GOVERNMENT POLYTECHNIC, SONEPUR

Lecture Note On-

THERMAL ENGINEERING- II

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IC- Engine

Introduction

→ The basic task in the design and development of engines is to reduce the cost and improve the efficiency and power output.

→ In order to achieve above task "development engineer" has to compare the engine development with other-engines in terms of its output and efficiency.

→ I.C engine are made to run at fixed speed by means of speed governor which is its rated speed.

→ The Performance of the engine depends on the inter-relationship between the power ~~of~~ developed, speed and the specific fuel consumption at each operating condition within the useful range of speed and load.

Mean effective Pressure

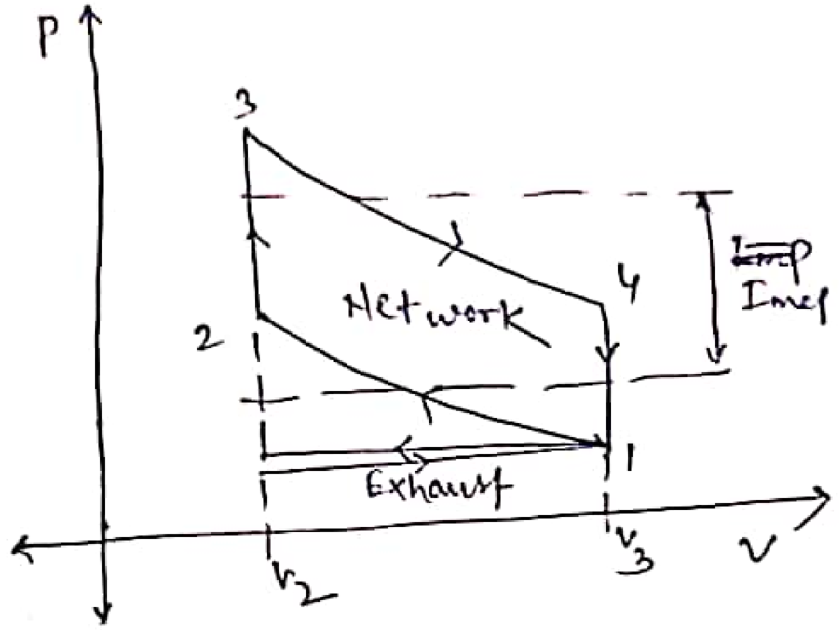
The algebric Sum of the mean pressures acting on the surface of the piston during each stroke over one complete cycle.

Indicated Mean Effective Pressure (Pim)

It may be defined as, the Constant pressure acting over the full length of the stroke and capable of producing the same amount of work, as is actually produced during the complete cycle of the engine.

⇒ It generally denoted by "P_{im}" or i.m.e.p

⇒ As the pressure in the cylinder varies throughout the cycles the variation can be expressed with respect to the volume or crank angle rotation to obtain P–V or P–θ diagrams respectively.



⇒ Referring figure, as the piston moves back and forth between TDC to BDC, the process lines on the P–V diagram indicated the successive states of the working fluid through the cycles.

⇒ The indicated network of the cycle is represented by the area 1-2-3-4 enclosed by the process lines for the cycle.

⇒ ~~Et means~~

⇒ If the area of rectangular A-B-C-D equals the area 1-2-3-4 the vertical distance between the horizontal lines AB and CD respectively gives

(X) Indicated Power

The power developed inside the engine cylinder due to Combustion of fuel is defined as Indicated Power

Indicated Power (I.P) = $\left(\frac{P_m L A N}{60}\right) K$

Where,

P_m = Indicated mean effective Pressure in N/m^2

L = Length of the Stroke (m).

A = Area of the inside cylinder or Bore area in m^2

n = Number of working Stroke per min.

n = N (for 2-Stroke).

n = $\frac{N}{2}$ (for 4-Stroke)

K = no. of Cylinder

the " Mean Indicated effective Pressure".

⇒ It means value expressed in N/m^2, which when multiplied by the displacement volume or swept volume, Vs gives the "Same Indicated network" as is actually produced with the varying pressure.

$$P_{im} \times (V_1 - V_2) = \text{Network cycle.}$$

$$\Rightarrow P_{im} = \frac{\text{Network cycle}}{(V_1 - V_2)}$$

(*) $$P_{im} = \frac{\text{Area of indicator digram} \times \text{Spring number}}{\text{Length of the indicator diagram.}}$$

