

CHAPTER 1

PISTON ENGINE PRINCIPLES

Objectives

1. This Chapter has been written with the aim of helping you to satisfy objectives in the relevant Skills and Knowledge Specifications (SAKS) for the trade in this subject area. When you have studied this Chapter you will be able to:

- a. Describe how the reciprocating movement of the piston in the cylinder of an internal combustion engine (ICE) is converted into rotary movement.
- b. State the factors necessary for continuous operation of the engine.
- c. Describe the strokes in a four-stroke cycle and define the related terms.
- d. State why it is necessary to modify the basic four-stroke cycle.
- e. Describe such modifications with particular reference to the operating times of the inlet valve, the exhaust valve and the ignition timing.
- f. Describe the basic operation of the valves.
- g. State why multi-cylinder engines are used in aircraft.
- h. Describe the three common cylinder arrangements in multi-cylinder engines.

Introduction

2. The purpose of a piston engine is to convert heat energy into mechanical energy. When the heat energy is applied inside the engine, we call the engine an internal combustion engine (ICE). If the heat is applied from outside sources, *eg* a steam locomotive, we call this an external combustion engine. The heat energy is supplied by igniting a combustible mixture of fuel and air inside a cylinder; this, in turn, forces a piston inside the cylinder downwards. The piston is connected to a crankshaft by a connecting rod which, in turn, is attached to a propeller shaft, sometimes through a reduction gear. This is the mechanical means of converting reciprocating motion (upwards and downwards movement) into rotary motion (circular). This conversion is illustrated at Fig 1.1.1.

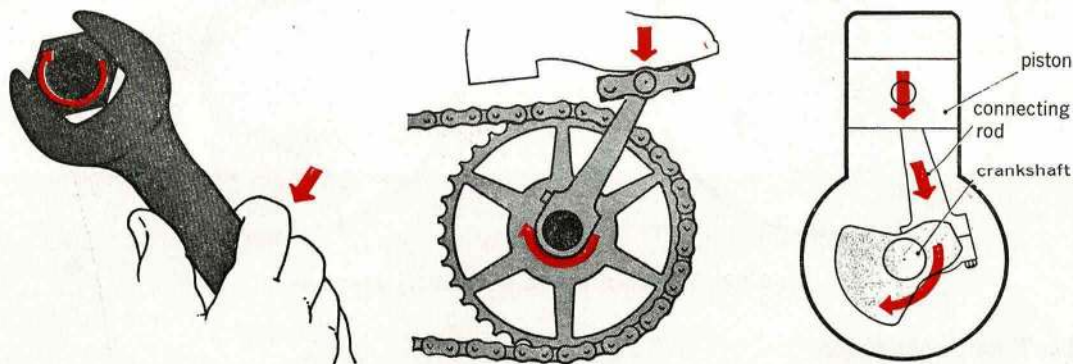


Fig 1.1.1 Conversion of reciprocating motion to rotary motion

3. To ensure continuous operation the following things must happen:
 - a. Air and fuel in the correct proportion must be supplied at the correct time in relation to the position of the piston.
 - b. Combustion must occur at the correct time so that the maximum expansion of the gases will occur as the piston is about to move down the cylinder.
 - c. The waste of exhaust gases must be expelled as soon as their useful work is completed.

Cycle of Operation

4. The sequence of operations is referred to as the four stroke cycle. The strokes are the number of piston movements up and down the cylinder which are required to complete a *cycle* of operations. Two upwards and two downwards movements contribute a four stroke cycle. A stroke is defined as the extent of the piston travel within the cylinder; the low limit of travel is known as 'Bottom Dead Centre' (BDC), and the high limit as 'Top Dead Centre' (TDC). For each stroke, the crankshaft turns 180° , *ie* one half of a crankshaft revolution. An illustration of TDC and BDC is shown at Fig 1.1.2.

5. The lowest and highest positions occur when a straight line can be drawn through the centre of the gudgeon pin which connects the piston to the connecting rod (small end), the connecting rod which connects the piston to the crankshaft, and the crank pin which connects the crankshaft through the main bearings to the connecting rod (big end).

