Subject :Internal combustion engines design	**موضوع: تصميم مكائن الاحتراق الداخلي**
Weekly Hours: Theoretical: 2	**الساعات الأسبوعية: نظري :2**
Tutorial: 1	**مناقشة: 1**
Experimental : 1	**عملي:1**
Units: 4	**الوحدات : 4**

week	**Contents**	**المحتويات**	**الأسبوع**
1.	Dynamic force activity on I.C.E	القوى الديناميكية المؤثرة على محرك الاحتراق الداخلي	.1
2.	=	=	.2
3.	=	=	.3
4.	=	=	.4
5.	Cylinder block design, materials	تصميم كتلة المحرك	.5
6.	=	=	.6
7.	Cylinder lining, types, design, materials	بطانة الاسطوانة، التصميم، المواد	.7
8.	=	=	.8
9.	=	=	.9
10.	Cylinder head, design, materials	رأس الاسطوانة، التصميم، المواد	.10
11.	=	=	.11
12.	=	=	.12
13.	Hold-down studs calculations	حسابات براغي تثبيت رأس الاسطوانه	.13
14.	=	=	.14
15.	=	=	.15
16.	Valves calculations	حسابات الصمامات	.16
17.	=	=	.17
18.	=	=	.18
19.	Pistons, types, design, material, rings	المكابس، الانواع، التصميم، المواد، حلقات المكبس	.19
20.	=	=	.20
21.	=	=	.21
22.	Connecting rod, analysis, design, materials	اذرع التوصيل، التحليل، التصميم، المواد	.22
23.	=	=	.23
24.	=	=	.24
25.	Crank shaft, design, material	المحور القلاب، التصميم، المواد	.25
26.	=	=	.26
27.	=	=	.27
28.	Bearing calculations	كراسي التحميل	.28
29.	=	=	.29
30.	Combustion chambers, design	تصميم غرف الاحتراق	.30

Subject: Design of Internal Combustion Engine

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<u>Content</u>

Design of internal combustion engines

Introduction:-

As the name implies, the internal combustion engines (briefly written as I.C. engines) are those engines in which the combustion of fuel takes place inside the engine cylinder. The I.C. engines use either petrol or diesel as their fuel. In petrol engines (also called *spark ignition engine* or S.I. *engines*) , the correct proportion of air and petrol is mixed in the carburetor and fed to engine cylinder where it is ignited by means of a spark produced at the spark plug. In these engines (also called *compression ignition engines or C.I. engines),* only air is supplied to the engine cylinder during suction stroke and it is compressed to a very high pressure, thereby raising its temperature train from 600°C to 1000°C. The desired quantity of fuel (diesel) is now injected into the engine cylinder in the form of a very fine spray and gets ignited when comes in contact with the hot air.

The operating cycle of an I.C. engine may be completed either by the two strokes or four strokes of the piston. Thus, an engine which requires two strokes of the piston or one complete revolution of the crankshaft to complete cycle, is known as *two stroke engine.* An engine which requires four strokes of the piston or two complete revolutions of the crankshaft to complete the cycle, is known *a four stroke engine.*

The two stroke petrol engines are generally employed in very light vehicles such as scooter motor cycles and three wheelers. The two stroke diesel engines are generally employed in marine propulsion.

The four stroke petrol engines are generally employed in light vehicles such as cars, jeep and also in aeroplanes. The four stroke diesel engines are generally employed in heavy duty vehicles such as buses, trucks, tractors, diesel locomotives and in earth moving machinery.

Classification of I.C. engines:-

The reciprocating piston engines can be classified as under:

(1) With regard to the fuel used in them:-

(i)Petrol or gasoline engines in which petrol or petrol gas is used;

(ii) Diesel engines in which diesel is used as fuel.

(2) With regard to the method of ignition in the engines:-

(i) Spark ignition engines in which ignition takes place by means of an electric spark.- Petrol engines are spark ignition engines.

(ii) Compression ignition engines in which the injected fuel is ignited due to the temperature of compressed air in the cylinder. Diesel engines are compression ignition engines.

(3) With regard to their cycle of operation:-

(a) Otto cycle engines or constant volume cycle engines. The Otto cycle comprises of the following events taking place one after the other: (i) Suction of fuel air mixture inside the cylinder;(ii) Compression of fuel air mixture; (iii) Ignition; (iv) Power impulse action (working); (v) Exhaust of burnt gases.

The engines which work on this cycle are known as Otto Cycle engines. In Otto Cycle, combustion takes place at constant volume as whole of the fuel is burned instantaneously as an explosion. Hence engines which work on Otto cycle are known as constant volume cycle engines. Petrol engines are Otto cycle engines.

(b) Diesel Cycle Engines or Constant Pressure Cycle Engines which work on diesel cycle or constant pressure cycle. In diesel cycle, the combustion takes place at constant pressure because burning takes place gradually without an explosion as the fuel enters. Hence this cycle is known as constant pressure cycle. In diesel cycle, the following events take place one after the other:- (i) Suction of only air; (ii) Compression of air; (iii) Injection of fuel; (iv) Action of power impulse (working); (v) Exhaust of burnt gases.

Diesel engines work on this cycle.

(4) With regard to the number of strokes per cycle:-

(i) Two stroke engines in which all the events of the cycle are completed in two strokes of the piston.

(ii) Four stroke engines in which all the events of the cycle are completed in four strokes of the piston.

(5) With regard to the type of cooling system of the engine:-

(i) Air cooled engines which are cooled by air. Air cooled engines contain fins around the cylinders, cylinder heads and exhaust ports etc. to provide more area for better radiation of heat.

(ii) Liquid or water cooled engines in which some liquid or water is used to cool them. These engines contain water jackets around the cylinders, combustion chambers and valve ports etc. A radiator is provided with them to cool down hot water.

(6) With regard to the number of cylinders in the engines:-

(i) Single cylinder engines which contain only one cylinder.

(ii) Multi cylinder engines which contain more than one cylinder.

(7) With regard to the shape of the engines:-

(i) In-line engines in which the cylinders are in one line or row.

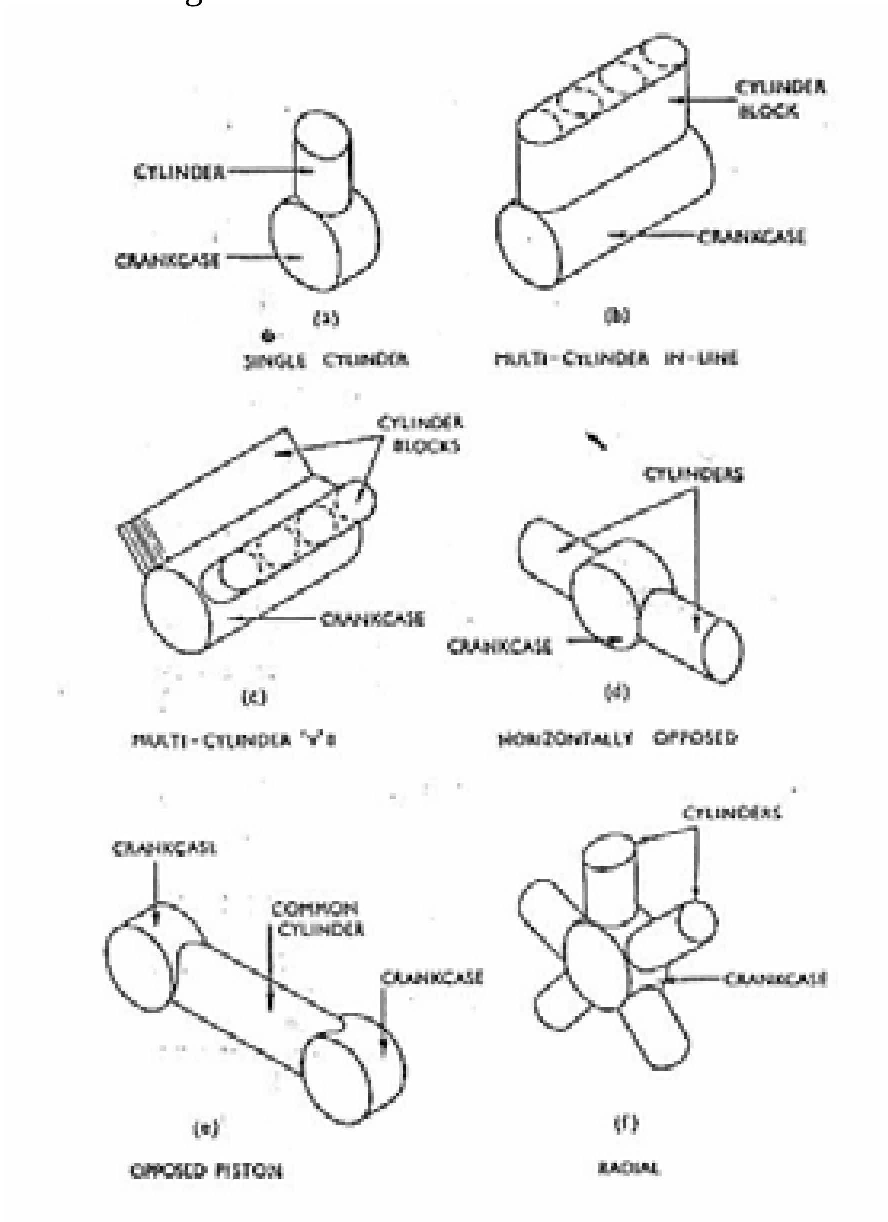
(ii) V-shaped engines in which the cylinders are placed in two rows. If centre lines are drawn in both rows of the cylinders, these will meet at the bottom forming the shape of 'V' and hence the 'V' shaped engine.

(iii) Opposed cylinder engines in which the cylinders are opposite to each other and the crankshaft is placed between them. These are multi cylinder engines and contain even number of cylinders, half the number on opposite direction to the other.

(iv) Radial engines in which the cylinder radiate from a common centre like the spokes of a wheel.

(8) Application:-

1. stationary engine,
2. automotive engine,
3. marine engine,
4. aircraft engine,
5. locomotive engine.



Engine Design

-Basic decisions and preliminary analysis:-

The decision to design and build a new engine should be taken only after the most careful consideration, which should result in answers to the following questions:

1. Reason for a new design: The reason for a new design may be very definite, such as
   b. Government or private contract,
   c. A vehicle with power requirements not satisfied by engines currently available,
   d. The hope of competing successfully with existing engines used for the same purpose.

2. Type of service:- The requirements of different types of service differ so widely that every engine must be designed with the intended type of major service in view. Success is very unlikely for designs not specifically oriented toward a particular service or group of services.

3. Type of fuel:- The fuel to be used must be one that is always available in suitable quantities and at reasonable cost. In the case of spark ignition road vehicle, the choice narrows to the petrol or propane-butane mixture gas fuels. In the case of diesel engines for road vehicle, the type of diesel oil available at roadside must be used. This is usually a light or medium grade. On the other hand, large marine diesels are forced to use very heavy oils for economic reason.

4. General service requirements:- every successful engine must have to a reasonable degree the general characteristics:-
   a. light weight,
   b. small bulk for a given power,
   c. good fuel economy,
   d. low initial cost,
   e. reliability,
   f. low maintenance requirements,
   g. long life.

5- Service overlapping:- If an engine services are overlapped (e.g. to be used for passenger cars, power generation etc), it is possible that manufacturing costs are lowered because of the consequent large production rate.

6- Power requirements:- When designing a new engine, one should keep in mind to obtain a maximum power from this engine which has a particular

cylinder capacity. It should not also be of less power than the competitive engines designed for same use. Future improvement on the design for increasing the power is an important factor to be considered too. For example, improving the cylinder head design will give a better engine breathing and improves the combustion process.

7- Fuel economy:- This factor to be considered when the engine consumes a great deal of expensive, good quality fuel when running it continuously for long time. The fuel economy factor becomes less important when the engine provides an occasional services.

2- stroke or 4-stroke cycle:-

The choice is usually based on the applications. The 2-cycle engines have a wide applications for small spark ignition engines and medium to large diesel and gas engines.

The small spark ignition 2-cycle engine is generally used for motorcycles, motorboat-engine (where it dominates the field) and as a light, portable engine for grass mowers, chain saw, etc. These applications have the following features in common:-

1. low first cost,
2. low use factor,
3. low weight/power ratio.

The specific output (power/weight) is generally somewhat higher than that of the competing 4-stroke type, so that cost and weight are basically lower for a given power.

On the other hand, the fuel economy is poorer by at least 25% on account of wastage of carbureted mixture during scavenging. For this reason the type predominates only where the use factor is low and fuel economy is not critical.

Disadvantages, in addition to poor fuel economy, are irregular idling and light-load operation, and relatively high oil consumption, especially when the lubricating oil is mixed with the fuel.

The 2-stroke spark ignition engines have a reputation for difficult starting. This disadvantage has been largely overcome by technical advances. Application of the 2-stroke engine to passenger automobiles is restricted to a very few manufacturer. The 4-stroke engine seems much more suitable due to its better idling and light-load operation and its better fuel economy.

In the case of 2-stroke diesel engines the simple crankcase-scavenging system is not suitable, because the relatively low fuel-air ratios at which diesel engines operate gives relatively low mean effective pressures with this system.

In adopting a separate scavenging blower, much or all of the cost advantage of the crankcase-scavenged engine is lost as compared with an unsupercharged 4-stroke engine.

The 2-stroke diesel engines are not common due to the following reasons:

1. the manufactures have greater background experience in 4-stroke engine design.
2. the development work to achieve good scavenging in a new 2-stroke design is likely to be greater than that required for good air capacity in a 4-stroke design.

3- unless simple loop-scavenged cylinders are used, the 2-stroke engine design is no less complex than the 4- stroke engine

4- most 2-stroke diesels have slightly poorer fuel economy than their 4-strokes competitors.

