

SECTION 5, CHAPTER 1

THE POWER UNIT

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Introduction

1. Something is needed to make an engine do work; a steam engine needs heat supplied to the boiler, a car engine needs fuel in the form of gasoline, and an electric motor needs electricity. The heat, gasoline or electricity supplies the energy or ability to do work, thus the *energy* of a body is defined as its capacity for doing work. *Work* is done whenever a force moves a body on which it acts: it is the product of force multiplied by distance, and is expressed in foot pounds (ft. lbs.). The rate at which work is done is termed *power* and is expressed in foot pounds per minute (ft. lbs./min.).

2. Heat is a form of energy and thus cannot be created. The obvious natural source of heat is the sun, which is indirectly responsible for the large natural stores of energy (or bottled sunshine) available throughout the world, some of it being in the form of substances (fuels) which in combination with oxygen will burn and produce heat. The main commercial sources of heat are fuels, and they may be solid, liquid or gas. The most extensively used solid fuel is *coal* which consists of mineralized vegetable matter, and thus its origin may be traced to the heat and light of the sun. *Crude petroleum*, from which gasoline and fuel oil

(A.L. 8, Dec. 60)

are obtained, is a liquid fuel of world-wide importance, and *natural gas*, discharged from wells bored into the earth's crust, is also used in certain localities.

3. All the common fuels contain carbon and hydrogen, and most of them also contain other elements. Carbon burns vigorously in air or in oxygen, normally forming carbon dioxide, and water is formed when hydrogen burns in air. During the combination of the carbon and hydrogen with the oxygen, much heat is liberated; it is this heat which provides the energy for such machines as the internal combustion engine.

4. Internal combustion engines are heat engines, i.e. their function is to convert heat energy contained in the fuel into mechanical work. The gasoline (petrol) and fuel oil engines are the ones with which we are at present concerned, therefore, this chapter will deal with the many similar aspects of these engines, and where the fuel oil (compression ignition) engine differs from the gasoline (spark ignition) engine will be dealt with separately in a later chapter in this Section.

General Principles

5. When a suitable fuel, in gas or vapour form, is mixed with air in such a proportion

as to form a combustible mixture, and is then ignited in a confined space, the heat generated by combustion will cause the gases to expand. If this combustion takes place in a straight cylinder containing a well-fitting piston, the piston is forced down the cylinder. By connecting the piston to a crankshaft, the up-and-down (reciprocating) motion of the piston is changed into rotary motion, the crank mechanism being similar to that of a bicycle (Fig. 1).

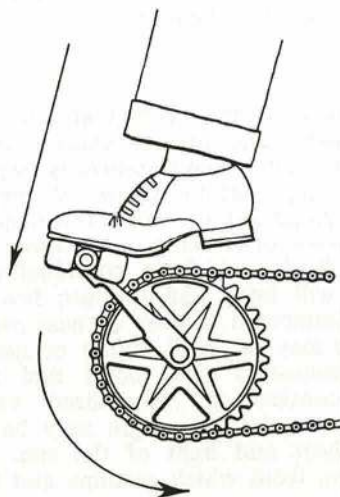
6. To enable the engine to operate continuously, provision must be made to ensure that the following operations, here summarized but detailed later, will continue satisfactorily for as long as the engine is required to run:—

(a) Air and fuel must be supplied in the correct proportions to the cylinder, and at the correct time in relation to the position of the piston.

(b) Combustion must occur at the correct time so that maximum advantage can be taken of the expansion of the gases, i.e. when the piston is moving down, otherwise the effort would be wasted in acting against the piston on the up stroke.

(c) The hot gases must be expelled from the cylinder immediately their usefulness is ended.

CYCLE



ENGINE

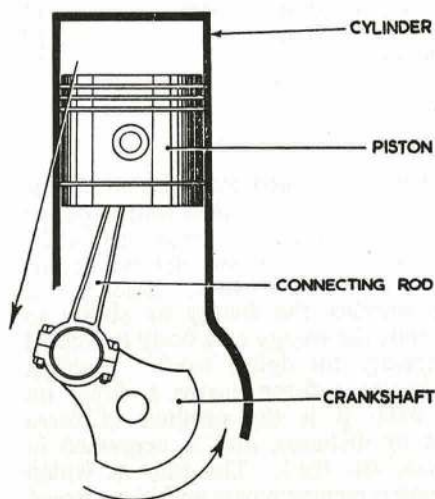


Fig. 1. CRANK MECHANISMS

Cycles of Operation

7. The sequence of operations used in engine practice is either the "four stroke cycle" or the "two stroke cycle". They are so called by the number of strokes of the piston taken to complete one cycle of operations, i.e. two up and two down for the four stroke, and one up and one down for the two stroke. The "stroke" is the extent of piston travel within the cylinder, the low limit of travel being known as "*Bottom Dead Centre*" or B.D.C. and the high limit, "*Top Dead Centre*" or T.D.C.

Four Stroke Cycle

8. This sequence of operations is often referred to as the "*Otto*" cycle (after the name

of the German engineer who first applied it in practice), and it takes four single piston strokes or two revolutions of the crankshaft to deal completely with each charge of fuel/air mixture. The cycle of operations is started by rotating the crankshaft until the first "*power*" stroke occurs; the moving parts then gain sufficient momentum from the power developed to complete the cycle and keep the crankshaft turning until the next power stroke. Control of the inlet and exit of the gases is by valves, not necessarily, in practice, of the type shown in the diagrams. The sequence of operations is as follows:—

(a) **Induction Stroke.** This stroke is illustrated in Fig. 2. The inlet is open and,

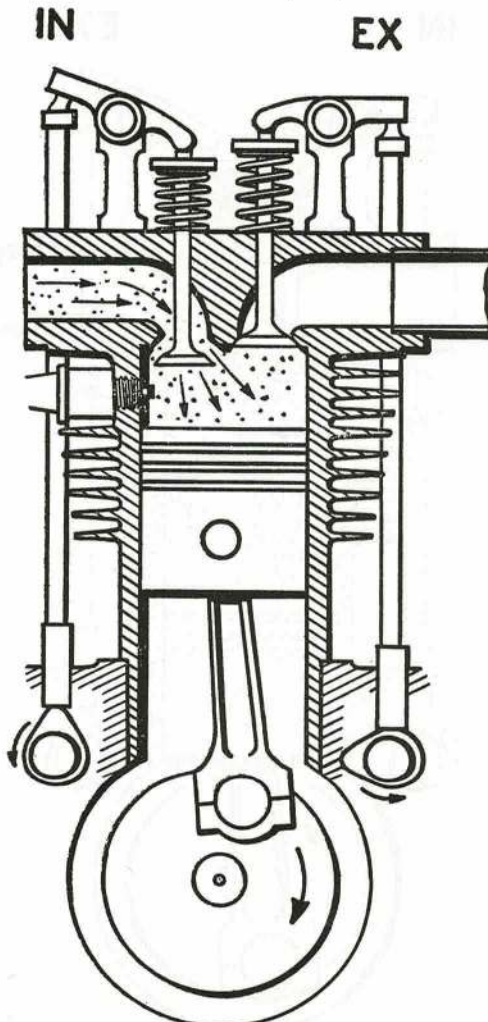


Fig. 2. INDUCTION STROKE

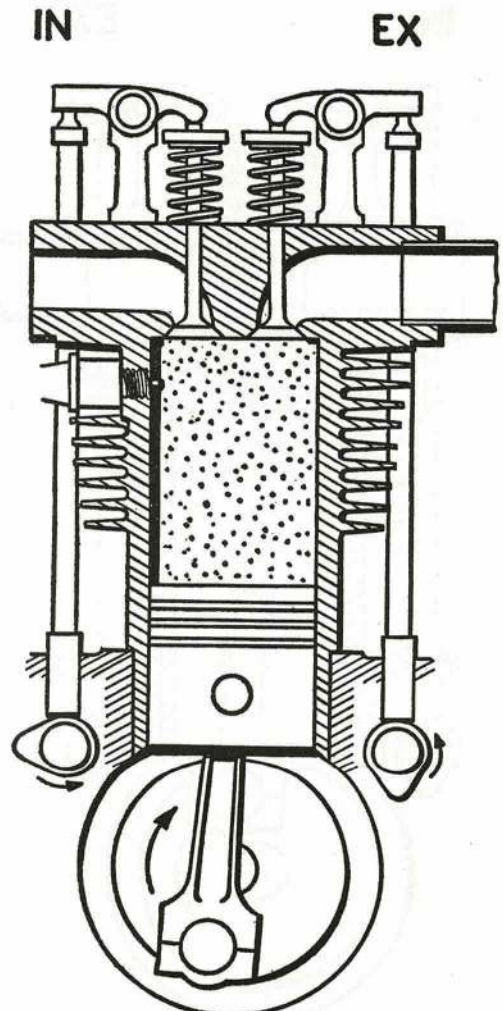


Fig. 3. COMPRESSION STROKE
(A.L. 8, Dec. 60)

because the piston is descending, the pressure in the cylinder falls below that of the atmosphere, thus, air or a fuel/air mixture, depending upon the type of engine, will flow into the cylinder, and this is termed the "*charge*".

