MODEL SET QUESTION FOR PRACTICE

Sub:- FM (Fluid Mechanics) SET-1

Full Marks - 80 Time - 3 hours.

Answer any five questions including question No - 01 and 02.

① ⟨a⟩ Define specific weight and specific gravity. 2×10

⟨b⟩ Define pressure and state its unit.

⟨c⟩ Define the term viscosity.

⟨d⟩ Write Archimedes's principle.

⟨e⟩ Define metacentre and metacentric height.

⟨f⟩ What is the difference between laminar and turbulent flow?

⟨g⟩ What is pitot tube?

⟨h⟩ State Darcy's formula for loss of head in pipe?

⟨i⟩ What do you mean by impact of jet?

⟨j⟩ What is venacontracta?

⟨2⟩ Answer any five. 5×6

(i) With neat sketch explain the working of Bourden's tube pressure gauge.

(ii) Derive an equation for the total pressure on a vertical immerged surface.

(iii) The diameter of a pipe at the section 1 and 2 are 10cm and 15cm respectively. Find the discharge through the pipe if the velocity of water flowing through the pipe at section ① is 5m/s. Find the velocity at section 2.

(iv) Write down the expression of loss of energy due to friction according to Darcy's formula and Chezy's formula with proper notation.

(v) A sharp-edged orifice of 5 cm diameter discharge water under a head of 4.5 m. Determine the coefficient of discharge if the measured rate of flow is 0.0123 m^3/s.

(vi) Derive an expression for the force of jet on a fixed plate.

(3) A rectangular plane surface is 2 m wide and 3 m deep. It lies in vertical plane in water. Determine the total pressure and position of centre of pressure on the plane surface when its upper edge is horizontal and coincides with the water surfaces. also find the total pressure and position of centre of pressure when the upper edge is 2.5 m below the free water surface. | 10

(4) Describe the orifice coefficients and write down the relationship among them. | 10

(5) Water flows through a pipe of 200 mm in diameter and 60 m long with a velocity of 2.5 m/s. Find the head lost due to friction using | 10

(a) Darcy's formula, $f = 0.005$

(b) Chezy's formula $C = 55$.

(6) Derive Bernoulli's equation and state the practical application in venturimeter. | 10

(7) A jet of water 40 mm diameter moving with a velocity of 120 m/s impinging on a series of vanes moving with a velocity of 5 m/sec. Find the force exerted, workdone and efficiency. | 10

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All The Best.

MODEL SET QUESTION FOR PRACTICE

Sub:- Fluid Mechanics [SET 2] Time - 3 hours

Full Marks - 80

Answer any five questions including question No. 01 and 02.

(1) (i) Define density and state its unit. [2X10

(ii) Define pascal's law.

(iii) Define the term surface tension.

(iv) What is the function of piezometer?

(v) Define Bouyancy force?

(vi) What is the difference between compressible and incompressible fluid?

(vii) What are the assumptions taken in deriving the Bernoulli's equation.

(viii) What is chezy's constant?

(ix) Define hydraulic gradient?

(x) Define pressure head and velocity head. [5X6

(2) (i) Explain absolute pressure, atmospheric pressure and gauge pressure and state their relations.

(ii) Explain the working and function of a pitot tube.

(iii) A simple U-tube manometer containing mercury is connected to a pipe in which fluid of specific gravity 0.8 and having vaccum pressure is flowing. The other end of the manometer is open to atmosphere. Find the vaccum pressure in the pipe if the difference of mercury level in the two limbs is 40cm and the height of fluid in the left from the centre of pipe is 15cm below.

(iv) Derive continuity equation.

(v) water is flowing through a pipe 1500 m long and 400 mm diameter with a velocity of 0.7 m/s. What should be the diameter of pipe if the loss of head due to friction is 8.7 m. Take f for the pipe is 0.01.

(vi) Explain hydraulic gradient and total gradient line. | 10

⟨3⟩ Describe different types of manometers.

⟨4⟩ (i) The head of water over an orifice of diameter 40 mm is 10 m. Find the actual discharge and actual velocity of jet at vena contracta. | 5

take $C_d = 0.6$, $C_v = 0.98$.