In the case of spark ignited natural gas engines, there are many 2-stroke types. Since the gas is injected after scavenging. There is no loss of fuel during the scavenging process. For engines of equal size, the fuel consumption of the 2-stroke engine is higher than the 4-stroke engine.

Principle parts of an I.C. Engine:-

The principle parts of an I.C. engine, as shown in Fig. are as follows:

1. Cylinder block, cylinder head and cylinder liner,
2. Piston, piston rings and piston pin or gudgeon pin.
3. Connecting rod with small and big end bearing,
4. Crank, crankshaft and crank pin, and

5. Valve gear mechanism.

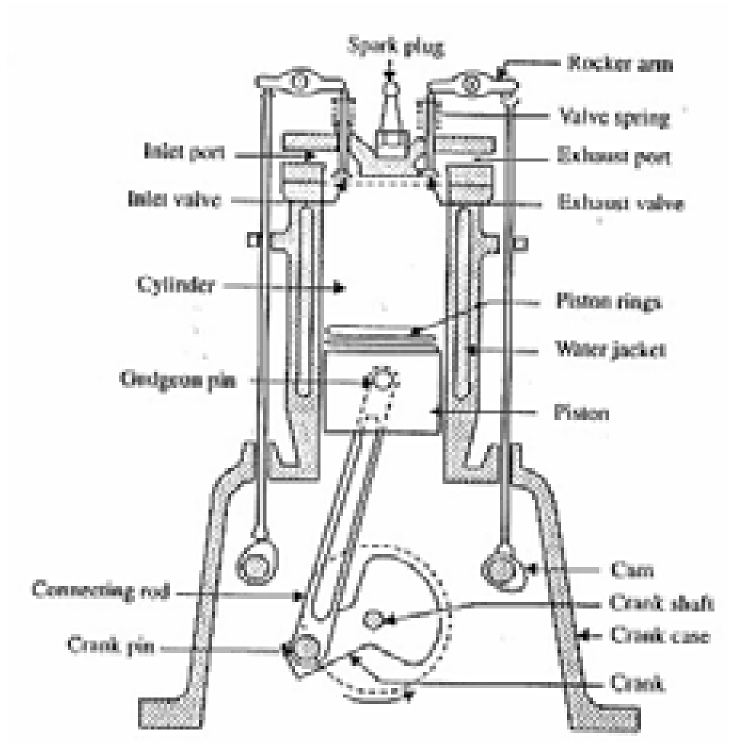


Fig.. Internal combustion engine parts.

Cylinder block construction:

1. The cylinder block (fig.1):

The cylinder-block assembly is the casting housing the cylinders, the crankshaft, and (depending on the design) the camshaft which controls the inlet and exhaust valves.

Within the cylinders, combustion produces rapid and periodic rises in temperature and pressure. These will induce circumferential and longitudinal tensile stresses - that is, around the cylinder and in the direction of the cylinder axis - see fig.1.

The reaction to the gas pressure is shown by the arrows tending to stretch longitudinally the set-bolts of the cylinder head and the main-bearing housing at the opposite ends of the cylinder block. Simultaneously the gas tries to expand outwards against the cylinder walls, so a plan section view of the cylinder walls would show a ring subjected to tensile circumferential stresses trying to expand the cylindrical sleeve. These induced stresses will be of a pulsating nature, so the cylinder will be continuously stretching and contracting while in operation.

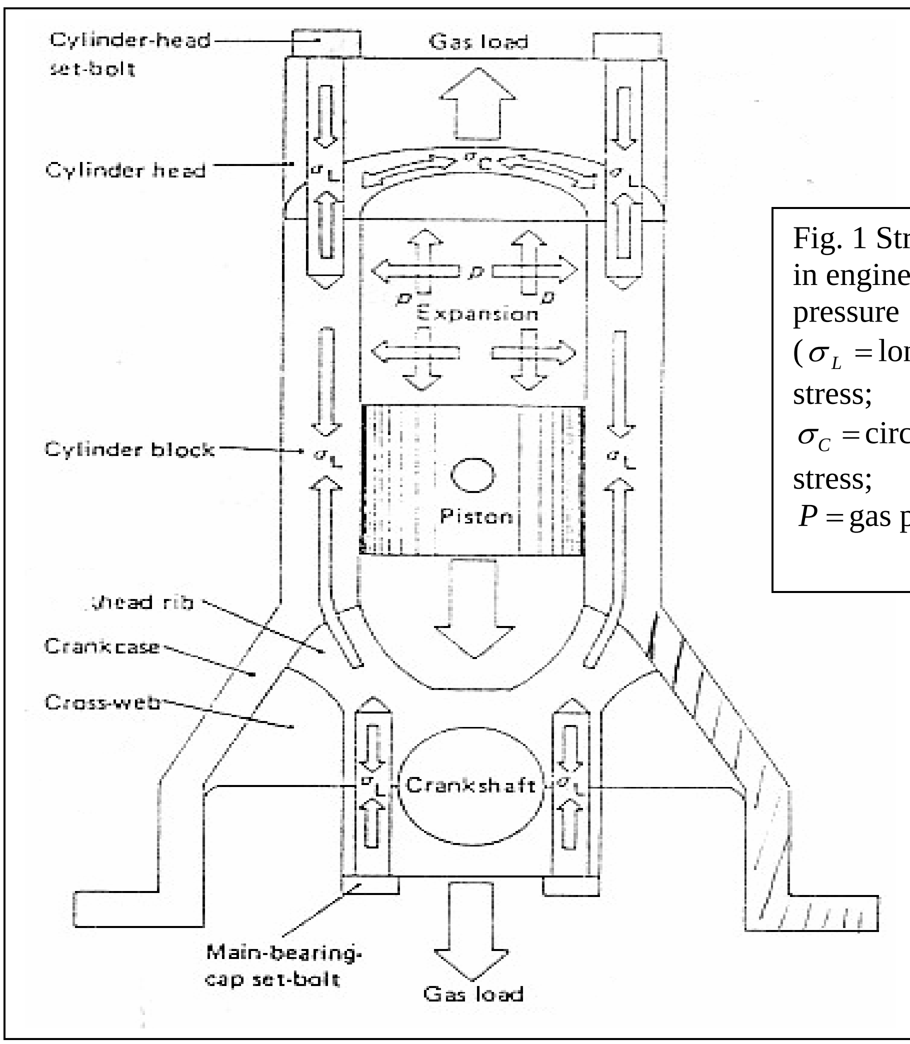


Fig. 1 Stress distribution in engine due to gas pressure (σ_L = longitudinal stress; σ_C = circumferential stress; P = gas pressure)

1.1 In-line cylinders (figs 2 to 5):

The in-line cylinder-block assembly can have several variations. One is a separate cylinder head with a single monobloc casting forming an integral cylinder block and crankcase (figs 2 and 3). Alternatively, the cylinder block and crankcase may be separate castings (fig. 4), or there may be separate crankcase with the cylinder head and block forming an integral single casting (fig. 5).

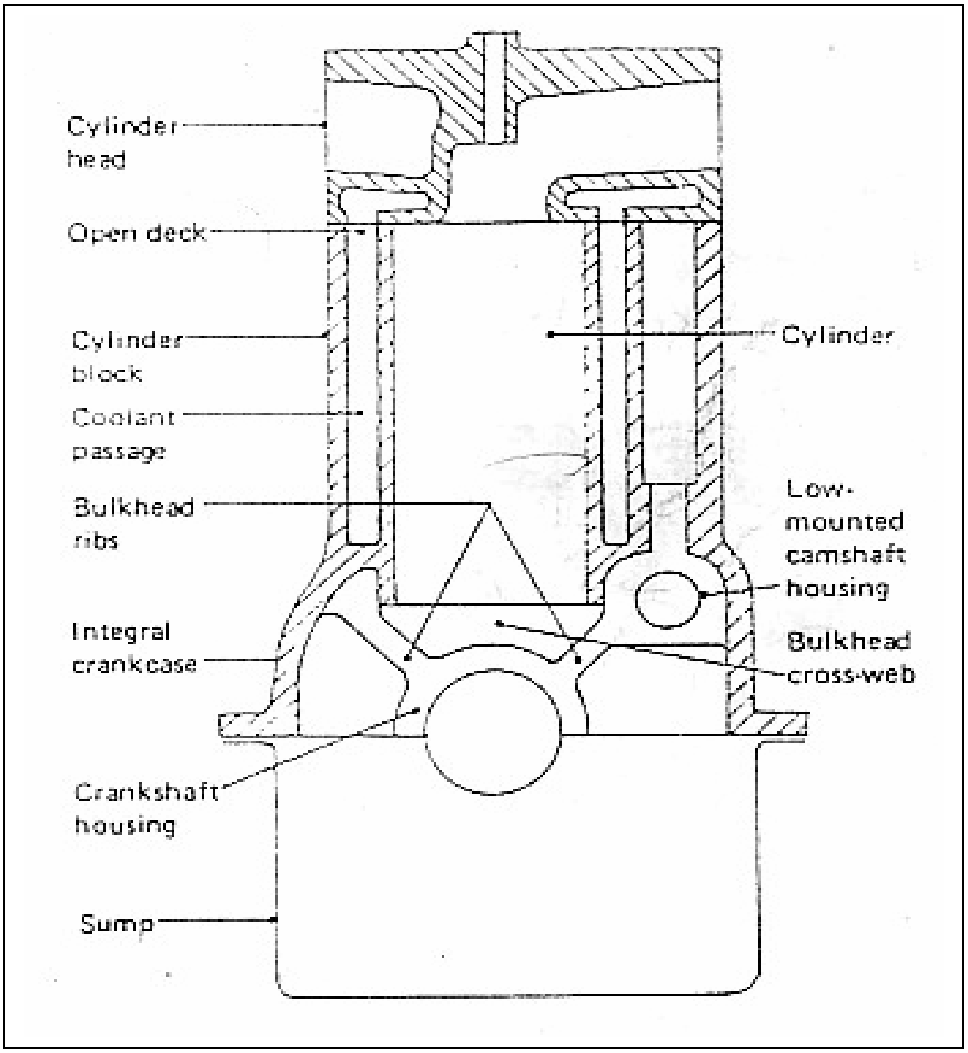


Fig. 2 Monobloc cylinder block and crankcase with low-mounted camshaft and open-deck coolant jackets.

The monobloc cylinder block and crankcase is the most popular arrangement for small and medium sized engines since it is relatively easy to cast, is cheap to produce, and produces a very stiff combined structure. The detachable bolt-on crankcase is used on some large diesel engines where, to save weight, an aluminum-alloy crankcase is bolted on to a cast-iron block. The combined head -and cylinder-block casting

with a bolt-on crankcase has been used for heavy-duty diesel-engine applications to minimise thermal distortion where the cylinder head meets the top of the cylinder bores, which is always a major consideration in design.

Alternative cylinder configurations which may be preferred are horizontally opposed cylinders and V-banked cylinders.

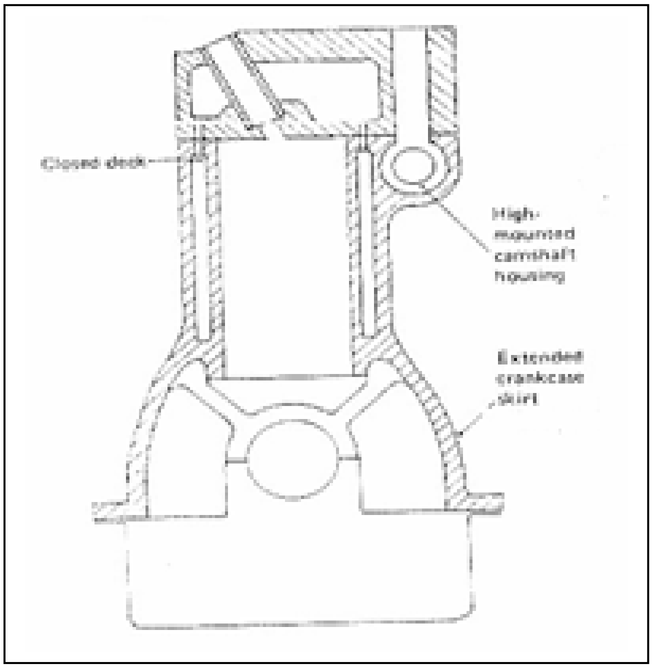


Fig. 3 Monobloc cylinder block and crankcase with high mounted camshaft and closed-deck coolant jackets.