(b) **Compression Stroke.** The next stroke (Fig. 3) commences when the piston reaches B.D.C. The inlet is closed to prevent escape of the charge, and the ascending piston compresses the gas into the "*combustion chamber*", i.e. the space left at the top of the cylinder when the piston is at T.D.C.

(c) **Power Stroke.** At this point, ignition of the charge causes a rapid rise of tem-

perature and pressure in the cylinder. The piston is forced down the cylinder (Fig. 4), restoring the momentum lost during the idle strokes.

(d) **Exhaust Stroke.** The hot gases having now served their useful purpose must be got rid of, thus, the exit or exhaust is opened which enables the hot gases to escape to atmosphere with the assistance of the ascending piston (Fig. 5).

9. The diagrams illustrating the four stroke cycle show that the openings and closings of the inlet and exhaust are related to the position of the piston in the cylinder, and also, of course, the position of the crank. In practice, these points are often shown by means

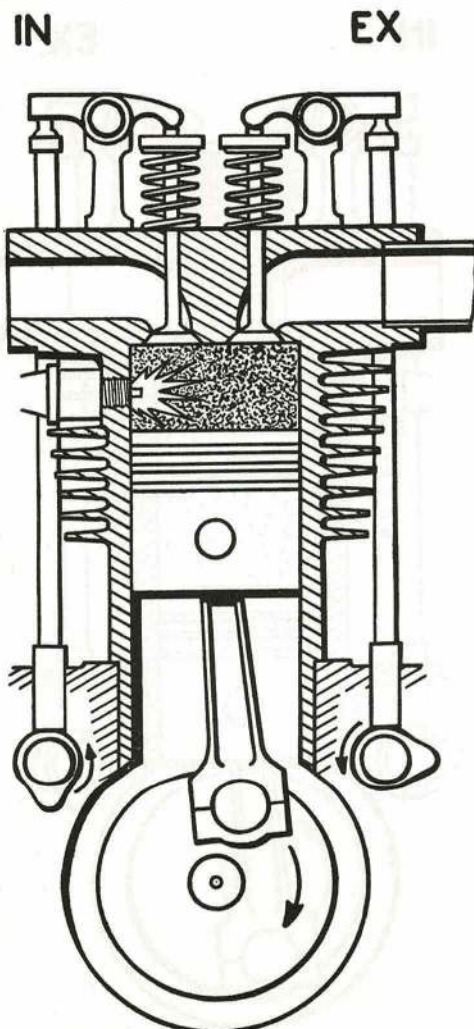


Fig. 4. POWER STROKE

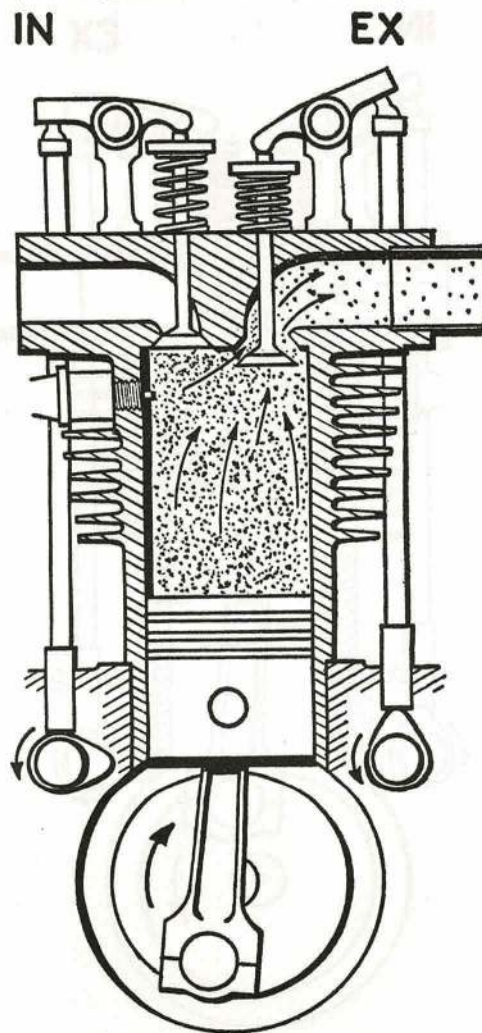


Fig. 5. EXHAUST STROKE

of a "timing diagram", the openings and closings being given in degrees of crankshaft movement. Thus, a timing diagram of the four stroke cycle (para. 8) would show everything happening either at B.D.C. or T.D.C. An engine operating on such a cycle would be far from efficient, and therefore such a cycle is often referred to as the "theoretical" cycle, a "modified Otto" cycle being used for the operation of modern internal combustion engines.

Modified Otto Cycle

10. In order to obtain efficient performance from an engine, the inlet and exhaust operations must be so timed that the maximum possible charge is induced into the cylinder on the induction stroke, and as complete as possible "scavenging" of the burnt gases takes place on the exhaust stroke. These requirements necessitate departure from the theoretical timings, due to practical considerations such as "ineffective crank angle" and the changes in speed of the gas flow through the engine.

11. **Ineffective Crank Angle.** This is the angular position around T.D.C. and B.D.C. where for a large movement of the crankpin there is a relatively small movement of the piston. Referring to Fig. 6A, the lines A1 B1 and A2 B2 represent the centre line of the connecting rod at the beginning and end respectively of 30° travel of the crankpin, and A1 A2 show the corresponding movement of the piston. At Fig. 6B, this same movement through 30° is shown, but this time for a different part of the stroke, i.e. just

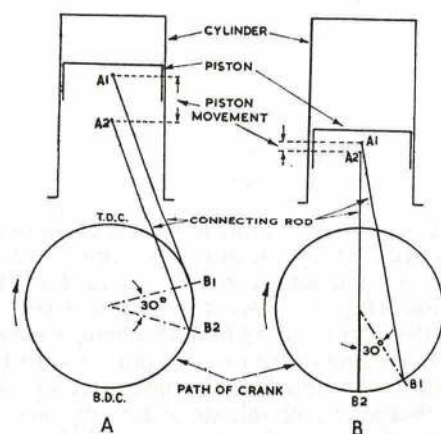


Fig. 6. INEFFECTIVE CRANK ANGLE

before B.D.C. A1 B1 and A2 B2 again show the limit of connecting rod movement through the 30° arc, and A1 A2 the corresponding movement of the piston. From this it can easily be seen that little or no piston movement takes place during a certain movement of the crank around B.D.C. and T.D.C., in comparison with the movement of the piston at other parts of the stroke.

12. It is usual to represent the opening and closing of the valves by means of a timing diagram such as is shown at Fig. 7. It will be noted that, unlike the theoretical cycle in which the valves are caused to open and close at T.D.C. and B.D.C., these valves are opened or closed before or after the dead centre positions, the actual number of crankshaft degrees being dependent upon the particular purpose for which the engine was designed. When a valve is opened before T.D.C. or B.D.C. it is said to "lead", and when it is closed after the dead centre position it is said to "lag". On most engines the inlet valve is opened before the exhaust valve is closed, so that there is a short period during which both valves are open; this is referred to as "overlap". The reasons for these variations from the purely theoretical cycle are given in the following paragraphs.

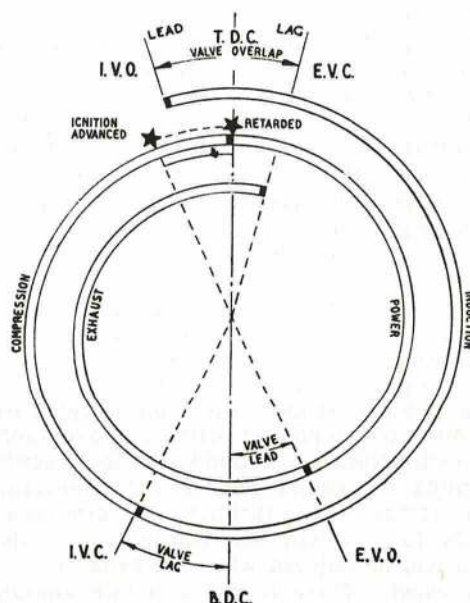


Fig. 7. TIMING DIAGRAM

13. Inlet Valve. The opening of the inlet valve is a fairly critical point, because if too early, the pressure in the cylinder would tend to blow back the incoming gas, but at the correct time, the lesser pressure in the cylinder, caused by the momentum of the out-going exhaust gases, will assist the flow of new gas into the cylinder. Further, the incoming gas will help to scavenge the exhaust gases remaining in the cylinder head, this being the chief reason for overlap. Another reason for opening the inlet valve early is that it will then be fully open by the time the piston is beginning to move down the cylinder, thus reducing the inevitable lag in flow which must occur with this method of charging the cylinder. The point where the inlet valve is opened is largely governed by the closing point of the exhaust valve and whether the engine is designed to operate at high or low R.P.M. The inlet valve is kept open as long as is possible so as to induce the maximum cylinder charge. Because of its momentum, the inflowing gas will continue to enter the cylinder even for some time after the crank has passed B.D.C., therefore, the closing of the inlet valve is delayed after B.D.C. until a point when the pressure in the cylinder is approximately equal to the pressure in the inlet manifold.