⟨4⟩ (ii) The discharge over a rectangular notch is 0.135 m³/s when the water level is 22.5 m above the sill. if the coefficient of discharge is 0.6 find the length of notch. | 5

⟨5⟩ Derive an expression for the force of jet on a fixed and inclined plate. | 10

⟨6⟩ Describe different types of flows. | 10

⟨7⟩ Derive the expression of actual discharge in venturimeter and state its practical applications. | 10

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All The Best.

NOTCHES AND WEIRS

Introduction :-

→ A notch is a device used for measuring the rate of flow of a liquid through a small channel or a tank.

→ It may be defined as an opening in the side of a tank or a small channel in such a way that the liquid surface in the tank or channel is below the top edge of the opening.

→ A weir is a concrete structure, placed in an open channel over which the flow occurs. It is generally in the form of vertical wall with a sharp edge at the top.

→ The notch is of small size while the weir is of a bigger size.

→ The notch is generally made of metallic plate while the weir is made of concrete structure.

Classification :-

The notches are classified as :

① According to the shape of ~~notch~~ opening

(i) rectangular notch
(ii) Triangular notch
(iii) Trapezoidal notch
(iv) stepped notch.

② According to the effect of the sides of nappe :-

(i) Notch with end contraction
(ii) Notch without end contraction.

Weirs are classified according to shape

(a) According to the shape of opening

(i) Rectangular weir
(ii) Triangular weir
(iii) Trapezoidal weir.

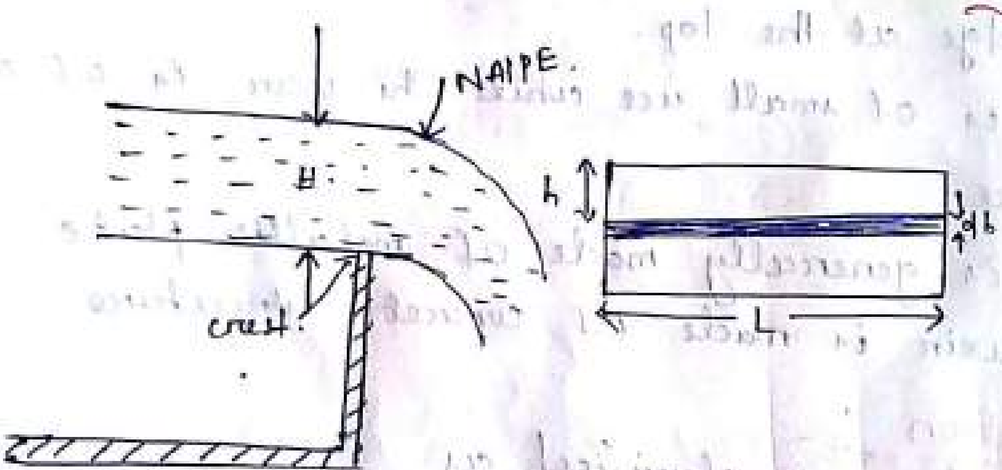
(b) According to the shape of crest

(i) Sharp-crested weir
(ii) Narrow-crested weir
(iii) Board-crested weir
(iv) ogee-shaped weir.

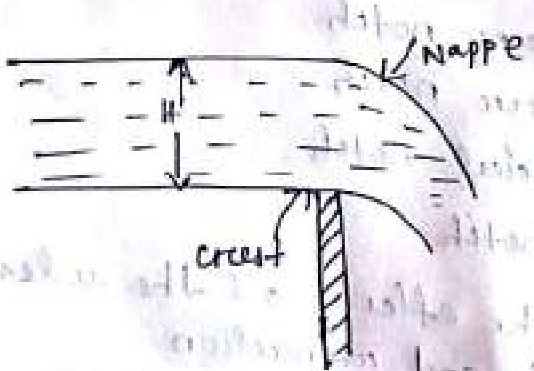
(c) According to the effect of sides on the emerging nappe:-

(i) weir with end contraction
(ii) weir without end contraction.

DISCHARGE OVER A RECTANGULAR NOTCH OR WEIR



Rectangular Notch



Rectangular Weir

consider a rectangular notch or weir provided in a channel carrying water.

H = head of water over the crest

L = Length of the notch or weir.