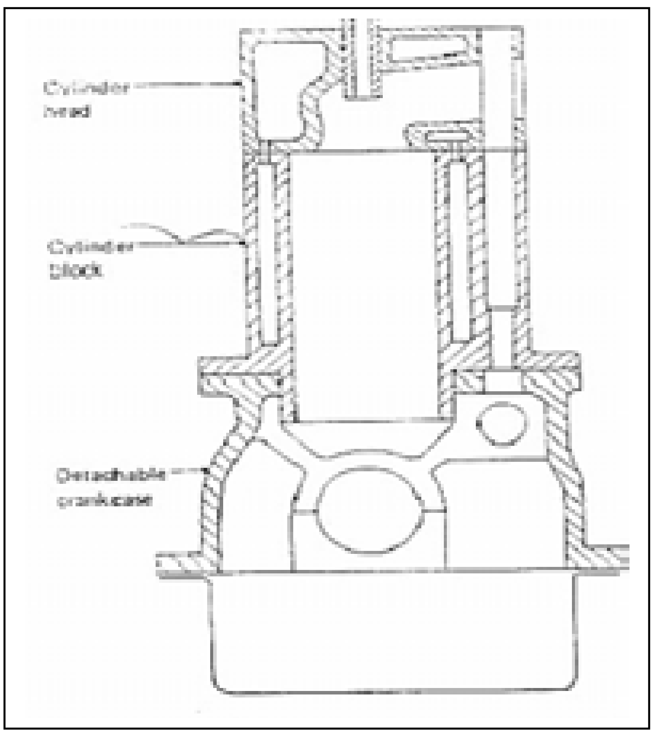


Fig. 4 cylinder block with detachable crankcase and crankcase-mounted camshaft

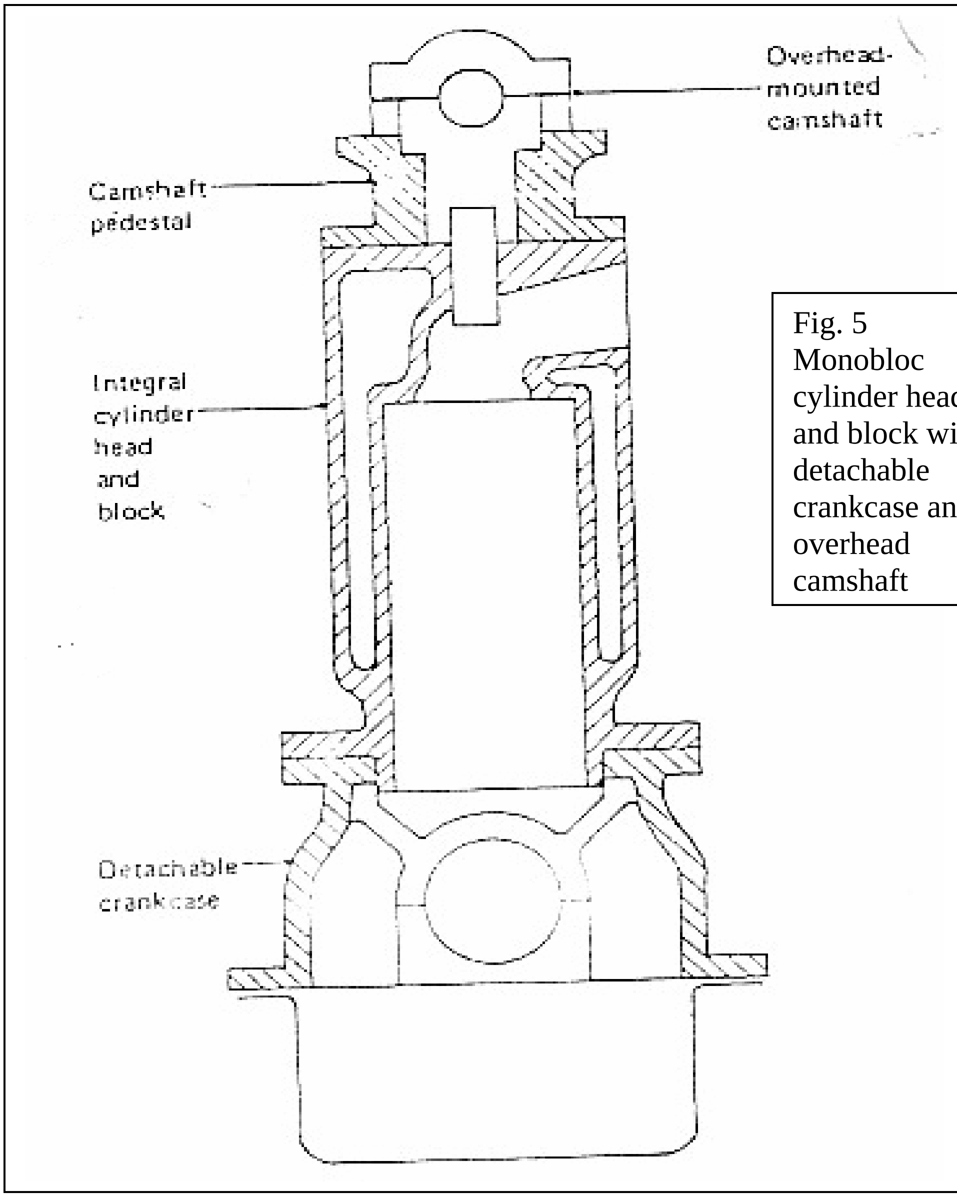


Fig. 5
Monobloc cylinder head and block with detachable crankcase and overhead camshaft

1.2. Horizontally opposed cylinders (figs 6 and 7)

To enable the engine to be assembled and dismantled, horizontally opposed cylinders may have either a separate crankcase with banks of two or three cylinders bolted on opposite sides (fig. 6) or two half integral cylinder-black-and-crankcase banks bolted together (fig. 7). There may be a central camshaft to actuate the valve push-rods, or two

camshafts - one for each bank -- may be more appropriate for high performance.

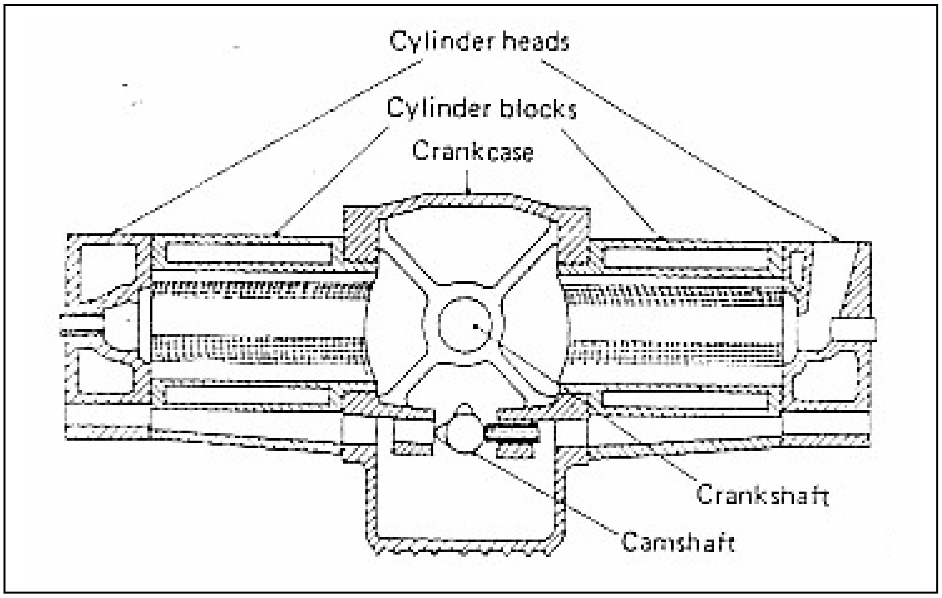


Fig. 6 Horizontally opposed cylinders with detachable crankcase.

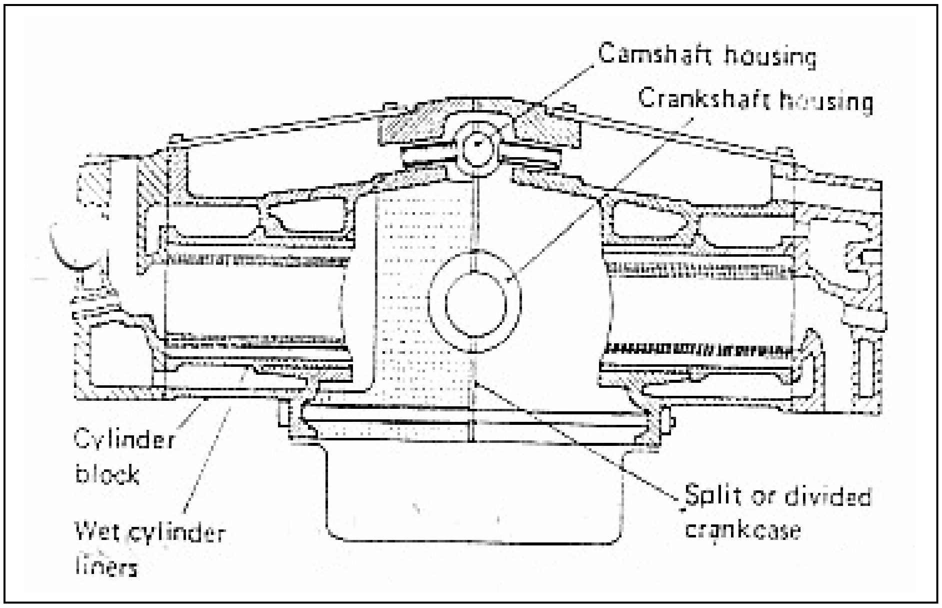


Fig. 7 Horizontally opposed cylinders with divided crankcase.

1.3 V-banked cylinders (figs 8 and 9)

For engine cylinder capacities of 2.5 litre or above, the most compact and rigid arrangements use V-banked cylinders. The most common angle between banks is 60° for four- and six-cylinder engines, while 90° is preferred for eight-cylinder engines.

It is usual to have an integral cylinder block and crankcase, with a central camshaft which actuates the valves in each cylinder bank (fig. 8). In some installations for heavy-duty diesel engines, a separate crankcase may be used, with a separate camshaft for each bank (fig. 9).

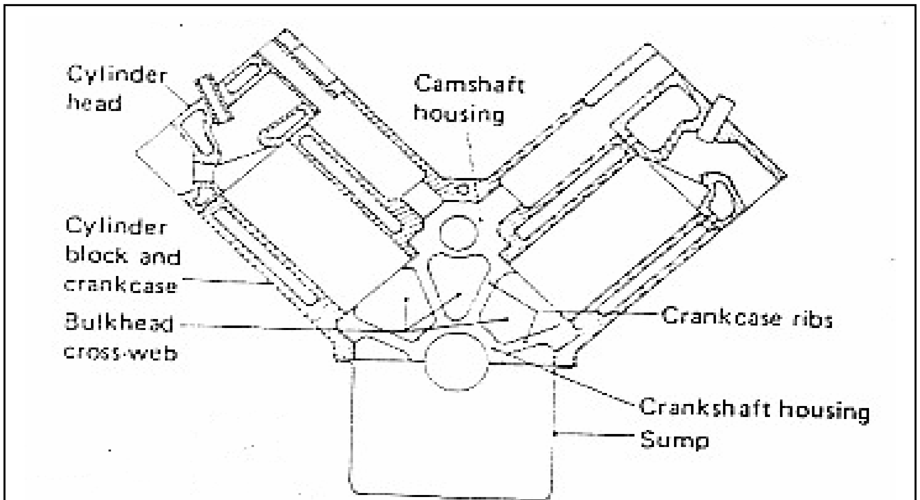


Fig. 8 Monobloc V cylinder block and crankcase

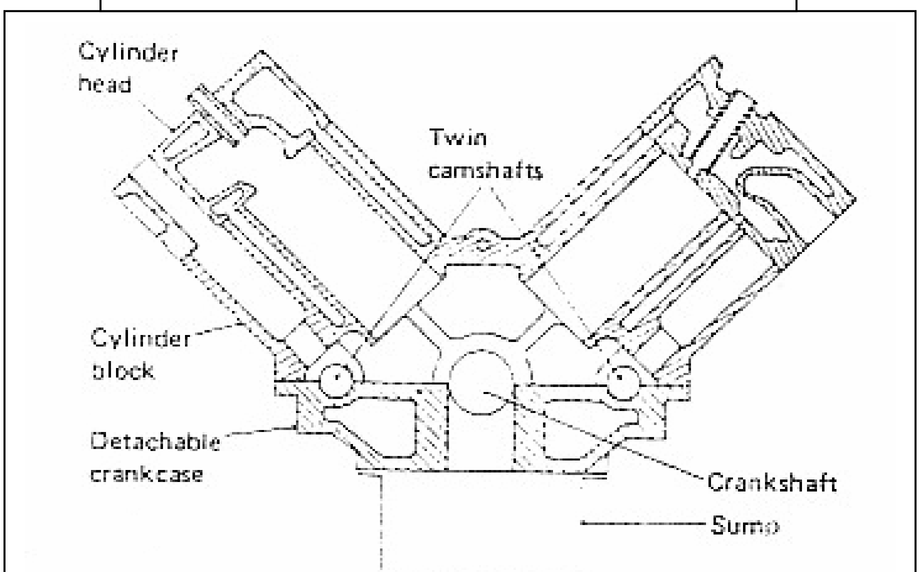


Fig. 9 V cylinder block with detachable crankcase

1.4 Coolant jacket (figs .2,3, and 10)

Cast in the cylinder block are coolant passages which surround the cylinder walls circumferentially and lengthwise. The sides of the block thus form the walls of the coolant jacket for approximately the full depth of the cylinders. Near the bottom of the cylinders, the coolant passages end and the cylinder walls merge with the crankcase.

At the top of the cylinder, the coolant passages end either at the level of the block's joint face, which is then referred to as an open-deck (fig. 2), or just below the block's machined face, the joint surface then being known as a closed-deck (fig. 3). With a closed-deck, the coolant circulation is provided by vertical drillings which communicate with corresponding holes in the cylinder head.

A closed-deck is preferred to an open-deck with respect to joint reliability, since the coolant-flow ducts between the head and the block can be drilled further away from the cylinder bore and there is normally more surface area to squeeze the gasket. On the other hand, it is easier to cast an open-deck cylinder block.

The cylinders arc cast parallel and in a straight line. There may be either a small gap between the adjacent outside cylinder walls, to allow coolant to pass as necessary for heavy-duty engines; or, where space is limited, the cylinder walls may be siamesed - that is, adjacent walls merge into a single continuous casting (fig. 10).