$$P_{im} = \frac{a \times s}{L}$$

Where,

P_{im} = Mean effective Pressure in N/m^2

if a = Area of indicator diagram $inch^2$ or mm^2

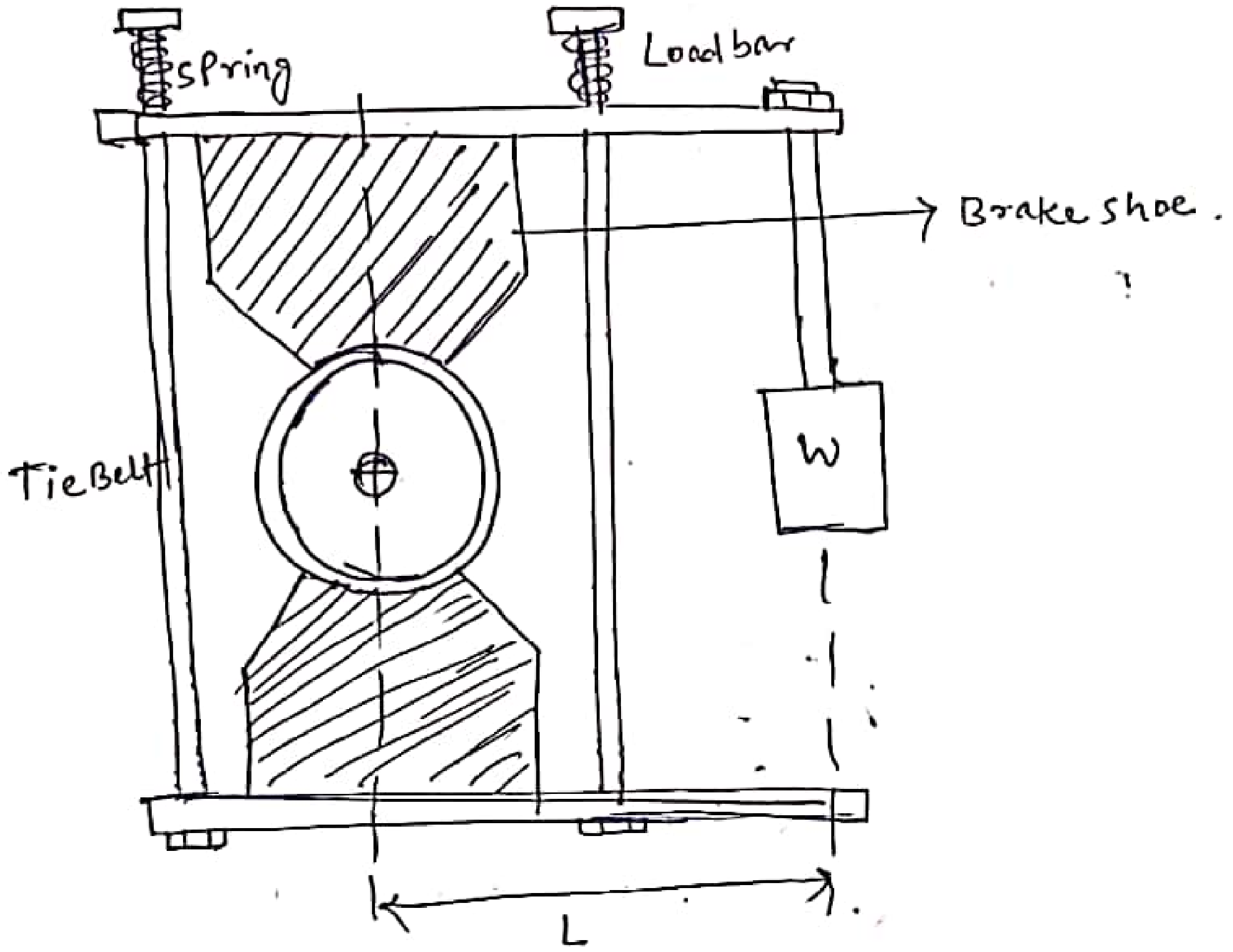
L = Length of the indicator diagram in cm or mm.

And s = spring number in N/m^2

Then. $$P_{im} = \frac{a \times s}{L} \; N/m^2$$

(v) Brake Power

⇒ The brake power (B.P) i.e the power obtained at the engine flywheel is measure with the help of dynamometers, a



In case of Proney brake, let

W = Brake load in newtons

L = Length of arm in meters,

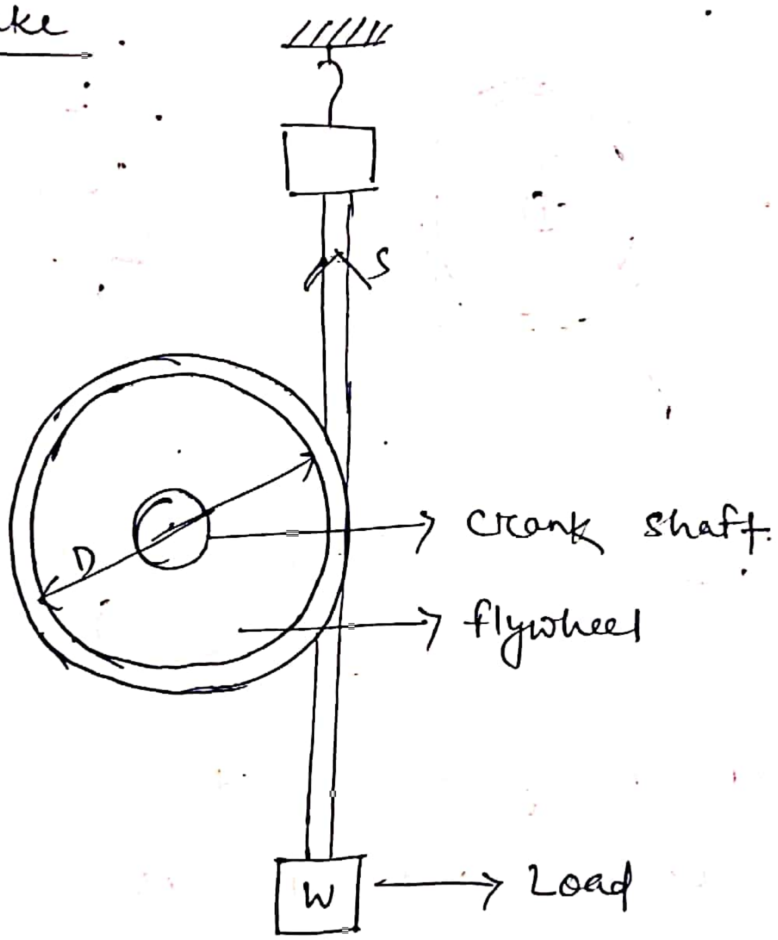
N = speed of the engine, R.P.m.