14. Exhaust Valve. The completion of the power stroke leaves burnt gases in the cylinder, which must be effectively got rid of before the next cycle commences, otherwise, there will be less room for the new charge and it will also be contaminated. Towards the end of the power stroke, because of the acute angle the connecting rod makes with the crankweb and the decreased pressure of the gas, very little useful work is done. By opening the exhaust valve before the crank reaches B.D.C., two advantages are obtained. Firstly, the residual gas pressure begins scavenging the exhaust gas even before the piston starts to move up the cylinder, and thus any slight loss of power is more than compensated for by more thorough scavenging and avoidance of back pressure. Secondly, the force acting through the centre line of the connecting rod rather than turning the crankshaft tends to overload the bearings, and this load will be relieved when the exhaust valve is opened. There is still a certain amount of exhaust gas in the combustion chamber when the piston has reached T.D.C., so advantage is taken of the ineffective crank

angle to leave the exhaust valve open for a time to allow the gas to flow out under its own momentum.

15. Ignition. To obtain the maximum benefit from the burning of the charge it must be arranged that the peak pressure generated in the cylinder occurs when the piston is just about to descend, i.e. the crank has just passed T.D.C. Burning of the fuel/air mixture takes time, and although rapid it is certainly not instantaneous, and peak pressure is not reached until the fuel has been completely burned. Thus ignition must be arranged to occur so that combustion will be complete at the time the piston is about to descend. Therefore, the faster an engine runs, the earlier will have to be the ignition point; this point is often shown on the timing diagram (Fig. 7).

Two Stroke Cycle

16. It is now quite clear that with an engine working on the four-stroke cycle, only one power stroke per cylinder is obtained for every two revolutions of the crankshaft; thus, the other three idle strokes, i.e. induction, compression and exhaust, have to be completed by the momentum usually stored in the flywheel. This led designers to seek another cycle giving more power strokes than the four-stroke cycle, and so the two-stroke cycle giving a power stroke per cylinder for each crankshaft revolution came into being. The elimination of two strokes as compared with the four-stroke cycle is accomplished by exhausting the burnt charge from, and inducing the new charge into the cylinder, while the piston is passing the bottom dead centre, and without sacrificing any great portion of the power and compression strokes.

17. The two-stroke engine is often referred to as a valveless power unit, because ports that are covered and uncovered by the movement of the piston are usually used to admit the charge and to allow of its exit when burnt. The cycle of operations of a typical "three-port" type engine can be seen in the illustration (Fig. 8). As the piston rises, the transfer port is closed first, this being followed by the closing of the exhaust port, and further upward movement of the piston compresses the charge of fuel and air or air only, according to the type of engine. It will be noted that the rising piston uncovers the inlet, thus allowing air or fuel and air, as appro-

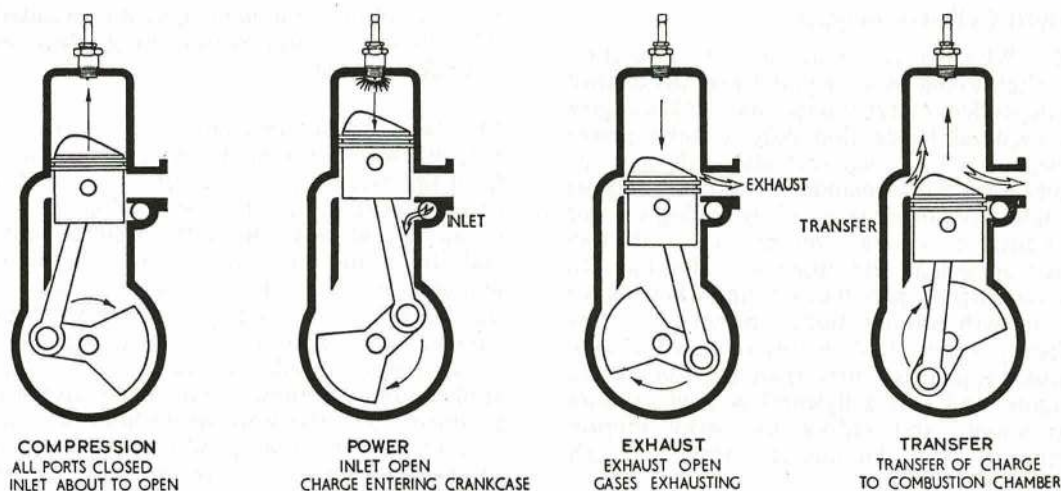


Fig. 8. TWO STROKE CYCLE (Three Port Engine)

prate, to enter the crankcase. As the piston nears the top of its stroke ignition occurs, and the resulting expansion of the gases forces the piston downwards. The descending piston first closes the inlet, uncovers the exhaust port, and at the same time pushes a new charge from the crankcase via the bypass to the transfer port which is then uncovered, the sequence of operations being then continued.

18. It will be realised that with this type of engine the crankcase must be gas tight, because the engine relies for its operation on the pumping action of the piston and crankcase, these items forming what is virtually another cylinder. As the piston rises to compress the new charge, the pressure in the crankcase decreases, and when the inlet port is uncovered, fuel and air or air will flow into the crankcase because of the existing difference of pressures. As the piston descends on the power stroke it closes the inlet port, and then compresses the fuel and air or air alone, which is in the crankcase, so that it will flow into the cylinder when the transfer port is uncovered. The crown of the piston used in this type of engine is shaped so that the incoming charge will be deflected up into the cylinder. This prevents the new charge from passing straight out through the exhaust port, and it also helps to scavenge the burnt gases remaining in the cylinder, the majority having been exhausted by their own pressure. This action is often referred to as "cross-

flow" scavenge, and similar effects are obtained on some types of engines by having the ports constructed so as to impart a tangential and upward flow to the charge, thus dispensing with the deflector, and this method is referred to as "reverse-flow" or "inverted" scavenge.

19. It is obvious that the two-stroke engine is basically simpler in construction than the four-stroke engine because there is no need for valve operating mechanism, but there is the added difficulty of keeping the crankcase gas tight. Theoretically it might be expected that the two-stroke engine, size for size, would develop twice as much power as a four-stroke engine, due to having double the number of power strokes. In practice, however, this is not realised; an increase of only between 10 to 40 per cent. is possible, and this is frequently accompanied by a higher fuel consumption. Practical applications of the two-stroke cycle have been many and varied, some of which have been such that it was not necessary to keep the crankcase gas tight, but although there are some very successful examples in modern use, the two-stroke has certainly not supplanted the very widely used four-stroke engine. Two inherent advantages which the two-stroke cycle will always be able to claim over the four-stroke are, firstly, a smoother torque or more uniform turning movement, and secondly, more favourable bearing load factors.

Multi-Cylinder Engines

20. Why so many cylinders? This question is often asked by a beginner and the answer is dependent on several factors. If the engine is required to develop only a small power output then a single-cylinder unit may be sufficient, but demands for higher outputs would have to be satisfied by having a larger cylinder or several smaller ones. Factors such as weight and space will also have to be considered, plus the very important factor of smooth turning motion or torque. It is already known that in this respect the two-stroke engine is better than the four-stroke engine, and that a flywheel is used to store up energy and reduce the jerky motion resulting from the uneven torque of such engines.

21. With a single-cylinder four-stroke engine only one power stroke is produced for every two revolutions of the crankshaft. Therefore, increasing the number of cylinders will likewise increase the number of power strokes, so that for every two revolutions of the crankshaft the same number of power strokes as there are cylinders will be obtained. Thus, the larger the number of cylinders, the more power impulses will be spread over the two revolutions of the crankshaft. This shortening of the period between each power stroke gives a sequence of quickly following power impulses in a multi-cylinder engine, imparts practically continuous turning effort to the flywheel, makes for smooth running and incidentally enables the weight of the flywheel to be reduced. This of course is not the complete story, for there are other factors such as cost of production, servicing, etc., which have to be taken into account, and which account for the four-cylinder engine being widely used as a useful compromise between too few and too many cylinders.

Balance

22. Another factor of vital importance in ensuring smooth running is *balance*. A moving part in perfect balance causes no vibration, but a badly balanced engine would vibrate unduly. If a bicycle be lifted and the back wheel spun rapidly, it will in all probability be found that the whole machine vibrates. The reason for this is that the tyre valve makes the wheel out of balance; it can be remedied by a counter-balance weight on the opposite side of the rim. To

ensure a smooth running engine it is essential that all rotating and reciprocating parts are in perfect balance.