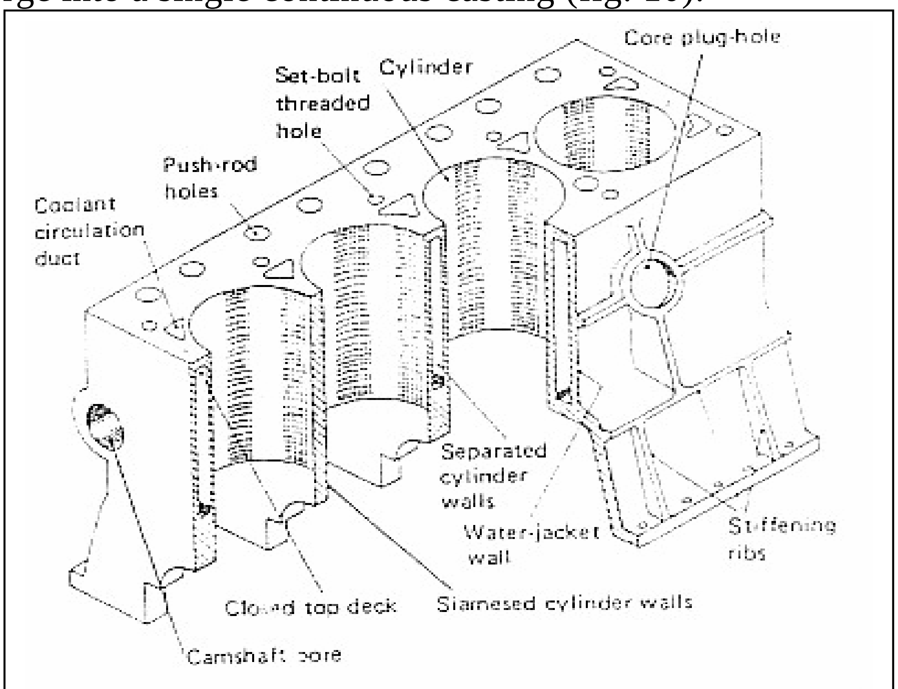


Fig. 10 Cylinder block with closed-deck coolant jackets, showing both separate and siamesed adjacent cylinder walls.

2. The crankcase (figs 2 to 11)

The function of the crankcase is to provide support for the individual main journals and bearings of the crankshaft and to rigidly maintain the alignment of the journal axes of rotation when they are subjected to longitudinal bending due to rotary and reciprocating inertia forces and the periodic torque impulses which tend to cause torsional distortion.

A tunnel-roof construction is provided which is partitioned-off by bulkhead cross-webs which mount and support the crankshaft main journals and bearings (fig. 11). This semicircular ceiling with spaced-out cross-webs provides a very stiff but relatively light crankcase construction.

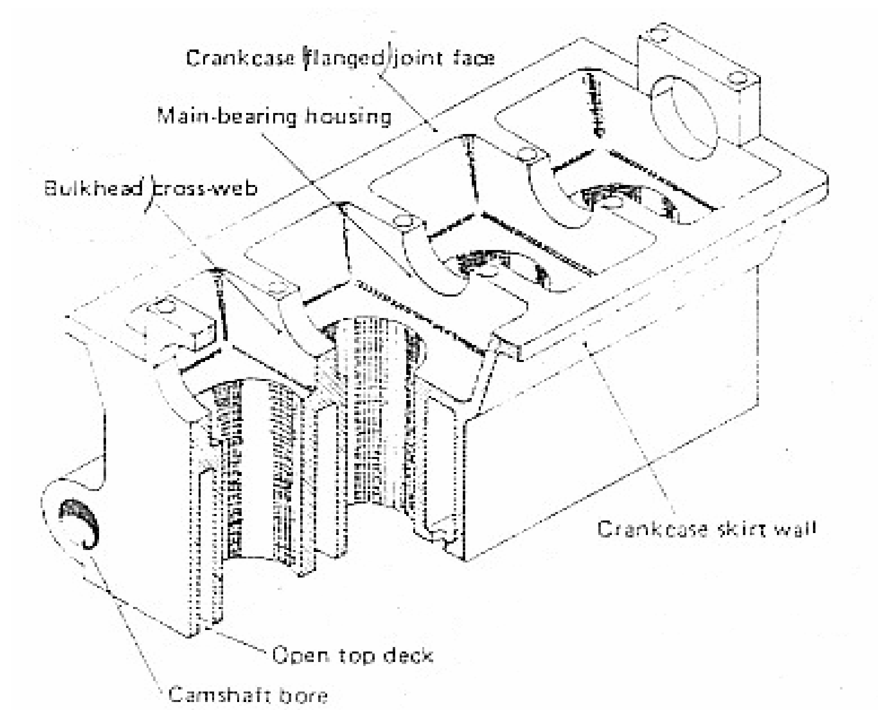


Fig. 11 Integral cylinder block and crankcase, showing both tunnel crankcase and open-deck water jackets.

Over the underslung crankshaft, the crankcase walls form a skirt which may either be separately attached to the cylinder block's lower deck (figs 4 and 5) or may merge into it as an integral casting(fig 1 and 2). The crankcase skirt may enclose the crankshaft from cylinder block to crankshaft-axis level (fig. 2), but for extra rigidity the walls may extend well below the crankshaft (figs 3, 4, and 5) this being preferred for both high-performance and heavy-duty engines.

To provide additional support to the cross-webs, ribs may run from the bottom of the cylinder block diagonally towards the main bearing housings for all or just the front and rear cross-webs. With some aluminum-alloy integral cylinder block-and-crankcase constructions, stiffening ribs are cast longitudinally and vertically downwards on the outsides of both the block and the crankcase walls.

The bottom of the crankcase walls are flanged both to strengthen the casing and to provide a machined joint face for the sump to be attached.

11.3 Camshaft location and support (figs 2 to 5, 12, and 13)

The function of the camshaft is to phase the opening and closing of each cylinder's inlet and exhaust cylinder-head poppet-valves relative to the crankshaft rotation.

Camshafts in the cylinder block are mounted parallel to the crankshaft and to one side of the cylinder (fig. 12) either low-down just above the crankshaft (figs 2 and 4) or high a little below the cylinder head (fig. 3). Alternatively, the camshaft can be mounted centrally over the cylinder head on a pedestal support (figs 5; and 13).

To support the camshaft there are usually three plain bush-type white-metal or tin-aluminum bearings which are a force fit in the cylinder-block or head-pedestal housing bores.

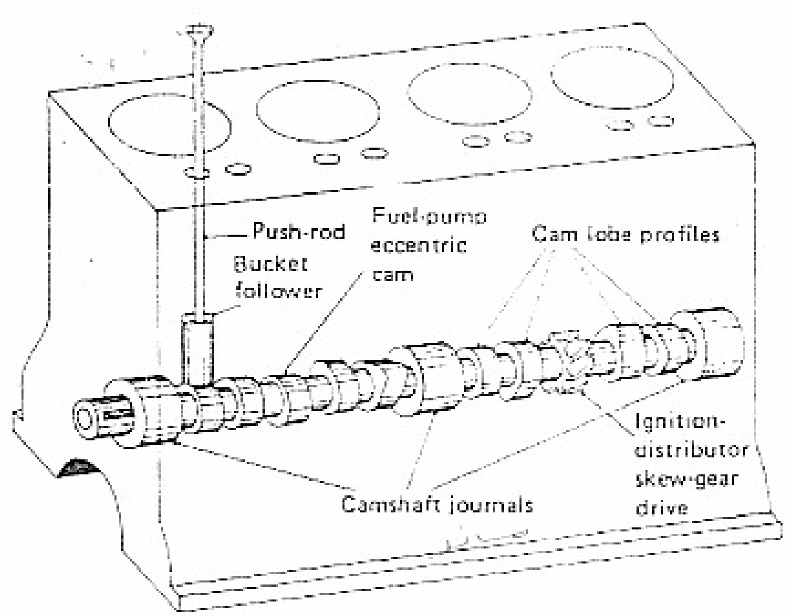


Fig. 12 Cylinder-block mounted camshaft

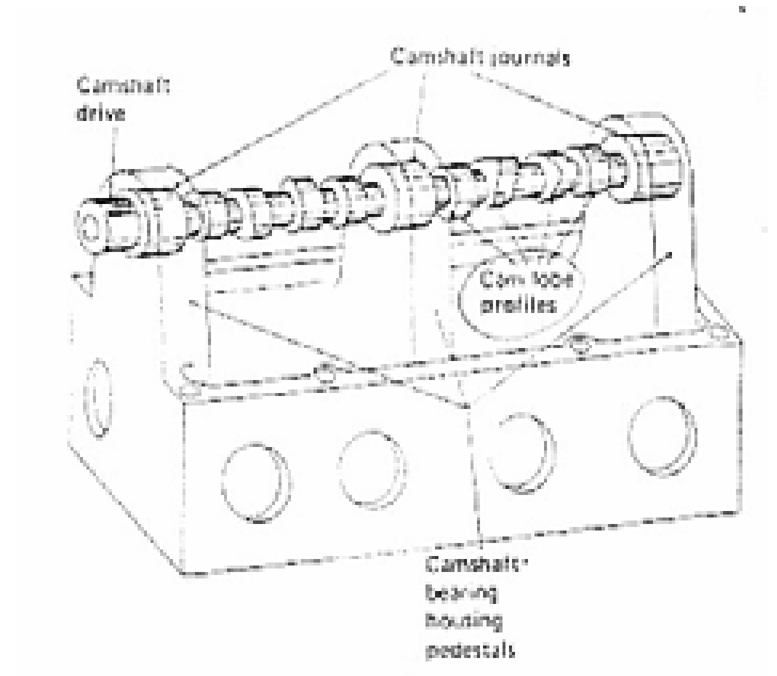


Fig. 13 Cylinder-head mounted camshaft

1.4. Cylinder-block materials

The cylinder block should be mad from materials which, when cast in a monobloc form, have adequate strength and rigidity in compression bending, torsion. This is essential so that the necessary support is provided against the gas loads and to the components which convert the reciprocating action of individual -cylinder's mechanisms into a single rotary action along the crankshaft length.

The desirable properties of a cylinder-block material are as follows:

a) it should be relatively cheap,

b) it should readily produce castings with good impressions,
c) it should be easily machined,
d) it should be rigid and strong enough in both bending and torsion,
e) it should have good abrasion resistance,
f) it should have good corrosion resistance,
g) it should have low thermal expansion,
h) it should have a high thermal conductivity,
i) it should retain its strength at high operating temperatures,

j) it should have a relatively low density.

Cast iron meets most of these requirements except that it has a low thermal conductivity and it is a comparatively heavy material.

because of these limitations with cast iron, there has been a trend for petrol engines to adopt light aluminium alloys as alternative cylinder-block materials. Cylinder liners may be incorporated in cast-iron blocks as an option, but they are essential with the relatively soft light aluminium alloys, which cannot be used directly for wear-resisting cylinders. To compensate for the lower strength of the aluminium alloys, the alloy blocks are cast with thicker sections and additional support ribs, which brings their relative weight to about half that of the equivalent cast iron blocks.

A typical cast iron would be a grey cast iron containing 3.5% carbon, 2.25% silicon, and 0.65 manganese. The carbon provides graphite to improve lubrication, with the silicon controlling the formation of a laminated structure known as pearlite which is mainly responsible for good wear resistance, while the manganese helps to strengthen and toughen the iron.

A common aluminium-alloy composition would he 11.5% silicon, 0.5% manganese, and 0.4% magnesium, with the balance aluminum. The high silicon content reduces expansion and improves castability, strength, and abrasion resistance, while the other two elements strengthen the aluminium structure. This alloy has good corrosion resistance, but it can absorb only moderate shock loads.

Crankcase sump (oil pan):-

The container underneath the crankcase is known as the sump, and its functions are:

1. to store the engine's lubricating oil,
2. to collect the return oil draining from the sides of the crankcase walls,
3. to store contaminations such as liquid fuel, condensed water, combustion products blown past piston rigs and metal particles,
4. to provide a degree of inter-cooling between the hot oil inside and the air stream outside.

The sump may be constructed from a single sheet steel pressing (fig. 1) or it may be an aluminum-alloy casting with cooling fins and sometimes strengthening ribs.

Cast aluminum alloy is much better than pressed steel in dissipating heat and it does not cause resonant (vibration) noise.

Baffle plates are sometime installed inside the sump to prevent oil surge.

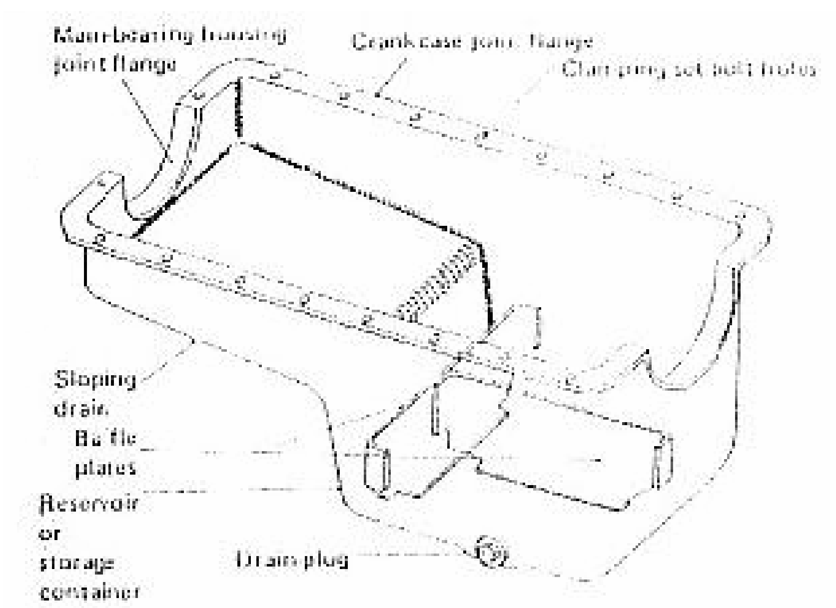


Fig. Steel crankcase sump with baffle plates.

The cylinder block $\frac{L_c}{D}$ ratio:-

The distance between the centre lines of adjacent cylinders in the cylinder block is determined by the ratio $\frac{L_c}{D}$, where L_c: is the distance between the centers of adjacent cylinders, D: cylinder diameter.

	$\frac{L_c}{D}$	
Engine type	Gasoline	Diesel
In-line with dry liners, double-span crankshaft main bearings	1.20-1.24	
In-line, single-span crankshaft main bearings	1.20-1.28	1.25-1.30
V-type with sliding friction main bearings	1.33	1.47-1.55
V-type with main roller bearings	1.30	1.30

Cylinder liners

Functions of cylinders

1. forming the combustion chamber,
2. undertaking the gas pressure,
3. transferring the generated heat to the surrounding water jacket,
4. guiding the piston.