Brake Power = $\dfrac{\text{Torque in N-m} \times \text{Angle turned in radian through 1 revolution} \times \text{R.P.M}}{60}$ watt

$$B.P = \frac{T \times 2\pi N}{60}$$

$$= \frac{WL \times 2\pi N}{60} \text{ watt}$$

<u>Rope brake</u>



In case of rope brake -

W = Dead load in newtons.

S = Spring balance reading in ~~meter~~ newtons

D = diameter of ~~rope~~ brake drum in meter

d = diameter of the rope in meter

N = Speed of the engine in r.p.m

Brake Power of the engine -

$$B.P = \frac{(W-S)\pi DN}{60} \text{ watts}$$ (without considering diameter (d) of the rope)

$$= \frac{(W-S)\pi(D+d)N}{60}$$ (with considering diameter (d) of the rope)

(*) Frictional power

→ Some of the indicated power developed in engine cylinder is lost in overcoming the friction at various engine parts and remaining power is obtained as brake power at crank shaft.

→ Frictional power = Indicated power - Brake power

$$F.P = I.P - B.P$$

→ It measured in kilo watt (kW)

AIR COMPRESSORS

→ Compression of air and vapour plays ~~is~~ an important role in engineering fields.

→ Compression of air is mostly used since it is easy to transmit air compressed with vapour

→ Source of air compressor is air, which can be received from the atmosphere.

Application of Air Compressor

(i) Air refrigeration and cooling of large buildings.

(ii) Driving pneumatic tools in shops like drills, riveters, screw drivers etc.

(iii) Cleaning purpose.

(iv) Blast furnance

(v) Hand excavation work, turning, boring, mining

(vi) Starting of heavy-duty diesel engine.

(vii) operating of air brake in buses, trucks and trains. etc.

(viii) Inflating automobile and aircraft.

(ix) Process Industries

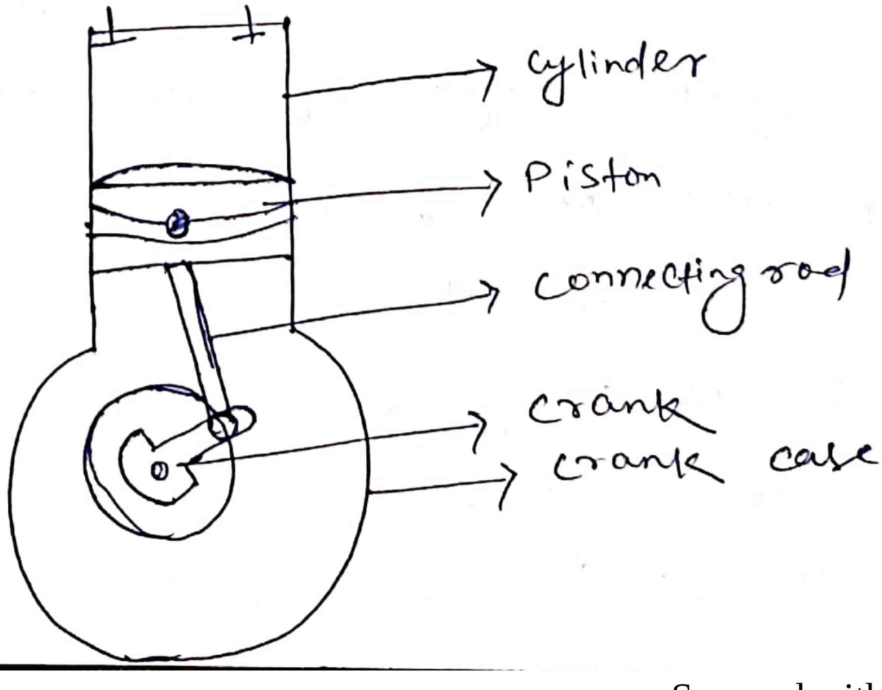
(x) Automobile suspension system.

