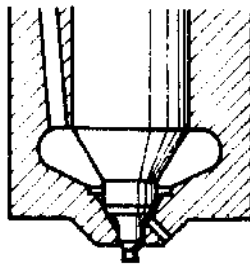
One way of improving this situation is to force the compression stroke air through a small orifice into a separate cell or combustion space, improving the swirling motion of the air.

Indirect combustion ensures good combustion over a wide range of load and speed conditions. In general the engine will be able to operate using poorer quality fuels with less risk of carbon formation.

Combustion chamber

In the previous lessons you have learned that the injection nozzle and its atomizing helps to mix the fuel and the air. The piston crown and the design of the cylinder head play an important role in improving the air and fuel mixture.

Turbulence chamber

Figure 1 shows a so-called open combustion chamber. In this chamber all fuel and air are confined to one area due to the concave shape of the piston crown, see Fig. 2. The piston comes close to the cylinder head and makes it easier for the fuel to be sprayed evenly into the chamber. The concave in the piston crown also sets up a turbulence of the compressed air. This speeds up the air and makes it easier to mix with the fuel.
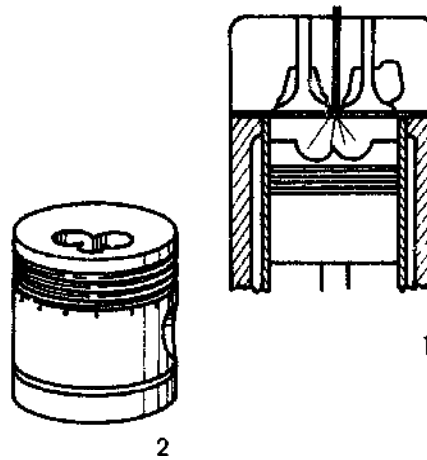
A turbulence chamber in the cylinder head is shown in Fig. 3. As you see, the fuel is injected into a small chamber in the cylinder head and shaped in such a way that it produces a highly turbulent condition.
As the piston starts the compression stroke, the air is forced into the chamber and sets up the rotary motion. Near the top of the piston stroke the fuel is injected into the swirling air, which results in a good mixture of air and fuel.
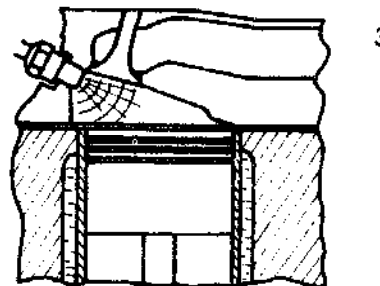
Pre-combustion chamber

This chamber is shown in Fig. 4-A and is similar to the turbulence chamber except that only part of the air charge is forced into it. If the fuel starts to burn with an insufficient amount of air, it ignites, forcing the burning fuel into the cylinder 4-B, where the fuel readily mixes with the remaining air during combustion.

Glow plug

Diesel engines are sometimes equipped with a glow plug to speed up the starting procedure by pre-heating the chamber. See Fig. 4-C.
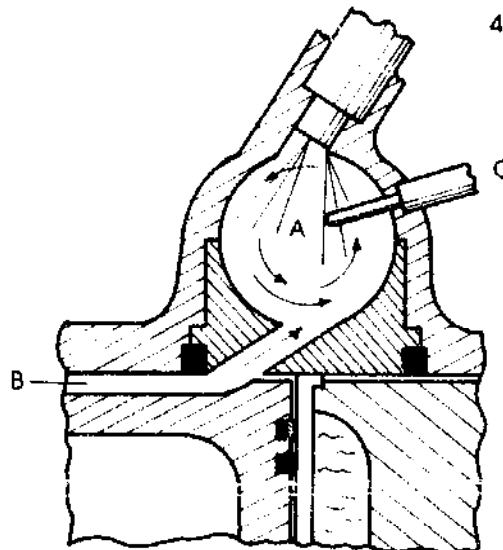
Injectors
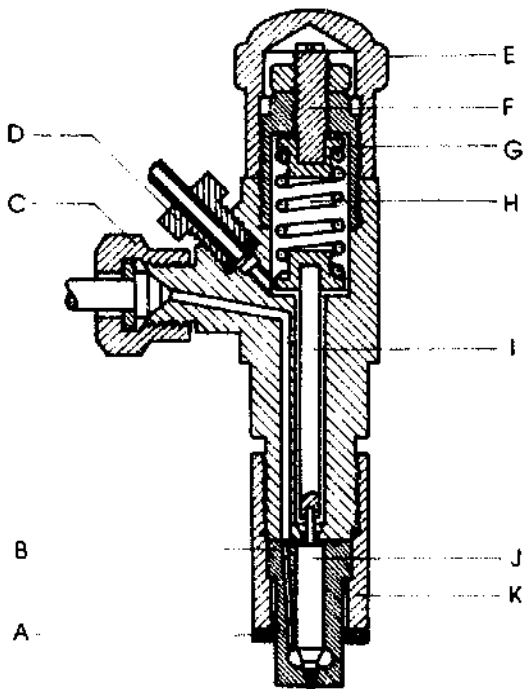
Injectors spray the fuel into the swirl chamber the moment the air in the swirl chamber has been compressed. Injectors consist of two principal parts:
- the *nozzle* with its *valve*,
- the *nozzle holder*.

A typical injector holder with nozzle is shown in Fig. 1, where you will see:
- Copper washer 1-A
- Nozzle body 1-B
- Fuel inlet connection 1-C
- Leak-off connection 1-D
- Protective cap 1-E
- Compression screw 1-F
- Spring cap nut 1-G
- Valve spring 1-H
- Valve spindle 1-I
- Nozzle valve 1-J
- Nozzle cap nut 1-K

When fixing the injector, you must make sure the nozzle cap nut is seated correctly and the copper washer 1-A is of good quality, because there must be no pressure leaks.

Injection nozzles

Two typical *inward-openening* nozzles are shown in Figs. 2 and 3. Both are of the *pintle type*.

The multiple hole type nozzle in Fig. 2 uses a tapered valve 2-A which seats in a single orifice 2-B in the valve body. When fuel is pressed through the fuel inlet 2-C, it pushes the valve upwards and allows fuel to pass towards the spray tip 2-D and be sprayed through the nozzle holes 2-E.

As soon as the fuel pressure drops, the valve resistance declines and the valve spring pushes the valve spindle and the nozzle valve down, thus closing off the fuel supply.
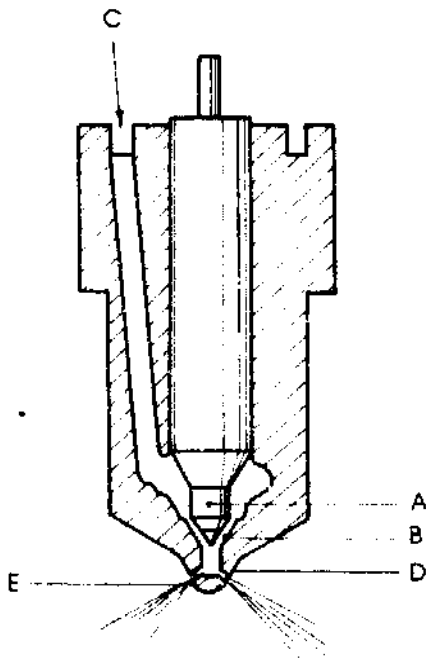
A closed pintle type nozzle is shown in Fig. 3. This type of nozzle has auxiliary spray holes 3-A to assist easy starting under cold conditions.
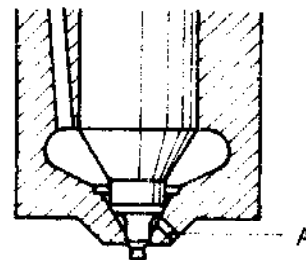
Faulty injectors

If you see excessive black or grey smoke coming from the exhaust of the engine, it is likely that one or more injectors are faulty. If the exhaust gives distinct puffs, probably one of the injectors must be serviced. White smoke shows that one or more cylinders have cut out. Uneven running or stalling under load are also symptoms of faulty injectors.

A good method of locating a faulty injector is to start the engine and let it warm up and then note the r.p.m. (revolutions per minute). Loosen one of the fuel lines. As the nut is loosened, the full pressure drops and injection stops at that particular injector. While doing this, keep your face and hands out of the way, because the fuel is under extreme pressure and may penetrate your skin. If the injector is good and working correctly, the engine slows down more than before and the sound of the engine changes. You understand that when the injector fuel inlet is loosened on a faulty injector, there will be no change in either sound or r.p.m.
Continue this test until all injectors have been checked. When you have identified the faulty injector remove it, service it or replace it with a new injector or nozzle.

Injector parts
- Valve cone 1-A
- Valve stem 1-B
- Valve seat 1-C
- Pintle 1-D
- Fuel inlet 1-F
- Pressure face 1-E
- Nozzle shoulder 1-G
- Nozzle trunk 1-H
- Fuel gallery 1-I
- Valve seating 1-J
- Pintle orifice 1-K
- Nozzle retaining shoulder 1-L
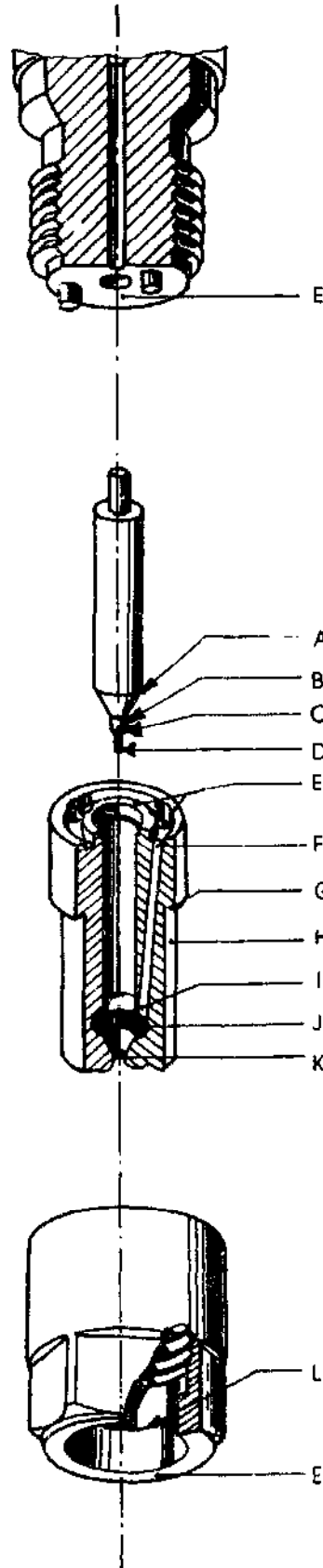
Servicing the nozzle
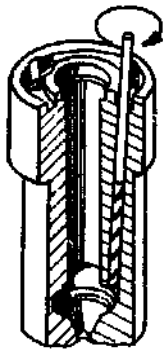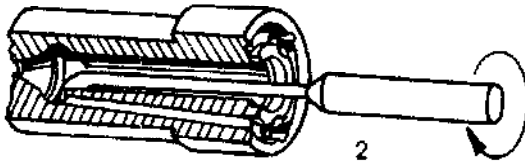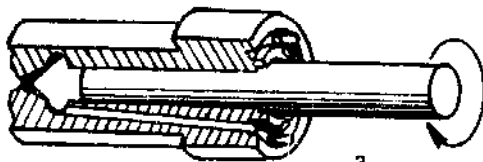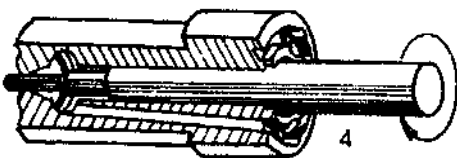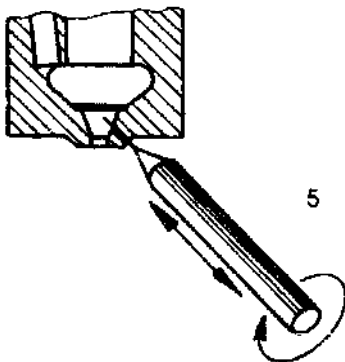
- If the nozzle is faulty, take it out of the nozzle body, examine it for carbon and check whether it lifts out freely.
- Examine the polished surfaces for scratches or dull patches.
- Examine the nozzle valve and the nozzle body for damage and blue parts, which are results from over-heating.
- Immerse the nozzle body and nozzle valve in clean diesel fuel to soak and soften the carbon.
- Brush all carbon from the outside of the nozzle body with a brass wire brush. *Never use a steel brush!*
- Clean the small fuel feed bore with a corresponding fine drill, see Fig. 1.
- Insert a special groove scraper until the nose latches into the fuel gallery. Press hard against the side of the cavity and rotate the groove scraper to clear all carbon deposits from this area, see Fig. 2.
- Clean all carbon from the valve seating with the correct valve seat scraper. Press the tool onto the seating and rotate it as shown in Fig. 3.
- Select the right pintle orifice cleaning tool and insert it into the nozzle body until it passes through the pintle orifice. Then rotate the tool to clear off all carbon as shown in Fig. 4.
- If there is an auxiliary spray hole, clean it with the relevant cleaning wire. It must be fixed into the tool chuck so that it protrudes about 2 to 3 mm, thus offering maximum resistance to bending. Extreme care must be taken to prevent the wire from breaking inside the hole, because such particles are almost impossible to remove.
- Put the wire into the hole and push and rotate it gently until the hole is clean, see Fig. 5.
- Flush the nozzle body and the nozzle valve with clean diesel fuel. All remaining carbon particles can be removed carefully with a piece of hardwood soaked in diesel fuel. Then flush again.
- After cleaning, do not dry the nozzle valve, just put it in the nozzle body. Check its gliding capacity by pulling it half out of the body; it should sink slowly by its own weight.
- Pressure faces must be very clean.

Nozzle test bench

A nozzle test bench consists of the following components, see Fig. 1:
- Fuel container/filtering unit 1-A
- Check valve 1-B
- Air vent screw 1-C
- Injection pump 1-D
- Hand pump lever 1-E
- Pressure gauge 1-F
- Pressure feed pipe 1-G
- Pressure adjusting screw 1-H
- Locking nut (adjusting screw) 1-I
- Protective shield (container) 1-J

Testing the injectors and nozzles
An injector and a nozzle can be tested on a nozzle test bench as shown in Fig. 1.
- Fill the tank with clean diesel fuel.
- Bleed the system for a few seconds, using the air vent screw. Operate the pump several times until the fuel flows from the pressure supply pipe.
- Then connect the injector to the fuel feed pipe.
- Close the check valve so the pressure gauge is out of circuit. Operate the hand lever several times to expel all air from the test bench and injector.
- Open the check valve to bring the pressure gauge into circuit.
- Set the opening pressure of the nozzle on the required *bar*; see the handbook.
- Wipe the face of the nozzle dry and pump up to the required bar. Hold this pressure for ten seconds. First wipe your finger across the face of the nozzle and inspect for wetness.
- With the check valve still open, pump again to just below the opening pressure, release the hand lever and let it fall on its own weight.
- Time the drop of the gauge needle from ... bar to ... bar; see handbook.

Note: Carry out this test only when the valve seat is in good condition and if there is no leakage at the valve tip. During this test, make sure the protective shield is in the correct position.

Injector/nozzle test on engine
If no bench tester is available, a simple injector/nozzle test can be carried out on the engine itself.
- Take out the injectors and mark them correctly.
- Re-fit them upside down on the fuel pipes and tighten them correctly.

- Crank the engine until all air is expelled from the fuel system.
- Crank the engine again and note the atomizing of the fuel spray. Also compare the atomizing of all injectors at the same time; they must be the same.

Warning
It cannot be said too often that great care must be taken during these tests. On no account should your hands come into contact with the fuel spray. It has a very great penetration force and the spray easily passes through the skin.
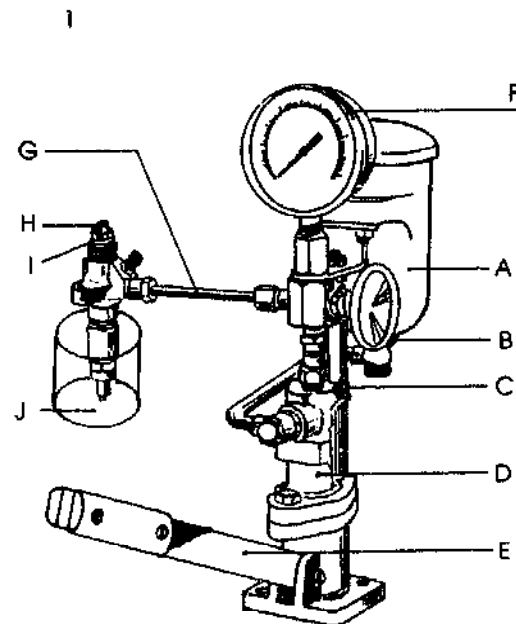
Injector testing
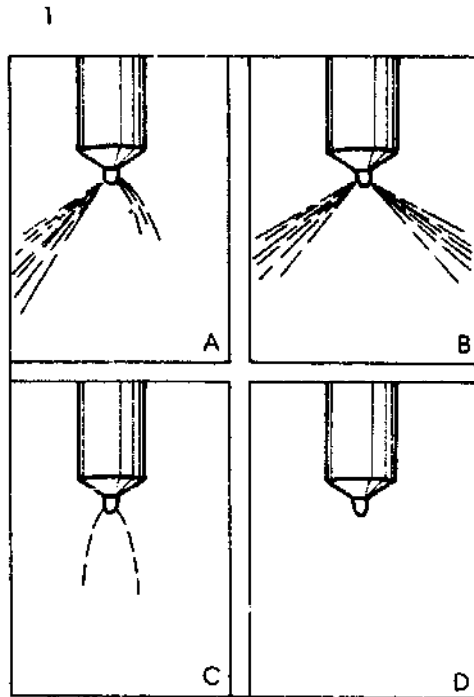
The primary function of a fuel injector nozzle is to atomize the liquid fuel so that it can be burned rapidly and efficiently in the cylinder of a diesel engine.

