MODULE 5

COMPRESSORS
Reciprocating compressors

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Introduction to Compressor

- The machine which takes in air or any other gas at low pressure and compresses it to high pressure are called compressors.
- A compressor is used for increasing the pressure of air is called Air compressor
- ***Applications of compressed air***
  - ✓ For filling the air in tube of vehicles
  - ✓ In automobile service station to clean vehicles.
  - ✓ For spray painting in paint industries.
  - ✓ In vehicle to operate air brakes.
  - ✓ For cleaning workshop machines.
  - ✓ For operation of pneumatic tools i.e. rock drills, vibrators etc.

Classification of Compressor

- 1. According to the design and Principle of operation

  Reciprocating Compressor

  Rotary compressor

- 2. According to action

  Single acting Compressor

  Double acting Compressor

- 3. According to the number of stages

  Single Stage Compressor

  Multistage Compressor

Classification of Compressor contd…..

- 4.According to pressure limit:

  Low pressure compressors in which the final delivery pressure is less than 10 bar,

  Medium pressure compressor in which the final delivery pressure is 10 bar to 80 bar

  High pressure compressors in which the final delivery pressure is 80 to 100 bar.

- 5. According to Capacity

  Low capacity compressor (delivers 0.15 cubic meter /s of compressed air),

  Medium capacity compressor (delivers 5 cubic meter /s of compressed air) and

  High capacity compressor (delivers more than 5 cubic meter /s of compressed air).

Reciprocating compressors

- ***In a reciprocating compressor,***

✓ Volume of air is drawn into a cylinder and compressed by piston and then discharged into the discharge line.

✓ The cylinder valves control the flow of air through the cylinder; these valves act as check valves.

Classification of Reciprocating compressors

- ***(a)Single acting compressors***

  ✓Suction, compression and delivery of air take place on one side of the piston.

  ✓It has one discharge per revolution of crankshaft.

- ***(b)Double acting compressors***

  ✓Suction, compression and delivery of air take place on both sides of the piston.

  ✓It has two discharge strokes per revolutions of crankshaft

- ***(c)Single stage reciprocating air compressor:***

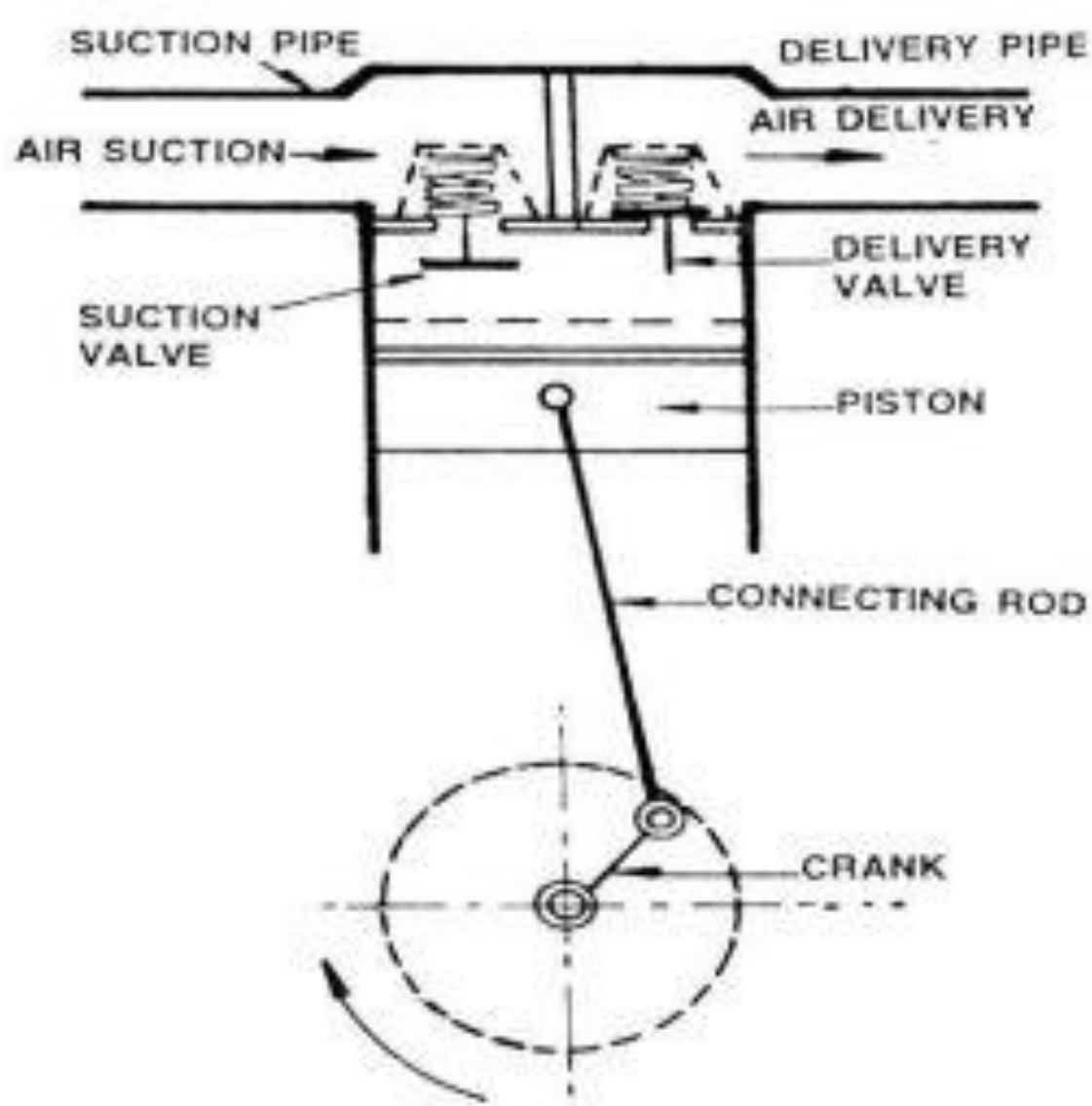
  ✓ The compression of air takes place in a single cylinder