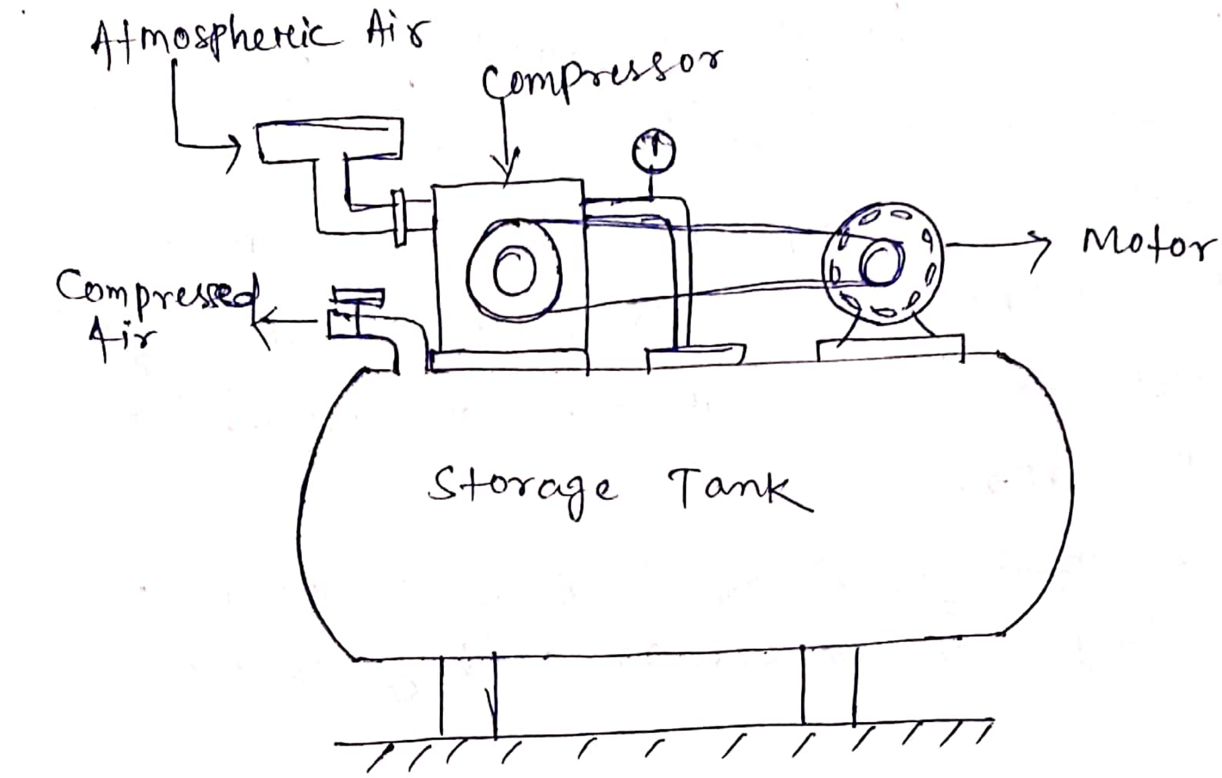
(*) Classification of Compressor.

Compressor

- Positive Displacement
  - Reciprocating
    - Single acting
    - Double-acting
    - Diaphragm
  - Rotary
    - Lobe
    - Liquid ring
    - Screw
    - Scroll
    - Vane
- Dynamic
  - Centrifugal
  - Axial.