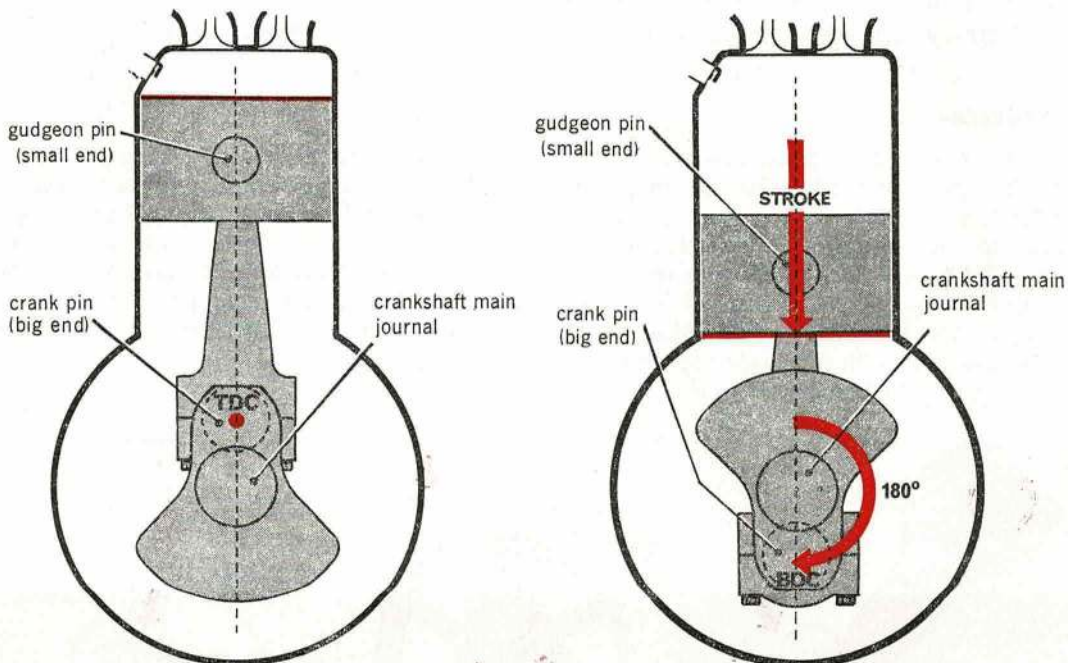


Fig 1.1.2 Top dead centre and bottom dead centre

The Four Stroke Cycle

6. The four stroke cycle 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 strokes of the piston to

two revolutions of the crankshaft to deal completely with each charge of the fuel/air mixture. The cycle is started by external means (an electric or cartridge fired starter turns the crankshaft); the fuel/air mixture enters the cylinder, the mixture is compressed and then ignited by a spark from a sparking plug, and the engine continues to run under its own power until the fuel or the ignition is turned off. The four strokes are illustrated at Fig 1.1.3.