23. In the past, an engine fitter was constantly aware of this question of balance, for it was essential to ensure that any rotating or reciprocating part that was being refitted to an engine was within the weight limits laid down by the manufacturer. Modern manufacturing methods have disposed of the need for the operator to worry about balance, and engines are now designed to be as perfectly balanced as the particular application will allow; spare parts also are produced to conform to weight limits so that they can be fitted as produced. On some engines balance of the reciprocating parts is achieved by weights attached to, or formed from, extensions of the crank webs; on others, for example, those with horizontally opposed cylinders, one set of reciprocating parts is made to balance its opposite set by operating them on diametrically opposed crank pins.

CONSTRUCTION

Introduction

24. The basic working principles and simple design of an internal combustion engine have been explained in the preceding paragraphs, but many refinements are required before it becomes a usable power unit. The finished product is made up of components and sub-assemblies arranged for convenience of manufacture, dismantling, assembly and servicing, even though, from the point of view of the tradesman, ease of servicing seems very often to have been given little consideration.

25. A piston engine consists of the following:—

(a) **Mechanical Parts.** These comprise the components used in converting the heat energy of the fuel into mechanical energy, which is then available in the form of rotary motion of the crankshaft for the particular application that is desired.

(b) **Fuel System.** This consists of the parts required to supply the correct fuel/air mixture to the cylinders for the varying conditions of operation.

(c) **Ignition System.** This system is only applicable to gasoline engines, and consists

of the parts that are required for ignition of the charge at the correct time for the varying conditions of operation.

(d) **Lubrication System.** Lubrication of the working parts of an engine is very important to its continued operation; this system therefore, covers the parts used to ensure efficient lubrication.

(e) **Cooling System.** The high working temperatures of the internal combustion engine are highly desirable from the efficiency viewpoint, but they are also undesirable because of the practical problems in construction and operation for which they are responsible. One of these problems is the getting rid of a great amount of heat in order to keep some parts of the engine within safe working limits, and this is done by the parts which make up the cooling system.

26. The rest of this chapter deals with the mechanical parts, and later chapters give the information required for the other systems. Many of the parts dealt with are common to all engines but may differ in design according to the particular requirements, for example, the greater strength required for some parts of compression ignition engines. The correct location of parts is ensured in various ways such as spigots, dowels, or by tight fitting bolts. Shafts are usually located by a thrust bearing, and allowance has to be made for the expansion of some components that will arise with increased running temperature. Many parts are marked to ensure correct positional assembly, care having to be taken to assemble mating parts correctly.

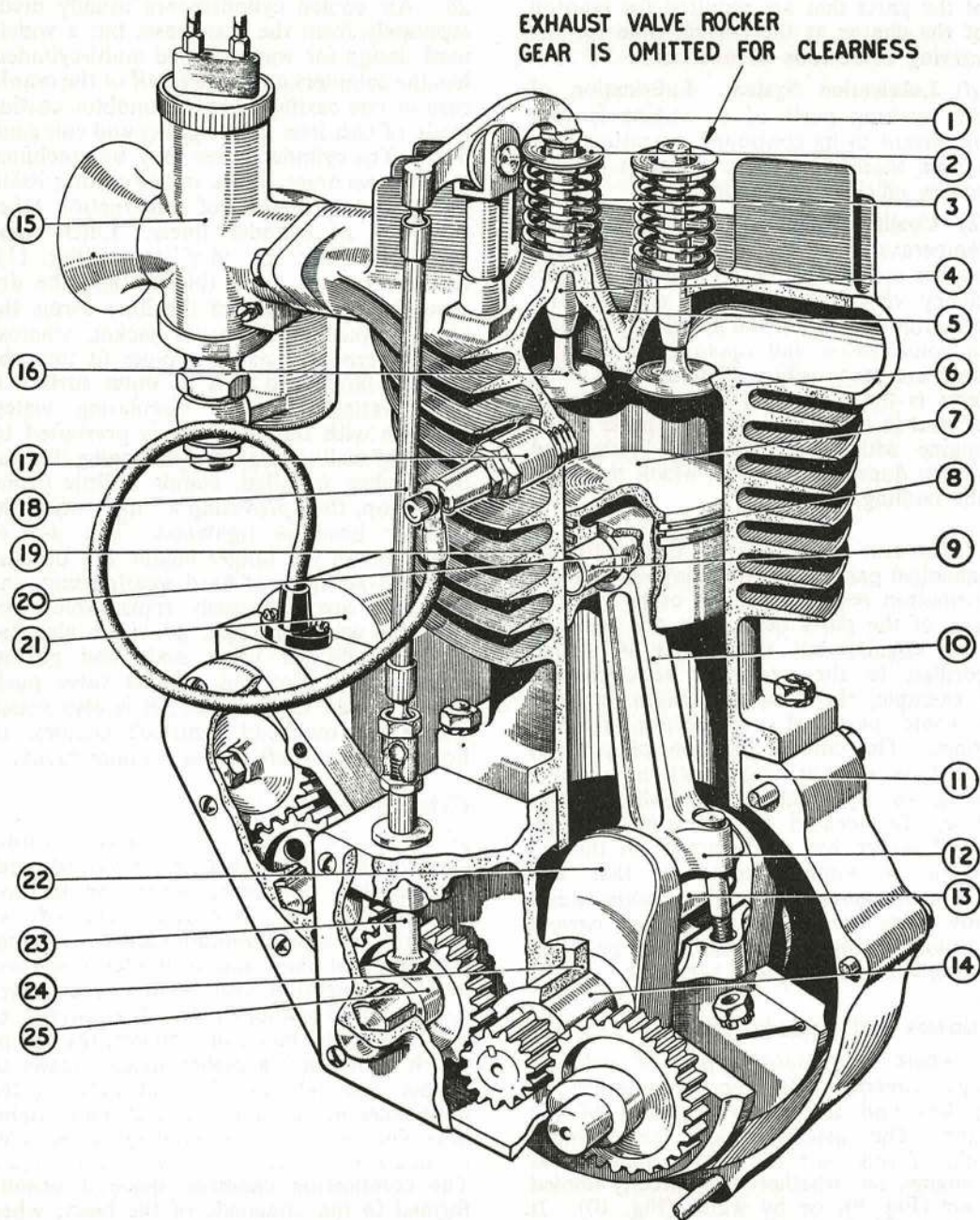
Cylinders and Cylinder Blocks

27. There are many types of cylinder design covering the varying number of cylinders and the required layout of the engine. The method used for cylinder cooling forms part of the classification of an engine, i.e. whether it is directly cooled by air (Fig. 9), or by water (Fig. 10). It may be said that indirectly all engines are air-cooled and this will be discussed later in the section on "Cooling Systems". When the cylinders are cooled directly by air they are provided with cooling fins; when water is used as the cooling medium, passages are provided so that the water can flow around the outsides of the cylinders.

28. Air cooled cylinders are usually made separately from the crankcase, but a widely used design for water cooled multi-cylinders has the cylinders and upper half of the crankcase in one casting. This monobloc casting made of cast iron gives rigidity and compactness. The cylinder bores may be machined to very accurate limits in the casting itself, but a modern method of construction takes the form of cylinder liners. Liners may be of the "wet" or "dry" types (Fig. 11); the wet type is made thicker than the dry type, for the outside of the liner forms the inner surface of the water jacket, whereas the dry type is usually a press fit into the cylinder block and thus its outer surface is not "wetted" by the circulating water. Leakage with the wet liner is prevented by means of sealing rings, and arranging that the liner, when installed, stands a little proud at the top, thus providing a "nip" when the cylinder head is tightened. The use of liners makes for longer engine life because they can be made of hard wearing material, and they are also easily replaceable. Besides the water passages, provision also has to be made for valve seats and guides, tappets, and inlet and exhaust valve ports if it is a side valve engine; it is also usual, except for overhead camshaft engines, to house the camshaft in the cylinder block.