Atomizing the fuel is a purely mechanical process in which the fuel is forced through small orifices under high pressure and the multi-hole nozzle shown in Fig. 1 is used to help spread the fuel charge over the entire combustion chamber area.

Under high pressure the nozzle should spray from all the holes evenly, as shown in Fig. 1-B. If one of the holes is blocked, the spray is not even, as shown in Fig. 1-A.

For satisfactory operation of the injector nozzle, it is essential that the nozzle valve *snap-shuts* in the shortest possible time to avoid dribble, shown in Fig. 1-C, which would rapidly cause excess carbon formation at the nozzle with blocking of the jets. For the valve to snap-shut, shown in Fig. 1-D, the pressure in the fuel line must have some positive means of being reduced to 30 bar almost instantaneously, when the strong spring on the delivery valve itself will ensure that the valve closes as desired.
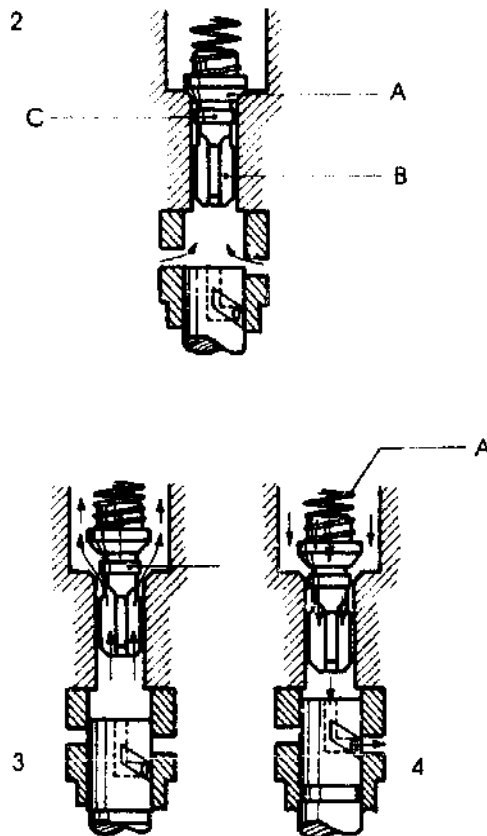
This pressure reduction is achieved by the construction of the mitre-faced delivery valve, see Fig. 2-A, fitted at the top of the pump body and by the flutes 2-B at the lower end of the valve. Just below the valve face there is a small plunger 2-C which has a very accurate fit in the bore of the valve guide. While the pump is actually delivering fuel to the cylinder, this plunger is raised clear of the valve body and fuel flows round it into the delivery pipeline, see Fig. 3.

On a slight pressure drop in the pump, the delivery valve starts to return to its seat through the action of valve spring 4-A in Fig. 4, resulting immediately in location of the plunger in the bore of the valve guides. This forms a hydraulic seal so, at the moment under consideration, the pipe from the delivery valve to the injector nozzle can be regarded as being a separate system in which the fuel is still under considerable hydraulic pressure. As the delivery valve moves fractionally towards its seat, the plunger displacement causes a small increase in volume of the fuel still under pressure, and the pressure is thus reduced immediately to zero, enabling the nozzle valve to snap-shut without sputtering or dribbling.

Fuel pipe fittings

Fuel filters, injectors, pumps and other units are connected by means of couplings or fittings. There are several types, such as:
- S.A.E. 45° flared
- Inverted flared
- Compression couplings
- Compression sleeve couplings

Each of these types consists of a male fitting, a seal and a female nut. To prevent damage to the seal when tightening or loosening a coupling, hold the fitting with one spanner while turning the nut with another. One of the most important rules for tightening tube fittings is:

Only tighten by hand lightly at first. Do not over-tighten.

If a fitting starts to break and seems to be loose, re-tighten it only up to the point where the leak stops.

S.A.E. 45° flared fitting
Figure 1 shows this type of coupling. The seal is achieved by compressing the flared tube between the tapered faces of the male and female connectors. One advantage of this connector is the locking action of the sleeve and the fact that the flared tube is not rotated during assembly.

Inverted flared fitting
This coupling is shown in Fig. 2. The seal produced by compressing the flared tube is the same way as the S.A.E. 45° fittings. In our opinion this connector gives the best seal.

Compression fitting
This coupling shown in Fig. 3 requires no flared tubing or sleeves. The seal results from the tubing being crimped by the male fitting when forced against the female nut. A disadvantage is that during tightening it tends to bind on the tubing, which may cause unequal sealing. The friction can also twist the tubing slightly.

Compression sleeve fitting
This type of fitting, see Fig. 4, uses a sleeve instead of flared tubing. The sleeve is placed on the tubing between the nut and the fitting. It crimps the end of the tube to seal it.
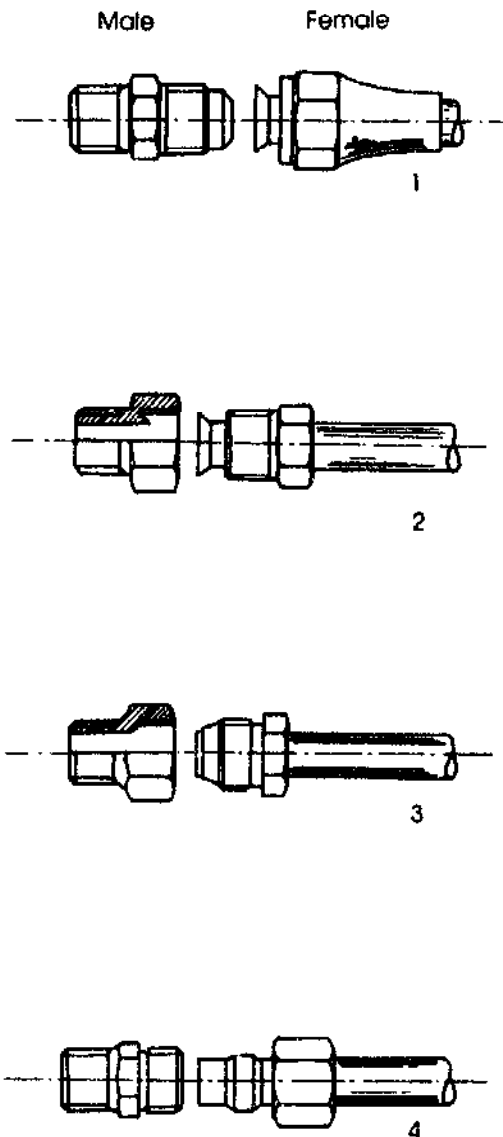
Bleeding air from the fuel system

When the diesel fuel system has run dry or has been dismantled, a lot of air has entered the system. If this air is left in the system it may form an air lock which will prevent the fuel from reaching or passing through the injection pump and then to the injectors. The result may be that the engine does not start, misfires or loses power.

Bleeding the air from the diesel fuel system must be carried out in the correct sequence, otherwise the air lock remains inside the system. A correct method of bleeding the fuel system is explained below:
- Fill the fuel tank with clean fuel.
- Open the shut-off valve at the tank.
- Loosen the bleeding plug on the fuel filters and pump with the primer lever of the fuel pump until a continuous flow of fuel, free and air bubbles, flows from the opening in the bleed plugs.
- Tighten the plug. If there is more than one filter, bleed the next one. When bleeding is completed, make sure you leave the primer lever on the fuel pump at its lowest point of stroke.
- Loosen the injection line nuts one by one and crank the engine until fuel flows without foam around the couplings. Foam is mixed air and fuel.
- Tighten the pipe connections carefully and check for leaks.
- Make sure you loosen the connections by only one turn to avoid excessive spray, which may be harmful.

Engine trouble-shooting

Engine trouble-shooting

Every diesel engine is accompanied by a handbook in which you will find a trouble-shooting guide to the engine and its fuel injection system. If the engine fails to start, is difficult to start or misfires, the main problems may be:
- No fuel in the fuel tank. Clogged fuel supply or water in the fuel.
- Fuel transfer pump not operating.
- Air lock in injection pump.
- Governor linkage to pump is loose or broken.
- Fuel pump(s) or distribution pump not working correctly.
- Delivery valves are not seated correctly which may be due to broken springs or dirt.
- Pump(s) out of time.
- Nozzles not operating because the valves are stuck or the orifices plugged.

Wrong idling speed
If the engine does not idle smoothly it may be due to:
- Dirty fuel filters.
- Governor idling speed adjustment is not set correctly or the trottle linkage is worn.
- Pump rack or control may be stuck or is sticky.
- Fuel pump plunger sticks.
- Nozzle opening pressure may be wrong.
- Stuck nozzle valves.
- Fuel pump(s) are not correct -- loose control sleeves, pump timing incorrect or leaky delivery valves.

Engine smokes and knocks
- Fuel pump out of time.
- Dirty or wrong nozzles.
- Valve stuck open.
- Opening pressure too low.
- Fuel stop setting incorrect.
- Excessive fuel delivery.
- Causes such as: broken valves, scored pistons or dirty air cleaner.

Engine lacks power
Sometimes the engine lacks power, which may be due to:
- Retarded pump timing.
- Worn pump plungers.
- Worn distributor.
- Faulty nozzles.
- Governor out of adjustment.
- Dirty or plugged air or fuel filters.

Manufacturer's handbook
It must be understood that it is essential to read the manufacturer's instructions on the particular engine you service. All adjustments must be made according to the technical data provided.

Fault-finding guide for injection system

Symptom	Possible cause	Remedy
Engine is difficult to start	Incorrect fuel pump timing Defective fuel injection pump Defective or incorrect injectors	Check fuel pump timing Renew fuel injection pump Check the fuel pump
Engine will not start	Broken fuel injection pump drive	Check the fuel pump
Engine misfires	Incorrect fuel pump timing Defective or incorrect type of fuel injection pump Defective or incorrect injectors	Check the fuel pump timing Check the fuel injection pump Check the injectors
Lack of power	Incorrect fuel pump timing Defective or incorrect type of fuel injection pump Defective or incorrect injectors	Check the fuel pump timing Check the fuel injection pump Check the injectors
Excessive fuel pump consumption	Incorrect fuel pump timing Defective or incorrect type of fuel injection pump Defective or in correct injectors	Check the fuel pump timing Check the fuel injection pump Check the injectors
Black exhaust	Incorrect fuel pump timing Defective or incorrect injectors	Check the fuel pump Check the injectors
Blue exhaust	Oil consumption by the fuel injection pump	Renew leaking gaskets
Engine knocking	Incorrect fuel pump timing Defective or incorrect injectors	Check the fuel pump timing Check the injectors
Erratic running	Incorrect fuel pump timing Defective injectors	Check the fuel pump timing Service the injectors
Excessive oil consumption	Consumption by the fuel injectionpump	Check the fuel injection pump
Engine overheating	Defective or incorrect injectors	Check the injectors
Engine starts and stops	Sticking injectors	Service the injectors

Cooling systems

Cooling systems
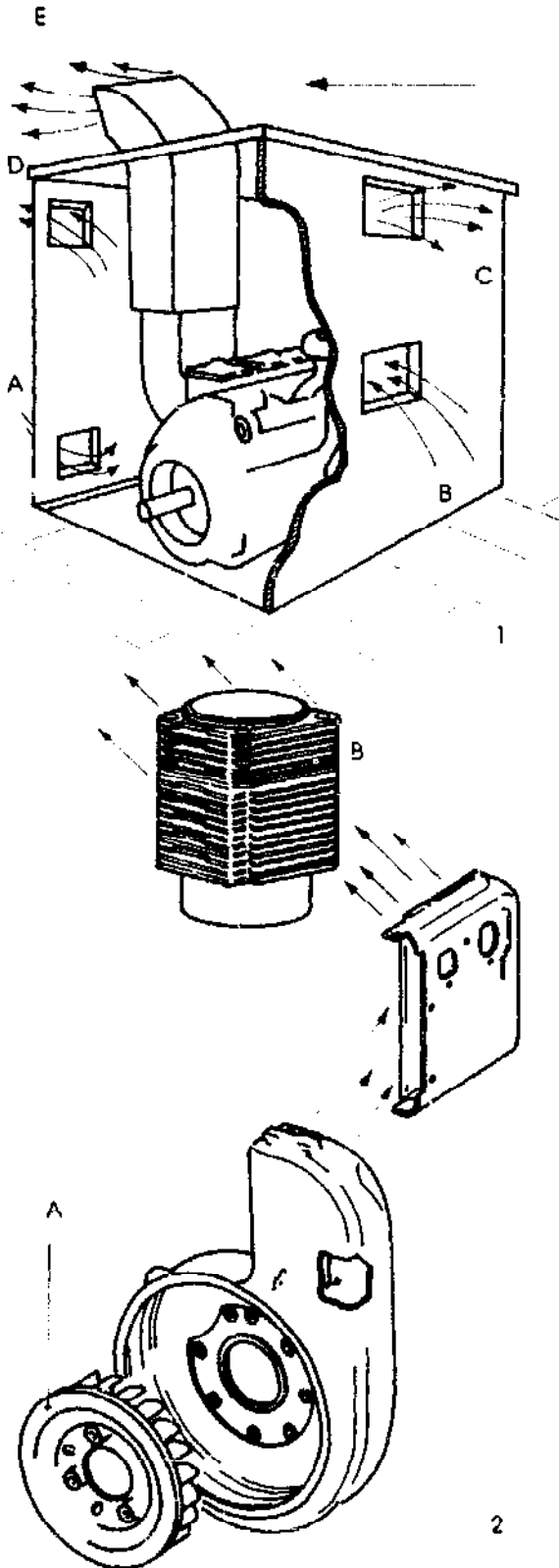
The operating temperature of a diesel engine is very critical to ensure maximum efficiency and to reduce wear on moving engine parts. If cooling is not adequate, the engine becomes over-heated causing possible:
- piston seizure,
- low engine performance,
- wear of movable parts,
- breakdown of lubricating parts,
- formation of carbon deposits.

Engine room design

Figure 1 shows an illustration of an engine room design. One of the cooling air intake holes must be near the bottom of the engine room to bring cool air in and also to strike along the engine sump to assist cooling of the lubrication oil, see 1-A. Another air intake hole 1-B must be opposite the air filter to ensure a good supply of cool combustion air. One or two cooling air holes must be near the top of the engine room to prevent an accumulation of hot air above the engine. Holes 1-C and 1-D allow hot air to leave the engine room. The exhaust leaves through the opening 1-E.

Two systems of engine cooling

We will explain two cooling systems:
- Air cooling
- Water cooling

Air cooling system

Air cooling is used widely on smaller engines used for water pumps, small electric plants, compressors etc. See Fig. 2. It is a simple but reliable principle using a fan 2-A secured to a flywheel which forces air through a system of deflector plates 2-B over the finned cylinder barrel and sometimes over a finned section of a sump for oil cooling.

Air cooled diesel engines require approximately 35% less air than water cooled engines.
It must be understood that in tropical climates special attention must be paid to the supply of fresh air. Clean the finned section 2-A regularly. The shroud or deflector plates must be taken off at regular intervals to make it possible to clean the fins of the cylinder barrel and thus ensure adequate cooling.

Water cooling systems

There are several systems to cool down an engine with cooling water. One such system is the *thermo-siphon* system, shown in Fig. 1. A gravity feed is taken from a tank 1-A located outside the engine room. This tank must be very well protected against the sun to ensure that the water used for cooling is not too hot. Water circulates through the engine cooling system 1-B and is returned to the tank by the thermo-siphon action alone. The water circulates due to expansion of the heated water in the engine jacket, thus becoming less dense and rising as a result to the highest point of the system. Its return from the top of the engine system to the top of the cooling tank is ensured by a sloping pipe 1-C which rises gradually to avoid possible air locks.

Since this system cools the water slowly, a large tank is necessary. Some 250 liters of water are needed per brake horse-power (b.h.p.) for 22 hours running. In tropical countries it is advisable to double this amount to 500 liters per b.h.p.
To aid the thermo-siphon action a circulation pump is sometimes mounted on the engine, increasing the flow of water through the system. If such a pump is provided, the total amount of water needed for cooling may be 20% less than recommended above.