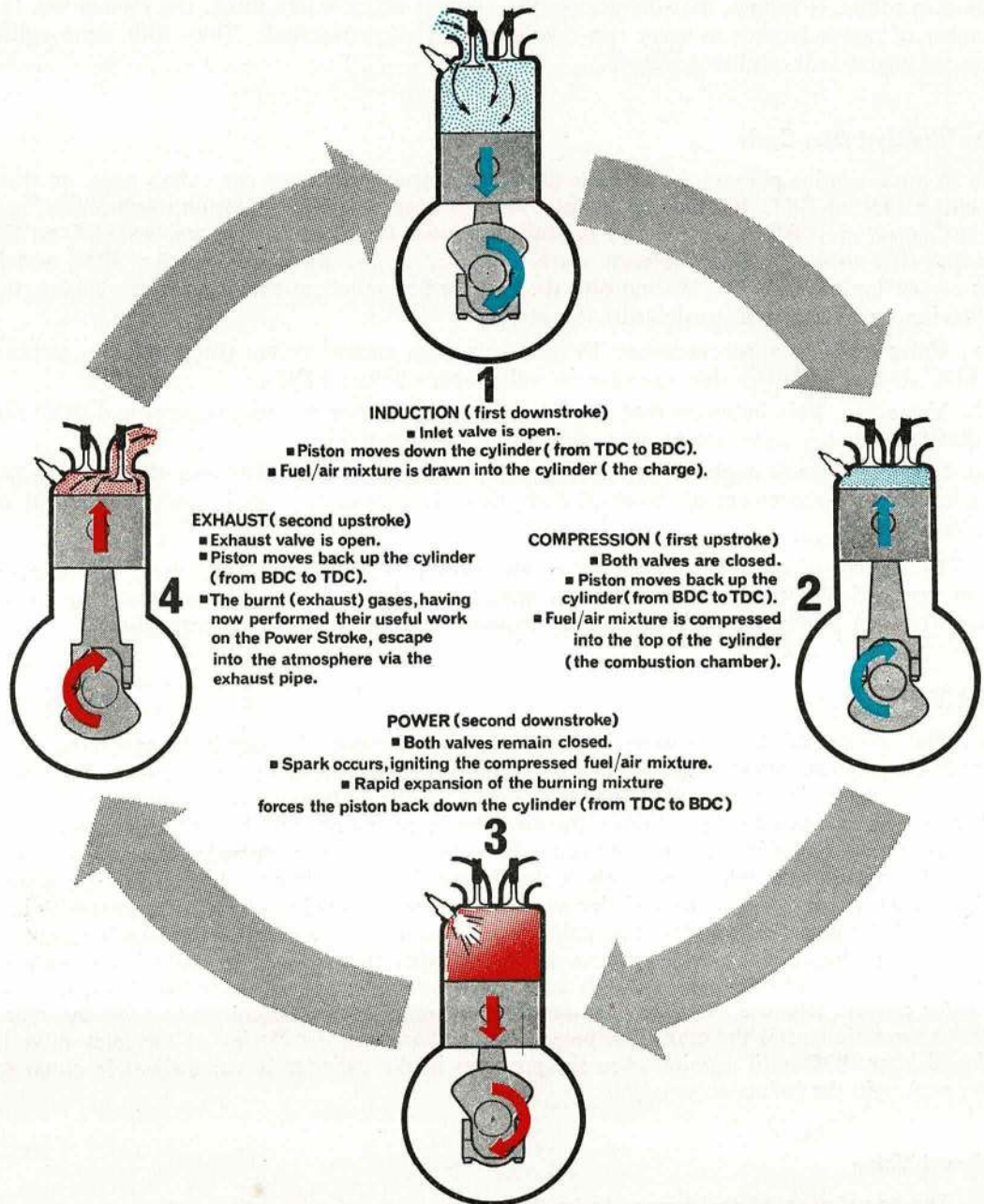


Fig 1.1.3 The four stroke cycle

7. Having explained the four basic strokes, it will be noted that these four operations necessitate two complete revolutions of the crankshaft. In the four stroke cycle, there is only one power stroke in each two revolutions of the crankshaft, and three idle strokes. In order that the engine may drive itself over the three idle strokes, the crankshaft and other rotating parts store up energy received from the power stroke and thus continue to rotate the crankshaft when the engine is on exhaust, induction and compression strokes. The engine, therefore, continues to rotate. It follows that the greater the number of cylinders fitted, the greater are the number of power strokes to every two revolutions of the crankshaft. Thus with more cylinders, an engine will run more smoothly.