Cylinder Head

29. This is usually a one-piece casting suitably water jacketed or provided with cooling fins, depending upon the method of cooling in use. It is often made of cast iron but, because aluminium alloy is a better conductor of heat and is lighter than cast iron, this metal is also frequently used for cylinder head manufacture. It is shaped to conform to the block or cylinder, the top of which it encloses; a gasket, usually made of copper and asbestos, is used between the joint faces to maintain gas and water tightness, and the head is secured to the cylinder or block by studs and nuts or set screws. The combustion chamber space is usually formed in the underside of the head; when overhead valves are used (Fig. 12), provision is made for valve seats and guides, inlet and exhaust ports, sparking plugs, rocker gear, and sometimes bearings, etc., for overhead camshafts. The ideal form of combustion chamber space is hemispherical, but this is rarely achieved in practice because of the complications it involves in valve gear



- 1. Valve Rocker
- 2. Valve Spring Cap
- 3. Valve Spring
- 4. Valve Guide
- 5. Cylinder Head
- 6. Cylinder
- 7. Piston
- 8. Piston Rings
- 9. Gudgeon Pin

- 10. Connecting Rod
- 11. Crankcase
- 12. Big End
- 13. Crank Pin
- 14. Crankshaft Journal
- 15. Carburettor
- 16. Inlet Valve
- 17. Sparking Plug

- 18. Push Rod
- 19. Cooling Fin
- 20. Small End Bearing
- 21. Magneto
- 22. Crank Web
- 23. Tappet
- 24. Main Bearing
- 25. Inlet Cam

Fig. 9. AIR COOLED ENGINE

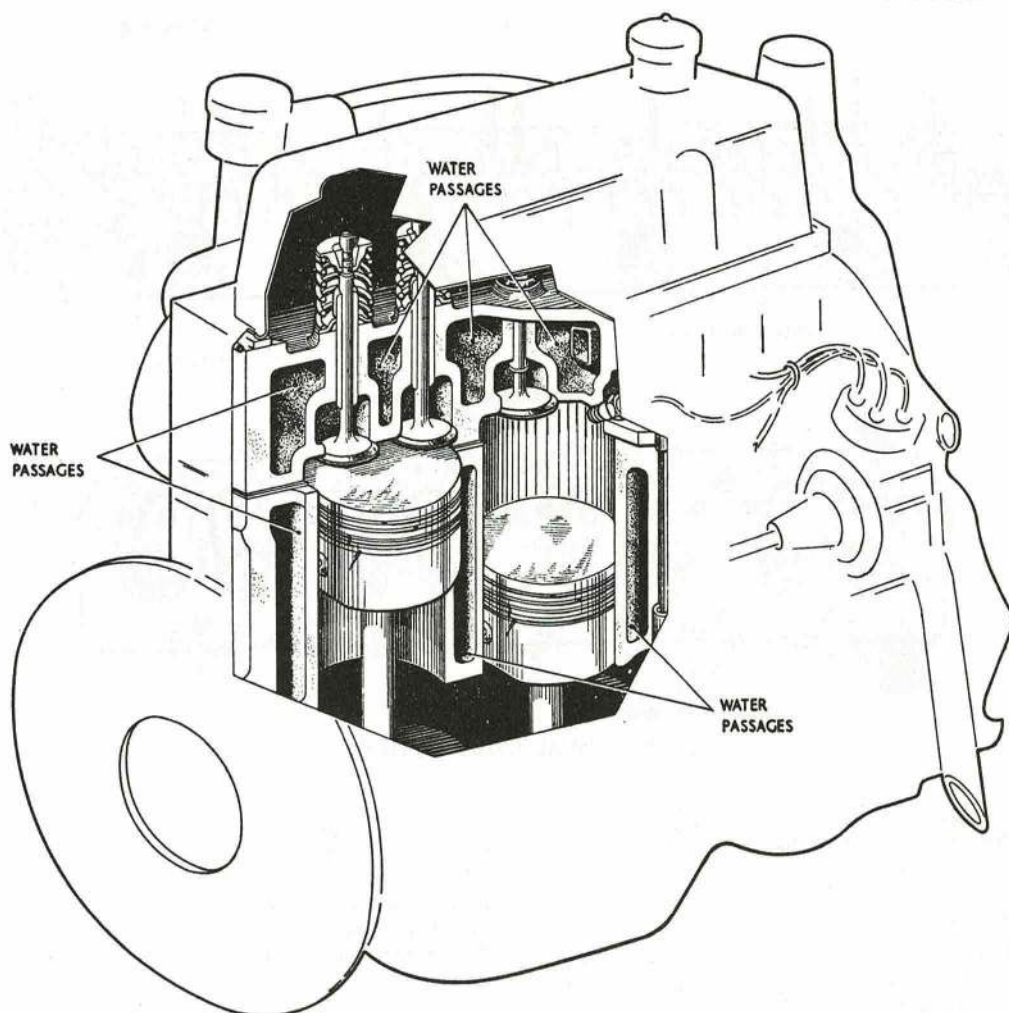


Fig. 10. WATER COOLED CYLINDER BLOCK

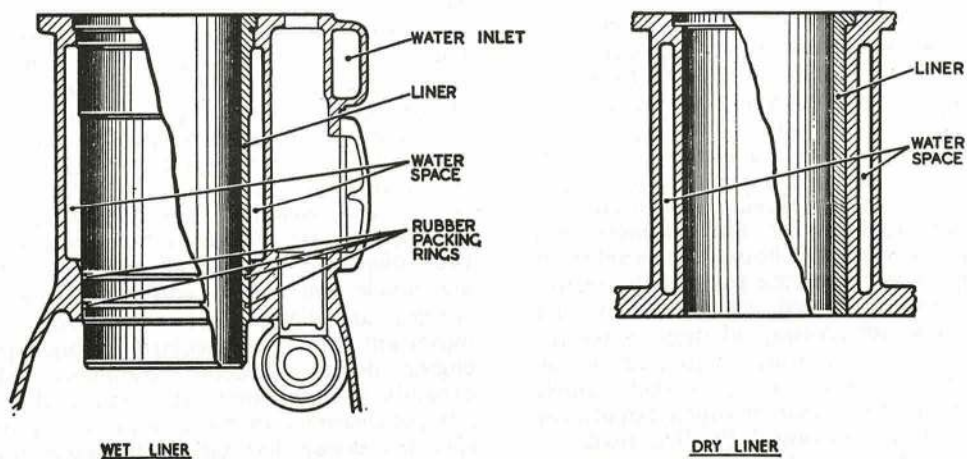


Fig. 11. WET AND DRY CYLINDER LINERS

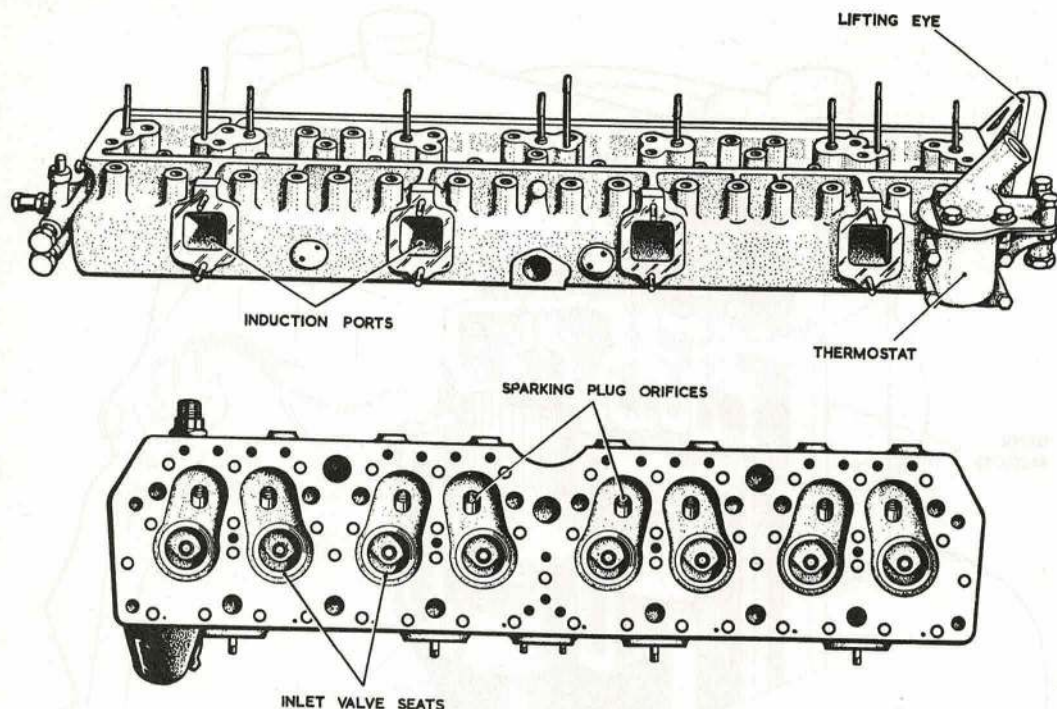


Fig. 12. TYPICAL CYLINDER HEAD

layout, consequently, most designs are a compromise to promote a "squish" or turbulent effect.

Crankcase

30. This is the name given to the part or parts that enclose the lower portion of the engine, although in some instances the very lowest part is called the sump. As stated previously (para. 28), the upper part of the crankcase is often cast integral with the cylinder block; otherwise, it may consist of a single casing or it may be built up from two or more sections depending on the type of engine. The parts are often light alloy castings but ferrous metal is also used, particularly when a separate sump, usually a steel pressing, is fitted. The crankcase forms the support for the cylinders and provision is made to house the crankshaft main bearings. Separate parts of the crankcase and sump, if fitted, are secured by nuts and bolts or set screws; oil tight joints are made with liquid jointing compound and/or one of the various types of gaskets which are available, the details of which can always be found in the relevant A.P. The reader is again reminded that the crankcase of many

two-stroke engines must be gas tight. Besides the many different mountings for other engine components which may be found on the different types of engines, the crankcase usually provides the means of attaching the power unit to its particular installation.