Another water cooling system is the *radiator cooling system*, as shown in Fig. 2. Water flows from 2-A through the radiator 2-B via a flexible rubber hose to the waterpump 2-C , where it is forced through the water jackets of the engine 2-D. The heated water returns to the radiator via a rubber hose 2-E. A cooling fan 2-F is driven from a suitable extension shaft on the engine with one or more V-belts to draw cool air through the radiator and over the engine. This type of radiator is illustrated in Fig. 3.
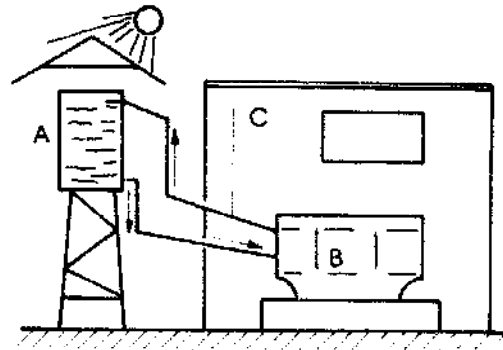
1
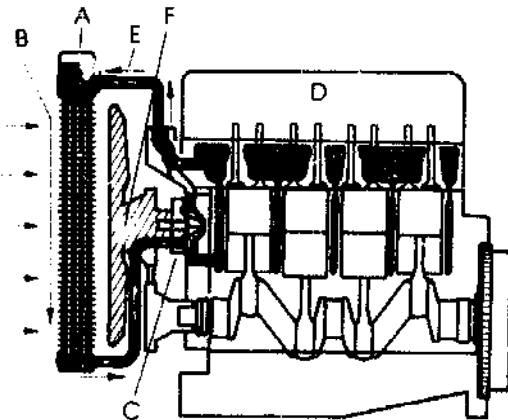
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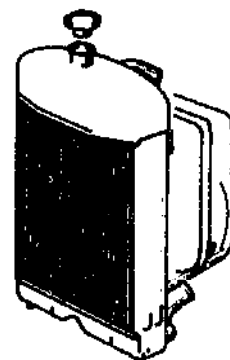
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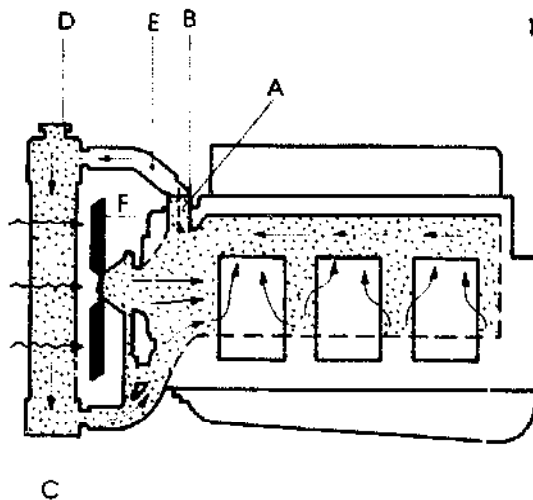
Water cooling system

A lay-out of a typical water cooling system is shown in Fig. 1.

The *water pump* 1-A draws hot coolant from the engine block and forces it through the radiator 1-C for cooling. The *thermostat* 1-B controls the flow of coolant to the radiator to maintain the correct operating temperature of the engine.

The *radiator* 1-C allows the coolant to cool before it re-enters the engine block. It also provides a reservoir for sufficient coolant for operation. The *radiator cap* 1-D is also used to fill the reservoir of the radiator with coolant. In addition it allows operation of the engine at a higher temperature without boiling or loss of the coolant by evaporation.

Rubber hoses 1-E make the connections between the rigid generator and the vibrating engine block.

The *blow* or *suction fan* 1-F makes cool air flow through the radiator tubes or water passages. The fan may also suck cool air through the radiator tubes.
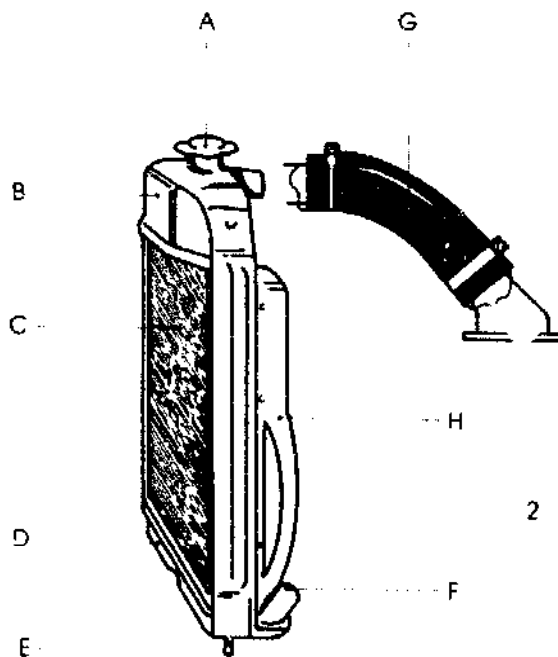
Radiator

A typical diesel engine radiator is shown in Fig. 2. The different parts are:
- Radiator cap 2-A
- Top reservoir radiator 2-B
- Radiator water passages and fins 2-C
- Bottom water reservoir 2-D
- Drain plug for coolant 2-E
- Bottom connection to engine block 2-F
- Top inlet for coolant from engine block 2-G
- Shroud to guide air flow 2-H

Note how the rubber hoses are connected with hose clips between the radiator and the engine block.

Core type radiators

A section of a tube-fin type core radiator is shown in Fig. 3. This type of radiator is common in all types of engines. Water from the engine block enters the radiator via the top tank and then passes down through the tubes 3-A. The fin 3-B ensures maximum air flow for cooling.
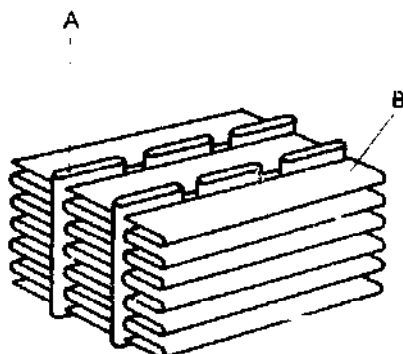
Radiator cap

The radiator cap shown in Fig. 1 is of the pressure system type. It allows the engine to operate at a higher temperature without boiling

Figure 2 shows the radiator cap with its valve 2-A closed completely. No coolant can escape via the overflow pipe 2-B.

Figure 3 shows the same radiator cap with the pressure valve 3-A completely opened. When in this position, the valve allows the coolant to escape under pressure and leave the radiator via the overflow pipe 3-B.

The vacuum valve shown in Fig. 4 opens as relevant to prevent a vacuum in the cooling system. Valve 4-A passes air via route 4-B.

As there may be pressure in the radiator, you must be careful to remove the radiator cap slowly, so that any pressure can escape first.

Thermostat
Figure 5 shows a part of the cooling system with the thermostat at 5-A in a closed position. If the thermostat is open, the water can circulate through the radiator marked 5-B. If the thermostat is closed, the coolant continues circulating through the pump in the engine block, see dotted area.

Figure 6 shows a typical bellows thermostat. The action of the thermostat valve 6-A is controlled by the bellows, to which valve 6-B is linked. In cold conditions the bellows are fully contacted and hold the valve tightly on the seat, so the coolant continues circulating from the cylinder head through the water pump and not through the radiator. This ensures a rapid rise in the coolant temperature. The thermostat in Fig. 6 is fully open, as you can see, so the coolant can circulate through the radiator, pump and engine block.
If the thermostat is not functioning correctly the engine may run too hot or too cold. Over-heating can damage the thermostat. As a result the valve does not function correctly and damages the engine. Rust caused by water in the system can also interfere with sound operation of the thermostat. Make sure you use a thermostat design recommended by the manufacturer.
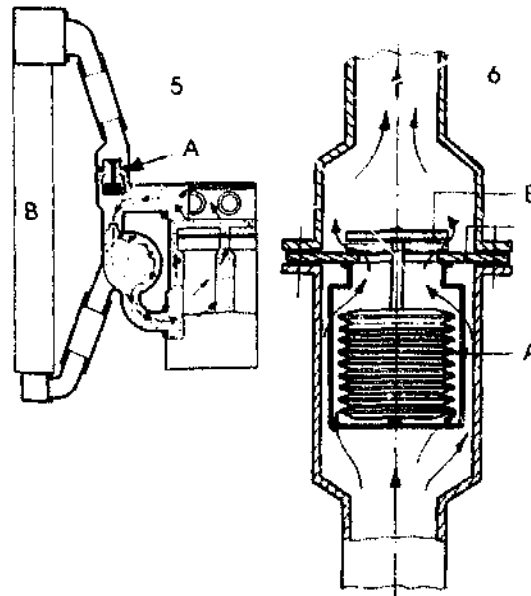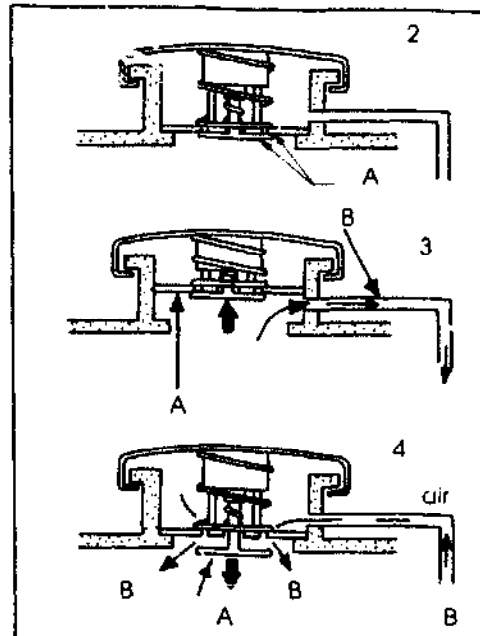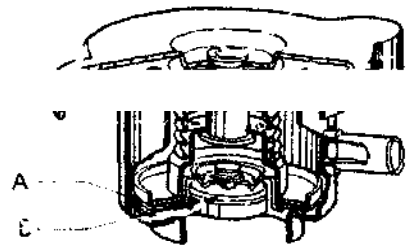
Water pump
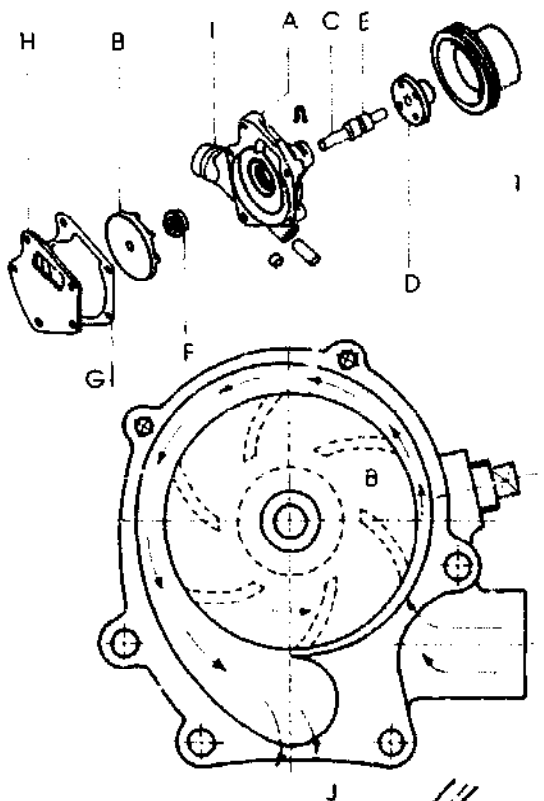
The water pump shown in an exploded view, Fig. 1, is bolted at 1-A to the engine block. The main part of the pump consists of an impeller 1-B in the form of a disc with tapered blades on one side. The impeller is force fitted to one end of the drive shaft 1-C. The hub 1-D is fitted at the front of the shaft and the pulley and fan blade are bolted to it, see Fig. 2. Two greased ball bearings 1-E are fitted on the drive shaft. Between the impeller and the pump housing, a seal 1-F is fitted to prevent leakage of the coolant. Between the pump housing and the engine block, a gasket 1-G prevents the leaking of coolant. Between the pump housing and the engine block a gasket prevents leakage of the coolant, while a hole in the plate 1-H allows the coolant to pass from the engine to the pump and then to the radiator. Coolant enters through 1-I and leaves the pumps to the engine at 1-J, see cross-section in Fig. 1.

Cleaning the cooling system
During engine operation, clogging materials such as rust, lime, scale and grease may prevent maximum cooling of the engine. Rust accounts for some 90% of clogging which forms on the walls of the engine jacket, see Fig. 3-A, and other metal parts. The coolant circulation may loosen the rust particles and carry them to the radiator, blocking the tubes. It is advisable to use clean rain water as a coolant to prevent lime deposits, due to so-called *hard* water forming a layer and thus blocking the circulation of the coolant. Lime may settle anywhere, while dirt settles at the bottom of the jacket 3-B and the radiator tank.

Flushing the cooling system
Before flushing the cooling system, take out the thermostat to make sure the water can run freely through the system. Then fill the system with clean water. Run the engine for some time. Stop the engine and open all drain plugs and drain the system completely. Also clean the radiator tubes and remove all insects from the fins.

Check the thermostat, radiator pressure cap and the cap-seat for dirt and corrosion.
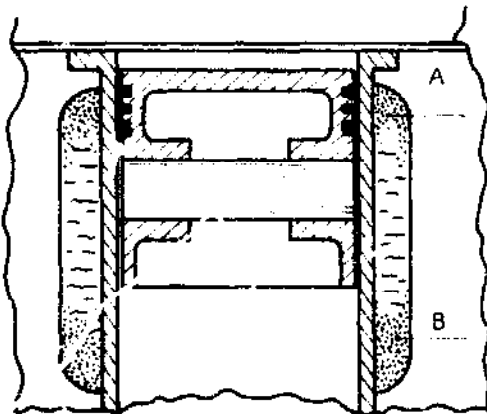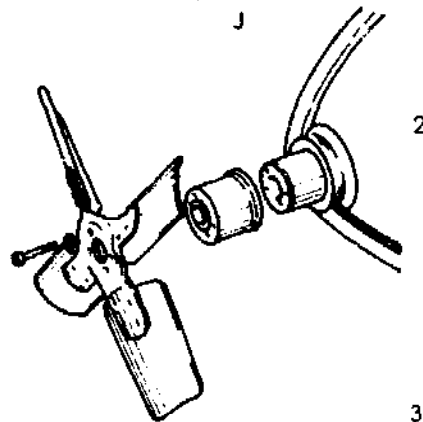
V-Belt construction

As already shown, a V-belt drives the water pump 1-C in Fig. 1 and sometimes also the alternator 1-B from a pulley attached to the crankshaft 1-A. Sometimes a separate V-belt is used for large alternators. The advantage of using a V-belt instead of a gear or chain drive is that the V-belt is a simple construction, cheap and noiseless.
A cross-section of a V-belt is shown in Fig. 2. V-belts are usually made of rubber incorporating steel wire and with cloth on the outside, see Fig. 3.

Shape of pulley and V-belt
A section of a pulley is shown in Fig. 4. The groove is shaped in such a way that it corresponds to the shape of the belt.
The force of the V-belt is transferred by friction between the V-belt shoulders and the pulley, see Fig. 4-A. That, as you will understand, is why the V-belt must fit correctly to be able to transfer the force. A V-belt of the wrong size fails to meet its purpose.

Length of the V-belt
If you have to measure the length of a V-belt, mark the belt with a pencil, see Fig. 5-A. Place the mark 5-A at 0 on a ruler and roll the belt along the ruler until the mark indicates the length.
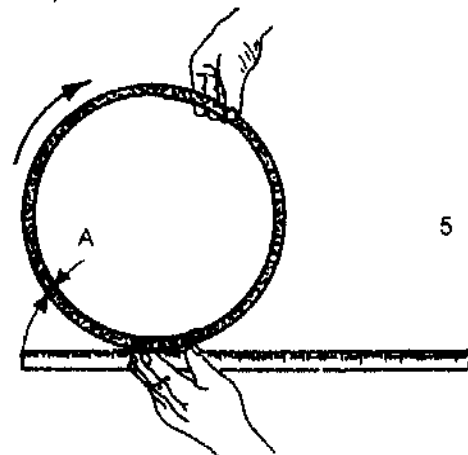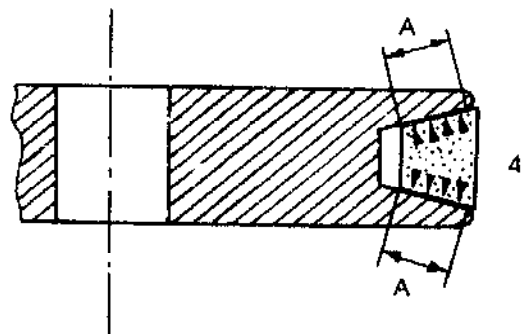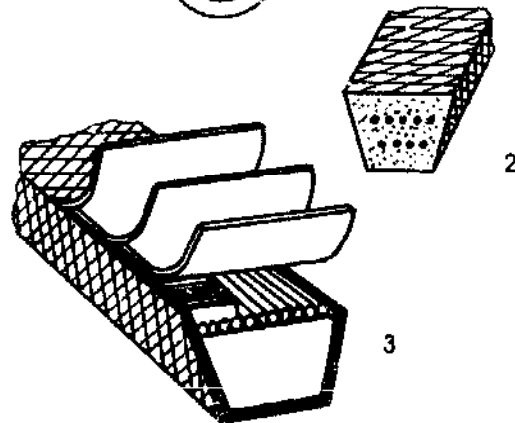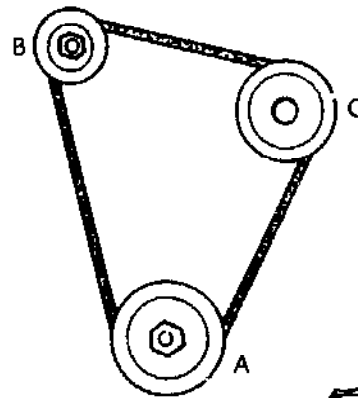
Checking the V-belt condition
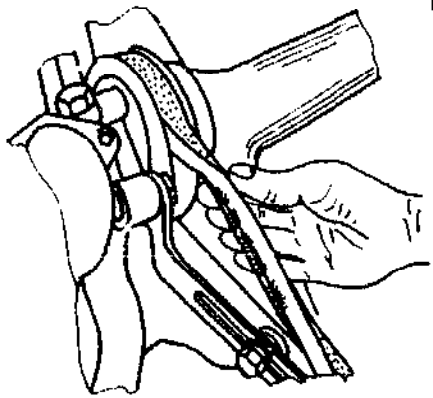
The demands made on the V-belt in connection with cooling the engine make it necessary to check the V-belt at regular intervals for signs of wear. The V-belt must be replaced if fibres along the sides become loose, see Fig. 1.
Also roll the belt over to inspect the bottom and sides If the belt is glazed, many small cracks appear and you must install a new belt. Also change the belt if signs of oil soaking or any other damage is visible.
Check too whether the belt still runs correctly in its groove.
Figure 2-A shows the correct position of the belt. Figure 2-B shows a V-belt which is too wide, so grooves will soon appear at its sides. Such belts must not be used. Sections of worn belts are shown in Fig. 2-C. These belts must be replaced to avoid over-heating through a slipping belt.
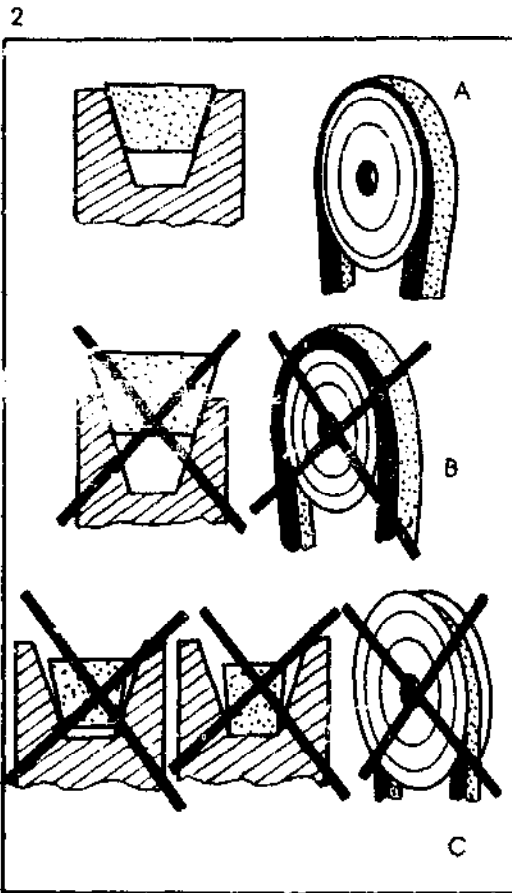
V-belt tension