- ***(d)Multi-stage air compressor:***

  ✓The compression of air takes place in more than one cylinder

Single stage reciprocating air compressor: (Construction & Working)

- ***Construction:***
- It consists of a piston which reciprocates inside a cylinder.
- The piston is connected to the crankshaft by means of a connecting rod and a crank.
- Thus, the rotary movement of the crankshaft is converted into the reciprocating motion of the piston.
- Inlet and outlet valves (suction and delivery valves) are provided at the top of the cylinder.


SUCTION PIPE
DELIVERY PIPE
AIR DELIVERY
AIR SUCTION
DELIVERY VALVE
SUCTION VALVE
PISTON
CONNECTING ROD
CRANK

Working

- When the piston moves down, the pressure inside the cylinder is reduced.
- When the cylinder pressure is reduced below atmospheric pressure, the inlet valve opens.
- Atmospheric air is drawn into the cylinder till the piston reaches the bottom dead centre.
- The delivery valve remains closed during this period.
- When the piston moves up, the pressure inside the cylinder increases.
- The inlet valve is closed, since the pressure inside the cylinder is above atmospheric.
- The pressure of air inside the cylinder is increased steadily.
- The outlet valve is then opened and the high pressure air is delivered through the outlet valve in to the delivery pipe line.
- At the top dead centre of the piston, a small volume of high pressure air is left in the clearance space.
- When the piston moves down again, this air is expanded and pressure reduces.
- Again the inlet valve opens and thus the cycle is repeated.

- ***Disadvantages***

  ✓Handling of high pressure air results in leakage through the piston.

  ✓Cooling of the gas is not effective.

  ✓Requires a stronger cylinder to withstand high delivery pressure.

- ***Applications:***

  ✓It is used in places where the required pressure ratio is small.