Pistons

31. A piston (Fig. 13) in conjunction with the piston rings, forms a sliding gas-tight plug to keep the charge in the cylinder. It also transmits the force of the burning charge to the connecting rod, and because it acts as a guide and bearing to the small end of the connecting rod it takes the side thrust due to the inclination of the rod. In the past, cast iron was widely used for the manufacture of pistons, but it has largely been displaced by aluminium alloys; these are much better heat conductors and, of course, are lighter than cast iron, two important factors particularly in high-speed engine design. Because aluminium alloy expands at a greater rate than cast iron, a larger clearance in the cylinder is required; also the piston has larger diameters lower down than at the top where the heat is

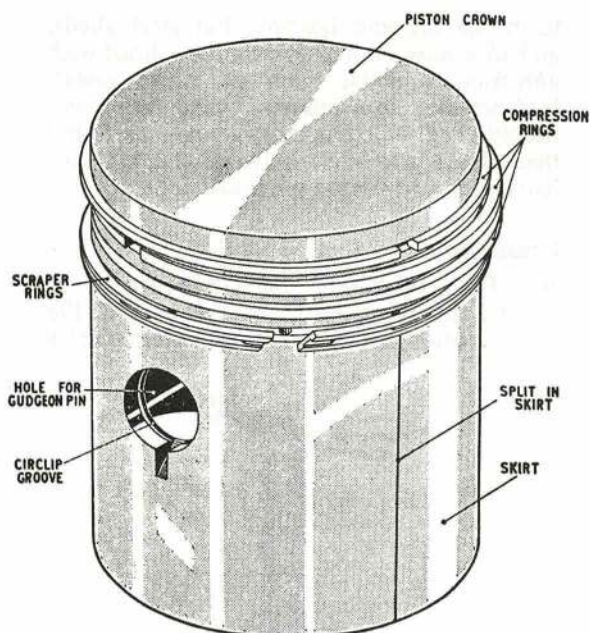


Fig. 13. TYPICAL PISTON

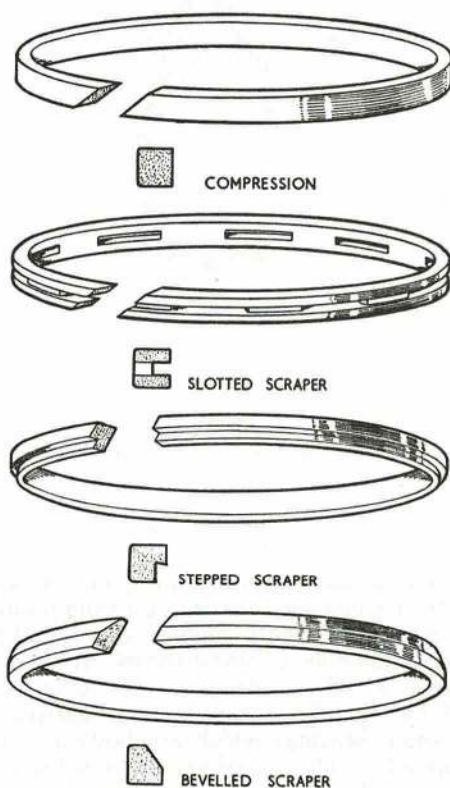


Fig. 14. PISTON RINGS

greatest. Splitting the skirt on the non-thrust side, and making the body of the piston oval are other methods that are used. The piston bosses are bored horizontally to house the gudgeon pin, and holes are drilled as required for the passage of oil. Piston rings are housed in grooves machined in the piston, or in an inserted ring-carrier of ferrous metal which is bonded to the light alloy.

Piston Rings

32. The number and types of rings will have been decided by the manufacturer to meet the performance required of an engine. Rings designed solely as gas seals are known as compression rings; others are purely oil scraper rings, some being specially designed to compensate for variations in the bore. They are all broadly classified as either compression or scraper (oil control) rings (Fig. 14). Piston rings are usually made of fine grained cast iron, because of its good heat and wear-resisting properties.

33. The gap cut in a piston ring may be as shown in Fig. 15, the scarf joint being the most widely used. A ring that is initially circular will, upon being closed when fitted

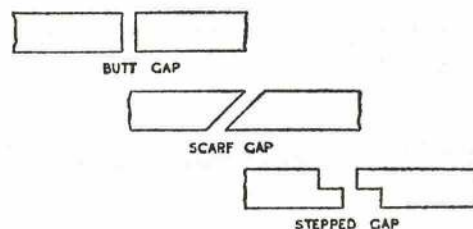


Fig. 15. PISTON RING GAPS

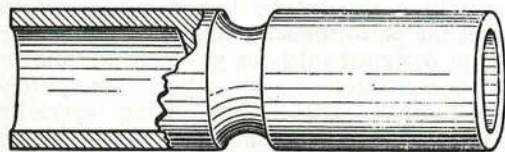
into the bore, only bear on the cylinder wall at the ends of the gap and at the back. The distribution of radial pressure around the circumference of the ring is very important, and correct initial loading is obtained by various methods. Vertical marks on the back of the ring indicate that the method of correction used was by "peening"; this is done in a special machine which ensures variation of the hammer blows as required.

Gudgeon Pin

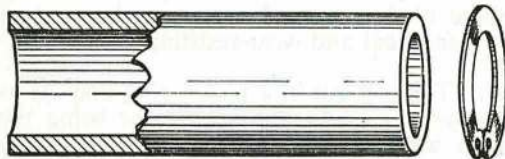
34. This component is used to attach the piston to the connecting rod; it is usually hollow, case-hardened steel, and is borne

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in the piston bosses. There are various methods of locating the gudgeon pin (Fig. 16), the most widely used being "fully floating"; this method usually employs circlips to limit end movement, but in some applications the pin is fitted with soft end pads, such as phosphor bronze or aluminium, to prevent scoring of the bore. In some methods the gudgeon pin is fixed in the piston by some means such as a grub screw, whilst in others it is clamped in the small end of the connecting rod.

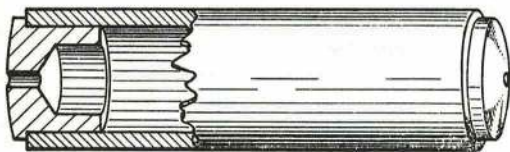


CLAMP TYPE WITH ANNULAR GROOVE



PLAIN PIN FOR CIRCLIP FIXING

CIRCLIP



FULLY FLOATING WITH END PADS

Fig. 16. TYPES OF GUDGEON PIN

form the big end bearing, but steel shells, and to a lesser extent bronze ones, lined with anti-friction metal such as white metal, lead-bronze, lead-indium, etc., are very widely used. Occasionally it may be found that shims are fitted between the big end halves for adjustment purposes.

Crankshaft

36. The purpose of this component is to change the reciprocating movement of the piston into rotary motion. Crankshafts

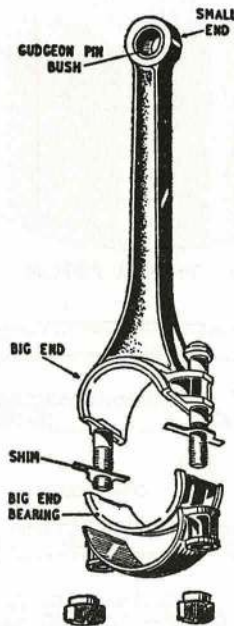


Fig. 17. CONNECTING ROD

Connecting Rods

35. A typical connecting rod complete with bearing shells is shown in Fig. 17. Connecting rods are usually H-section steel forgings or stampings, although light alloy rods have been used. The small end is either a solid eye fitted with a phosphor bronze bush, or the eye is split and "pinched" by a set screw or a nut and bolt when it is designed to clamp the gudgeon pin. The big end works on the crankpin, therefore, for assembly purposes, it is normally split, the "cap" being secured by nuts and bolts, studs, or setscrews; a connecting rod made in one piece is used with a built-up crankshaft. In certain engines ball or roller races

are usually alloy steel forgings, although one firm of world wide repute have successfully used cast alloy steel crankshafts in their production engines for a long time. They are often hollow to decrease weight, increase strength, and to provide a channel for the passage of lubricating oil. Crankshafts are classified according to the number of cranks, a shaft having one crankpin being known as a "single throw" shaft, four cranks a "four throw" shaft (Fig. 18), and so on. The crankshaft is carried in the main bearings which are housed in the crankcase. The remarks on big end bearings in para. 35 apply also to main bearings. When main bearings are of the plain type, it is usual to arrange for one bearing to have

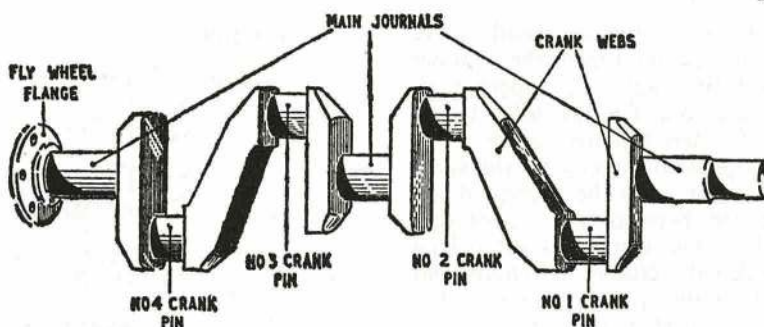


Fig. 18. FOUR THROW CRANKSHAFT

thrust faces for location purposes. The journals and crankpins are hardened to resist wear, and the crankwebs are often formed to provide the required balance weights. The cranks are arranged 180° , 120° or 90° apart, depending on the number and layout of cylinders, the required firing sequence, and balance of the moving parts in the interests of smooth running.