Figure 3 shows a quick and good method of checking the tension of the V-belt. Place a straight edge over the pulleys and press the belt inwards in the centre between the two pulleys, using moderate pressure. Measure the deflection with a ruler. Deflection varies according to the length and size of the belt.
The following can be taken as a general rule:
- Distance between the centres of the two pulleys is 1500 mm. The deflection may be 15 mm.
- Distance between the centres of the two pulleys is 2000 mm. The deflection may be 20 mm.
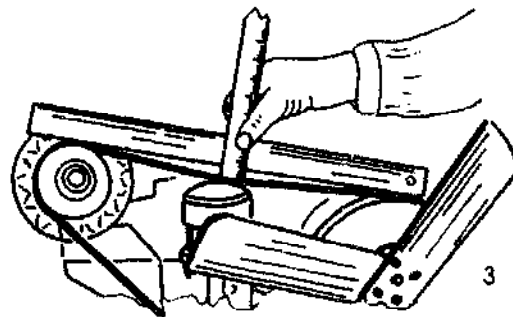
Lubrication system

Friction between metals
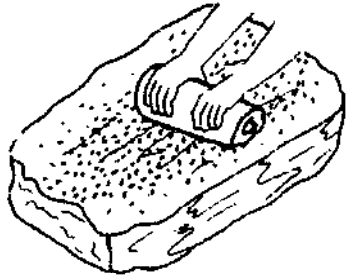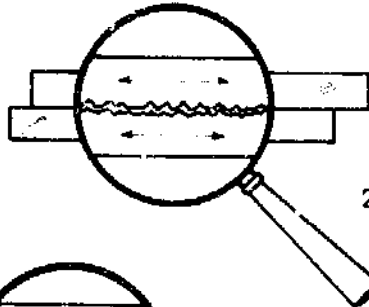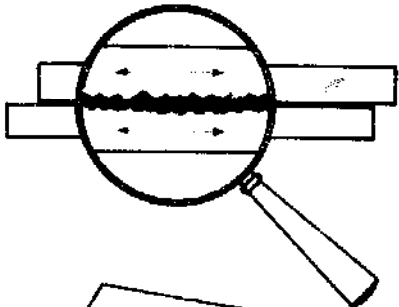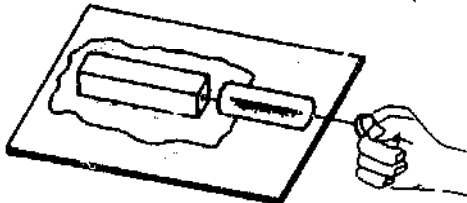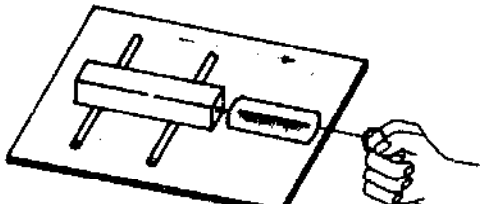
To understand the working of the lubrication system in an engine you must be aware of the effects of friction. You are already familiar with the properties of friction from your childhood. When you watched a woman grinding grain to make flour, you perhaps noticed at some stage that the small stone she used to grind the grain became hot after a while. If she had used the small stone without adding the grain, the stone would have become even hotter due to the friction between the large and the small stone. She reduced the friction by adding the grain, which acted as a lubricant, see Fig. 1.

For these lessons it is good to remember that two metal surfaces are made up of hills and valleys when they are seen under a microscope, see Fig. 2. These hills and valleys tend to interlock and grab each other when pushed in motion. Even highly polished surfaces are still made up of these valleys and hills, though to a lesser degree.

A stable oil film prevents this interlocking if the hills and valleys are not too big, see Fig. 3.

Sliding friction

To experiment with sliding friction, take a square polished steel bar and hook it onto a spring balance, see Fig. 4. Drag the bar over a polished steel surface and, while doing so, record on a piece of paper the reading on the spring balance.

After finishing the first experiment, cover the steel surface with a film of engine oil. Drag the square bar over the surface again and record the reading, see Fig. 5.

You will discover that dragging the bar over the oil-coated surface takes far less force. Even if water or any other kind of liquid is used, the friction is less, so less power is needed.

Rolling friction

Repeat the experiment described above but this time use two round pencils. Position the pencils between the flat plate and the square bar. Pull the bar as above and record the reading on the spring balance.

Less force is needed to overcome rolling friction, see Fig. 6.

1

2

3

4

5

6

Fluid friction

On the previous page you saw how a film of lubricant prevents contact between two solid materials. The same thing happens when a shaft rotates in a bushing or a bearing, see Fig. 1-A. A film of oil under pressure ensures that the two metal surfaces slide over one another, see Fig. 1-B. The only friction that occurs is in fact between the oil particles themselves.
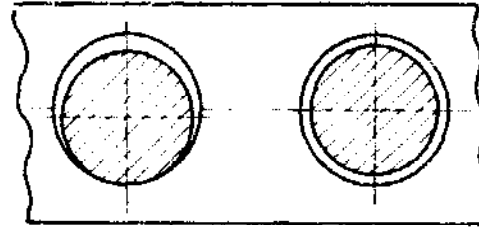
1

Mixed friction

Mixed friction is friction between two metals with a good film of lubricant between them, but this film is not thick enough to completely avoid any contact between the two metal surfaces.

Friction between cylinders and cylinder walls is an example of mixed friction. The metal of both parts touches for a short time, but just long enough to produce a lot of heat.

It must be noted that roller and ball bearings are also exposed to mixed friction, see Fig. 2.
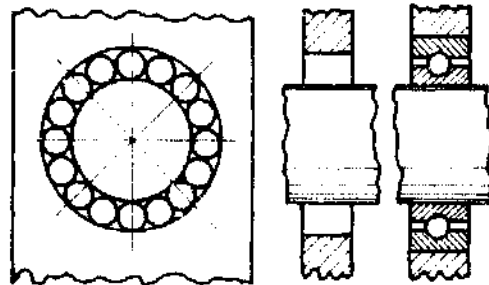
2

Boundary friction

Boundary friction occurs between two materials with a little lubricant. Gear joints, hinges, linkage joints etc. are all subject to boundary friction, see Fig. 3. A regular check must be made for lubrication in the form of oil or grease.

Dry friction

Examples of dry friction without any lubricant are between brake lining and brake drum (Fig. 4-A), the clutch plate and flywheel (Fig. 4-B) etc. A lot of heat is generated, so this friction must not be applied for too long at one time.
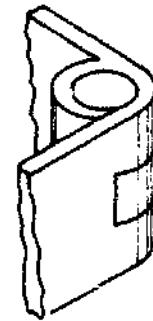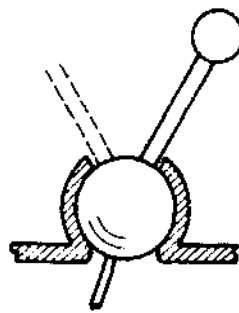
3
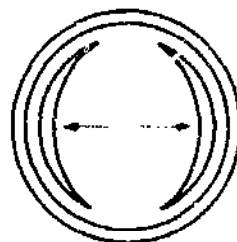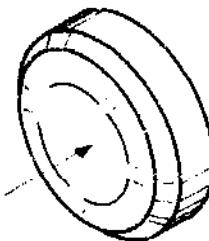
A   4   B

Classification of oils

In order to specify the different classes of engine oil, the American Petroleum Institute (API) has introduced a system of classification which is accepted all over the world.

The classification for petrol engine oil is made up of five classes, all starting with the letter S and followed by the letter A, B, C, D, or E. The letter S comes from Service, meaning that this type of oil is normally available from service centres. The letters A, B, C, D and E indicate the actual quality of the engine oil. For example: an oil with the letters SE indicates an oil of very high quality.
Oils used for diesel engines are marked with the letter C followed by the letter A, B, C or D. Diesel engine oil marked with the letters CA is of a low quality, while oil marked with the letters CD is of a high quality.

Sometimes oils are sold of a quality which can be used for both petrol and diesel engines. If this is the case, you will find both marks on the oil container – for example the letters SE-CC, see Fig. 1.

Technical data on engine oils
Oil for petrol engines is marked with the following letters:
SA = Is not used in modern engines.
SB = Used in engines running under very favourable conditions.
SC = This oil can be used in older types of petrol engines
SD = Is the lowest quality oil which can be used in modern engines.
SE = This type of oil is top quality and can be used in all modern engines even under severe conditions.

Oil for diesel engines is marked with the letters:
CA = This oil can be used in engines running under favourable conditions.
CB = Suitable for diesel engines running under fairly difficult conditions using a low grade fuel.
CDC= This oil can be used in engines running under fairly difficult conditions using a good type of fuel.
CD = This oil is suitable for diesel engines with a high output. It is a top quality oil used in engines running under severe conditions.

Note: If an engine has been running on low quality engine oil and a change is to be made to a high quality oil, an extra oil change is recommended because the high quality oil has a high cleaning ability and after the first change combustion particles are washed out quickly, making the first oil dirty.

Always follow the manufacturer's recommendations regarding the quality and the grade of the engine oil to be used for that particular engine.

1
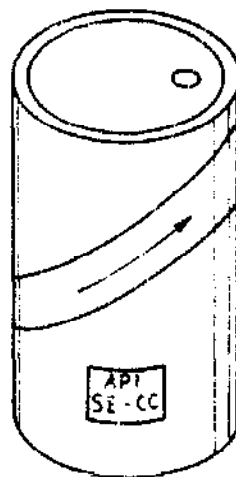
Engine oils

Crude oil found in several parts of the world is the raw material from which different products are made, such as petrol, kerosine, diesel fuels, gas and lubrication oils etc.

Engine oil is a high quality oil designed especially for the lubrication of particular engines under specific conditions. The basic function of engine oil is to ensure that all the moving parts in the engine function efficiently with a minimum of wear and friction. As noted above, engine oil has to provide a durable and protective film between the moving parts from the first to the last moment under both hot conditions and full load.

Oxidation occurs very fast at high temperatures and a good oil should also clean the internal parts of the engine, removing carbon and other deposits caused by combustion. Cylinder walls, bearings and other engine components must be protected against corrosion due to moisture and acids. This can be done with a good grade of engine oil.

A good grade of lubrication oil must form a correct sealing film between the pistons and cylinder walls so the high pressure needed for combustion is not lost due to leakage. A good engine oil should not form air bubbles when it is being splashed about, because this could prevent good lubrication.

Another function of engine oil is heat conduction, even when it becomes hot.

As you have now seen, engine oil has several functions to perform and the straight mineral oil is modified by various additives, such as:

- *Oxidation inhibitors* which reduce the tendency of the oil to absorb oxygen and so cause oxidation.
- *Rust inhibitors* which assist the oil in preventing corrosion of the engine parts.
- *Pressure agents* which reduce friction.
- *Detergents* which increase the cleaning efficiency of the oil.

Engine oil quality and viscosity

To guarantee all the requirements listed above it has been necessary to develop standards for the quality and viscosity of oils which are uniform and acceptable all over the world. When selecting oil for an engine it is important to choose the correct one. Two important factors which determine the choice of oil are:
- The oil must have the right thickness, which is called *viscosity*.
- The oil must meet the quality required by the manufacturer of the engine.

Viscosity
The term viscosity refers to the relative thickness of an engine oil. A thin free-flowing oil has low viscosity and a thick slow-flowing oil has high viscosity. The viscosity of oil changes as the temperature changes. At high temperatures the oil becomes thinner and at low temperatures it becomes thicker. That is why correct viscosity of the is essential to efficient running of the engine. If the oil is too thick it causes resistance and much more power is needed to turn the engine, which also makes it difficult to start the engine when it is cold. Thick oil does not circulate freely enough during the starting period, causing insufficient lubrication of the engine parts.

On the other hand, if oil is too thin the combination of high temperature and heavy load presents the risk of oil being pressed out from between the working surfaces of bearings of other engine parts. This causes the oil film to break down. Oil which is too thin does not provide an efficient seal between the cylinder wall and the piston rings.

Grades of engine oil
Engine oils are graded by the Society of Automotive Engineers (SAE) and numbered according to thickness.
The viscosity of oil grades SAE 5W, 10W, 15W and 20W is measured at a temperature of 18 °C. Oil grades SAE 20, 30, 40 and 50 are measured at an oil temperature of 100 °C, which is the normal oil temperature when the engine is running. Note that the lower the numbers, the thinner the oil.

The correct oil viscosity
Oils with a viscosity of SAE 5W to 20W are suitable for climates with a low temperature. Oils with a viscosity of SAE 20 and 30 are suitable for moderate to hot climates. Oils with a viscosity of SAE 40 and 50 are used in old engines or in badly worn engines with high oil consumption.

Multigrade oil
For practical reasons it is not possible to use a low viscosity oil for cold starting and then change to an oil with a higher viscosity when the engine is running and hot. That is why a multigrade oil has been developed which overcomes these difficulties.

Technical data on engine oils
A general technical specification for engine oils has been accepted;
- Single grade oil which covers one SAE grade, such as SAE 40.
- Double grade oil which covers two consecutive SAE grades, such as SAE 20/30W.
- Multigrade oil which covers three SAE grades, such as SAE 20/40W.
- Super multigrades which cover more than three SAE grades, such as 15/50W.

Lubrication system

A typical one cylinder diesel engine may have
a lubrication system as shown in Figs. 1 and 2.
The lubrication oil flows through:
- Sump 1-A
- Strainer 1-B
- Oil supply pump 1-C
- Pressure valve 1-D
- Main bearing 1-E
- Drilling main bearing 1-F
- Rocker arms 1-G
- Dip stick 1-H
- Lubrication oil level mark 1-J
- Lubrication oil level 1-K

Lubrication system

A typical 4-cylinder diesel engine may be equipped with a pressure feed lubrication system, see Fig. 1. A pump forces the oil to the various engine parts requiring lubrication. The oil is sucked from the sump through a primary gauze filter (strainer) and then pumped under pressure to the full flow oil filter. An adjustable pressure relief valve is fixed in the filter head. The pressurized oil then passes to the main oil gallery where the pressure gauge is fixed. Front, centre and rear main bearings are connected directly to the oil gallery, where a pressure gauge is fixed. Front, centre and rear main bearings are directly connected to the oil gallery by oil feed drillings. The big end bearings and camshaft bearings are lubricated from the cramshaft main bearings. The cylinder walls and the small end bearings are splash lubricated. The rear pedestal of the rocker arm shaft is supplied with oil from the rear crankshaft main bearing via the rear camshaft bearing. From there, oil passes through the hollow rocker shaft to each rocker and push rod. It then flows back to the sump. Lubrication oil is supplied by the front crankshaft bearing to the chain tensioner, the timing chain and, via the front camshaft bearing, to the fuel injection pump drive. See Fig. 2.

Pressurized lubrication oil system

The pressurized oil in the sump is pumped through a strainer and the oil pump to the oil filter and from there to the main oil gallery and oil passages which lead to the crankshaft and camshaft bearings, the rocker shaft and the rocker arms. Oil splashed from the crankshaft lubricates the piston and other internal moving parts of the engine.

After lubricating the moving parts the oil drips back into the sump.