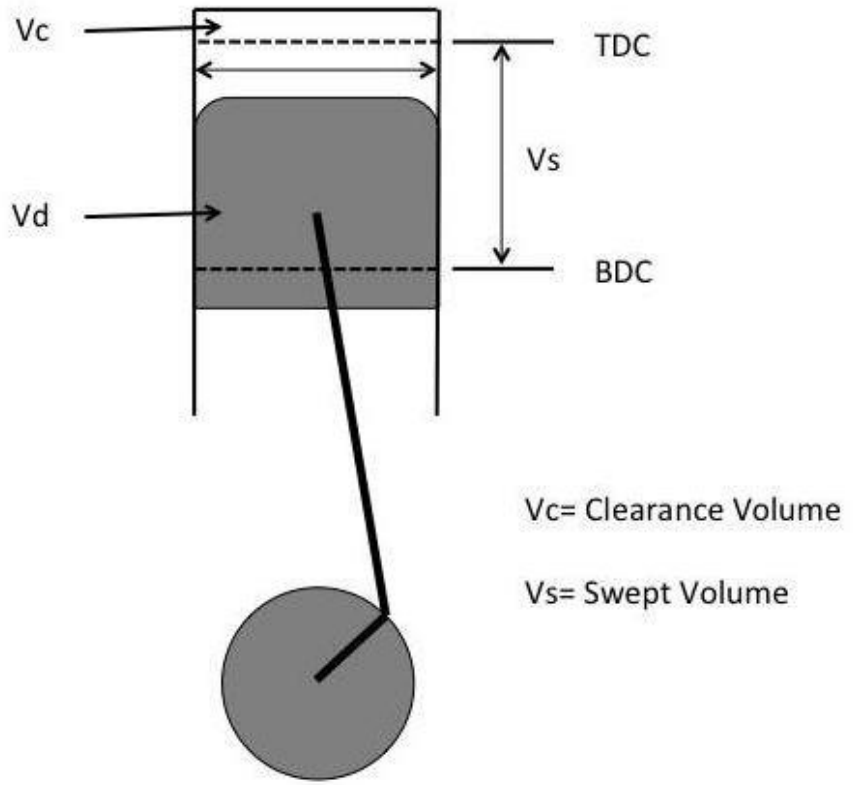
Important Terms

- Suction Pressure, P_1
  - ✓Absolute pressure of air at the inlet of a compressor
- Discharge Pressure, P_2
  - ✓Absolute pressure of air at the outlet of a compressor
- Compression Ratio, r
  - ✓Ratio of the absolute stage discharge pressure to the absolute stage suction pressure.
  - ✓Ratio of total volume of the cylinder to the clearance volume of the cylinder.
- Suction volume, V_1
  - ✓Volume of air sucked by the compressor during its suction stroke.

- Piston Displacement volume or Stroke volume or Swept volume, V_S
  - ✓It is the volume between top dead center (TDC) and bottom dead center (BDC).
  - ✓As the piston travels from top to bottom, it "sweeps" its total volume.

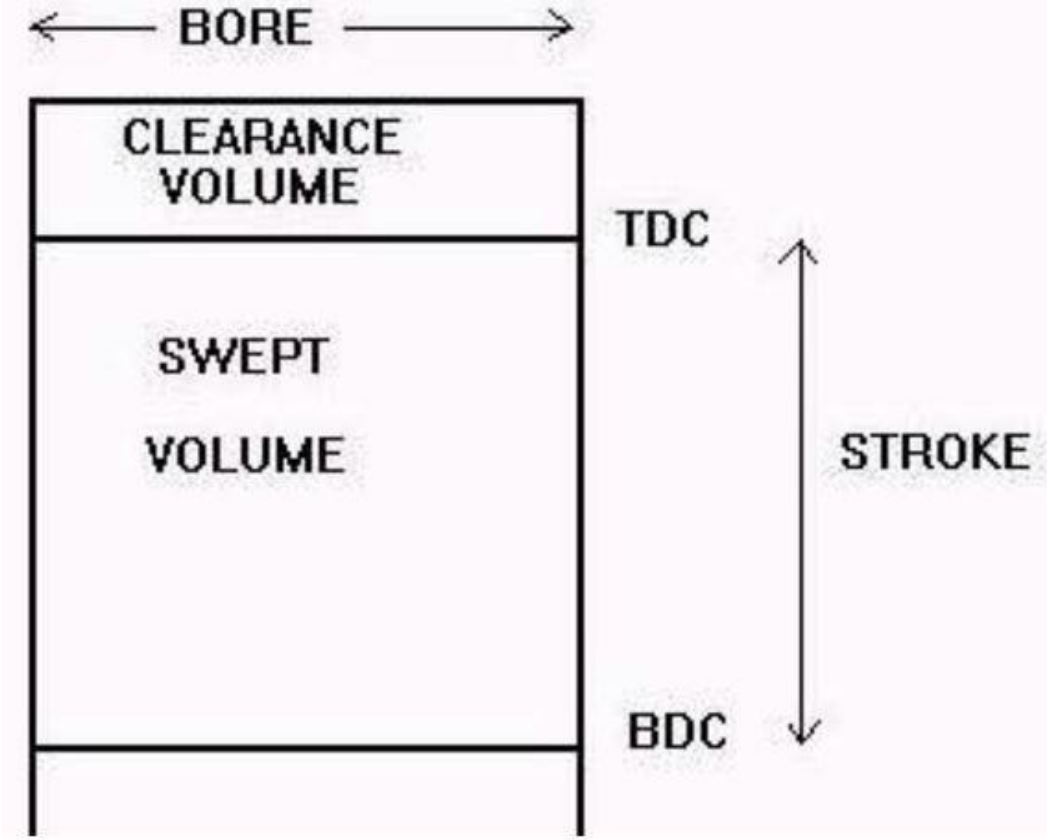
- Clearance volume V_C

  ✓Volume between the cylinder head and the piston top when the piston is at top dead center (TDC). It can also be defined as the volume of cylinder that is not swept by the piston.