→ To find the discharge of water flowing over the weir or notch, consider an elementary horizontal strip of water of thickness dh and length L at a depth h from the free surface.

Area of strip $= L \times dh$.

theoretical velocity of water flowing through strip $= \sqrt{2gh}$

The discharge dQ, through strip is

$$dQ = C_d \times \text{area of strip} \times \text{Theoretical velocity}$$

$$\boxed{dQ = C_d \times L \times dh \times \sqrt{2gh}}$$

$$Q = \int_0^H C_d \times L \times \sqrt{2gh} \times dh$$

$$= C_d \times L \times \sqrt{2g} \times \int_0^H h^{1/2} dh$$

$$= C_d \times L \times \sqrt{2g} \times \left[\frac{h^{1/2+1}}{1/2+1}\right]_0^H$$

$$= C_d \times L \times \sqrt{2g} \times \left[\frac{h^{3/2}}{3/2}\right]_0^H$$

$$= C_d \times L \times \sqrt{2g} \times \frac{2}{3} \times (H)^{3/2}$$

$$Q = C_d \times L \times \sqrt{2g} \times \frac{2}{3} \times (H)^{3/2}$$

$$\boxed{Q = \frac{2}{3} C_d L \sqrt{2g} \times (H)^{3/2}}$$

Q) Find the discharge of water flowing over rectangular notch of 2m length when the constant head over the notch is 300mm. $C_d = 0.60$

Head over the notch $H = 300\ mm = 0.30\ m$

$L = 2\ m.$

$C_d = 0.60$

$Q = \frac{2}{3} C_d \times L \times \sqrt{2g} \times (H^{3/2})$

$= \frac{2}{3} \times 0.6 \times 2.0 \times \sqrt{2 \times 9.81} \times (0.30)^{3/2}$

$Q = 0.582\ m^3/s$

Q) Determine the height of a rectangular weir of length 6m to be built across a rectangular channel. The maximum length of water on the upstream side of the weir is 1.8 m and discharge is 2000 litre/s. Take $C_d = 0.6$

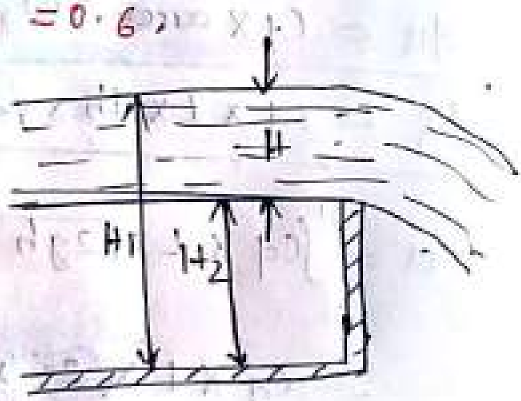
$L = 6m.$

$H_1 = 1.8\ m$

$Q = 2000\ lt/s.$

$= 2\ m^3/s.$

$C_d = 0.6$



$Q = \frac{2}{3} C_d \times L \times \sqrt{2g} \times H^{3/2}$

$\Rightarrow 2 = \frac{2}{3} \times 0.6 \times 6.0 \times \sqrt{2 \times 9.81} \times H^{3/2}$

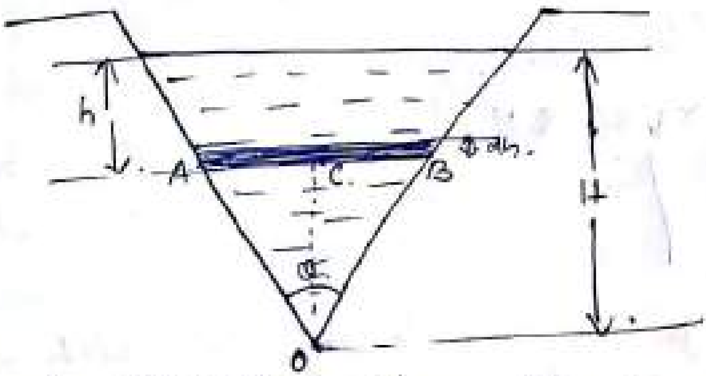
$\Rightarrow H^{3/2} = \frac{2.0}{10.623}$

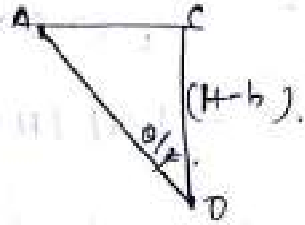
$H = 0.328\ m$

$H_2 = H_1 - H$

$= 1.8 - 0.328 = 1.472\ m.$ (Ans).