The cylinder is subjected to:-

1. high pressure, 40-60 bar in gasoline engines and 50-80 bar in diesel engines
2. high temperature, the temperature of cylinder walls in water cooled engines is 80-120 ^{0}C and it is 100-220^{0}C in air cooled engines,
3. high frictional forces due to piston movement inside the cylinder.

Materials:-

The materials used manufacting cylinders should have the following:-

1. good lubrication characteristics,
2. high wear resistance,
3. high thermal conductivity,
4. light weight,
5. good corrosion resistance,
6. good castibility.

Cast in cylinders use a grey cast iron which has the desired casting and machining properties and adequate mechanical properties.

As for cylinder lines, they are made from lightly alloyed cast iron, centrifugally cast into a cylindrical sleeve, machined and heat-treated.

Types of cylinder liners:-

1. dry liners
2. wet liners

Dry cylinder liners

In dry cylinder liners, the outer surface of the liner is not in direct contact with the cooling water. The liners are characterized by:-

1. good wear résistance,
2. reduced overall length of cylinder block,
3. the cylinder block with dry liners is more robust than that of wet liners,

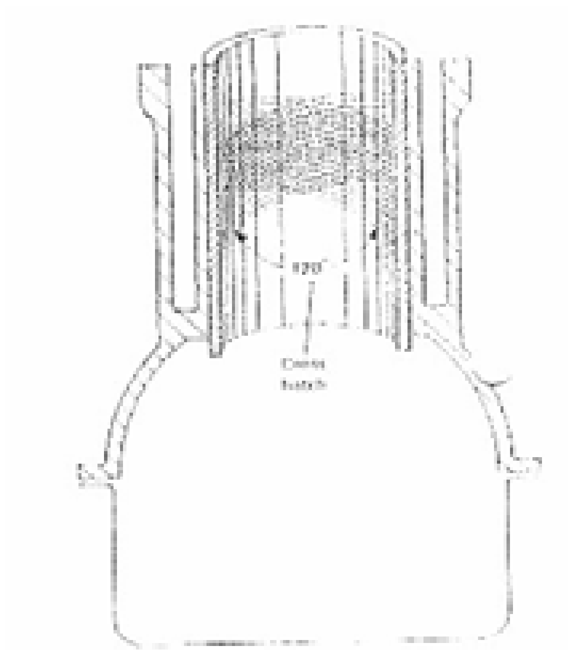
4. dry liners may be used to restore the original size of a cylinder block which has been rebored two or three times due to excessive wear.

Types of dry liners:-

1. force-fit (press-fit) liner:-

The liner is a plain cylindrical sleeve which is held in position by the interference between its outer diameter and the bore-hole walls. The liner is located by drawing a pushing the sleeve into the cylinder block with considerable force by using a screw and nut draw bar attachment or a hydraulic press set up.
Typical interference fits between the sleeve and the cast-iron cylinder block are:

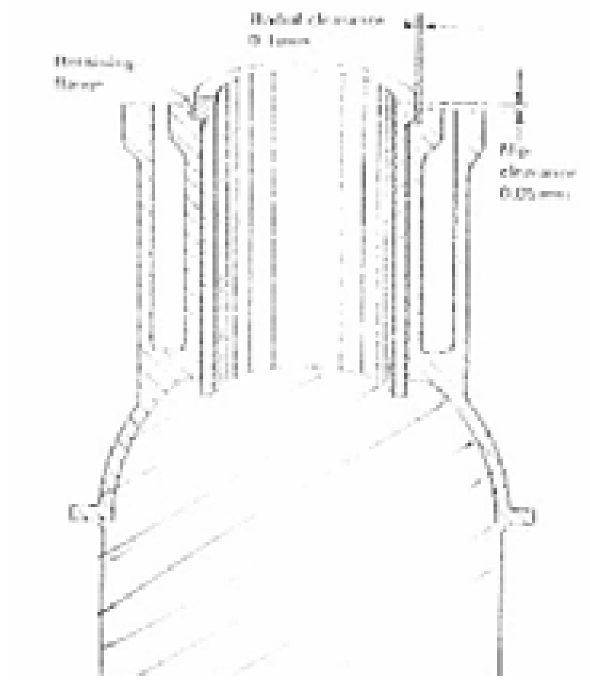
Bore diameter	Interference
75- 100mm	0.05mm
100-150mm	0.075mm



2. slip-fit liner:-

The liner is a cylindrical sleeve, flanged at one end to locate it and secure it in position. There is little or no interference between the liner and the block walls, and the liner is inserted by hand pressure. The flange should project above the block face by 0.05 to 0.125 mm to prevent vertical movement

relative to block while in service. Slip-liners have lower heat conductivity and non uniform temperature distribution.



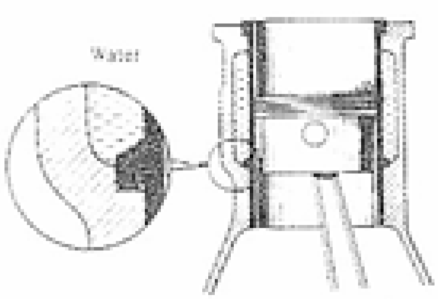
Wet cylinder liners

In wet cylinder liners, the cooling water is in direct contact with the outer surface of the liner. Thus, only the inner surface is machined. These liners are characterized by the following:-

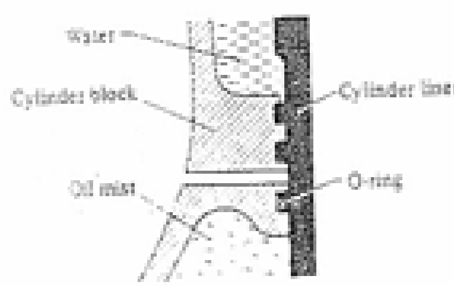
1. easier casting and machining of liner,
2. improved heat transfer and more uniform temperature distribution,
3. easier maintenance and repair.

The main problem of wet liners is sealing to prevent the leakage of cooling, rubber seals and o-rings are used for this purpose.

Wet cylinder liner



cylinder liner seal



cylinder liner seal with O-rings

Design of Cylinder Liner

The cylinder liner is subjected to two types of stresses:-

1- Circumferential tensile stress due to gas pressure inside the cylinder:-

(-------------------eq.1--------------------------------)

2- Thermal stress due to the difference in temperature between the inner and outer surface of the liner:-

(-------------------eq.2--------------------------------)

(-------------------eq.3--------------------------------)

(-------------------eq.4--------------------------------)

(-------------------eq.5--------------------------------)

(-------------------eq.6--------------------------------)

(-------------------eq.7--------------------------------)

Examples:

The cylinder head:

The cylinder head is a casting which is assembled on the top of the cylinder block. Its functions being to house the inlet and exhaust poppet-valves and their respective ports, to house the spark-plug or injector location holes, and to form the upper face of the combustion chamber and take the combustion-pressure reaction. In addition, within the casting are coolant passages, cavities, and channels which surround the valve seats and ports and the spark plug or injector bosses. These passages communicate with the coolant in the cylinder-block jacket through vertical ducts or drillings in corresponding contact faces in both the head and the block.

Cylinder-head valve and port layouts:

Both the inlet and the exhaust ports may emerge from the same side of the cylinder head, with the valves arranged side by side in a single row along the length of the head. This valve and port layout forms a loop-flow cylinder head (fig.1). with this arrangement, both the inlet and the exhaust manifolds are on the same side, so that the induction can be pre-heated by the hot exhaust manifold improved cold-running.

The same valve positioning can be used but with the inlet ports emerging on one side of the head and the exhaust ports on the other. This is known as an offset cross-flow head (fig. 2); and the advantages claimed are better breathing and lower exhaust-valve temperatures.

An alternative configuration, which is slightly more expensive but preferred for high performance, positions the valves transversely across the cylinders, so that the inlet and exhaust valves form two separate rows along the cylinder head. The ports then emerge from the respective sides of the cylinder head to form an in-line cross-flow head (fig. 3). Generally the valves are inclined to each other in a hemispherical combustion chamber which permits larger valves to be used.

Thermostat housing

To control the rate of coolant circulation to suit the amount of heat released by combustion, a thermostat valve is housed within and at one end of the cylinder head. It is usually situated in the main coolant passage which takes the coolant from the head through to the top hose to the radiator, so that it can interrupt the flow of coolant before the engine has reached its working temperature. Once the operating temperature of the engine has been reached, the temperature sensitive valve element

will automatically open, thus permitting the heated coolant in the cylinder head to pass unrestricted to the radiator which dissipates the heat to the atmosphere.

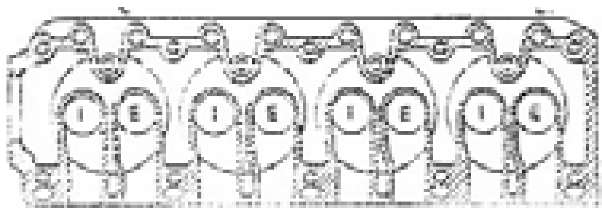


Fig. 1 Cylinder head with side-by-side valves and ports.

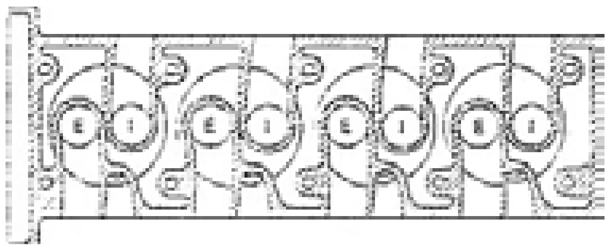


Fig. 2 Cylinder head with side-by-side valves and cross-flow ports.

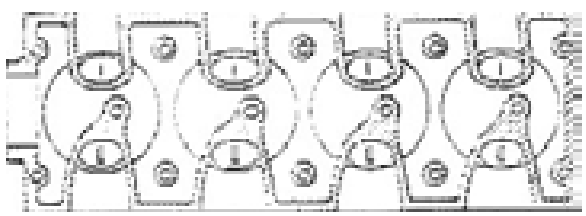


Fig. 3 Cylinder head with transverse valves and cross-flow ports.

Cylinder-head materials:

The cylinder head should be made from a material which can readily be cast with complicated internal shapes both for the coolant passages and for the inlet and exhaust ports. The material's mechanical and thermal properties should be such that it is strong enough in compression to be clamped rigidly to the cylinder block by hold-down bolts or studs and is able to operate continuously under fluctuating gas pressures and temperatures. Generally the gas-pressure loads are not excessive for the available engineering materials, but the temperature gradients established across the thickness of metal between the combustion-chamber side and the coolant passages, between adjacent inlet and exhaust valve seats, and from the centre of the combustion chamber to the cylinder walls will produce an unevenness in the

expansion and contraction of the metal in these regions. Consequently, thermal stresses will be created across the cylinder head, and these may eventually distort or even crack critical areas which are exposed to the heat of combustion.

The ideal cylinder-head material is the one which can limit the temperature of the cylinder-head combustion-chamber surface so that lubrication remains effective, combustible petrol-and air mixtures do not overheat to cause detonation, hot spots are not established to promote pre-ignition, and high cyclic thermal stresses are avoided. Unfortunately under various operating conditions such as continuous full-load running on motorways or under part loads with weak mixtures and late ignition, surface temperatures will rise and local thermal stresses can easily reach dangerously high values if the heat cannot be adequately dissipated through the cylinder head.

The choice of materials is generally restricted to grey cast iron and aluminium alloys, but neither of these cast materials has anywhere near all the desirable properties.

The traditional cylinder-head cast iron meets most of the requirements, such as cheapness; good castability; good machinability; good corrosion resistance; adequate rigidity, strength, and hardness; and low thermal expansion. However, cast iron has the disadvantages of being heavy and having a low thermal conductivity.

The alternative material, aluminum alloy, provides slightly different merits: it has half the weight of equivalent cast-iron heads and its thermal conductivity is three times better than that of cast iron, so that the cooler-operating head allows higher compression-ratios to be used and there will be lower temperature gradients in the head so the likelihood of thermal distortion is reduced. The shortcomings of aluminium alloy are that it is more expensive; the corrosion resistance is not so good as cast iron's and can under certain circumstances lead to problems; it is much softer than cast iron and more care is needed during maintenance; it has a high thermal expansion, which can cause fretting between an aluminium-alloy head and a cast iron cylinder block during starting and stopping conditions; and, finally, separate wear-resisting valve seats and guide inserts are essential.

The composition of the cast iron used is similar to that for the cylinder block, but slightly different aluminium alloys are preferred for the cylinder head. There are two commonly recommended, as follows:

i) 3.0% copper, 5% silicon, 0.5% manganese in a matrix of aluminium;

ii) 4.5% silicon,0.5% manganese, 0.5% magnesium in a matrix of aluminium;

The additions of both copper and silicon reduce the thermal expansion and contraction and improve the fluidity and castability of aluminium. Copper added to aluminium hardens and strengthens the structure over a period of time (this is known as age-hardening), and silicon improves the abrasion resistance. Both manganese and magnesium improve the strength of the alloy. Unfortunately the corrosion resistance of the otherwise slightly superior alloy containing copper is inferior to that of the copper-free silicon-aluminium alloy.

Stud and set-screw threaded cylinder-block holes:

The cylinder head is assembled on the top deck of the cylinder block and is attached by either studs or set-screws which encircle the cylinder bores. The screwing down of the cylinder head to the block puts the cylinder head in compression and the studs or set-screws in tension, which tends to pull out and strain the metal around the threaded region on top of the cylinder block (fig. 4).To provide adequate support, therefore, the mass of the metal bosses surrounding the threaded holes should be as large as possible. To give sufficient stud or set-screw joint strength, the depth of the threaded counterbore should be at least twice the diameter; and, to prevent local distortion on the surface of the deck when under tension, the threads cut in the block should start at least 0.3 times their diameter below the surface.