- Clearance ratio, C
  - ✓Clearance ratio is the ratio of Clearance volume to the swept volume

C = clearance volume /swept volume



Compression processes:

- The air may be compressed by the following processes.
- (a) Isothermal compression
- (b) Polytropic compression and
- (c) Isentropic or adiabatic compression,

Power required for driving the compressor:

- The following assumptions are made in deriving the power required to drive the compressor.

1. There is no pressure drop through suction and delivery valves.
2. Complete compression process takes place in one cylinder.
3. There is no clearance volume in the compressor cylinder.
4. Pressure in the suction line remains constant. Similarly, pressure in the delivery line remains constant.
5. The working fluid behaves as a perfect gas.
6. There is no frictional losses.

- The cycle can be analysed for the three different case of compression.
- Work required can be obtained from the P - V diagram.

Let, P_1 = Pressure of the air (kN/ m^2), before compression

V_1 = Volume of the air (m^3), before compression

T_1 =Temperature of the air (K), before compression

P_2 V_2 T_2 be the corresponding values after compression.

m - Mass of air induced or delivered by the cycle (kg).

N - Speed in RPM.

(a) Isothermal compression

- When compressed air (or gas) is stored in a tank, it loses its heat to the surroundings. It attains the temperature of surroundings after some time. Hence, the overall effect of this compression process is to increase the pressure of the gas keeping the temperature constant. Thus isothermal compression is suitable if the compressed air (or gas) is to be stored.

$$PV=C$$

(b) Polytropic compression

- The compression follows the law $PV^n = C$. This type of compression may be used in

  Bell-Coleman cycle of refrigeration

(c) Isentropic or adiabatic compression,

In internal combustion engines, the air (or air fuel mixture) is compressed isentropically.

By isentropic compression, maximum available energy in the gas is obtained.

$$PV^{\gamma} = C$$

Efficiencies of reciprocating air compressor

Isothermal efficiency: Isothermal efficiency is defined as the ratio of isothermal work input to the actual work input. This is used for comparing the compressors.

Isothermal efficiency, $\eta_{iso} = \frac{Isothermal\ work\ input}{Actual\ work\ output}$

Adiabatic efficiency: Adiabatic efficiency is defined as the ratio of adiabatic work input to the actual work input. This is used for comparing the compressors.

Adiabatic efficiency, $\eta_{adia} = \frac{Adiabatic\ work\ input}{Actual\ work\ output}$

Mechanical efficiency:

The compressor is driven by a prime mover. The power input to the compressor is the shaft power (brake power) of the prime mover. This is also known as brake power of the compressor.

Mechanical efficiency is defined as the ratio of indicated power of the compressor to the power input to the compressor.

$$\eta_m = \frac{\text{Indicated power of compressor}}{\text{Power input}}$$

Volumetric efficiency:

The clearance volume in a compressor reduces the intake capacity of the cylinder. This leads to a term called volumetric efficiency.

The volumetric efficiency is denned as the volume of free air sucked into the compressor per cycle to the stroke volume of the cylinder,the volume measured at the intake pressure and temperature or at standard atmospheric conditions,(p_s =101.325 kN/m^2 and T_s = 288K)

$$\text{Volumetric efficiency, } \eta_{vol} = \frac{\text{Volume of free air taken in per cycle}}{\text{Stroke volume of the cylinder}}$$

$$= \frac{\text{Effective suction volume}}{\text{Swept volume}}$$

Clearance ratio: Clearance ratio is defined as, the ratio of clearance volume to swept volume. It is denoted by the letter C.

$$\text{Clearance ratio, } C = \frac{Clearance\ volume}{Swept\ volume} = \frac{V_c}{V_s} = \frac{V_c}{V_{1-V_3}}$$

$$\text{Pressure ratio, } R_p = \frac{Delivery\ pressure}{Suction\ pressure} = \frac{p_2}{p_1} = \frac{p_3}{p_4}$$

① Effective power, P_m

$$P_m = \frac{\text{Work done required per cycle}}{\text{Swept volume}}$$

Swept volume; $V_1 = \frac{\pi}{4} D^2 L$

D – dia of cylinder, L – stroke length

② Indicated Power IP

$$IP = P_m \times \left(\frac{N}{60} \times n\right) \times L \times A$$

IP = Indicated power

N – in rpm (Speed of Compressor)

n = 1 for single acting

n = 2 for double acting

A – Area of the cylinder

③ Piston speed = $2LN$

- WORK DONE BY A RECIPROCATING COMPRESSOR WITH OUT CONSIDERING THE CLEARANCE VOLUME
- (a) Isothermal compression
- (b) Polytropic compression and
- (c) Isentropic or adiabatic compression,
- *Proof is uploaded as videos*
- WORK DONE BY A RECIPROCATING COMPRESSOR CONSIDERING THE CLEARANCE VOLUME

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