The Modified Otto Cycle

8. In the foregoing paragraphs we have discussed theoretically how the valves open or close at either TDC or BDC. In practice, the inlet valve is opened *before* the piston reaches TDC and is not closed until BDC; the fuel/air mixture is ignited *before* the piston reaches TDC on the compression stroke; and the exhaust valve is opened *before* the piston reaches BDC and is not closed until *after* TDC. To indicate the modified or practical operation in the engine, the following terms are used to describe the above:

- a. **Valve lead.** This indicates that the inlet valve has opened before the piston has reached TDC. It also indicates that the exhaust valve opens before BDC.
 - b. **Valve lag.** This indicates that the inlet valve closes after the piston has passed BDC and that the exhaust valve closes after the piston has passed TDC.
 - c. **Ineffective crank angle.** This is the angular position around TDC and BDC where, for a large rotary movement of the crankshaft, there is a relatively small linear movement of the piston.
9. The degrees of opening and closing of the valves at TDC and BDC vary, and depend upon the particular purpose for which the engine was designed. The reasons for these variations from the purely theoretical cycle are explained in the following paragraphs.

Inlet Valve

10. The opening of the inlet valve is a critical point because, if opened too early, the pressure in the cylinder would tend to blow back the incoming gas; at the correct time, the lower pressure in the cylinder, caused by the momentum of the outgoing 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 is the chief reason for 'valve 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 and this reduces the lag in flow which occurs 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 by whether the engine is designed to operate at high or low rev/min. The inlet valve is kept open as long as possible to induce the maximum cylinder charge. Because of its momentum, the incoming gas will continue to enter the cylinder for some time after the crank has passed BDC; therefore, the closing of the inlet valve is delayed after BDC until a point when the pressure in the cylinder is approximately equal to the pressure in the induction manifold.

Exhaust Valve

11. The completion of the power stroke leaves burnt gases in the cylinder. These gases must be effectively discharged before the next cycle commences, otherwise there will be less room

for the new charge. Towards the end of the power stroke, because of the acute angle that 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 BDC, two advantages are obtained:

- a. The residual gas pressure begins scavenging the exhaust gas before the piston starts to move up the cylinder, and thus any slight loss of power is compensated for by better scavenging and the avoidance of back pressure.
- b. 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 gases in the combustion chamber when the piston has reached TDC, 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.

12. It is usual to represent the opening and closing of the inlet and exhaust valves, together with the point of ignition of the charge, by means of a timing diagram and this is illustrated at Fig 1.1.4.

Ignition

13. 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—that is, when the crank has just passed TDC. Burning of the fuel/air mixture takes time, and although rapid, it is not instantaneous. Peak pressure is not reached until the mixture has been completely burned. Thus ignition must also be arranged to occur so that combustion will be complete at the time the piston is about to descend. Remember that the faster the engine runs, the earlier the ignition point must occur.

14. We have now discussed the terms 'internal combustion engine' and the 'four stroke cycle'; we have also seen why the valves must open and close at certain times in the cycle of operations, and how important

it is that ignition must occur at the proper time, *ie* after the mixture has been compressed. All these things must happen in the proper sequence to obtain maximum efficiency. The sequence of operations is related to crankshaft movement and is always expressed in degrees (see Fig 1.1.4).

Valve Operation

15. The valves are spring loaded into the closed position and are opened by a mechanism geared to the crankshaft. The mechanism operates at *half* crankshaft speed so that each valve opens and closes once for each two revolutions of the crankshaft. The valves are actuated by

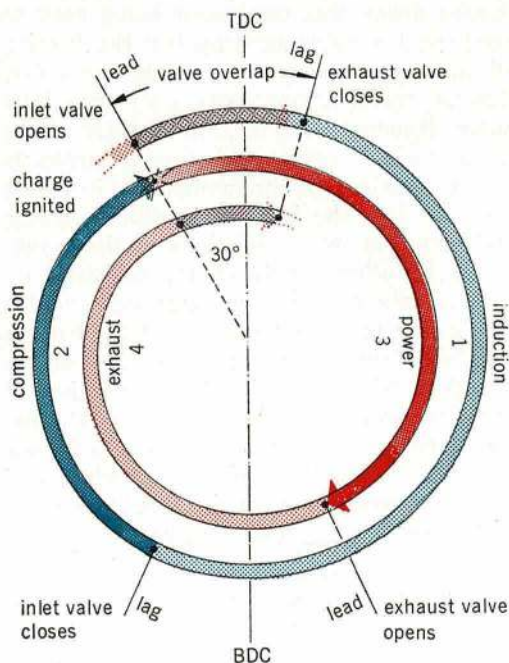


Fig 1.1.4 Valve timing

using cams, tappets, push-rods and rockers. Fig 1.1.5 illustrates one method in which these four parts are used.