The hold-down-screw holes should be as close as possible to the bore, but if they are too near they will distort the top of the cylindrical bore out of roundness. Conversely, if the threaded holes are too far from the edges of the bores, the joint faces will tend to pull open during combustion and so their squeeze and sealing effectiveness will be reduced.

When using an aluminium-alloy cylinder head, it should always be held down by set-screws, otherwise any corrosion products formed between the studs and their respective holes in the cylinder head make it almost impossible to withdraw the head over studs which have been screwed into the block.

The minimum number of threaded hold-down holes in the top deck of the block is four or in cases five for engines with individual cylinder capacities up to about half a litre. Above this cylinder size for diesel engines, six,

seven, or sometimes even eight or nine hold-down screws may be considered necessary to secure the head joint. There are generally two rows of threaded holes along each side of the cylinder-block top deck, and they are normally arranged with one hole in each far corner with the remainder spaced between pairs of cylinder bores. Thus, except for the ones at each end at the front or back, all the studs or set-screws share their compressive damping effort between pairs of adjacent cylinder bores. Therefore each stud or set-screw influences the sealing of the top of the cylinder walls to the cylinder head lower deck over approximately a quarter of the circumference of each adjacent cylinder.

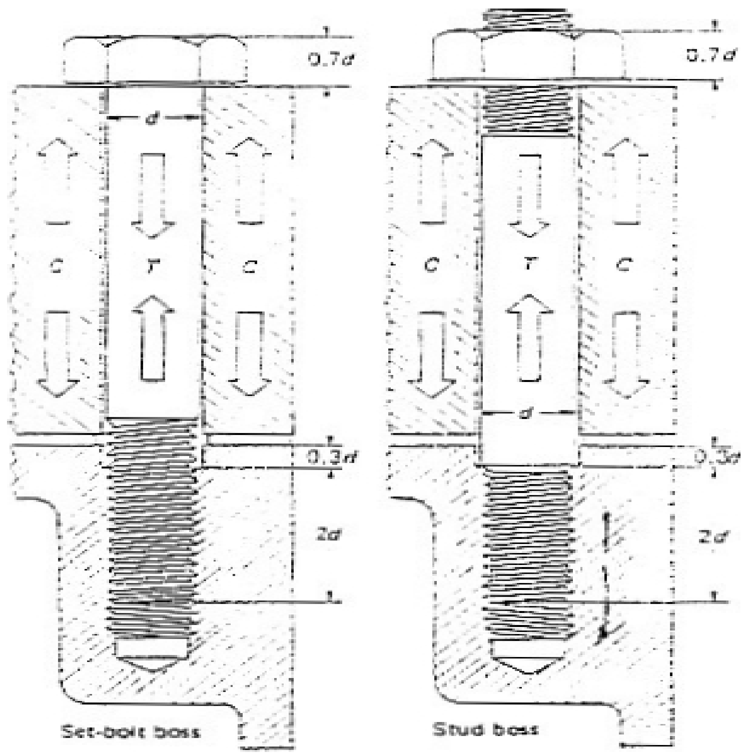


Fig. 4 Counterboring for cylinder head (T= tensile load, C= compressive load)

Stress distribution in a tightened cylinder head set-screw joint:

Figure 5 shows a section of a cylinder-head set-screw hold-down joint, and the stresses are represented by the grid lines. Widely spread lines indicate low stresses, and closely spaced lines imply a high stress concentration. This illustration shows that within the set-screw there is considerable stress concentration at the shoulder of the set-screw head and

where the set-screw enters the cylinder-block top deck. Within the threaded region of the block, at the joint interface, and where the shoulder of the set-screw head contacts the top of the cylinder head, the vertical and horizontal stress lines are close together. The horizontal crowded stress lines curving upwards as they merge into the threaded holes imply that the metal around the thread is being pulled away from the block towards the cylinder head. At the same time, as the set-screw is in tension, the horizontal stress lines around the cylinder-head hold-down set-screw hole curve and diverge both upwards and downwards away from the wall of the hole - this means that the stress is greatest near both the top and the bottom of the head and is least in the middle region.

The information provided by the stress grid lines within the cylinder-head clamping elements when a normal pre-tension is applied to the set-screw shows that a non-uniform complex stress distribution exists throughout the structure. Local stress concentrations such as occur around the threaded joint may exceed the elastic limit of the set-screw material; so, although the tensile load may be far below the tensile strength of the steel, plastic strain may occur and eventually the static and pulsating loads may lead to fatigue failure.

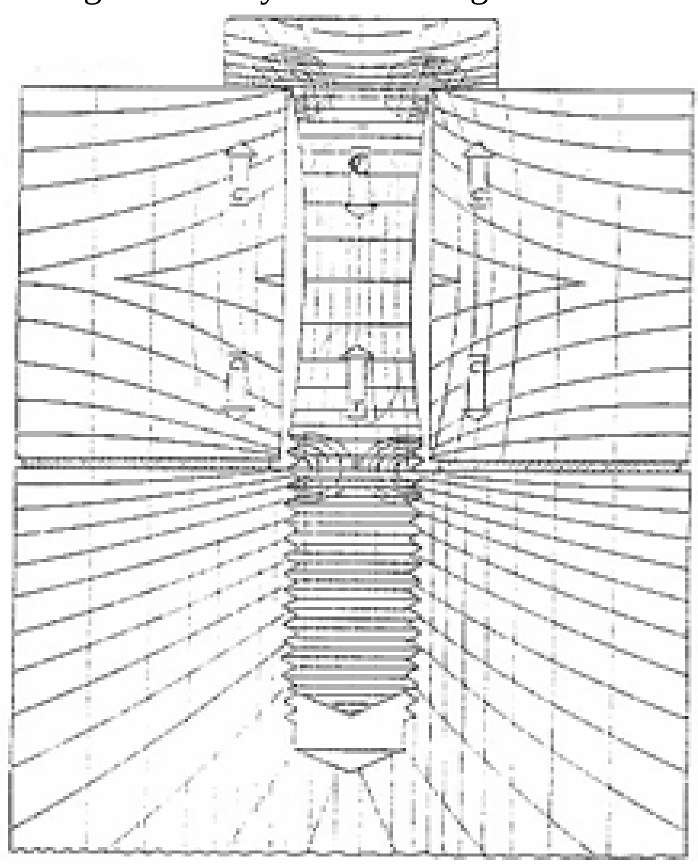


Fig. 5 Stress distribution in cylinder head and set-screw

Design of Cylinder Head

The cylinder head is subjected to-------

(--------------------eq.1--------------------------------)

(--------------------eq.2--------------------------------)

(--------------------eq.3--------------------------------)

(--------------------eq.4--------------------------------)

(--------------------eq.5--------------------------------)

(--------------------eq.6--------------------------------)

(--------------------eq.7--------------------------------)

Examples:

Piston and connecting-rod assemblies

1. Friction and heat distribution of the piston assembly:

The whole piston assembly absorbs something like 50 to 60% of the mechanical losses of the engine. For a typical piston with three rings, the first compression ring accounts for 60% of the friction work, the second compression ring for 30%, and the third oil-control ring for only 10%.

The energy from combustion heats the crown of the piston, and this heat has to be dissipated by way of the ring zone and skirt. Approximately 50 to 60% of the crown heat energy is transferred from the piston to the rings and then to the cylinder walls. The remaining heat-flow distribution is of the order of 20% through the ring lands and 20 to 30% through the skirt, 5% of this heat being carried away by the gas and oil but most being conducted through the cylinder walls.

2. Piston materials:

The materials that pistons are made from should meet certain requirements such as good castability; high hot strength; high strength-to-mass ratio; good resistance to surface abrasion, to reduce skirt and ring-groove wear; good thermal conductivity, to keep down piston temperatures; and a relatively low thermal expansion, so that the piston-to-cylinder clearance can be kept to a minimum. Some of these properties will be considered.

2.1 Mass considerations:

For high speeds, the reciprocating forces created by the pistons reversing their direction of motion must be as small as possible. This has made it necessary to turn to lighter materials than the cast iron and steel which were used on early slow-speed engines.

The obvious choice of the light metals was aluminium, which has a relative density of 2.6, compared with 7.8 for cast iron. Thus for a given volume, aluminium is one third of the mass of cast iron. This would reduce the mass of the piston in proportion, but, to maintain the rigidness of cast iron, the sections of the aluminium structures will be larger, offsetting the advantage to some extent. Aluminium is always alloyed with small amounts of other elements such as copper or silicon, the relative densities of these being 8.9 and 2.3 respectively.

This will considerably improve the strength -to- mass ratio of the pistons, but will only marginally alter the mass compared to a piston made of pure aluminium.

Figure 1. shows a family of curves of piston mass against cylinder bore size. These clearly indicate how piston mass increases with diameter and how the piston metal or alloy influences the mass. At first sight it might be thought that magnesium or a magnesium alloy would be the ideal material; however, due to their poor abrasion resistance, these are limited to car racing, where new pistons are fitted after each race meeting.

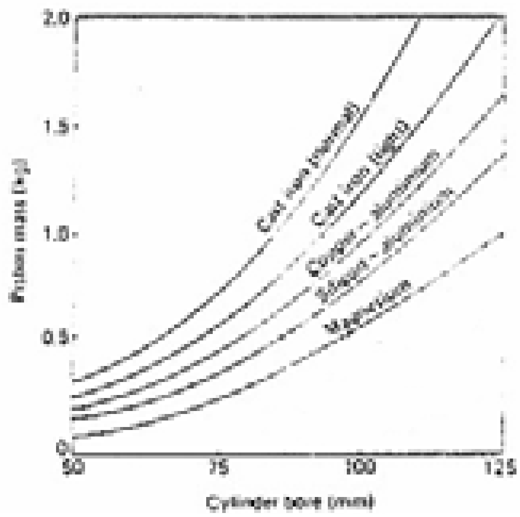


Fig. 1. Piston diameter and mass relationship for different materials

2.2 Strength and wear considerations:

Pure aluminium is not strong enough for use as a piston material, as it has a low tensile strength - about 92 to 124 N/mm^2 at room temperature, falling off progressively to about 31 N/mm^2 at 300^{0}C, which is roughly the operating temperature in the centre of the piston crown. Furthermore, the soft aluminium has very little resistance to wear and scores readily. To overcome these limitations, small percentages of other elements such as copper, nickel, silicon, magnesium, and manganese may be alloyed with the aluminium, singularly or in various combinations. These elements produce not only improved strength over the operating temperature range, but also improved resistance to abrasion, this being mainly due to the elements forming hard particles within the aluminium.

Figure 2 shows the hot strengths of pure aluminium, of Y-alloy having 4% copper and 2.5% nickel, of 12%-silicon alloy, and of 22%-silicon alloy. At 100°C the Y-alloy is the strongest and the 22%-silicon alloy the weakest, with the l2%-silicon alloy in between. With increased temperature their hot strength decreases, but the rate of decline of the 22%-silicon alloy is less than that of the other two, thus at about 280°C its hot strength is superior to the other two alloys.

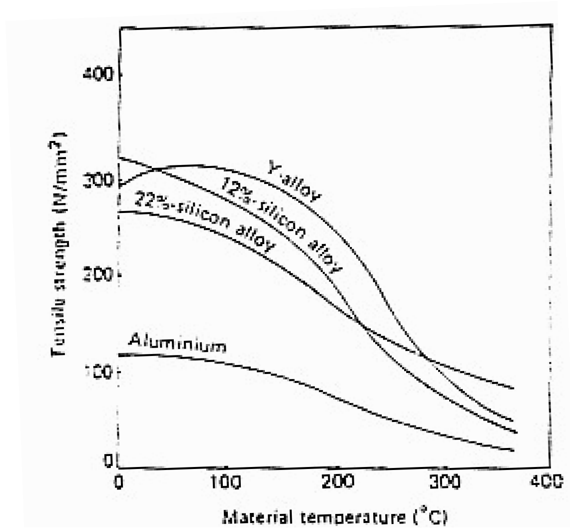


Fig. 2 Piston material strength at various temperatures

2.3 Heat-conduction considerations:

Aluminium is a much better conductor of heat than cast iron. Considering silver as 100%, aluminium and cast iron have relative conductivities of 38% and 11.9% respectively. As the aluminium can conduct 3.2 times more heat away in a given period and alloy pistons have thicker sections than cast-iron pistons, heat transfer is superior with these light pistons. The better heat dissipation of aluminium alloy pistons compared to cast-iron pistons greatly reduces the maximum piston-crown operating temperature, which is normally in the region of 250 to 300°C for alloy pistons and 400 to 500°C for cast iron.

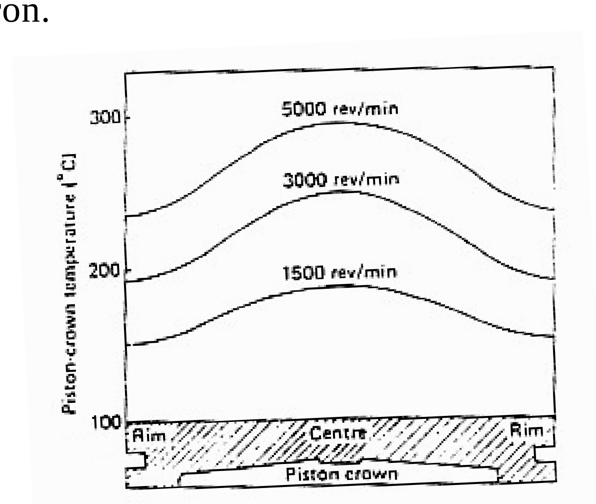


Fig. 3 Piston crown temperature at various engine speed

Figure 3 shows how the piston's operating temperature increases as the engine speed rises and that the centre of the crown is the hottest region of the piston.