Camshaft

37. The most widely used method of opening and keeping a valve open for the correct number of crankshaft degrees is by use of a cam (Fig. 19). Single and twin-cylinder engines often use separate cams driven directly off the crankshaft, but on multi-cylinder engines the cams are integral with a shaft which is driven by the crankshaft through gears, or by a chain and sprockets. The camshaft is made of steel suitably hardened to resist wear on the cams; it may

be borne in plain bushed or unbushed holes in suitable bosses in the crankcase, but in some engines bearings are employed. Each valve in a four-stroke engine is opened and closed once in every two revolutions of the crankshaft, therefore, whatever type of drive is used, be it chain or gears, the camshaft must be driven at half the speed of the crankshaft. To enable the camshaft to be "timed" correctly to the crankshaft, some method of marking is usually used. This may take the form of marking certain gear teeth which must be meshed on assembly, or scribed lines on the sprockets may have to be aligned (Fig. 20); the relevant A.P. should always be consulted before attempting this operation.

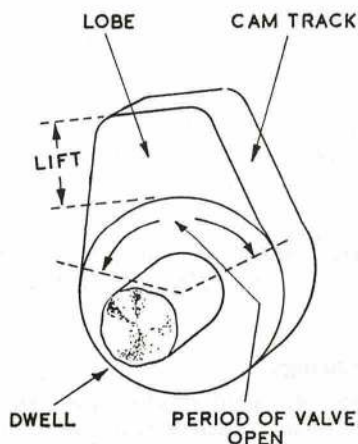


Fig. 19. CAM PROFILE

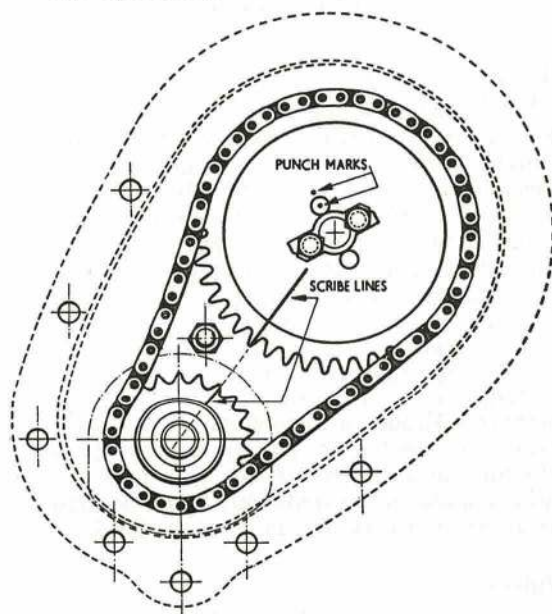


Fig. 20. VALVE TIMING MARKS

38. Camshafts of some overhead valve engines are mounted on top of the cylinder head, and may be single, i.e. operate all valves, or double, one for the inlet valves and the other for the exhaust valves. The valves may be operated directly by the cams (Fig. 21a), or they may be operated by rockers interposed between the valves and cams (Fig. 21b). The camshafts are driven from the crankshaft either by chain and sprockets with some form of tensioning device, or by vertical shaft and gears.

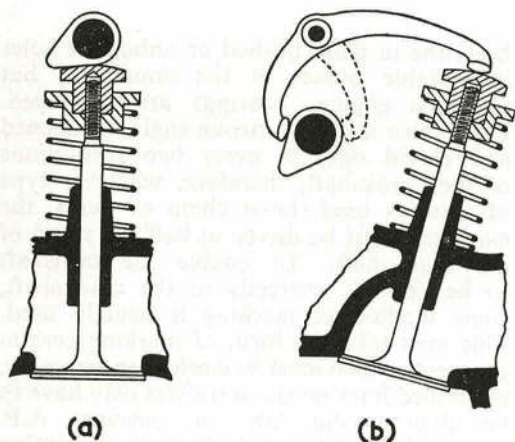


Fig. 21. OVERHEAD CAMSHAFT—VALVE OPERATION

Tappets

39. Tappets are sometimes known as followers for the reason that they follow the profile of the cam, their consequent movement being used to open directly the valves on a side valve engine; the movement is transmitted via push rods and rockers to the valves of a push rod operated overhead valve engine. Side valve tappets are usually provided with the means for adjusting "valve clearance" (Fig. 22), although there have been engines fitted with hydraulic self-regulating or mechanical self-adjusting tappets. Tappets are sometimes fitted inside bronze or cast iron guides to provide a bearing surface, the exhaust and inlet for each cylinder being frequently manufactured as an assembly known as a tappet block.

Valves

40. The most widely used method of controlling the flow of the combustible mixture (or air) to, and exhaust gases from,

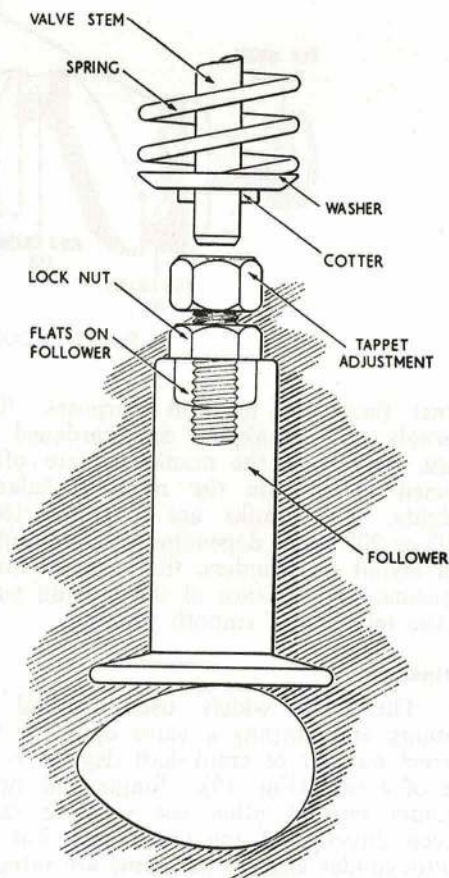


Fig. 22. SIDE VALVE TAPPET

the cylinder, is by poppet valves (Fig. 23); these are heat-resisting alloy steel forgings. On some engines the inlet valves have larger heads, or may be made of different steel from the exhaust valves. The valve face is usually machined at 45° , although sometimes a flatter angle of about 30° is used; some valves have the actual valve face formed of an extremely hard alloy such as "stellite" which is welded to the head. Provision is made for retention of the valve springs towards the end of the stem by some such means as tapered split collets, cotter pins, etc.

Valve Springs

41. These are used to close the valves and to keep them closed except when opened by the action of the cams. They are often duplicated to reduce valve bounce, and wound in opposite directions. They are

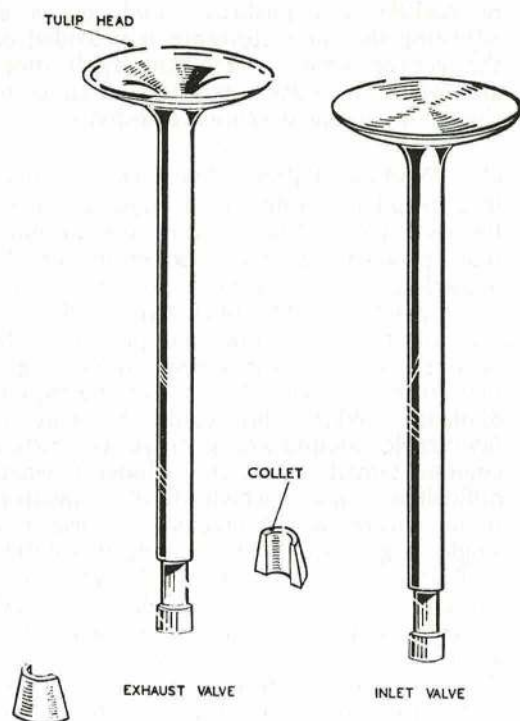


Fig. 23. TYPICAL POPPET VALVES

fitted with at least one end washer or retaining plate, this being used in conjunction with the provision made on the valve to retain the springs. It will be found in practice that many valve springs are of the "progressive rate" type, i.e. the springs have one end that is close-coiled; these close-coiled ends should be fitted nearest to the valve head (Fig. 24).