In Fig. 1 the following components can be recognized:
- Oil pan/sump 1-A
- Strainer 1-B
- Oil pump 1-C
- Relief valve 1-D
- Main oil gallery 1-E
- Oil pressure indicator 1-F
- Oil filter 1-G
- Dip stick 1-H
- Filler cap 1-I
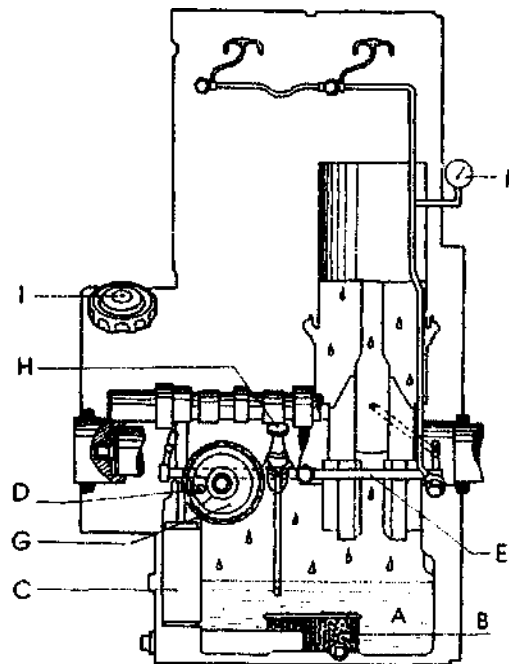
The working of lubrication oil

In the previous chapter we learned about the working of lubrication oil. Remember that, even when they appear to be smooth and polished, surfaces are in reality uneven, as shown in Fig. 2.
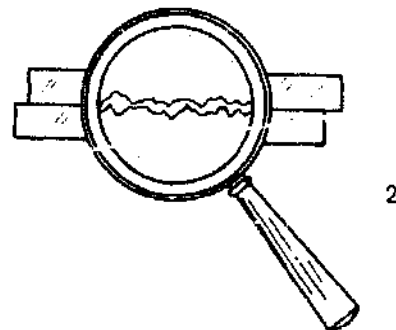
Oil enters the bearing under pressure and a very small clearance is needed to allow the oil to form a film between the bearing and the shaft. The clearance data can be found in the manufacturer's manual.

What actually happens with the shaft and the oil film is shown in Fig. 3.
- When the shaft is not rotating it rests on the bearing and only a very thin film of oil separates the surfaces. This thin oil film is important because it is the only lubrication during the first revolutions of the shaft when the engine starts. See Fig. 3-A.
- As soon as the engine starts and the revolutions increase, the oil pump starts to deliver oil and press it into the bearings. It forms a kind of wedge on which the shaft is raised from the bearing. See Fig. 3-B.
- At full speed and with the right kind of oil and oil pressure, the shaft rotates freely in its bearing on the oil film. See Fig. 3-C.
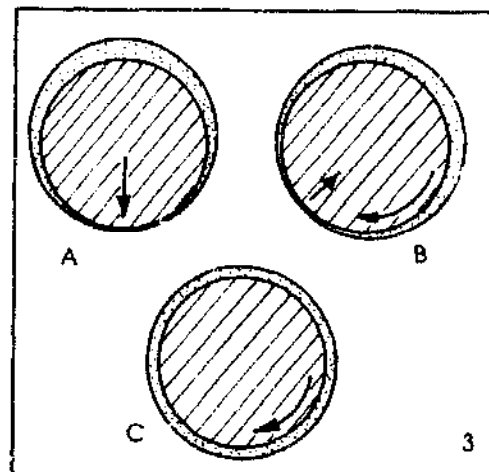
Clearance

You realize it is very important that the bearings of an engine have the correct clearance. Too much clearance allows the oil to escape from the bearing without being able to create the required oil wedge. Too little clearance restricts the entry of the oil into the space between bearing and shaft, thus causing metal-to-metal contact. In both cases wear increases.

Figure 1 shows how the oil is pressed out from the bearings and splashed around, forming an oil mist which lubricates the inside cylinder wall and the piston.

Figure 2 shows that in some cases the connecting rod has a hole drilled from the side of the connecting rod into the bearing shell to spray oil onto the cylinder wall.

Oil pan

When you fill the engine with engine oil 3-D, see Fig. 3, it sinks through the engine 3-A to the bottom where it is held in a reservoir 3-C. This reservoir is either integral with the engine or sometimes it is attached to the engine block by bolts, in which case it is called the oil pan. One end of the oil pan shown in Fig. 5 is lower and forms a reservoir called the sump. A drain plug 3-E is located at the bottom of the sump so that dirty oil can be drained off.

The oil level in the oil pan in Fig. 3 can be checked with a so-called dip stick 3-B on which the minimum and maximum oil levels are marked, see Fig. 4.
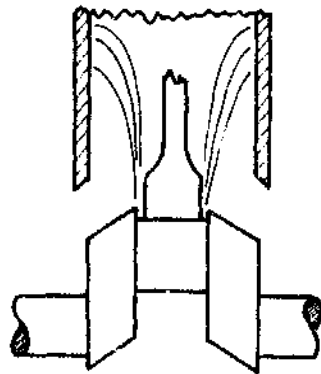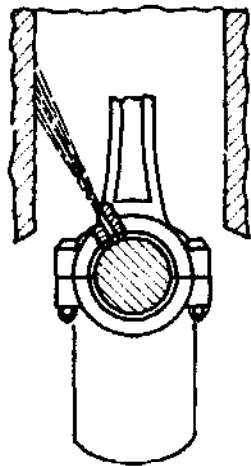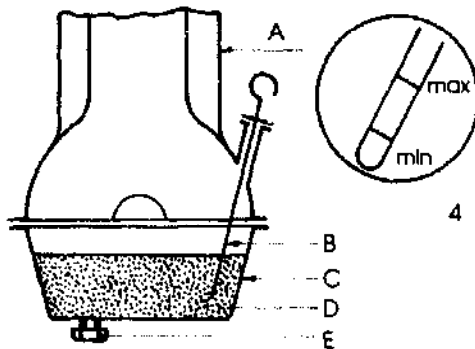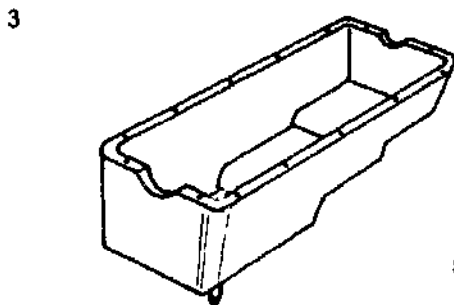
Typical oil pump

The oil pump in a diesel engine creates the
pressure required to force the oil from the
sump to the various lubrication points.
Different pumps are used in different engines,
such as a piston pump shown in Fig. 1. This
kind of oil pump is used in small diesel
engines and the push rod is moved by a cam on
the camshaft. Parts of this pump are:

− Push rod 1-A
− Spring 1-B
− Plunger 1-C
− Valve spring 1-D
− Ball valve 1-E
− Valve holder 1-F
− Pump housing 1-G
− Valve holder 1-H
− Plug 1-I
− Strainer 1-J

The oil pump pushes oil into the main gallery
and from there to other parts of the engine. A
relief valve is attached to the main oil pipe, see
Fig. 2.

Relief valve

When the engine speed increases the oil pump
produces a higher oil pressure than required.
This pressure can damage the oil pump. So a
relief valve is used to take away some of the
extra pressure and maintain it at a suitable
level for the bearings.

The relief valve is connected either to the
pump or to the main gallery and can be of any
shape. All pumps consist mainly of a plunger,
as shown in Fig. 3, or a ball held in position by
a spring.

When the oil pressure rises above the setting
specified by the manufacturer the plunger 3-C
is pushed back against the spring 3-D and
opens the outlet to the sump via the oil pipe
3-B. When the plunger is pushed back the
pressure decreases and the rest of the oil 3-A is
forced under the correct pressure to the
bearings via.

Figure 3 also shows the relief valve in a closed
position; no oil returns through the oil pipe 3-B
to the sump.

Figure 4 shows a typical oil ball relief valve in
the closed position. It works in the same way
as the plunger relief valve.
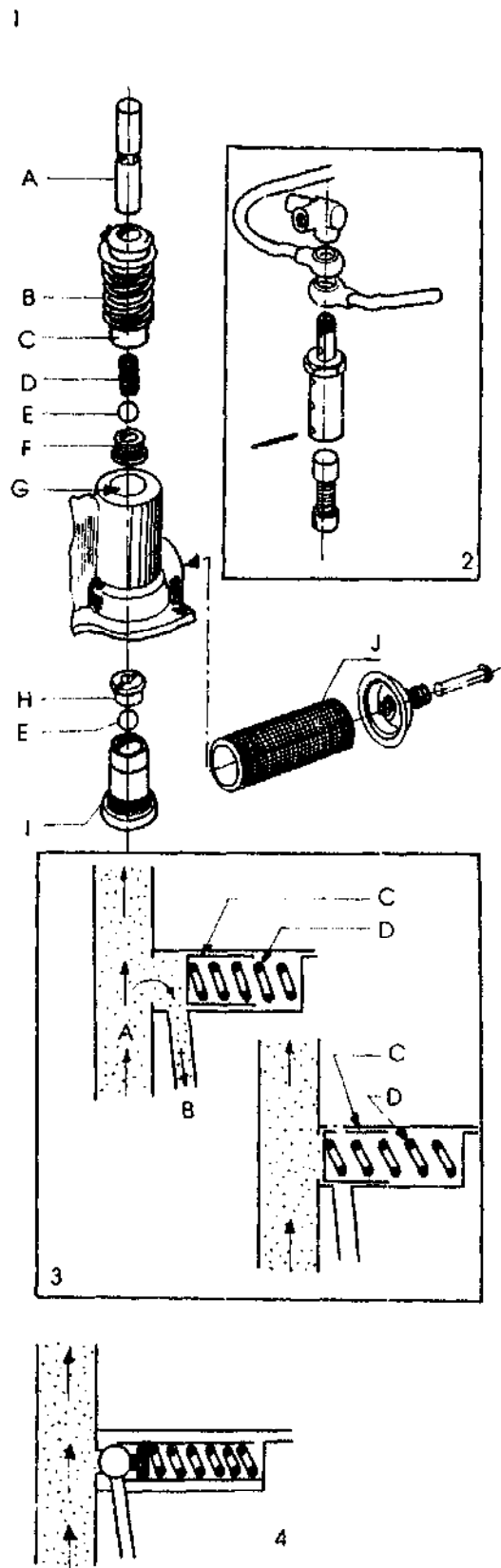
Typical gear pump
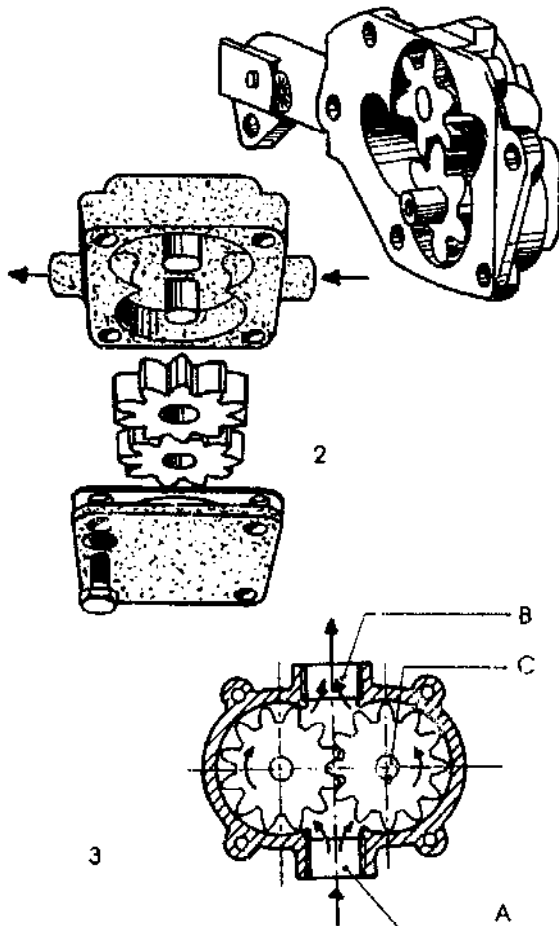
Gear pumps as shown in Figs. 1 and 2 are commonly used in diesel engines. They are either attached to the engine block as in the case of the pump in Fig. 1, or they are closed with a cover as shown in Fig. 2.
This pump consists of two gears as shown in Fig. 3, one of which is driven by a helical gear 3-C from the camshaft or an auxiliary shaft, depending on the type of engine and its manufacturer. Oil is sucked in at 3-A and pressed into the system at 3-B. The gears mesh with a minimum amount of clearance and they also only just clear the sides of the housing.
It is clear that the housing must be connected very tightly against the engine block or the cover must close very tightly.

Oil gear pump operation
The oil gear pump operates as follows:
- When the driven gear rotates, it turns the other gear as well. See Fig. 4. When both gears are rotating, the oil enters through inlet port 4-A into the space at the bottom of the pump.
- While rotating, the teeth of each gear catch the oil and carry it along the casing towards the other end of the pump housing, see Fig. 5.
- The oil leaves the pump under pressure through outlet port, see Fig. 6 and enters the main oil gallery.
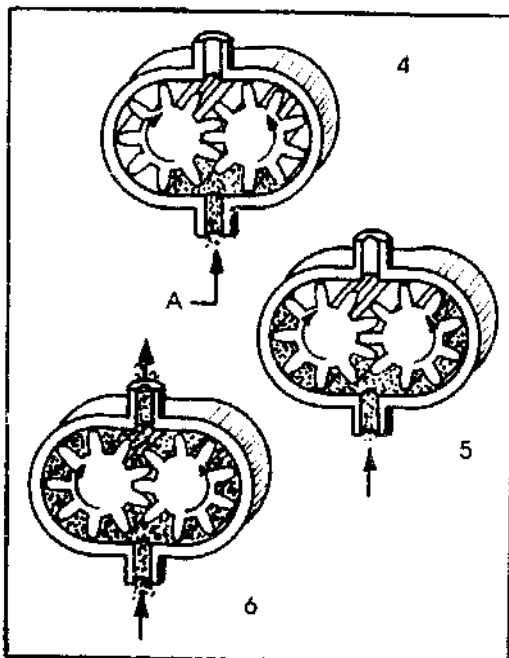
The rotary oil pump

Figure 1 shows a rotary pump consisting of the following components:
- Inner rotor 1-A
- Outer rotor 1-B
- Oil pump housing 1-C

The inner rotor is driven from a gear 1-D on the camshaft 1-E.

Rotary pumps may differ in design but the principle is always the same.

Rotary pump design

Rotary pumps are designed in the form of a shaft 2-D with four lobes 2-A, see Fig. 2. It is fitted off-centre inside the outer rotor 2-B with five recesses corresponding to the lobes. When the inner rotor turns, its lobes slide over the corresponding recesses in the outer rotor and turn it round in the pump housing 2-C.

The working of the rotary oil pump

Figure 3 illustrates the working of the oil pump. Oil enters at 3-D and leaves the pump at 3-E through the inlet and outlet ports in the oil pump housing 3-C.

As the inner rotor 3-A turns (see arrow), the lobe 3-G sliding inside the recess of the outer rotor 3-B creates a space which, as it becomes larger or smaller, produces an alternating suction and pumping action.

When the space between the lobe 3-G and the recess 3-F increases, the oil is sucked into the pump through the inlet 3-D. As the rotor turns further, the following lobe of the inner rotor closes the inlet port and the space reaches its maximum.

With further rotation of the rotor, the outlet port 3-E opens, the space decreases and the oil is pushed out.
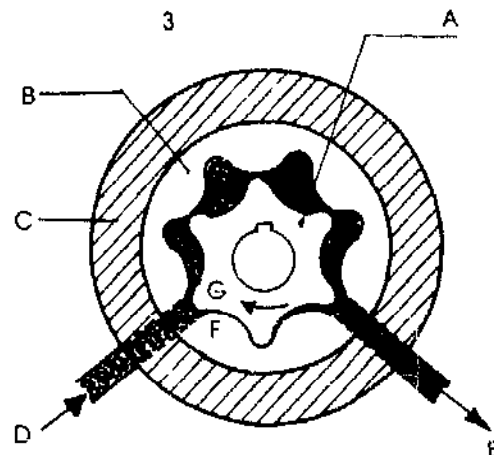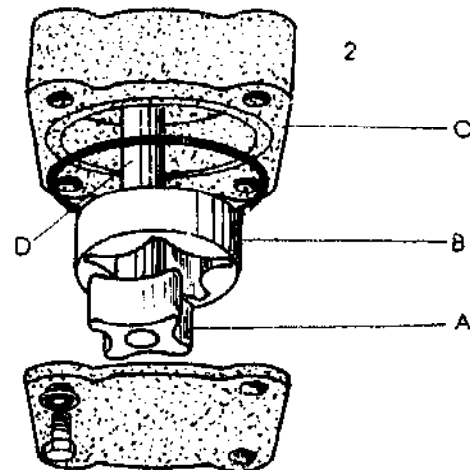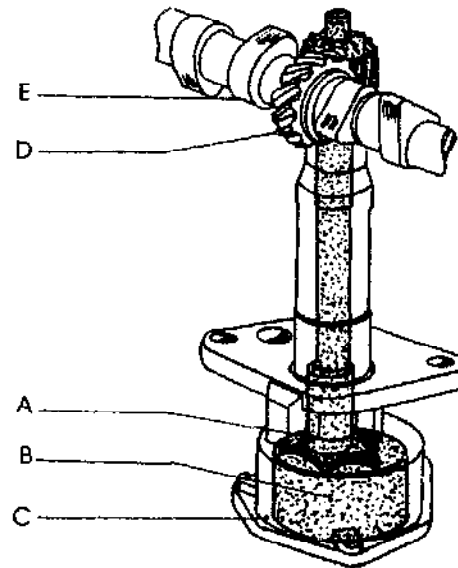
Servicing the oil gear pumps

The oil pump must be checked for wear or damage during a general engine overhaul or when the oil pressure indicator shows the pressure is too low.
While loosening and handling the oil pump, be very careful not to damage the mounting surfaces, the housing or the cover.
Some pumps do not have a gasket, only the machined surfaces act as a seal.
In a gear pump, Fig. 1, most wear develops between the teeth of the gears. In a rotary pump, Fig. 2, wear develops mostly between the lobes on the rotor ring.

