

Module 5: Combustion Technology
Lecture 40: Internal Combustion Engine

Keywords: Petrol engine, diesel engine, clearance volume, top dead center, bottom dead center, crankshaft, Otto cycle, Diesel cycle

5.9 Internal Combustion Engine

Historical background

In the internal combustion(IC) engine, the gases produced from the combustion of gaseous or liquid fuels at high pressure are expanded in a piston cylinder arrangement which helps to transmit the mechanical energy to the crankshaft. Therefore, this device is used to convert thermal energy to mechanical energy. In 1860, J. J. E. Lenoir developed the commercial IC engine where coal gas- air mixture was used as a fuel. The four stroke engine first developed by N. A. Otto in 1867 and the two stroke commercial engine first introduced in 1881 by D. Clerk. Thereafter, Rudolf Diesel invented a different form of internal combustion engine in 1892. Continuous efforts have been given by the researchers for the improvements of the IC engines.

Classification of Internal Combustion Engine

The engines are classified as the two strokes engine and four strokes engine by the operating principles. The process of ignition and mixing of air and fuel are carried out in two different ways in Otto and Diesel's engines.

In Otto engine, air and fuel are premixed together in the approximate ratio of 15:1 in the carburetor and then introduced into the cylinder for compression. In this engine petrol or gas can be used. Then the mixture is ignited by an electric spark plug and the a flame front progresses across the combustion chamber. So it's another name is Spark Ignition Engine(SI-engine).

In Diesel engine, pure air is compressed first and the fuel is injected in the form of droplets at the front of the compressed air. Then the temperature of air increases with the heat of compression

and the ignition starts. It is also called as Compression Ignition Engine (CI-engine) . Air fuel ratio varies from 20:1 to 100:1. In this engine diesel oil is used as a fuel.

Four Stroke Engine

The four strokes of engines are as follows:

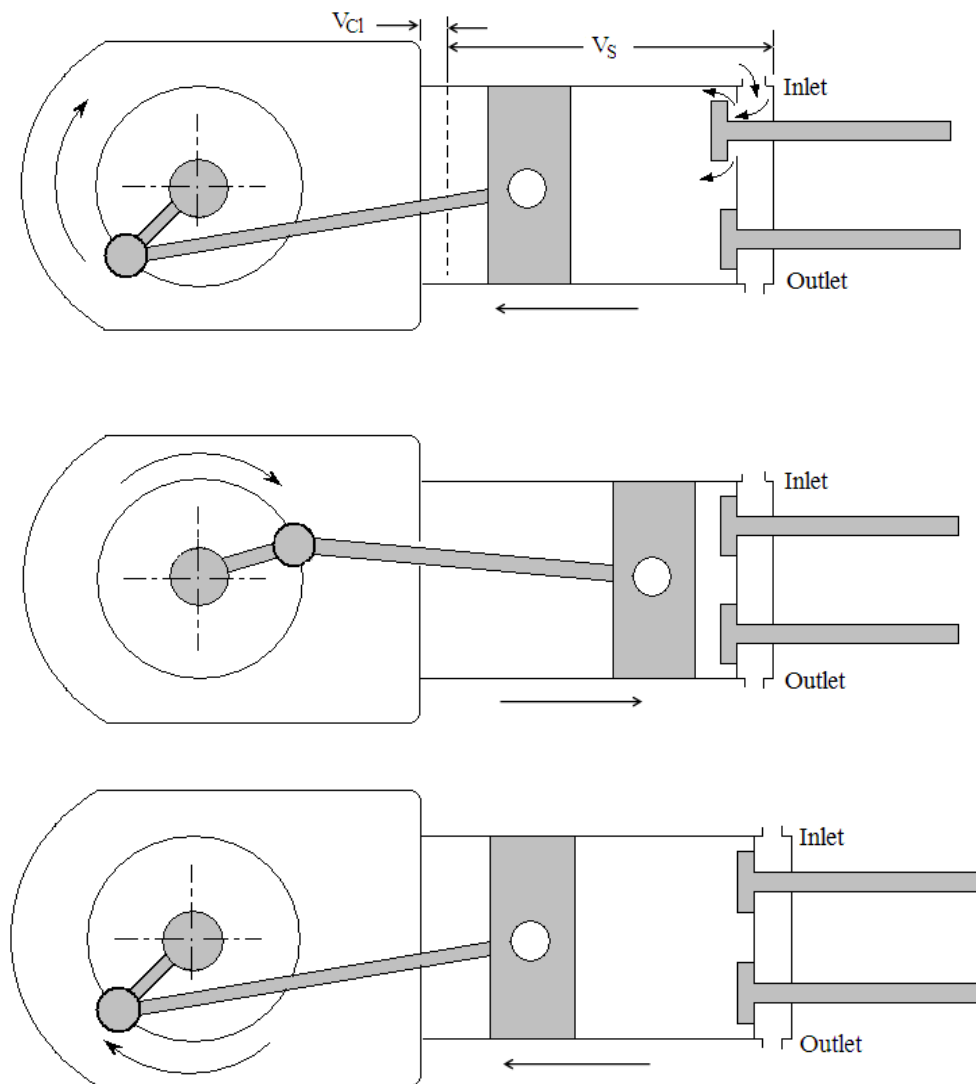
1. First stroke: the intake of fuel-air mixture.
2. Second stroke: the compression stroke followed by ignition
3. Third stroke: the expansion of the combustion gases are work is delivered to the crankshaft
4. Fourth stroke: The exhaust of the flue gases.