(*) Reciprocating Air-Compressor



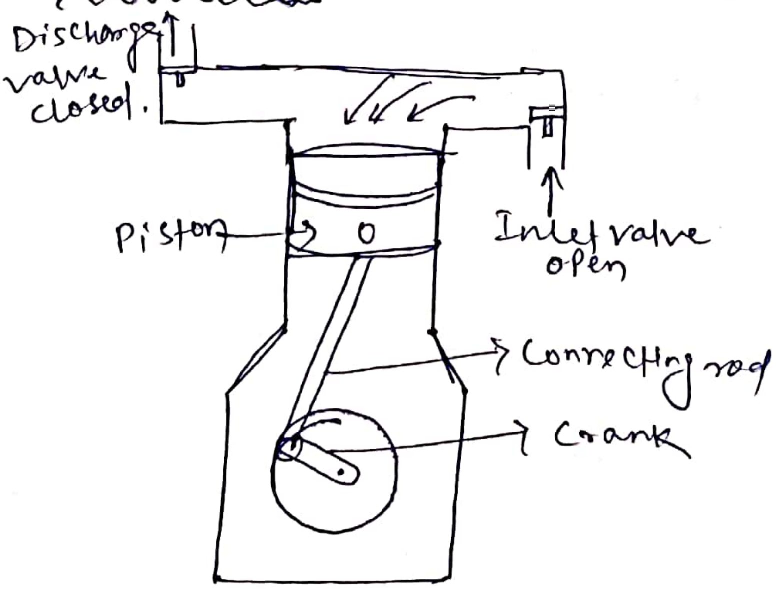


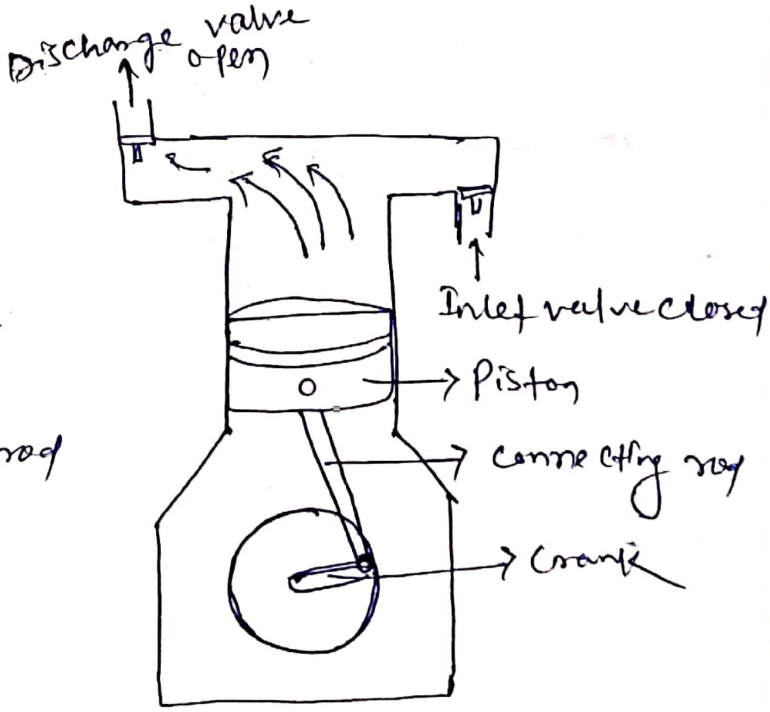
→ It consists of a cylinder in which piston reciprocate by means of an external source of work

→ The cylinder cover accommodates two valves one in intake valve, and other discharge valve.

→ Both valve are opened and closed automatically due to pressure difference.

Working





Work done and power required by single stage Compressor

⇒ A reciprocating air compressor, the air is first sucked, compressed and then delivered.

⇒ So there at three different operations of the compressor.

⇒ Thus we ~~that~~ get work is done on the piston during compresson as well as delivery of the air.

⇒ ~~A little~~

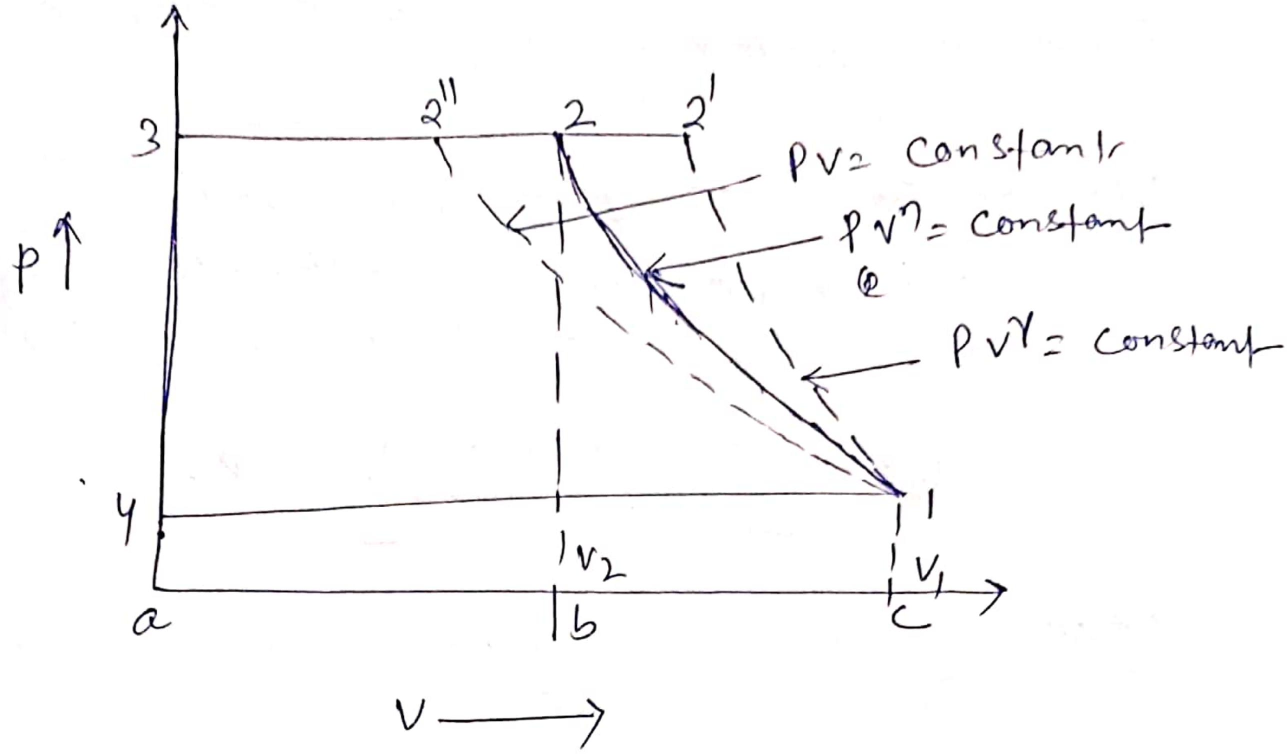
⇒ A little consideration will show, that the work done by a reciprocating air compressor is mathematically equal to the work done by the compressor during suction.

⇒ The following two important case of workdone:-

(I) Where there is no clearance volume in the cylinder.

(II) When there is clearance volume in the cylinder.

(*) Neglecting clearance volume



(*) Process – 4–1

→ Represent the suction of air at pressure P_1. During operation inlet valve remains open.

(*) Process 1–2

→ Represent the compression of air polytropically. During this operation inlet and outlet valves remain closed

(*) Process – 2–3

→ Represent the discharge of air to the receiver at pressure P_2. The delivery valve remains open during this period.

(6)

→ We know that, work done/cycle is equal to area of the P-V diagram.