Measuring the clearance
Refer to Fig. 3. With the gears mounted in the pump housing, place a straight edge 3-A across the top of the pump housing to act as the cover and measure the clearance between the gears and the straight edge with a feeler gauge 3-B. The number on the feeler gauge blade should comply with the manufacturer's recommendations.

Clearance between the teeth of the gears and the housing can be measured as shown in Fig. 4. Place the correct feeler blade between the side of the housing 4-A on top of the teeth 4-B and measure the clearance while moving it backwards and forwards.

Almost all the pumps have a screen over the inlet to strain out dirt and foreign material. If possible, remove the screen and clean it. Also inspect all the bushings in the housing and replace them if necessary.
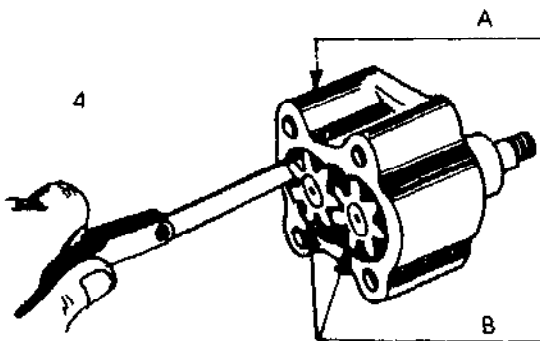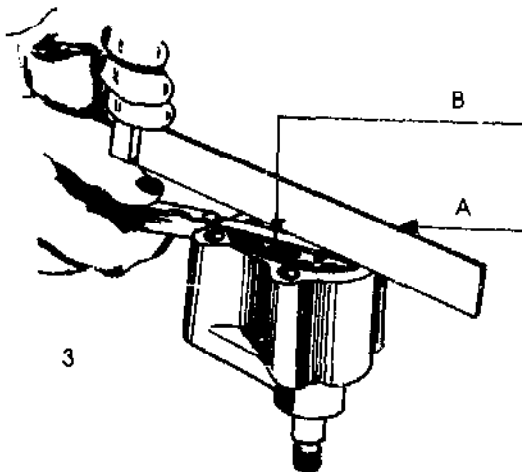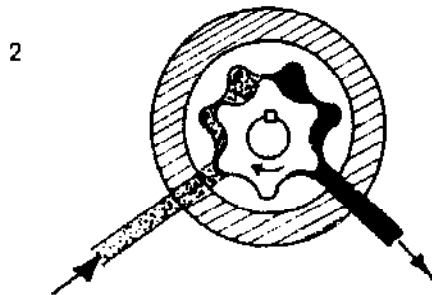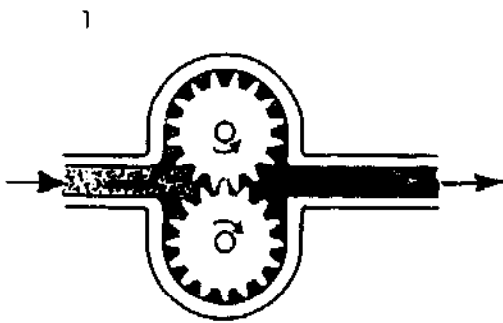
Engine oil filtration

When oil passes through the engine during operation it becomes contaminated with metal particles, carbon, dust etc. As you realize, all these impurities cause engine parts to wear if they are left in the oil and that is why the oil system must be equipped with an oil filtering system.

Full flow filtration system
Nowadays all engines are equipped with a filtering system that filters all the engine oil before it reaches the lubrication system.
In this system of oil filtration, see Fig. 1, all the oil is pumped from the sump 1-A through the oil pump 1-B to the oil filter 1-C. In the filter the oil is pressed through a cleaning material and leaves the filter to pass to the main oil gallery and the engine parts. A relief valve 1-D regulates the pressure in the system and the oil pressure gauge 1-E indicates the actual pressure of the oil during operation.
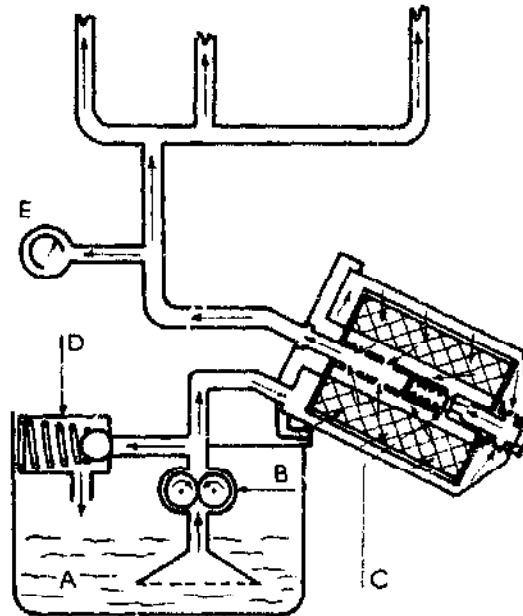
Bypass filtration system
Sometimes a bypass filtration system is fixed on the engine, so only a portion of the oil passes through the filter. Figure 2 shows how the oil is pumped from the sump straight into the lubrication system. But some of the oil passes through a filter 2-A and returns to the sump after filtration.
The volume of oil bypassed through this filter is controlled by a restriction in the filter outlet. If the filter is dirty or clogged, the volume of oil passing through the cylinder is reduced. Due to the two separate oil flows, oil pressure at the bearings is constant regardless of the condition of the filter, which is an advantage, but only checking can tell you whether the filter is dirty or clogged. That is why both filter and oil must be changed regularly to prevent loss of filtering.

Full flow/bypass filtration system
Some modern engines have both the full flow and the bypass filtration systems to ensure maximum cleaning of the oil during operation.
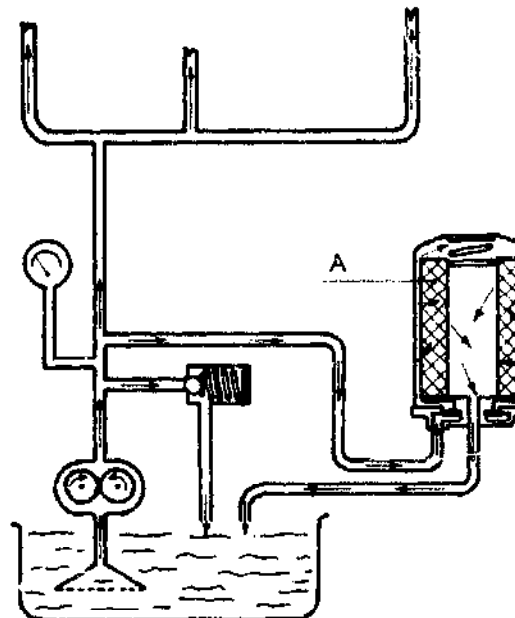
Oil pressure regulating valves
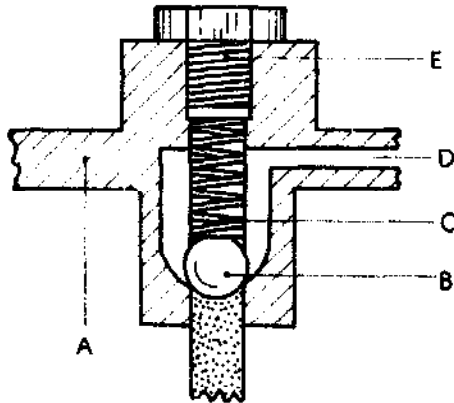
As you have already learned, the oil pressure built up by the oil pump may exceed the valve setting. That is why the oil pressure regulating valves are designed in such a way that, in the event of over-pressure, the valve opens by itself and the excess oil returns to the oil sump. Regulating valves are usually connected to the main oil gallery through passages in the engine block, may be part of the oil pump and may be installed at bypass oil filters.

Figure 1 shows a typical oil pressure regulating valve installed in a bypass oil filter. It consists of a body 1-A which is part of the oil filter assembly. A ball valve 1-B, held in position by a spring 1-C, closes off oil passage 1-D by normal pressure. The pressure put on the ball by the spring can be increased by adding shims at 1-E.
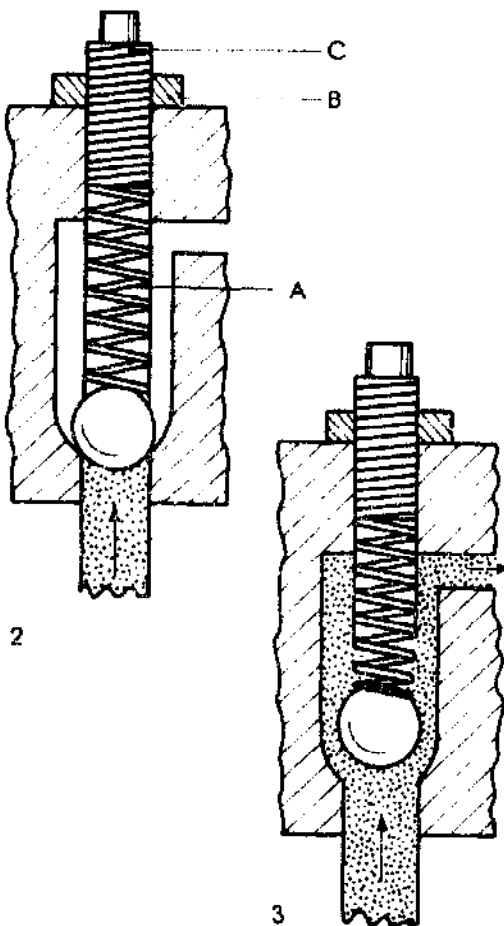
Another oil regulating valve is shown in Fig. 2. At normal oil pressure the ball valve remains closed due to the pressure from the spring 2-A. If the oil pressure builds up, the ball is pressed upwards, the oil passes the ball and returns to the sump, see Fig. 3.

In this type of oil pressure regulating valve the pressure can be changed by loosening nut 2-B and turning screw 2-C in or outwards, depending on whether you want to increase or decrease the pressure. After adjusting the screw, tighten the nut properly to ensure the correct setting.

Oil filters

In different engines you may find different oil cleaning systems and filters. A good oil filter must be capable of stopping the flow of very small particles of dirt, carbon and metal without restricting the oil flow. Resin impregnated paper is the most commonly used material nowadays. This paper is folded and enclosed in perforated cylinders, one inner cylinder and one outer cylinder, as shown in Figs. 1 and 2.

When the oil passes through the paper the dirty particles accumulate on the surface of the paper. As shown in Fig. 2, the oil enters through the perforations at the outside of the cylinder, passes through the filter element and leaves the filter through the inner cylinder.
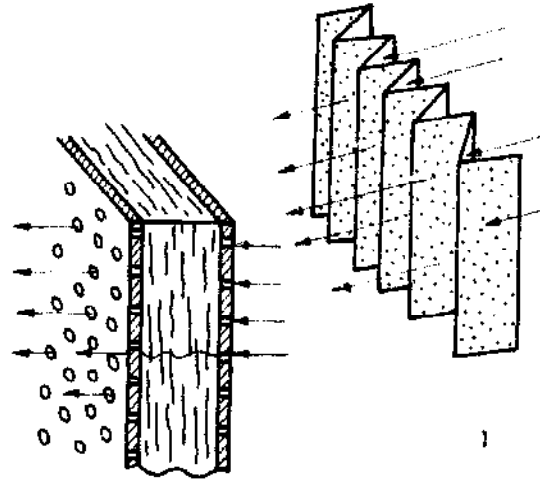
Cartridge filter
Some filter elements are enclosed in metal containers, see Fig. 3, forming one unit. When the oil is changed, the whole cartridge has to be replaced.
Cartridges are removed with the special tool shown in Fig. 4. Do not use pliers to fasten the new cartridge because you will damage the metal container. Once the container is loosened, the element is simply changed out.
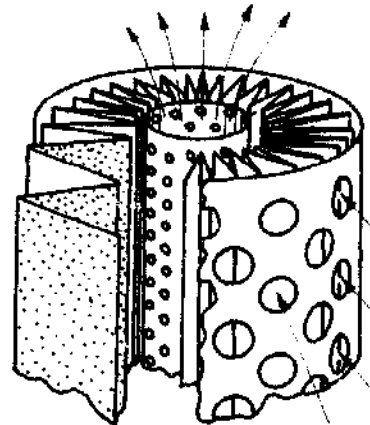
Other types of filter
Other filter elements are used sometimes, such as the depth filter made from cotton waste. In this filter the oil moves in many directions before it finally enters the top of the lubrication system.
Manufacturers recommend the kind of filter to be used. It is advisable to follow their instructions.

1

2

3

4
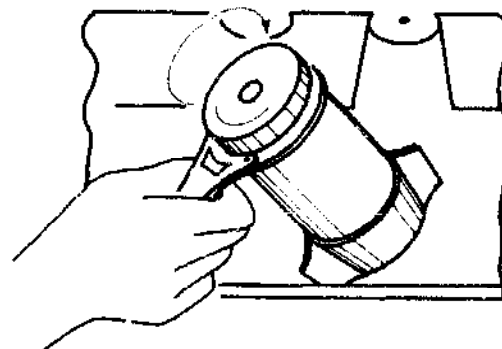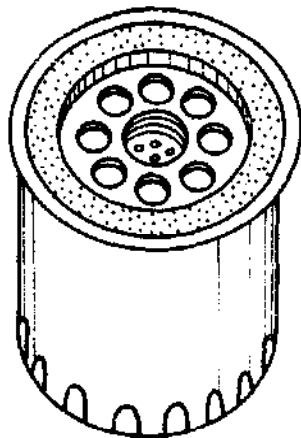
Typical oil filter parts
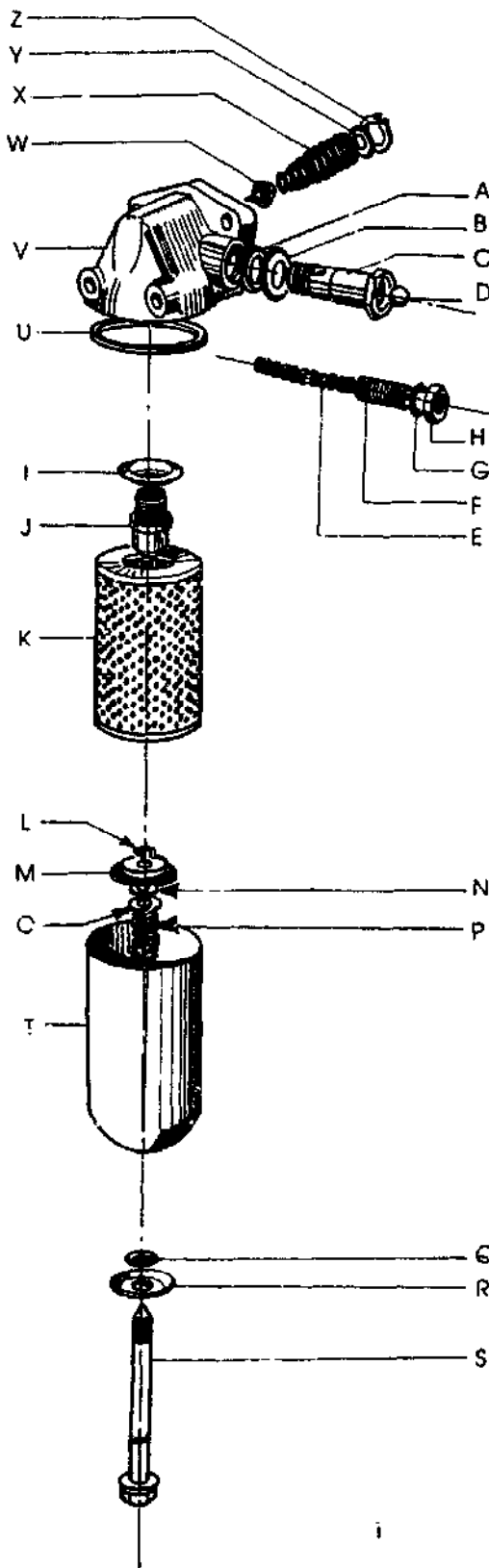
A typical oil filter assembly is shown in Fig. 1, in which the parts are:
- Relief valve seal 1-A
- Relief valve washer 1-B
- Valve body 1-C
- Ball valve 1-D
- Spring 1-E
- Adjusting screw 1-F
- Lead washer 1-G
- Lock nut 1-H
- Top guide element 1-I
- Centre tube 1-J
- Filter element 1-K
- Circlip 1-L
- Bottom guide element 1-M
- Seal 1-N
- Washer 1-O
- Spring 1-P
- Sump seal 1-Q
- Reinforcing washer 1-R
- Centre bolt 1-S
- Sump assembly 1-T
- Head seal 1-U
- Head 1-V
- Relief valve 1-W
- Relief valve spring 1-X
- Relief valve washer 1-Y
- Relief valve circlip 1-Z

Intake and exhaust

Intake system

The air needed for combustion enters the engine through an air filter, as shown in Fig. 1. The air filter 1-A-B-C is attached to the intake manifold 1-D. It may be a straight connection or via a rubber hose. The manifold is connected rigidly with bolts to the cylinder head of the diesel engine 1-H. Figure 1 shows the inlet manifold near the exhaust manifold. But since diesel engines do not require heat, they may also be located on the other side of the cylinder head.

Intake system parts are:
- Air filter cover 1-A
- Filter housing 1-B
- Sump or oil pan 1-C
- Rubber hose 1-D
- Clamp 1-E
- Inlet manifold 1-F
- Exhaust manifold 1-G
- Cylinder head, inlet valve 1-H

Exhaust system

Figure 2 shows the exhaust system. It consists of the exhaust valve in the cylinder head, the exhaust manifold and the muffler. The exhaust valve seals the burning gases in the cylinder until the energy is spent, then opens so the burned gases can escape via the manifold, which brings them to the exhaust pipe. The muffler 2-B reduces the engine noise during operation.