Operation of Four Strokes Engine

The four stroke engine operates on a reciprocating motion of the piston in a cylinder. By the to and fro motion of the piston in a cylinder, the power is transmitted to the crankshaft as shown in Fig. 1. The minimum cylinder volume is called the clearance volume (V_{Cl}) when the piston is closed to the valves end. The volume swept out by the piston is called the swept volume (V_S). Where, $V_S = V_{tot} - V_{Cl}$ and V_{tot} = total volume of the cylinder.

In the first stroke of the engine, the inlet valve opens and oil-air mixture enters the cylinder. This stroke continues from the valve end to the other end. When the piston moves the full length of the cylinder, the inlet valve closes. Then the mixture is compressed by the reverse movement of the piston, which is the second stroke. The oil is ignited at this high pressure by applying a spark when the piston reaches near the end of the cylinder which is called the *top dead center* (TDC). Then the combustion starts and the gases are expanded in the cylinder. Then both the valves are

closed and both the pressure and temperature of the gases increase. In the third stroke of the piston, the gases expand and the piston moves. The crankshaft starts to rotate and at the end of expansion, the pressure decreases. The outlet valve opens to exit the gases from the cylinder and then the outlet valve closes. In the last stage, the rest of the flue gas escapes from the cylinder and the outlet valve closes. Now the inlet valve opens and the cycle continues by the intake of the fresh air-fuel mixture. All strokes of the pistons are described in Fig.1



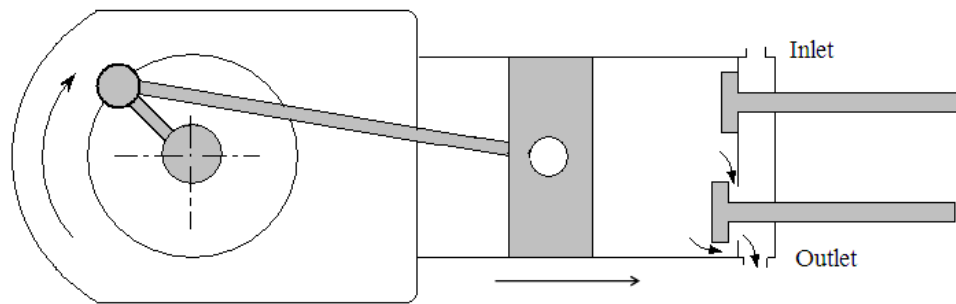


Fig.1 Operation of four stroke engine

Ideal Engine Cycles

Otto Cycle

The Otto cycle consists of a four internally reversible processes by which the operation of a petrol engine can be analyzed. The cycle is represented in both the P-V and T-S diagrams. The cycle starts at Top Dead Centre (TDC) and ends at the Bottom Dead Centre (BDC). The distance travelled by the piston from TDC to BDC is called a stroke. The clearance volume (V_{cl}) is measured after the TDC. The four stroke engine in Otto cycle may be represented as follows:

1. The compression from state 1 to state 2 in a constant entropy process.
2. The constant volume (Isochoric) process from 2 to 3, where the heat (Q_h) is added to the system and the gas-fuel mixture is ignited. Both the pressure and temperature increases.
3. The reversible and adiabatic (isentropic) expansion process occurs from 3 to 4. Work is done on the piston by the expansion of gas mixtures. Both the pressure and temperature decrease.

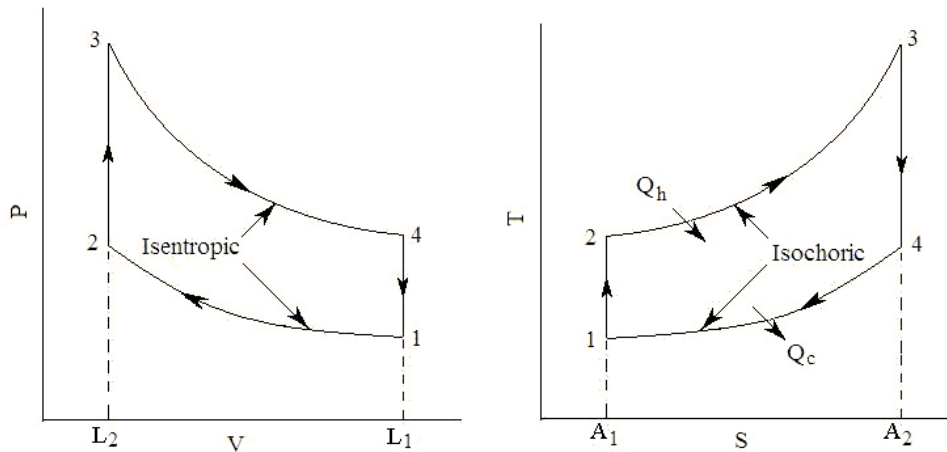


Fig. 2 Otto cycle on P-V and T-S diagrams

4. The process 4 to 1 is constant volume cooling, i.e. the heat (Q_c) is removed from the gases.

Considering unit mass of oil-air mixture, the heat and work relation can be explained by the above two diagrams.