2.4 Expansion considerations:

One of the major disadvantages of aluminium as the base metal of a piston alloy is its high coefficient of linear expansion - in the region of 0.0000221 per °C, compared with 0.0000117 per °C for cast iron. This shows that the expansion of aluminium is almost twice that of cast iron, therefore extra clearance between the piston and cylinder at room temperature has to be provided, otherwise the piston would become tight and seize under operating conditions. However, this clearance usually gives rise to piston slap when the engine is cold and consequently rapid wear. The development of low-expansion aluminium alloys has helped to reduce this problem, and their expansion properties are now discussed.

The best-known early aluminium-based alloy - the Y-alloy - has a high coefficient of linear expansion of 0.0000245 per °C over a temperature range from 20 to 300°C. Most pistons are now made from silicon-aluminium alloys, there being tow grades: with 12% silicon and with 22% silicon, these having thermal expansions of 0.000021 and 0.0000175 per °C respectively. It can be seen that, as the silicon content increases, the thermal expansion is reduced, so that the cold clearance can be made smaller. The reductions in expansion relative to the Y-alloy are 11% and 40% for the 12%- and 22%-silicon respectively, but the latter alloy still has a thermal expansion 50% higher than for cast iron.

Figure 4 shows the variation in expansion between cast iron and aluminium for various piston sizes at a mean temperature of 250°C. The increasing width of the shaded area indicates the greater expansion differences as piston diameter increases.

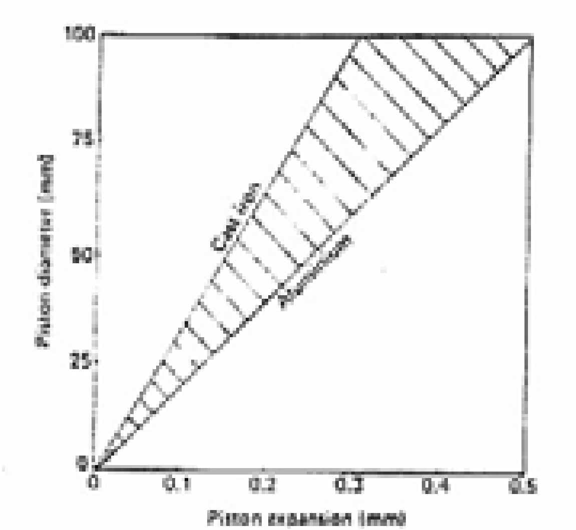


Fig. 4 Piston and cylinder expansion for different diameter

Figure 5 compares the expansion of cast iron and aluminium for a 75mm diameter piston over a temperature range of 20 to 300°C. The shaded area can be considered as the difference between the expansion of a cast-iron cylinder and that of an aluminium-alloy piston. In selecting a working clearance for a given mean working temperature, this difference will give the minimum working clearance when the engine is cold.

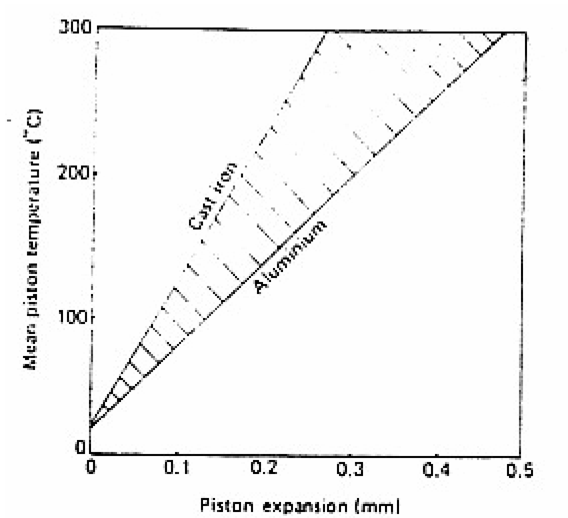


Fig. 5 Piston and cylinder expansion over a temperature range

3. Piston nomenclature and design considerations:

The highly worked piston has many features which influence its operating performance. These will now be identified and considered in some depth.

3.1 Ring-belt lands:

Several grooves are cut in and around the top of the piston to locate and house the piston rings. The metal bands left between the grooves are known as 'lands', and their function is to support squarely the rings against the generated gas pressure and to guide them so they may flex freely in a radial direction.

The zone in which the rings and lands are grouped together is referred to as the ring-belt, and located in this belt are normally two compression rings and one oil control ring. Sometimes for heavy-duty diesel applications there may be a third compression ring above the gudgeon-pin boss and a second oil-control ring situated near the bottom of the skirt.

3.2 Skirt:

The piston skirt is that portion of the piston which continues below the ring-belt. Its function is to form a cross-head guide capable of absorbing the gas pressure side-thrust created by the oblique angle made by the connecting-rod relative to the cylinder axis. The skirt should be internally structured to support the gudgeon-pin boss and of sufficient length to resist tilting of the piston under load, but it is not designed to support the piston crown against compressive loads.

Pistons are designed to operate with very small skirt clearances and, to prevent seizure under heavy loads, some petrol-engine piston skirts are mach flexible so that their radial profile can adjust to the very running conditions.

Some of the early pistons were provided with a vertical split from the bottom of the piston to the underside of the ring-belt on the same side of the skirt as the crankpin when the piston has passed TDC on its down-stroke (known as the non-thrust side). Some even had intersecting circumferential slots cut in the oil-control-ring groove above the gudgeon-pin bosses (fig. 6(e)) - such designs being known as fully-split-skirt pistons. If the operating temperature became very high and the working clearance marginal, then the skirt would be free to expand and close the split - in other words, the split provided a means of relief if the piston became tight due to overheating, particularly when initially ‘bedding in’. The disadvantage of having a split is that it reduces the skirt's rigidity, so that the skirt tends to collapse inwards without elastic recovery. Thus the outcome will be a permanently reduced piston diameter, with a consequent increase in the piston slap, noise, and wear which the split was originally designed to cure.

Skirts with splits which go only about half-way up are known as semi-split skirts. These are usually preferred as a compromise, and they also have blunting holes drilled at the end of the split to reduce the stress concentration created due to the split’s notch effect (fig.6(d)).

High-performance or heavy-duty pistons do not have any part of the piston skirt split. These are the known as solid-skirt pistons.

3.3 Piston webs:

Webs are cast inside the piston between the crown and the gudgeon-pin bosses to act as struts. The compressive gas loads can then be transmitted direct from the crown to the gudgeon pin bosses, and these forces are then transferred by way of the gudgeon pin to the connected-rod. Unfortunately the thick web sections form heat paths from the crown to

the gudgeon-pin bosses which can lead to expansion problems if they are not carefully designed.

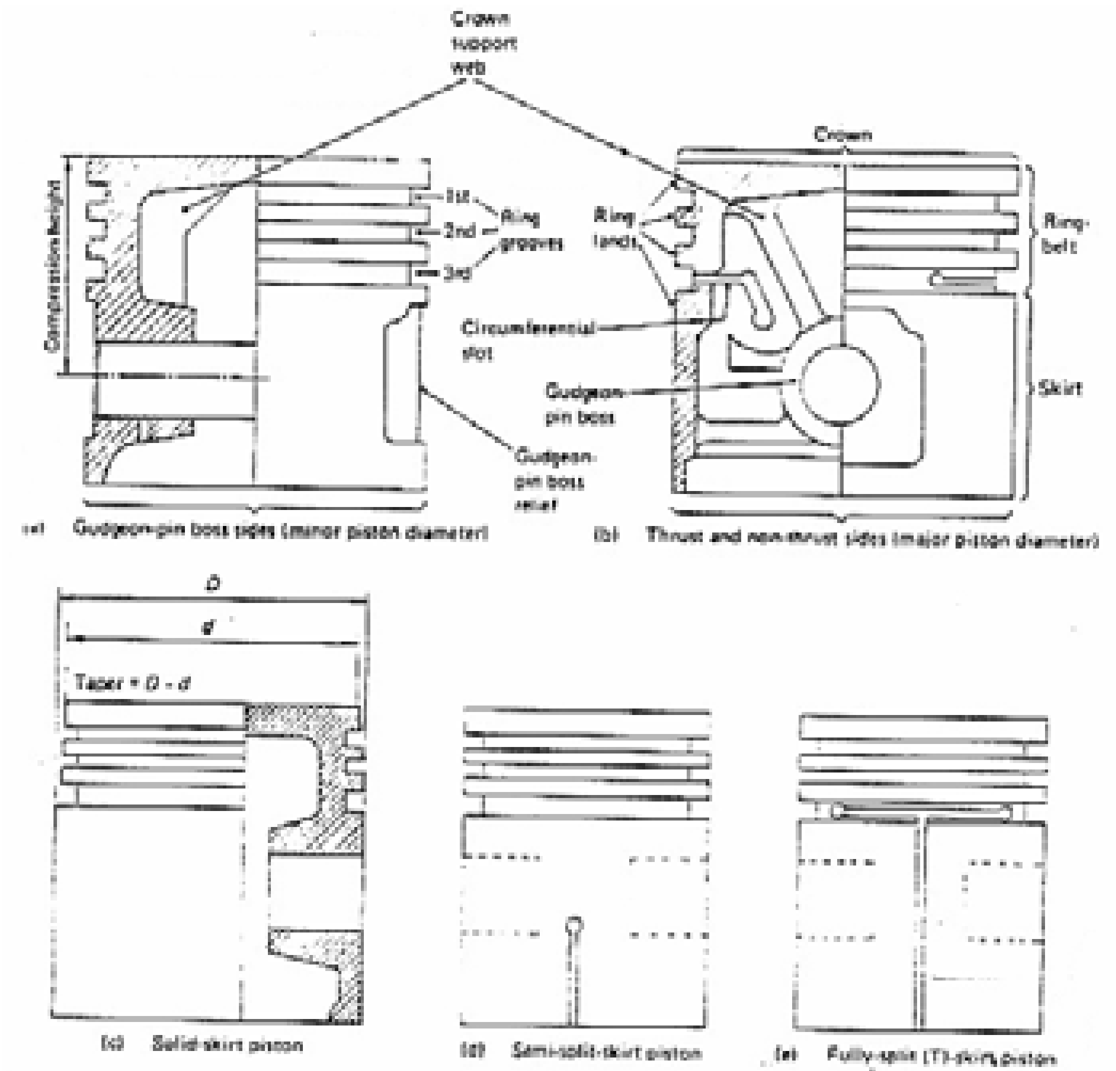


Fig. 6 Piston nomenclature

4. Piston parts:

4.1 Piston crown (head): It is the top area of the piston which withstand the forces generated by combustion. The simplest head is the flat head which is characterized by a uniform load and heat distribution. With the increase in compression ratio dome head pistons were developed. In recent years with the regulations on using unloaded gasoline, the compression ratios had to be reduced to avoid knocking thus dish or cup head pistons were developed. Some piston heads have a cup or bowl which improves turbulence of air-fuel mixture.

4.2 Piston skirt: The part of the piston below the rings. Its function is to form a guide for the reciprocating piston inside the cylinder. The skirt must be long enough to resist tilting of the piston under load. Piston skirts have elliptical shape having the smallest diameter across the gudgeon pin, thus providing larger clearance at the gudgeon pin axis for expansion. At working temperature the elliptical shaped will take a circular form and thus matches the piston to cylinder bore.

Some early pistons had a vertical split from the bottom of skirt to the underside of the oil ring, this provides a means of expansion control which reduce piston clearance. In recent designs, steel inserts which are cast with the aluminum alloy inside the piston skirt is used for expansion control. Since the steel has lower thermal expansion then aluminum it reduces the skirt expansion.

The piston / cylinder clearance for passenger car engines is about 25-100 microns (0.025-0.1mm) when the engine is running this clearance is filled with oil. If the clearance is too small there will be loss of power from excessive friction and serve wear results. If the clearance is too large piston slap will occur.

There are three types of piston skirt, full-skirt, semi-slipper and full-slipper skirt. The reduction of compression ratios in modern engine, resulted in using a shorter connecting rod therefore the skirt had to be cut to avoid hitting the counterweights on the crankshaft and for this purpose semi-slipper and full-slipper pistons were developed. Since the pistons are lighter, this reduces the inertia loads and also makes the engines more responsive.