16. The cam, which is eccentric, is carried on a shaft called the camshaft or a cam drum and is rotated by the crankshaft through gearing. Held against the face or contour of the cam is a tappet, this being fixed at the end of the pushrod. As the camshaft rotates, the tappet will move up and down, this movement being communicated to the pushrod. The pushrod bears against one end of the lever termed the 'rocker' which is pivoted on a bracket. As the push rod end of the rocker is forced up, the other end will be forced down, this movement being used to push on the valve stem against the loading of the valve spring surrounding the valve. Let us consider one valve only—the inlet valve. Remembering that, in the four stroke cycle, there is only one induction stroke in two revolutions of the crankshaft, it should be clear that the inlet valve needs opening only *once* in two revolutions of the crankshaft. In other words, if the camshaft revolves only once in the same time as the crankshaft revolves twice, the desired result will be obtained by using a gear wheel on the camshaft which has double the number of teeth as the gear on the crankshaft. The exhaust valve has also to be operated once every two revolutions of the crankshaft and at the correct moment in relation to the piston and the particular stroke.

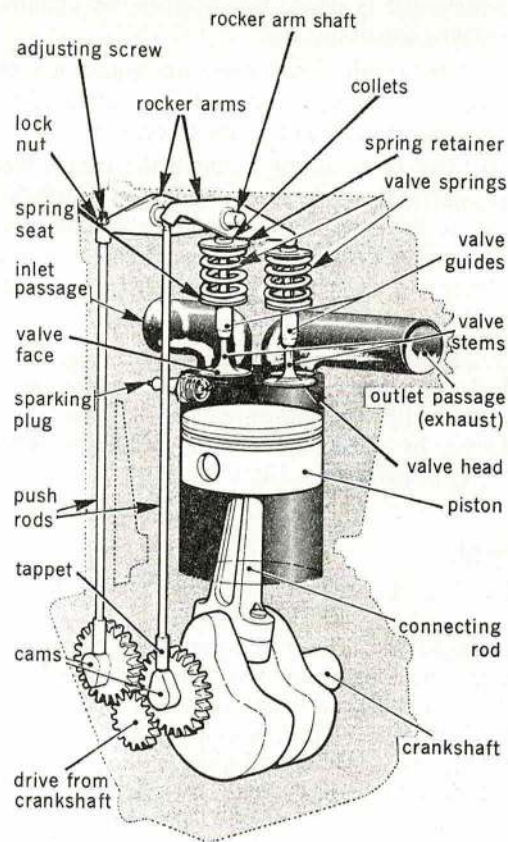


Fig 1.1.5 Valve operation

17. **Valve clearance.** When an engine is assembled for running there is always a certain space called 'clearance' left between the end of the rocker and the end of the valve stem. This clearance is measured in thousandths of an inch. The reason for the clearance is that, when the engine is on compression stroke for example (*ie* after the inlet valve has closed), it is obviously very important that the inlet and the exhaust valves *remain closed*, otherwise the mixture being compressed will leak past the valves. If no clearance space were left—*ie* the top of the valve touching the rocker, the other end of the rocker touching the push rod, the push rod touching the tappet, and the tappet touching the cam, so that all the mechanism were rigid—the slightest maladjustment or alteration in the length of the valve through expansion would cause it to remain slightly open when it was supposed to be closed. *Therefore, so that there shall be no chance of this occurring, a valve clearance is maintained.* The amount of valve clearance is adjusted by means of a screw pad in the push rod end of the rocker.