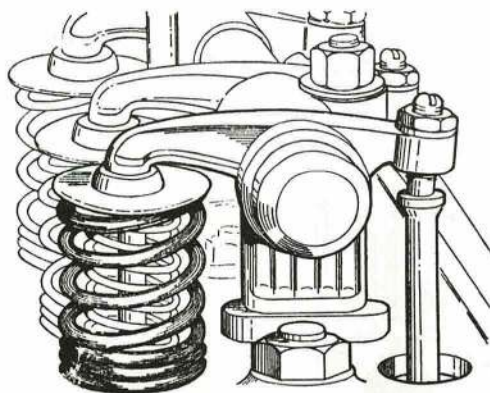


Fig. 24. PROGRESSIVE RATE SPRINGS

Valve Guides

42. Although the valve stems of some engines work directly in bores machined in the head or block, the majority are fitted with bronze or cast iron guides that are normally a press fit in the casting. Valve guides are prone to wear because lubrication presents something of a problem, and as wear would allow leakage, they are therefore made to be easily renewable. The valve guides of overhead valve engines are often fitted with oil seals.

Valve Seats

43. Although the seating for the valve is often machined directly in the block or head as applicable, the use of valve seat inserts is extensive. They may be made of bronze, special heat-resisting cast irons, or "stellited steel". Amongst the various methods used for securing them in the block or head are screwing and shrinking.

Valve Location

44. The location of the valves in a four-stroke engine is decided by the designer, having full regard to many requirements and the overriding factors imposed by the particular performance required of the engine. Much could be written about this subject but it would be far beyond the scope of these notes, which are, therefore, confined to brief information on the three layouts which the tradesman is likely to have to service; these are side valves, overhead valves, and a combination of the two types. Whatever the design, it is essential that heat variation will not result in the valves not seating when the engine is hot; this can be ensured by maintaining a small gap—"valve clearance"—between the tappet or rocker and the valve stem.

45. **Side Valves.** These are fitted in the cylinder block (Fig. 25), the inlet and exhaust ports being formed in the block itself with the valves opening upwards. Thus, the layout is simple and requires a minimum number of parts, so keeping the cost of production as low as possible. The shape of the combustion chamber is far from being the most efficient, the size of the valves and port cooling present a problem, and the induced charge is further limited by the changes in direction of the gas flow. Nevertheless, for all ordinary purposes a side valve

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engine is satisfactorily efficient. As stated previously (para. 39), provision is usually made for adjustment of the valve clearance. This consists of flats on the follower enabling it to be held by a spanner; the tappet bolt screws into a fine thread in the follower and is locked by a locknut. The actual clearance and procedure to be used when setting the valve clearance can be found in the relevant A.P., but it is important that the setting must only be done when the tappet is resting on the back of the cam.

46. Overhead Valves. These valves allow a more efficient shape of combustion chamber than is possible with side valves, i.e. the shape can be nearer to the ideal hemispherical head. Also, the flow of the induced charge is better, scavenging is more complete, and, therefore, size for size, an overhead valve engine will be more efficient and will develop more power than a side valve engine. Overhead valves are fitted in the cylinder head, the inlet and exhaust ports being formed in the head with the valves opening downwards into the combustion space. The most widely used layout is shown in Fig. 25, the valves being operated by means

of rockers and pushrods, and means of adjusting the valve clearance is provided on the rocker arms. There are applications also where the valves are operated either by single or double overhead camshafts.

47. Combined Valves. The power produced in a cylinder depends, to a large extent, on the weight of fuel/air mixture (or air only) that is taken into the cylinder during the induction stroke. Among other factors, the diameter of the inlet valve influences the volume of gas that can pass into the cylinder, and it might appear, at first sight, that all that is required is a valve of adequate diameter. While this could be true in favourable circumstances, there are certain engines (small diameter cylinders) where difficulties, some of which are of a constructional nature, would preclude the use of a single large valve. One practical solution is found in the adoption of 'twin' inlet valves; each valve has a relatively small diameter and is thus free from the troubles associated with excessive size, but because the two valves operate as one the pair together pass the required amount of charge. Another method which is currently being

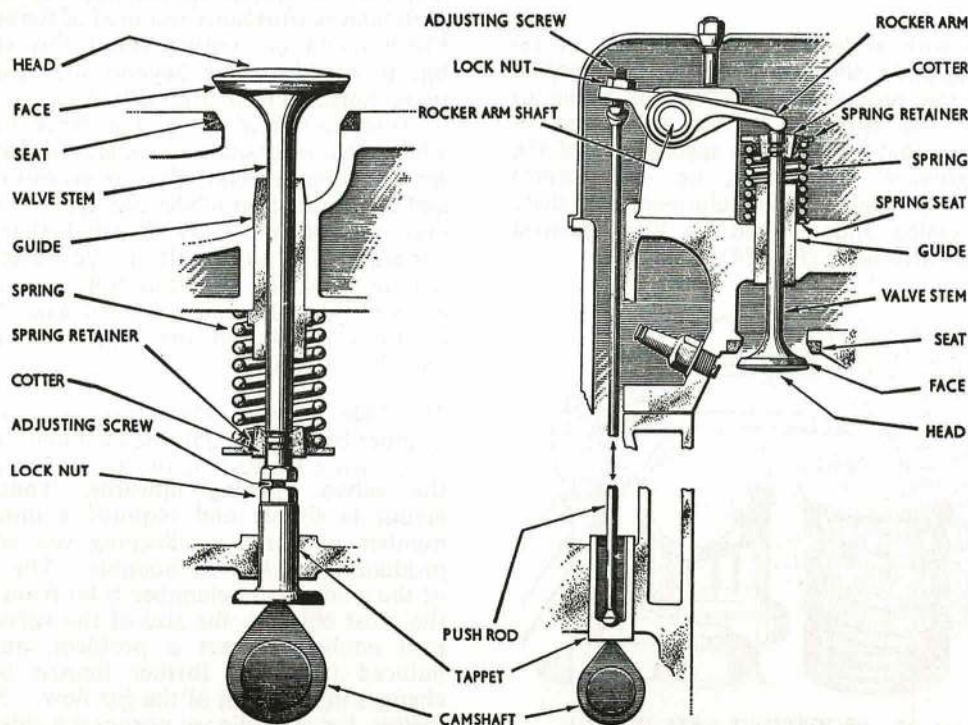


Fig. 25. POPPET VALVES—SIDE AND OVERHEAD

applied successfully by several manufacturers, is a combination of overhead inlet valves with side exhaust valves. With this type of layout where only the inlet valves are housed in the cylinder head, large diameter valves with free entry for the charge can readily be provided. The valves may be operated in one of the following ways:—

(a) By means of a single camshaft provided with rockers to operate the side exhaust valves, and push rods and rockers to operate the overhead inlet valves (Fig. 26).

(b) By two separate camshafts, one for operation of the exhaust valves and the other for the inlet valves.

Flywheel

48. The purpose of a flywheel is to promote smooth and continuous running. On small single and twin cylinder engines, the flywheel is often built up as part of the crankshaft, taking the place of the crankwebs, and thus is situated inside the crankcase. On multi-cylinder engines it is usually situated outside the crankcase, being attached to the crankshaft by some means such as tapering and keying or by bolting to a flange. When an electric motor is used to start the engine, the flywheel usually has a ring of teeth on its circumference termed a "starter ring"; this ring is engaged by the starter pinion whenever the starter motor is operated. The ring of teeth may be machined on the flywheel itself, but it is

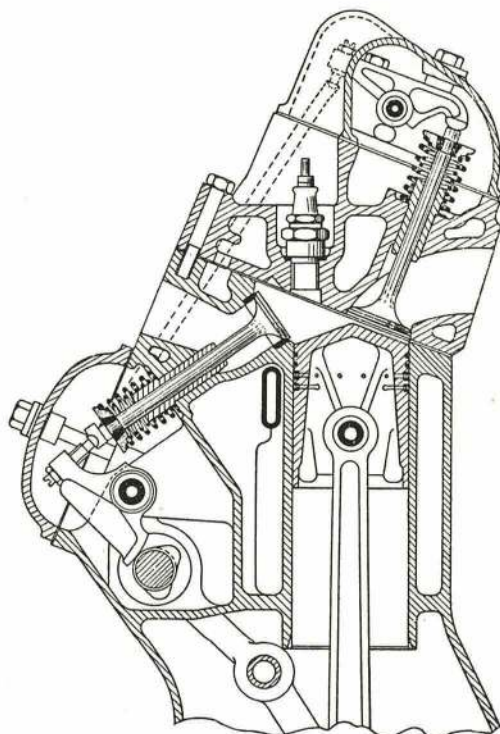


Fig. 26. COMBINED VALVE LAYOUT

more usual for the ring to be made separately and then shrunk into place on the flywheel. It is quite common practice for dead centre positions, valve timing and ignition timing points, to be marked on the flywheel.

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