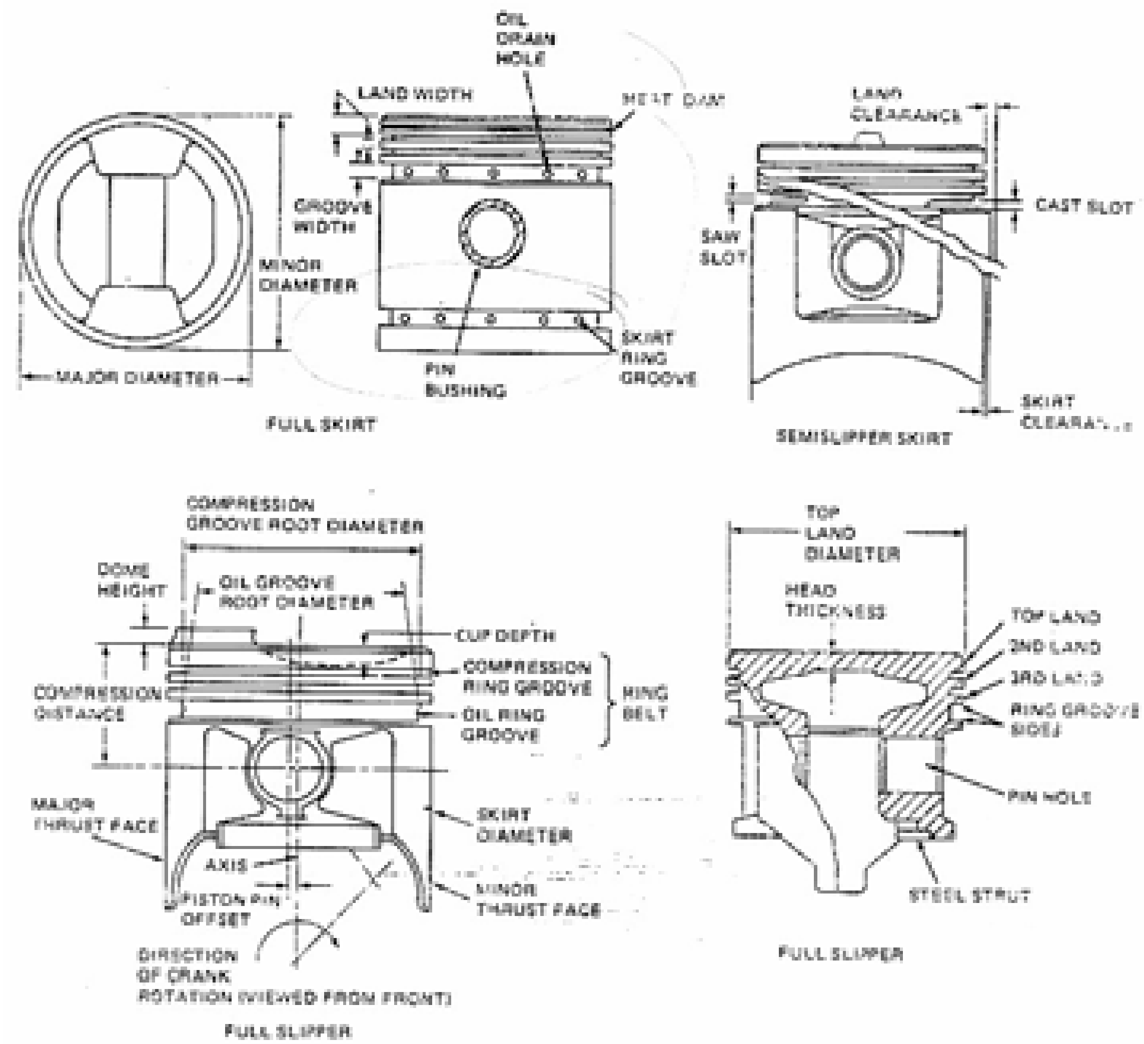


Fig. 7 Full skirt, semislipper, and full-slipper pistons

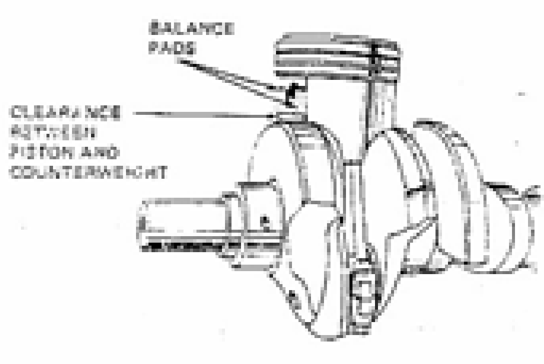


Fig. 8 A slipper piston and connecting rod assembled to crankshaft.

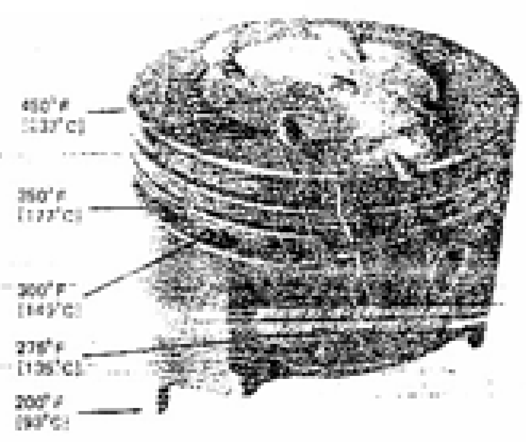


Fig. 9 Typical operating temperatures of various parts of a piston.

4.3 Piston rings: Are made of cast iron. Piston rings are divided into two types:

a) **Compression rings:** Usually two rings are used for each piston. Their function is to seal the space between the piston and the cylinder wall so that the compressed charge or gas cannot escape.

The ring is designed to expand radially outward when fitted in its groove, so there must net be any interference between the ring side faces and the ring groove. In its free state, the ring slightly larger than the cylinder bore so when it is closed up in the cylinder, it will spring outwards to apply pressure on the cylinder wall, however, it is gas pressure acting behind the piston ring which supplies most of the radial sealing force.

b) **Oil rings:** Usually one oil control ring is used for each piston, however on early full-skirt pistons two oil rings were used. The function of oil rings is to control the amount of lubricant passing up to the top of the cylinder walls.

During crankshaft rotation, more oil then is needed is splashed from the big-end bearing on to the cylinder walls. The oil-control ring scraper ring performs two functions: firstly it regulates the amount of oil passing to the combustion chamber zone of the cylinder, and secondly it distributes a film of oil over the whole cylinder surface to lubricate the compression rings, the skirt and the upper cylinder region.

4.4 Gudgeon pin: a steel hollow pin used for connecting the piston to the small end of the connecting rod.

The gudgeon pin is located in position by two methods:

i) Semi-floating: the pin is fixed to the small end of the connecting rod by a bolt (fig-a) or press fit (fig-b) or fixed to one end of the piston bosses by a bolt (fig-c).

ii) Fully-floating: The pin is free to float in their piston bosses and small end (fig. d & e) which reduces pin wear.

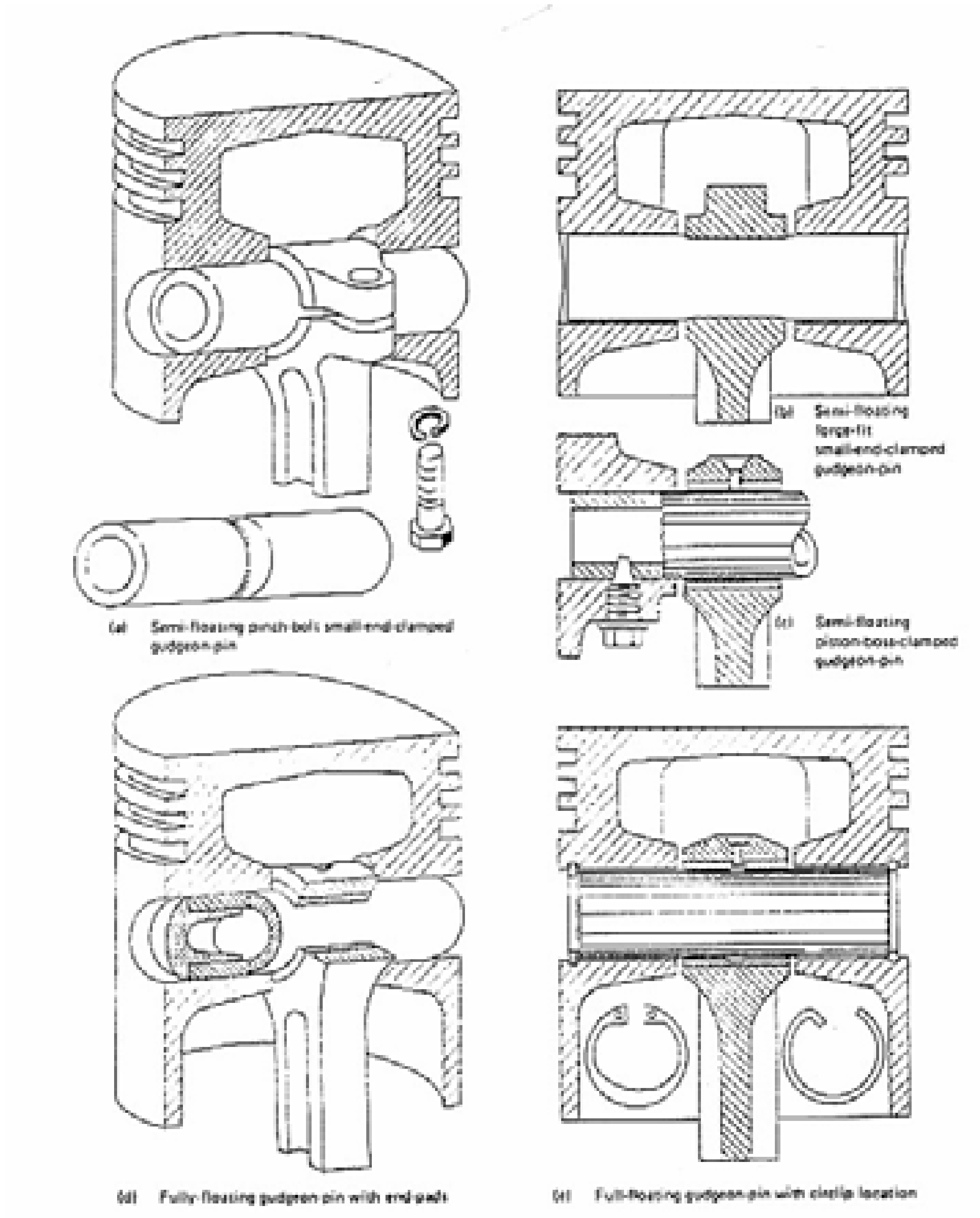
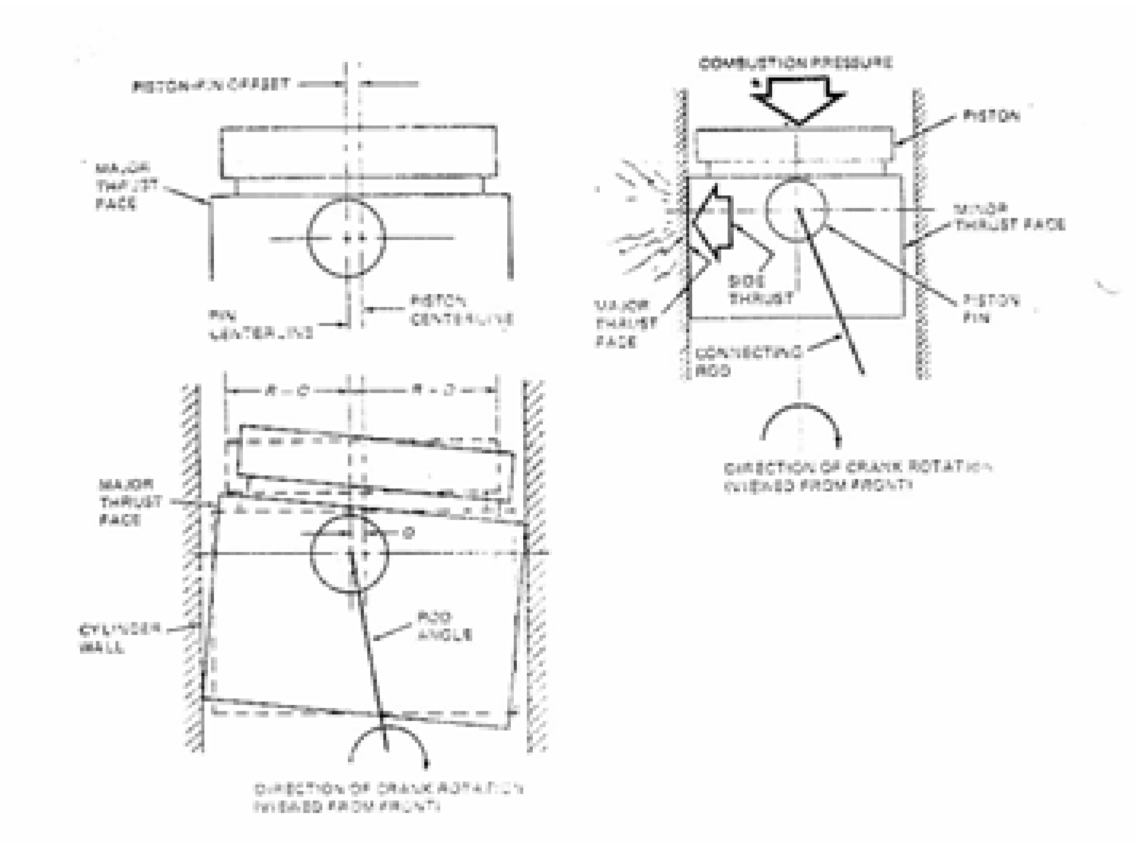


Fig. 10 Piston and connecting rod joints

In most engines, the gudgeon pin is offset from the centerline of the piston towards the major thrust to reduce piston slap during power stroke and to reduce piston wear.


PISTON-PIN OFFSET
MAJOR THRUST FACE
PIN CENTERLINE
PISTON CENTERLINE
MAJOR THRUST FACE
CYLINDER WALL
ROD ANGLE
DIRECTION OF CRANK ROTATION (VIEWED FROM FRONT)
COMBUSTION PRESSURE
PISTON
MINOR THRUST FACE
SIDE THRUST
MAJOR THRUST FACE
PISTON PIN
CONNECTING ROD
DIRECTION OF CRANK ROTATION (VIEWED FROM FRONT)

Design of Piston

<u>Thickness of Piston Crown (Head)</u>

(--------------------eq.1---------------------------------)

(--------------------eq.2---------------------------------)

(--------------------eq.3---------------------------------)

(--------------------eq.4---------------------------------)

(--------------------eq.5---------------------------------)

(--------------------eq.6---------------------------------)

(--------------------eq.7---------------------------------)

<u>Design of Gudgeon Pin</u>

(--------------------eq.8---------------------------------)

(--------------------eq.9---------------------------------)

(--------------------eq.10---------------------------------)

(--------------------eq.11---------------------------------)

(--------------------eq.12---------------------------------)

Piston and Gudgeon Pin dimensions-Imperical Design

Examples:

Hold-down Studs or Bolts

The hold-down studs are used for fastening the cylinder head to the block, providing the required tightness to prevent gas leakage.

Each hold-down stud is tensioned by:

(--------------------eq.1---------------------------------)

(--------------------eq.2---------------------------------)

(--------------------eq.3---------------------------------)

(--------------------eq.4---------------------------------)

(--------------------eq.5---------------------------------)

Examples:-