18. It is customary with aero-engines to set the valve clearance of the cylinder being timed to the hot or running clearance. This clearance will inevitably differ from the clearance specified for Servicing purposes (cold engine). To set the valve clearance, the camshaft must be turned until the lobe (peak) of the cam is 180° away from the tappet. Slacken the locknut and the tappet adjusting screw and insert a feeler gauge of the specified thickness. Adjust

the tappet screw until the feeler gauge is a tight fit but can also be withdrawn. Lock the lock-nut and recheck that the clearance is still correct. Re-adjust as necessary.

The Multi-cylinder Engine

19. When explaining the principles of the four stroke engine, only one cylinder was considered. A single cylinder four stroke engine would not provide enough power for an aircraft and neither would it run very smoothly because the propeller would receive only one power impulse from the crankshaft every two revolutions. Therefore, increasing the number of cylinders will increase the number of power strokes for every two revolutions of the crankshaft. 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 rapid sequence of power impulses in a multi-cylinder engine. This imparts almost continuing turning effort to the propeller shaft and results in smoother running.

20. There are several arrangements for multi-cylinder engines. The most common, illustrated at Fig 1.1.6 are:

- a. Single in-line row like a car engine (Gypsy).
- b. A radial arrangement, single or double bank (Leonides).
- c. Flat 4 or 6 cylinder. (Continental or Lycoming.)

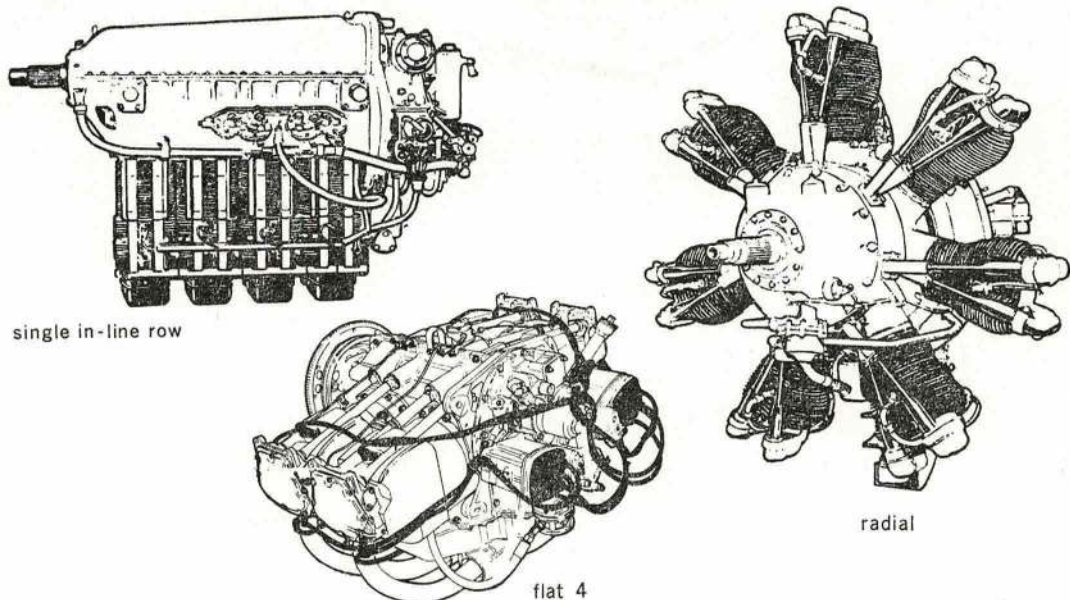


Fig 1.1.6 Cylinder arrangements

Balance

21. Another factor of vital importance to ensure smooth running is balance—not only in the engine but also in the propeller. Moving parts in perfect balance cause no vibration. The ideal situation is an engine which excludes reciprocating motion and modern aircraft have engines fitted with purely rotary movement. However, the piston engine, with modern manufacturing techniques, is now designed to be as perfectly balanced as the particular application will allow. On some engines, balance of the reciprocating parts is achieved by weights attached to, or formed from, extensions of the crankwebs; 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.

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