Exhaust system parts are:
- Exhaust pipe 2-A
- Muffler 2-B
- Clamp 2-C
- Drain plug 2-D
- Plug 2-E
- Exhaust manifold 2-F
- Inlet manifold 2-G
- Cylinderhead, exhaust side 2-H
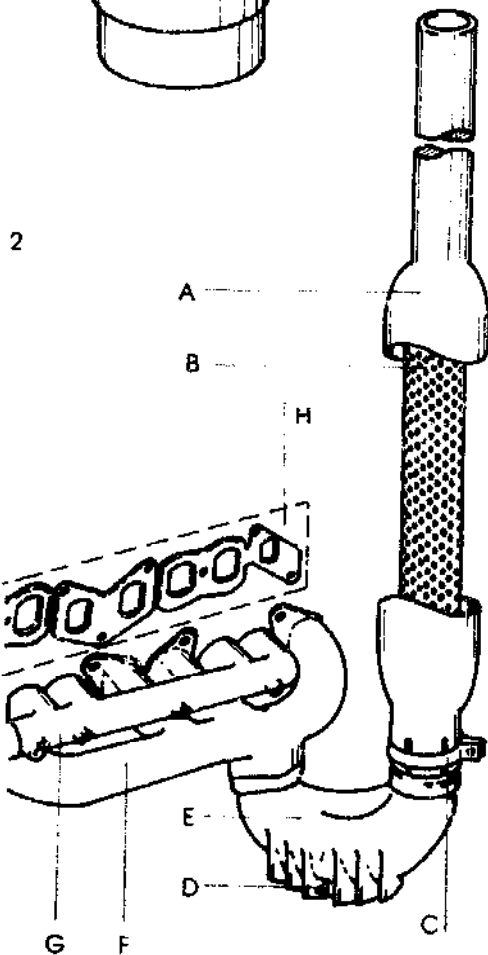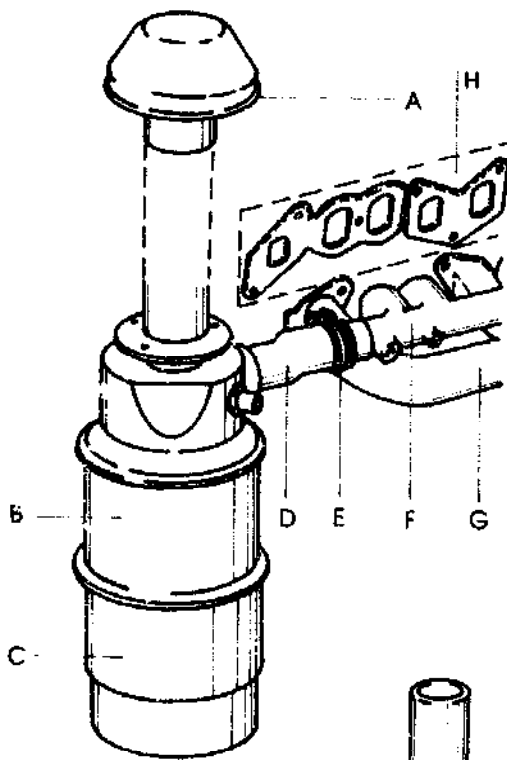
Air cleaners

When air is sucked into the cylinder during its inlet stroke, dust or other material may enter as well. Dry wind during the harmattan or dust blown by storms are a potential danger because they can cause severe wear on cylinders and pistons, leading to loss of power, higher oil consumption and possible clogging of the lube oil system.

To prevent these particles entering the cylinder, air is passed through a filter. Types of air filters are:

- *Dry filters*, where air passes through a porous paper element.
- *Oil bath filters*, where air passes over an oil surface and through a filter of meshed wire.

Pre-cleaners

Figure 1 shows a cross-section of a pre-cleaner, in which air passes through a gauze-protected container and then through a glass bowl where, through whirling action, the dust settles at the bottom of the glass bowl.

Dry filter

Figure 2 shows a cross-section of a typical dry filter assembly. Air enters the filter at 2-A and passes round the filter element. The air is then filtered through the element and leaves at 2-B. Figure 3 shows a paper filter.

Dry element air cleaners

Dry element air cleaners are used in engines with a high demand for more air. Figure 4 shows a cross-section of an air cleaner assembly in which air is directed into the cleaner at a high speed so that it sets up a centrifugal rotation, see 4-A, assisted by tilted fins attached to the end of the dry filter element. The air leaves the filter at 4-B to the manifold. The centrifugal action continues until the air reaches the far end of the cleaner housing, where the dust collects in a dust cap 4-C at the bottom of the housing.

Instead of a dust cap, a dust bowl can be installed as shown in Fig. 5. The bowl can be removed to take away the dust.
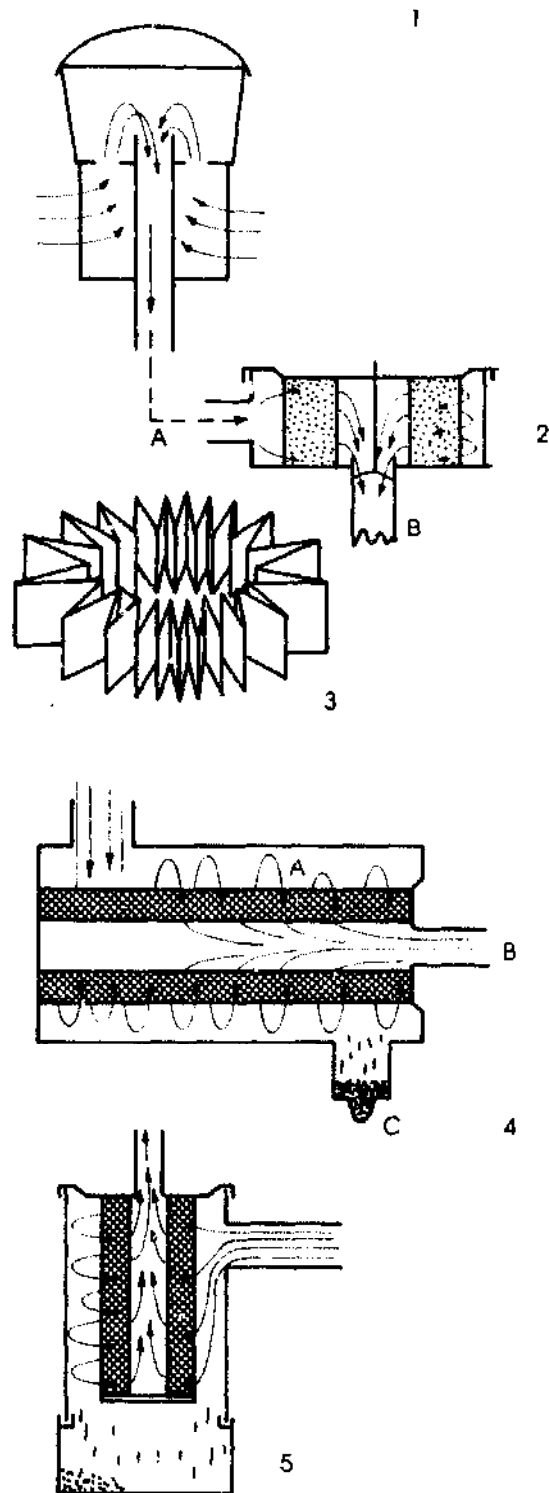
Light duty air cleaner
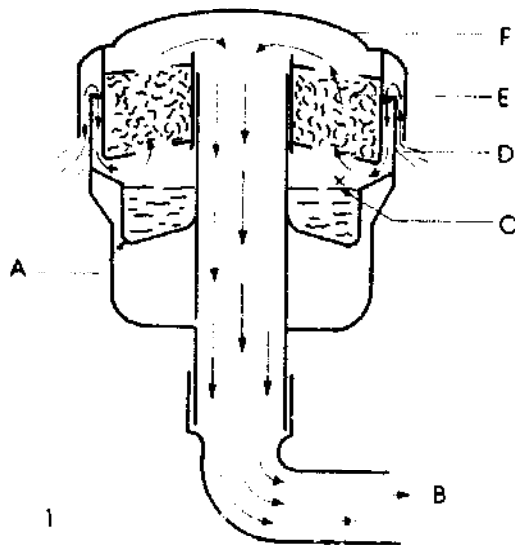
Figure 1 shows a cross-section of a light duty oil bath air cleaner. It consists of:
- Oil pan 1-A
- Air outlet to engine 1-B
- Oil bath 1-C
- Air inlet 1-D
- Meshed wire filter element 1-E
- Air filter assembly cover 1-F

The air cleaner may be loosened from the engine, after which the cover can be taken off and the filter element taken out. The oil sump has a level mark to which engine oil is filled. Air entering at 1-D first passes over the oil before it is sucked through the actual filter. The filter element in this kind of filter can be cleaned in kerosine and dried, after which it is soaked in clean engine oil and lowered so the excess oil drips out. Before assembling, fill the oil sump with clean engine oil to the level mark 1-X.

Heavy duty air cleaner
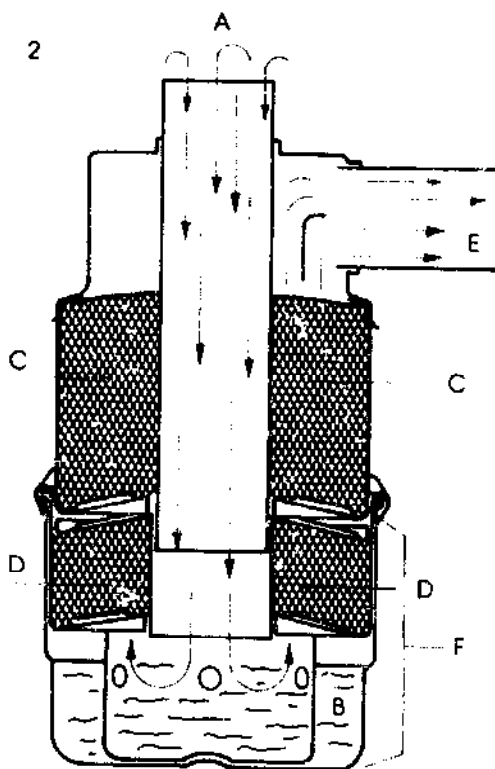
Figure 2 shows a partly opened heavy duty oil bath air cleaner. Air enters the filter through the tube 2-A and passes over the oil surface 2-B, from where it is sucked through a filter element 2-D at the top of the sump 2-F. From the filter element, the air is then sucked through a second filter in the top housing 2-C and leaves the air cleaner through the tube 2-E. This filter is not directly connected to the inlet manifold but connected with a rubber hose, so that it is not affected by vibration from the engine itself.

Miscellaneous

General safety precautions

- Keep a clean and well ventilated workshop.
- Keep all the tools in locked cupboards.
- Before working on an engine, check on all technical data in the workshop manual.
- Before dismantling an engine, make a clean space available in which all parts can be placed in correct sequence.
- Make the necessary notes about faults found in parts etc.
- Question the engine attendant before you attempt to work on the engine.
- After questioning, study the fault-finding chart for possible solutions.
- Ensure the engine is mounted securely.
- Ensure a general supply of air is available for the engine.
- Keep all safety guards in good condition.
- Keep hands and loose clothing away from air filters, shafts, belts, manifolds, fans and all other moving and hot parts.
- Do not smoke near starting batteries.
- Disconnect the battery before starting maintenance work (if installed).
- Do not allow the starting handle to rotate on the shaft.
- Keep all fuel and oil pipes free from chaffing.
- Do not allow rubber hoses to come into contact with the exhaust system.
- Never allow unprotected skin to come into contact with high pressure fuel oil – for example, when testing fuel injection equipment.
- Thoroughly remove any diesel fuel and lubricating oil from your skin as soon as practicable after contact.
- Rectify all fuel oil and water leaks as soon as practicable.
- Ensure the engine and surrounding area are kept clean.
- The lifting plates and eyes supplied on the engine are designed for carrying the engine and fitted accessories. They must not be used to lift complete assemblies such as a complete power unit.
- Check all fuel, oil and coolant levels before starting.
- When using a starting handle, hold the handle firmly with the thumb on top of the grip, not around it.
- When using a rope, do not wind the rope round your hand or wrist. Do not use a twisted or frayed rope or one that is contaminated with fuel or oil.

Guide to starting and running problems

1. Difficult starting

Fuel
- Overload trip/excess fuel device not operated
- Incorrect grade of fuel
- No fuel in tank
- Choked fuel filter
- Air lock in fuel system
- Injector nozzle valve stuck open
- Fuel pump delivery valve scored
- Sticking fuel pump rack
- Stop/start lever in wrong position
- Retarded injection

Compression
- Injector loose on seat
- Leaking valves
- Sticking piston rings
- Exhaust valve sticking
- Worn cylinder
- Choked air lifter
- Incorrect decompressor clearance

Cranking
- Unsuitable lube oil (too heavy)
- Load not disconnected
- Turning the crankshaft the wrong way

2. Knocking
- Valve, probably exhaust, sticking in guide and touching piston
- Worn connecting rod bush or bearing
- Worn gudgeon pin or small end bearing
- Insufficient clearance between piston and cylinder head
- Injection too early
- Flywheel coupling or pulley loose
- Too much crankshaft end float
- Excessive carbon deposit on piston
- Excessive clearance between piston and cylinder
- Engine loose on its mountings
- Wrong type of fuel

3. Excessive carbon deposits
- Choked air filter
- Choked exhaust system
- Unsuitable fuel oil
- Unsuitable lube oil
- Continuous idling
- Defective injector spraying
- Late injection of fuel
- Too much side clearance on valve rockers
- Low load running
- Low temperature running

4. Dark blue smoke
- Piston rings worn
- Cylinder bore worn

Faint blue smoke
- Light load

White smoke
- Water in the fuel supply
- Water in the cylinder combustion area

Black smoke
- Overload
- Choked air filter
- Inlet air temperature too high
- Defective injector spraying
- Unsuitable fuel oil or water in fuel

5. Engine stops
- Lack of fuel
- Choked air filter
- Inlet air temperature too high
- Defective injector spraying
- Excessive overload
- Over-heating
- Loss of compression
- Loss of oil

6. Loss of power
- Loss of compression
- Incorrect tappet clearance
- Choked air filter
- Choked exhaust filter
- Defective fuel pump or injector
- Choked fuel filter

7. Failure to attain normal speed
- Engine started at overload
- Fuel system not properly primed
- Insufficient fuel
- Injection retarded
- Governor out of adjustment
- Wrong type of governor weights etc. for speed expected

8. Loss of oil pressure
- Low oil level
- Strainer choked
- Fractured pipe or leaking joint
- Badly worn bearings
- Relief valve not seating
- Oil pump worn or drive failed
- Oil cooler choked
- Oil diluted with fuel
- Unsuitable lube oil (too thin)

Guide to starting and running problems (continued)

9. Overheating

Air cooled engines
- Cooling air being recirculated
- Fins of cylinder head or cylinder blocked with dirt
- Cooling air inlet obstructed
- Cooling air outlet obstructed
- Engine cooling air used to cool driven unit as well
- Overload
- Lube oil level too low
- Injection timing faulty

Water cooled engines
- Thermostat faulty
- Injection timing faulty
- Overload
- Cooling water level too low
- Lube oil level too low
- Water pump belt slipping
- Blockage in water cooling system

10. Low compression
- Injector loose on its seat
- Injector washer scored
- Piston ring caps in line
- Inlet or exhaust valve not seating
- Cylinder head gasket leaking

11. Hunting
- Tight spots on governor linkage
- Fuel pump rack not free
- Air in fuel system
- Faulty injector

12. High oil consumption
- Valve guides worn
- Piston rings worn
- Cylinder bore worn

13. Loss of crankcase vacuum
- Worn piston rings
- Worn cylinder barrel bore
- Worn oil seals
- Too much oil in the sump
- Oil filter cap not seating

14. Leaking oil seals
- Too much oil in the sump
- Loss of crankcase vacuum

Decarbonizing

Only a few engine manufacturers give a specific number of running hours after which decarbonizing should be carried out. The number of running hours depends on such factors as the type of fuel used, ambient temperature, period of low load running and others. Perhaps the best indication that carbonizing is due, is when the engine shows loss of compression or blow-by past the pistons. To decarbonize an engine thoroughly clean and examine for wear the following components, replacing any defective parts as necessary:
- Piston, piston rings and grooves and gudgeon pin
- The combustion chamber or cell
- Valves, valve springs, ports and seats
- Exhaust manifold, piping and silencer
- Inlet manifold and trunking
- Cylinder barrel, head and crankcase cooling fins
- Injector

Conversion factors

Length

	metre m	inch in	foot ft	yard yd
1 metre =	1	39.3701	3.2808	1.0936
1 inch =	0.0254	1	0.0833	0.0278
1 foot =	0.3048	12.00	1	0.3333
1 yard =	0.9144	36.00	3.00	1

Capacity

	UK pint pt	UK gallon gal	US pint pt	US gallon gal
1 UK pint =	1	0.1250	1.2009	0.1501
1 UK gallon =	8.00		9.6076	1.2009
1 US pint =	0.8327	0.1041	1	0.125
1 US gallon =	6.6614	0.8327	8.00	1

1 UK pint = 0.5683 litre
1 litre = 1.7598 UK pint

Volume

	cubic metre m^3	cubic decimetre dm^3	cubic inch in^3	cubic foot ft^3
$1\,m^3$ =	1	1000.0	61023.8	35.3147
$1\,dm^3$ =	0.001	1	61.0238	0.0353
$1\,in^3$ =	1.6387×10^{-5}	0.0164	1	5.7870×10^{-4}
$1\,ft^3$ =	0.0283	28.3168	1728.0	1