Area of the PV-diagram 4-1-2-3-4

= (Area of a-b-2-3-a) + (Area of 1-2-b-c-1) − (Area of a-c-1-4-a)

$$= P_2V_2 + \left[\frac{-(P_1V_1 - P_2V_2)}{n-1} \right] - P_1V_1$$

~~Negte~~ Negative sign indicates workdone on the system.

$$= P_2V_2 + \left[\frac{-(P_1V_1 - P_2V_2)}{n-1} \right] - P_1V_1$$

$$= (P_2V_2 - P_1V_1)\left[1 + \frac{1}{n-1} \right]$$

$$= \frac{n}{n-1}(P_2V_2 - P_1V_1)$$

$$= \frac{n}{n-1} mr(T_2 - T_1)$$

$$= \frac{n}{n-1} \times P_1V_1 \left(\frac{P_2V_2}{P_1V_1} - 1 \right)$$

We know that pressure and temperature relation in polytropic process

$$P_1V_1^n = P_2V_2^n$$

$$P_1 V_1^n = P_2 V_2^n$$

$$\left(\frac{V_2}{V_1}\right)^n = \left(\frac{P_1}{P_2}\right)$$

$$\Rightarrow \quad \frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{\frac{1}{n}} = \left(\frac{P_2}{P_1}\right)^{-\frac{1}{n}}$$

Substituting the value of $\frac{V_2}{V_1}$ in equation

$$W = \frac{n}{n-1} \times P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)\left(\frac{P_2}{P_1}\right)^{-\frac{1}{n}} - 1\right]$$

$$= \frac{n}{n-1} \times P_1 V_2 \left[\left(\frac{P_2}{P_1}\right)^{1-\frac{1}{n}} - 1\right]$$

$$= \frac{n}{n-1} \times P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$W = \frac{n}{n-1} \times mRT_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

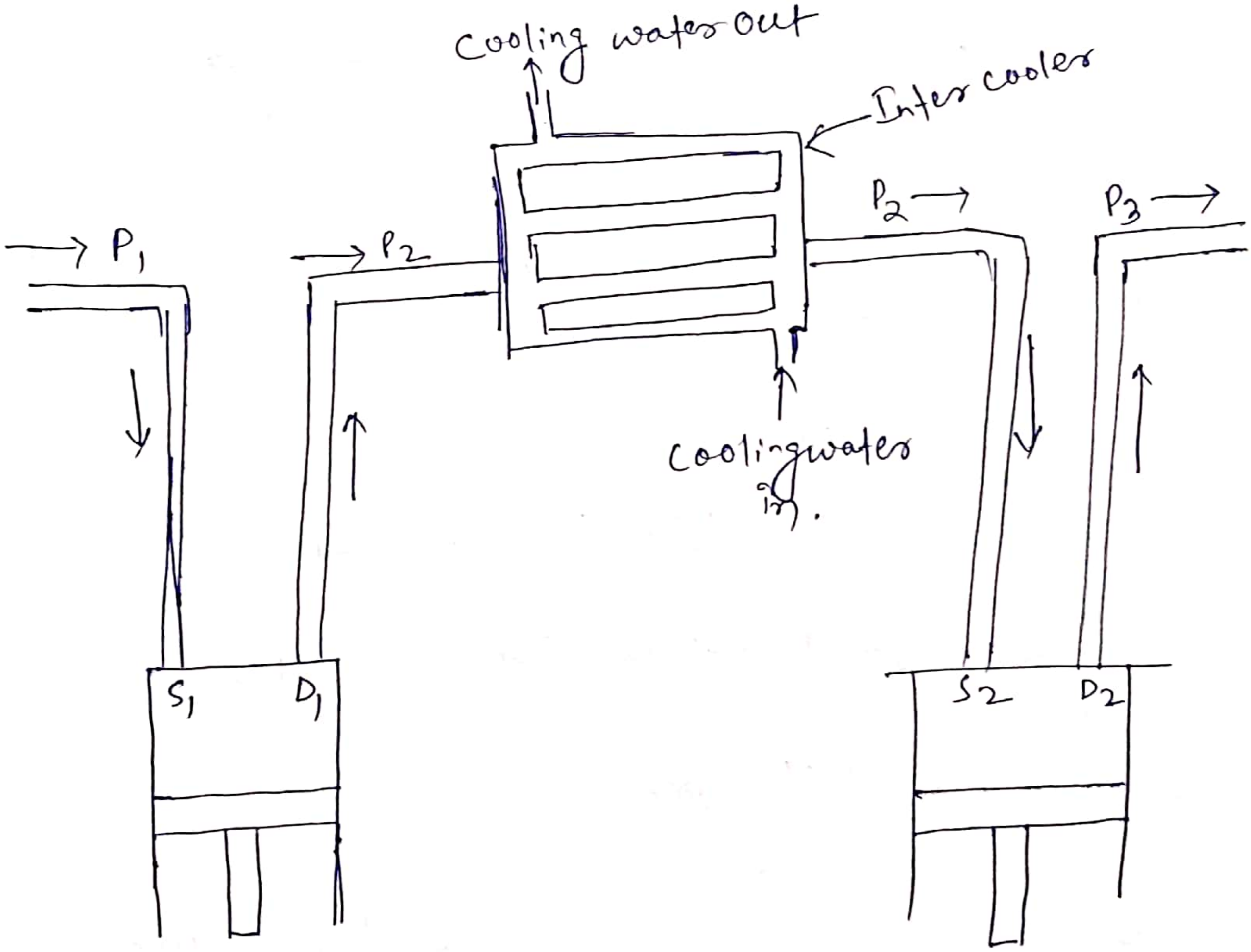
work done/kg of air.