Heat transfer to the gas mixture (heating) per unit mass =

$$Q_h = \int_2^3 T ds = \text{area of } 23A_2A_12 \text{ (Fig 2.)}$$

Heat transfer by the gas mixture to surrounding (cooling) per unit mass =

$$Q_c = \int_4^1 T ds = \text{area of } 41A_1A_24 \text{ (Fig 2.)}$$

The net heat added to the cycle per unit mass = $Q_h - Q_c$

Similarly from p-V diagram, it may be observed that the work done to the fuel-air mixture per

$$\text{unit mass} = \int_1^2 P dV = \text{Area of } 12L_2L_11$$

$$\text{And work delivers by the engine per unit mass} = \int_3^4 P dV = \text{Area of } 34L_1L_23$$

The net work done by the engine = area enclosed by the curves in P-V diagram.

$$\text{In an isentropic process } \Delta S = 0 = C_V \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1} \quad (1)$$

It is an adiabatic and reversible process.

For ideal gas assuming C_P and C_V are constant, then $C_P - C_V = R$ and $\frac{C_P}{C_V} = k$

We have, $C_V = \frac{R}{k-1}$ From eqn. (1) $\frac{R}{k-1} \ln \frac{T_2}{T_1} = -R \ln \frac{V_2}{V_1}$

$$\left(\frac{T_2}{T_1}\right)^{\frac{R}{k-1}} = \left(\frac{V_1}{V_2}\right)^R$$

$$\text{Or, } \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1} \quad (2)$$

The efficiency in this cycle is given by

$$\eta = \frac{T_2 - T_1}{T_2} = 1 - \frac{T_1}{T_2}$$

$$\eta = 1 - \left(\frac{V_1}{V_2}\right)^{1-k} \quad \text{also, } \frac{V_1}{V_2} = \text{compression ratio} = \eta$$

Diesel Cycle

Diesel cycle is an ideal cycle by which the working principle of a diesel engine can be represented. In this cycle, air is first compressed to a high pressure and then fuel injected to the cylinder where the fuel is self ignited due to high temperature by compression. The process is thus called as compression ignition. In this cycle, the heat is transferred to the fluid at constant pressure.

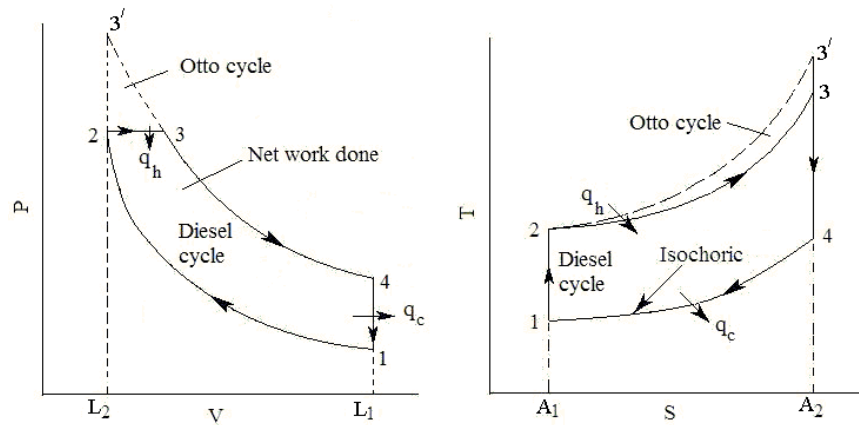


Fig.2 Diesel cycle on P-V and T-S diagram

In Diesel cycle, air is taken into the cylinder and is undergone reversible and adiabatic reversible, i.e. isentropic compression from state-1 to state-2. It is shown in the P-V and T-S diagrams. Then oil is sprayed into the cylinder and it ignites. In the process from state-2 to state-3, it receives the heat q_h at constant pressure. Then the combustion gases undergo the isentropic expansion from state-3 to state-4 with the increase in volume. In the next stroke, the constant volume cooling is performed from 4 to 1 by removing heat (q_c). Next the cycle is continued. In Diesel engine, the amount of work required will be less by the area $23'3$ in the P-V diagram. So this engine is economic.

References

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2. Fundamental of Engineering Thermodynamics, John R. Howell and Richard O. Buckius, McGraw-Hill Book Company, New York, 1987