Linear velocity

	metre per second m/s	foot per second ft/s	foot per minute ft/m	inch per second in/s
1 m/s =	1	3.2808	196.85	39.3701
1 ft/s =	0.3048	1	60	12
1 ft/m =	0.0051	0.0167	1	0.2
1 in/s =	0.0254	0.0833	5	1

Rate of flow – mass

	kilogram per second kg/s	kilogram per hour kg/h	pound per second lb/s	pound per hour lb/h
1 kg/s =	1	3600	2.2046	7936.6
1 kg/h =	2.7777×10^{-4}	1	6.1239×10^{-4}	2.2046
1 lb/s =	0.4535	1632.9	1	3600
1 lb/h =	1.2599×10^{-4}	0.4535	2.7777×10^{-4}	1

Conversion factors

Rate of flow – volume

	cubic metre per second m³/s	litre per second l/s	cubic foot per second ft³/s	UK gallon per second gal/s
1 m³/s =	1	1000	35.3147	219.969
1 l/s =	0.001	1	0.0353	0.22
1 ft³/s =	0.0283	28.3168	1	6.2288
1 gal/s =	4.5460×10^{-3}	4.5461	0.1605	1

Pressure

	newton per square millimetre N/mm²	kilogram-force per square centimetre kgf/cm²	pound-force per square inch lbf/in²	pound-force per square foot lbf/ft²
1 N/mm² =	1	10.1972	145.038	20885.4
1 kgf/cm² =	9.8066×10^{-2}	1	14.2233	2048.16
1 lbf/in² =	6.8947×10^{-3}	0.0703	1	144
1 lbf/ft² =	4.788×10^{-5}	4.8824×10^{-4}	6.9444×10^{-3}	1

Pressure

	bar bar	atmosphere atm	kilogram-force per square centimetre kgf/cm²	pound-force per square inch lbf/in²
1 bar =	1	0.9869	1.0197	14.5038
1 atm =	1.0132	1	1.0332	14.6959
1 kgf/cm² =	0.9807	0.9678	1	14.2233
1 lbf/in² =	0.0689	0.068	0.0703	1

Pressure

	inch of water inH₂O	foot of water ftH₂O	millimetre of mercury mmHg	inch of mercury inHg
1 inH₂O =	1	0.0833	1.8683	0.0735
1 ftH₂O =	12	1	22.4198	0.8827
1 mmHg =	0.5352	0.0446	1	0.0394
1 inHg	13.5951	1.1329	25.4	1

Conversion factors

Torque (moment of force)

	newton-metre N m	kilogram-force metre kgf m	pound-force foot lbf ft	pound-force inch lbf in
1 N m =	1	0.102	0.7376	8.8507
1 kgf m =	9.8066	1	7.2330	86.7962
1 lbf ft =	1.3558	0.1382	1	12
1 lbf in =	0.1130	0.0115	0.0833	1

Energy

	kilowatt hour kWh	kilogram-force metre kgf m	foot pound-force ft lbf	horsepower hour hp h
1 kWh =	1	3.6709×10^{5}	2.6552×10^{6}	1.341
1 kgf m =	2.7240×10^{-6}	1	7.233	3.6530×10^{-6}
1 ft lbf =	3.7661×10^{-7}	0.1382	1	5.0505
1 hp p =	0.7457	2.7375×10^{5}	1.98×10^{6}	1

Power

	kilowatt kW	metric horsepower CV	brake horsepower bhp	British thermal unit per hour Btu/h
1 kW =	1	1.3596	1.341	3412.14
1 CV =	0.7355	1	0.9863	2509.63
1 bhp =	0.7457	1.0139	1	2544.43
1 Btu/h =	0.00029	3.9846×10^{-4}	3.9301×10^{-4}	1

Temperature

The unit of temperature most commonly used in practice in many countries is the degree Celsius (°C), though the terms Centigrade (°C) and Fahrenheit (°F) are still in use. The Fahrenheit scale is not formally defined, but it is generally recognized that the temperature difference of 1 °F is equal to five ninths of the temperature difference of 1 °C.

$$°F = \frac{9}{5}\,°C + 32$$
$$°C = \frac{5}{9}\,(°F - 32)$$

Metric prefixes

Prefix	Symbol	Factor by which the unit is multiplied
tera	T	1 000 000 000 000
giga	G	1 000 000 000
mega	M	1 000 000
kilo	k	1 000
hecto	h	100
deca	da	10
deci	d	0.1
centi	c	0.01
milli	m	0.001
micro	υ	0.000 001
nano	n	0.000 000 001
pico	p	0.000 000 000 001
femto	f	0.000 000 000 000 001
atto	a	0.000 000 000 000 000 001

Tightening torques for nuts and bolts

The table gives the torque in Nm and lbf ft for unified and ISO metric nuts and bolts. The unified ones are to BS1768: 1963 Grade S for bolts and Grade 3 for nuts, whilst the ISO metric are to BS3692: 1967 Grade 8.8 for bolts and Grade 10 for nuts.

	Diameter of thread	Threads per inch or mm pitch		Torque Nm	lbf ft
UNF, UNC (fine and course)	1/4"	28/20	thds/"	11.5	8.5
	5/16"	24/18		20.3	15.0
	3/8"	24/16		43.4	32.0
	7/16"	20/14		67.8	50.0
	1/2"	20/13		92.2	68.0
	9/16"	18/12		135.6	100.0
	5/8"	18/11		203.4	150.0
	3/4"	16/10		271.3	200.0
	7/8"	14/9		440.7	325.0
	1"	12/8		678.2	500.0
ISO	4 mm	–/0.7	pitch	3.0	2.2
	6 mm	–/1.0		8.8	6.5
	8 mm	1.0/1.25		21.0	15.5
	10 mm	1.25/1.5		40.7	30.0
	12 mm	1.25/1.75		78.7	58.0
	16 mm	1.5/2.0		196.7	145.0
	18 mm	1.5/2.5		271.3	200.0
	20 mm	1.5/2.5		393.3	290.0
	24 mm	2.0/3.0		678.2	500.0

Standard bolt and nut torque specifications

Thread size	260M bolt torque Nm	260M bolt torque (lb-ft)
1/4 – 20	9 – 9	5 – 7
1/4 – 28	8 – 11	6 – 8
5/16 – 13	14 – 18	10 – 13
5/16 – 24	15 – 19	11 – 14
3/8 – 16	31 – 35	23 – 26
3/8 – 24	35 – 40	26 – 29
7/16 – 14	47 – 51	35 – 38
7/16 – 20	58 – 62	43 – 46
1/2 – 13	72 – 76	53 – 56
1/2 – 20	84 – 95	62 – 70
9/16 – 12	92 – 102	68 – 75
9/16 – 18	109 – 119	80 – 88
5/8 – 11	140 – 149	103 – 110
5/8 – 18	171 – 181	126 – 134
3/4 – 10	244 – 254	180 – 188
3/4 – 16	295 – 305	218 – 225
7/8 – 9	417 – 427	308 – 315
7/8 – 14	483 – 494	356 – 364
1 – 8	590 – 600	435 – 443
1 – 14	697 – 705	514 – 521

Thread size	280M or better torque NM	280M or better torque (lb-ft)
1/4 – 20	10 – 12	7 – 9
1/4 – 28	11 – 14	8 – 10
5/16 – 18	18 – 23	13 – 17
5/16 – 24	20 – 26	15 – 19
3/8 – 16	41 – 47	30 – 35
3/8 – 24	47 – 53	35 – 39
7/16 – 14	62 – 68	46 – 50
7/16 – 20	77 – 83	57 – 61
1/2 – 13	96 – 102	71 – 75
1/2 – 20	113 – 126	83 – 93
9/16 – 12	122 – 136	90 – 100
9/16 – 18	146 – 159	107 – 117
5/8 – 11	186 – 200	137 – 147
5/8 – 18	228 – 242	168 – 178
3/4 – 10	325 – 339	240 – 250
3/4 – 16	393 – 407	290 – 300
7/8 – 9	556 – 569	410 – 420
7/8 – 14	644 – 657	475 – 485
1 – 8	786 – 800	580 – 590
1 – 14	928 – 942	685 – 695

Useful terminology

Abrasion: The wearing or rubbing away of a metal surface.

Air cleaner: Various types of device for removing particles of dust from air before it enters the engine.

Ambient temperature: The mean temperature of the combustion and cooling air entering the engine.

AP: The American Petroleum Institute.

Atmospheric pressure: The weight of air at sea level, this is usually taken as being 1 Bar or 14.7 lbs/in^2.

Backlash: The clearance or movement between the teeth of meshed gears.

Back pressure: A resistance to free flow, such as the restriction in an exhaust line.

Balancing fuel pumps: In multi-cylinder engines with single-element pumps the pump racks are adjusted to enable all pumps to deliver a similar amount of fuel.

Bearing: A precision finished surface that allows another part to turn or move against it.

B.h.p.: Brake horse-power is the measurement of the total power of the engine available at the flywheel.

Blow-by (past): The loss of compression past the piston rings.

Bore: The internal diameter of the cylinder barrel.

BS (I): British Standard (Institution).

Bypass: Usually used as an alternative route for oil when the filter is blocked.

Calibration marks: Marks on the fuel pump or pump rack to show when the pump is delivering optimum fuel.

Camshaft: The camshaft is timed to the crankshaft and cams operate the inlet and exhaust valves.

Celsius: Celsius has generally replaced centigrade, though the two are identical.

Cetane: The term used to show the pressure and temperature at which fuel ignites and burns.

Combustion: The process of burning.

Combustion chamber: The space between the underside of the cylinder head and the top of the piston when it is at the top of its stroke.

Compression: The reduction in volume of a gas by squeezing.

Compression ratio: The total volume of air in the cylinder compared to the volume in the combustion chamber, for example 16:1.

Connecting rod: The part which connects the piston to the crankshaft.

Constant speed: An engine with its governor adjusted to give one speed only.

Crankcase: The lower casting of the engine which contains the camshaft, bearings, crankshaft, oil etc.

Crankcase breather: A method used to maintain a crankcase vacuum.

Crankcase (sump) dilution: When fuel finds its way into the oil and dilutes it.

Crankcase pressure: Usually caused by combustion gases finding their way into the crankcase.

Crankcase vacuum: A slight vacuum in the sump is required to prevent oil seals and joints leaking oil. A vacuum is sometimes called negative pressure.

Crankshaft: The main drive shaft of the engine which transforms reciprocating motion into rotary motion.

Crankshaft counterweights: Either an integral part of or bolted onto the crankshaft to offset the weights of the piston and connecting rod.

CV: Cheval Vapeur (Metric Horse Power). Also known as CH in some countries.

Cyclic irregularity: Indicates the degree by which the flywheel varies from uniform rotary motion.

Cylinder: The component the piston is fitted into. Often called the barrel in air cooled engines and the block in water cooled engines.

Cylinder bore: The internal diameter of the cylinder.

Cylinder head: Fits onto the top of the cylinder and contains the valves, injector ansd manifold ports.

Decarbonize: Removal of the build-up of carbon from the piston and heads.

DEMA: American equivalent of BS.

De-rating: At certain site levels and temperatures the oxygen content of the air is less and the load must therefore be reduced to compensate.

Detergent: An additive used in lubricating oils to hold deposits of carbon in suspension and to help prevent frothing. The oil is usually referred to as having a mild or heavy duty detergent.

DIN: German equivalent of BS.

Diesel engine: This type of engine is called a compression ignition engine as the fuel is ignited by the heat of compression without the need of a spark.

Direction of rotation: Looking onto the flywheel, this is the way the engine is turning.

Dynamometer: Test equipment used to measure energy expended from an engine or mechanical force.

Exhaust: The waste products of combustion.

Exhaust manifold: The component used to collect the exhaust gases to pass them to the silencer.

Exhaust valve: A spring-loaded valve operated from the camshaft to allow the exhaust gases in the cylinder to pass out at the correct time.

Excess fuel device: An automatic or manual method of moving the fuel pump rack to allow extra fuel to pass through the fuel pumps for starting.

Filter (oil, water, fuel): A device for removing particles of dirt from the fluids to protect the engine components concerned.

Flash point: The temperature at which a liquid or vapour will ignite when heated.

Flywheel: The flywheel is used mainly to provide the rotary motion for the driven unit; it also helps to reduce the variation in the speed of the crankshaft which is caused by the reciprocating motion of the cylinders.

Four-stroke cycle: The crankshaft turns twice but the cylinder fires only once.

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

FP: Firing point, when fuel is sprayed into the combustion chamber.

Fuel consumption: The amount of fuel used by the engine to give a certain output rating.

Glazed bore (see also Polished bore): Used to describe the surface of a cylinder barrel bore when it has become extremely smooth and polished. Usually asssociated with using the wrong type of oil.

Governor: A device to control the speed of the engine by regulating the amount of fuel passing through the fuel pumps.

Gudgeon pin: Used to connect the piston to the connecting rod and held in position by two circlips.

Heat exchanger: Only used on water cooled engines to cool the water after it has circulated round the system. Works in a similar way to a radiator but uses colder water instead of the fan and air flows.

Hertz (Hz): Unit of frequency. The number of repetitions of a regular occurrence in one second.

Humidity: The measure of the percentage of water vapour held in suspension in the air.

Hunting: Often caused by a fuel pump rack or governor with tight spots resulting in the speed of the engine increasing and decreasing over a wide range.

Idling speed: The lowest speed setting on a variable speed engine.

Injection pump: A single-element or multi-cylinder pump used to meter and deliver fuel under pressure to the injector.

Injector: Used to inject atomized fuel into the combustion chamber at a very precise moment.

Injector leak off: A small diameter pipe allowing excess fuel from the injector to be fed back to the engine fuel tank.

Injector set pressure: The pressure at which the injector valve opens. This is adjustable and is controlled by an internal spring.

Inlet manifold: The casting which carries the combustion air from the air cleaner to the cylinder head.

Inlet valve: A spring-loaded valve operated from the camshaft to allow the combustion air to enter the cylinder barrel at the correct time.

Intercooler: A method of cooling the combustion air charge in some turbo-charged engines.

Internal combustion: The process of burning the air/fuel mixture in an enclosed chamber.

ISO: International Organization for Standardization.

Journal: The part of the crankshaft which runs in the main and connecting rod bearings.

Lapping: The process of rubbing two surfaces with an abrasive material until a seal is formed, as is performed with a valve and valve seat.

Lbf ft: Pounds-force feet.

Manometer: An open ended U-shaped tube partly filled with a liquid used to measure a vacuum.

Mechanical efficiency: The ratio between the indicated and the brake horse power of an engine.

Micrometer: An instrument to measure external or internal dimensions.

MIL.: American military standards as applied to lubricating oils.

Nm: Newton metres.

Overload: The amount of load given by the engine above its rated load.

Piston ring: A ring fitted into a piston ring groove to prevent gases or oil passing.

Polished bore (see also Glazed bore): A term used to describe the cylinder barrel bore when it has become smooth and polished, usually after the engine has run for a high number of hours.

P.s.i.: Pounds per square inch.

Pumping oil: A term describing the condition when an engine is using an excessive amount of lube oil.

Push rod: A metal rod operating from the camshaft to open and close the inlet and exhaust valves.

Rated load: The amount of power the engine is designed to deliver at a given speed.

Radiator: A series of enclosed pipes through which the engine water passes to enable air, which is fan driven across the pipes, to dissipate the heat.

Rotary motion: A circular movement such as the rotation of the crankshaft.

R.p.m., rev/min, r/min: Revolutions per minute.

SAE: Society of Automotive Engineers.

SI: System International.

Sludge: A composition of oxidised petroleum products and contaminants usually found in the crankcase oil sump or fuel tank.

Stroke: The distance the piston moves from its highest to lowest points.

Tachometer: An instrument for measuring the speed of an engine.

Tappet: The component which operates the fuel pump from the camshaft.

Tappet clearance: The clearance between the valve stem and the valve rocker arm.

TDC: Top Dead Centre.

Thermostat: A device used to regulate the flow of water from a cylinder block to the radiator or heat exchanger.

Throw: The distance between the centres of the crankshaft and connecting rod journals.

Thrust washer: A flat bearing surface fitted between a shaft and its housing to absorb any thrust.

Timing marks: Marks used to show the crankshaft and other driven gears are correctly aligned to ensure the valves and fuel pumps operating at the correct time. Marks on the flywheel show when the piston is at TDC or FP.

Torque: The effort of turning.

Torque wrench: An adjustable spanner or wrench to measure the applied turning force being put onto a bolt head or nut.

Turbo-charger: An engine-mounted device using the engine exhaust to drive a rotor and turbine to enable a larger combustion air charge to be delivered to the combustion chamber, resulting in a higher b.h.p. being obtained.

Vacuum: A term used to describe a pressure less than atmospheric pressure. Also known as negative pressure or, in case of an engine, crankcase depression.

Valve bounce: Occurs when the valve does not seat correctly and opens and closes fractionally.

Valve clearance: The distance between the valve stem and valve rocker when the engine is at TDC on the compression stroke.

Valve grinding: See lapping.

Valve guide: A bush through the cylinder head into which the valve fits.

Valve seat: The matched surface in the cylinder head onto which the valve seat mates.

Valve seat cutting. A process used to cut the untrue surface of the valve seat until it is correct to the profile of the valve head.

Variable speed engine: An engine designed to run at various speeds throughout a pre-determined range.

Viscosity: The resistance to flow of a liquid. The viscosity of oil is denoted by numbers, for example 10W, 20W, 30W etc.

Viscous damper: A device usually fitted to larger multi-cylinder engines to reduce the twisting or torsional vibration of the crankshaft.

Wrist pin: See gudgeon pin.

Contents