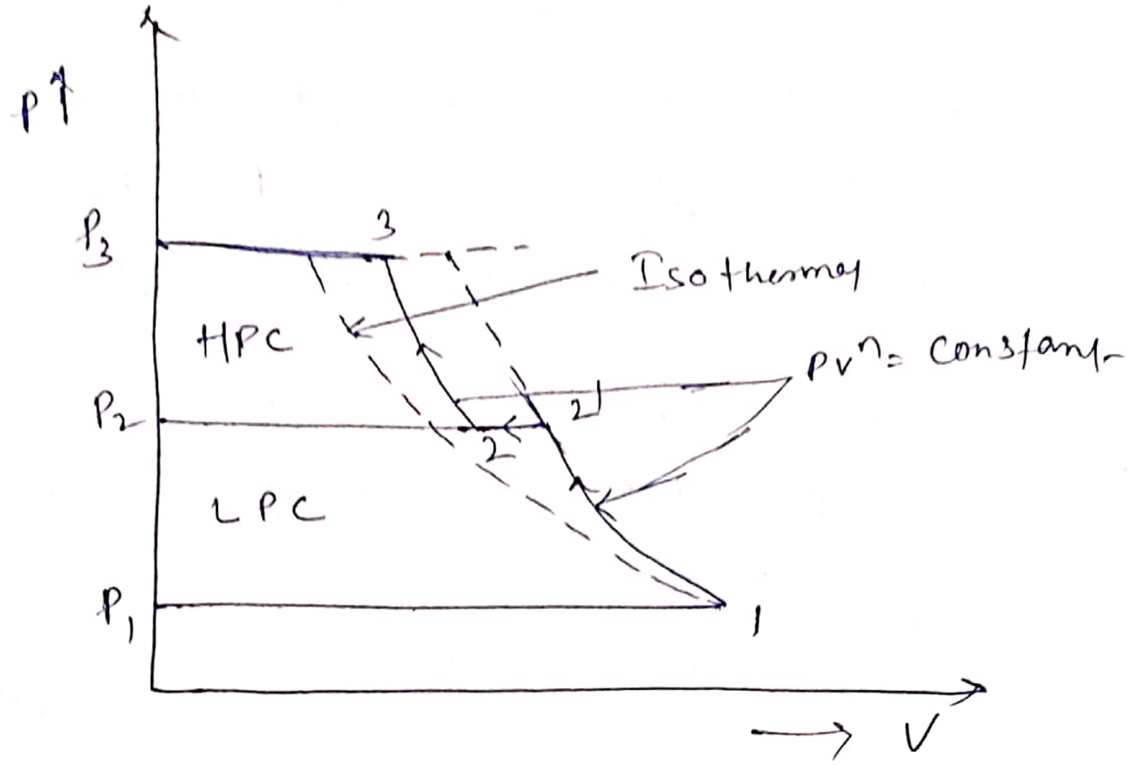
$$W = \frac{n}{n-1} RT_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

Multi-Stage Air Compressor

→ The compression of air in single-stage has ~~may~~ many disadvantages and it used is limited where low delivery pressure is required

→ Multi-Stage Compression is more efficient and mostly employed for rising the ~~high~~ high pressure.





→ In multi stage air compressor, compression of air takes place in more than one cylinder.

→ It consist of

(I) Low pressure cylinder (LP)

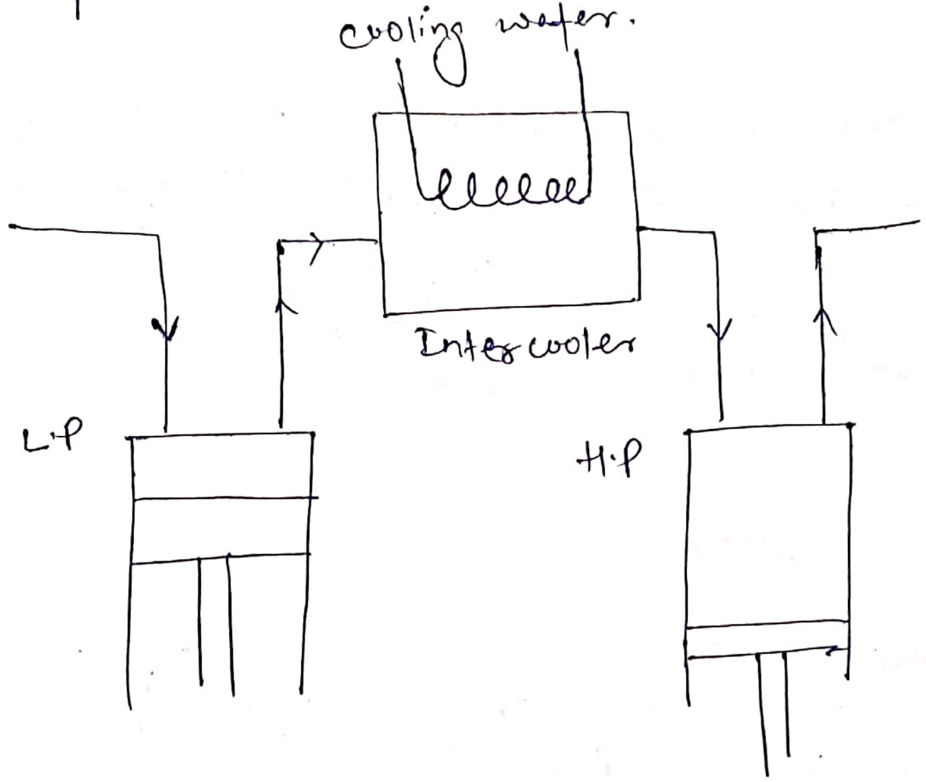
(II) High pressure cylinder (HP)

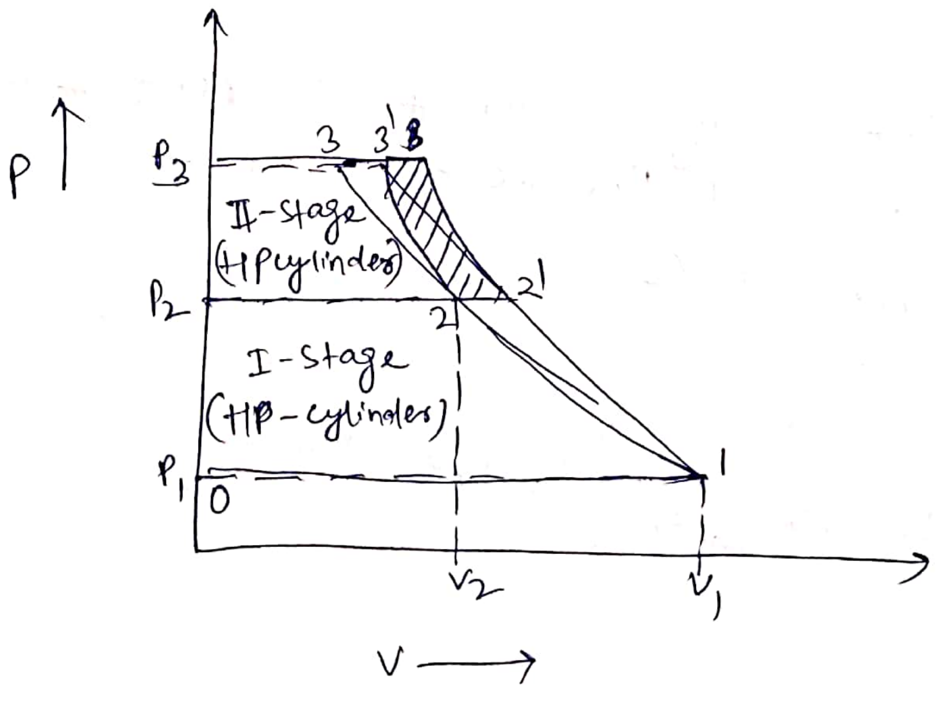
(III) Inter cooler.

→ Both the pistons are driven by a prime mover through a common shaft.

(7) Work Required for Multi-Stage Compressor

→ The work required for multi-stage compression is less, for same inlet conditions and the same delivery pressure than ~~that~~ the single stage compression.





→ In L·P cylinder, the air is compressed to intercediate pressure, P_2 according to the Law PV^n = constant

work ~~done~~ required per cycle in L·P cylinder

$$W_1 = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right]$$

→ Similarly, the air is compressed in 2nd stage to increase pressure from P_2 to delivery pressure (P_3)

~~Exp~~

$$W_2 = \frac{n}{n-1} P_2 V_2 \left[\left(\frac{P_3}{P_1}\right)^{\frac{n-1}{n}} - 1 \right]$$

Total work required

$$W = W_1 + W_2$$

$$= \frac{n}{n-1} \left[P_1 V_1 \left\{ \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right\} + P_2 V_2 \left\{ \left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 1 \right\} \right] \quad \text{—(i)}$$

If the intercooling is perfect, the point 2' will be on the isothermal line i.e at point 2

then - $P_1 V_1 = P_2 V_2$

from eqn (i) we get

$$W = \frac{n}{n-1} P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} + \left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}} - 2 \right]$$

Total work required,

$$W = \frac{n}{n-1}\left[P_1V_1\left\{\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}-1\right\}+P_2V_2\left\{\left(\frac{P_3}{P_2}\right)^{\frac{n-1}{n}}-1\right\}\right]$$

If the compression is adiabatic, then the total work required

$$W = \frac{\gamma}{\gamma-1}P_1V_1\left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}+\left(\frac{P_3}{P_2}\right)^{\frac{\gamma-1}{\gamma}}-2\right]$$

(*) Power required $= \frac{W \cdot N}{60}$

where N = Speed of compressor in RPM.

Heat rejected in Intercooler

Let m = mass of air compressed

C_p = Specific heat of air at constant pressure

Then, Heat rejected in intercooler
$= m \cdot C_p (T_2' - T_2)$

If the intercooler is perfect then

$T_2 = T_1$