DISCHARGE OVER A TRIANGULAR NOTCH OR WEIR





H = head of water above the V-notch.

θ = angle of notch.

consider the horizontal strip of water of thickness 'dh' at a depth of h from the free surface of water.

$$\tan \theta/2 = \frac{AC}{OC} = \frac{AC}{(H-h)}$$

$$AC = (H-h)\tan \theta/2$$

AB = width of strip = $2 \times AC$

$$= 2 \times (H-h)\tan \theta/2 \times dh$$

theoretical velocity of water through strip $= \sqrt{2gh}$

Discharge through the strip

$dQ = C_d \times$ Area of strip $\times$ velocity

$$= C_d \times 2(H-h)\tan \theta/2 \times dh \times \sqrt{2gh}$$

$$= 2 \times C_d \times (H-h)\tan \theta/2 \times \sqrt{2gh} \times dh$$

$$Q = \int_0^H 2C_d \times (H-h)\tan \theta/2 \times \sqrt{2gh} \times dh$$

$$= 2C_d \times \tan \theta/2 \times \sqrt{2g} \times \int_0^H (H-h)\, h^{1/2}\, dh$$

$$= 2 \times C_d \times \tan \theta/2 \times \sqrt{2g}\left[\int_0^H H h^{1/2}\, dh - \int_0^H h^{3/2}\, dh\right]$$

$$= 2 \times C_d \times \tan \theta/2 \times \sqrt{2g}\left[\frac{2}{3}H^{5/2} - \frac{2}{5}H^{5/2}\right]$$

$$= 2 \times C_d \times \tan \theta/2 \times \sqrt{2g} \times \left[\frac{4}{15}H^{5/2}\right].$$

$$Q = \frac{8}{15} C_d \times \tan \frac{\theta}{2} \times \sqrt{2g} \times H^{5/2}$$

for a V-notch $C_d = 0.6$

$\theta = 90^\circ$, $\tan \theta/2 = 1$.

$$Q = \frac{8}{15} \times 0.6 \times 1 \times \sqrt{2g} \times H^{5/2}$$

$$Q = 1.417 H^{5/2}$$

Q) Find the discharge over a triangular notch of angle 60° when the head over the V-notch is 0.3 m. $C_d = 0.6$.

Ans $\theta = 60^\circ$

$H = 0.3$ m.

$C_d = 0.6$

$$Q = \frac{8}{15} \times C_d \times \tan \theta/2 \sqrt{2g} \times H^{5/2}$$

$$= \frac{8}{15} \times 0.6 \times \tan 30^\circ \times \sqrt{2 \times 9.81} \times (0.3)^{5/2}$$

$Q = 0.040\ m^3/s$. (Ans)

FLOW THROUGH PIPES (CHAPTER-6)

Loss of energy in pipe: –

when a fluid is flowing through a pipe, the fluid experiences some resistance due to which some of the energy of fluid is lost. This loss of energy is classified as follows:

Energy loss

- **Major energy loss**
  - This is due to friction.
  - (a) Darcy-Weisbach formula.
  - (b) Chezy's Formula.
- **Minor energy loss**
  - (a) Sudden expansion of pipe
  - (b) Sudden contraction of pipe
  - (c) Bend in pipe.
  - (d) pipe fittings
  - (e) obstruction in pipe.

(1) Loss of energy due to friction.

(a) Darcy-Weisbach Formula: –

This loss of energy in pipes due to friction is calculated from Darcy-Weisbach equation.

$$h_f = \frac{4fLV^2}{2gd}$$

h_f = Loss of head due to friction.

f = Coefficient of friction $= \frac{16}{R_e}$

$$f = \frac{16}{R_e} \quad (R_e < 2000)$$

$$f = \frac{0.079}{R_e^{1/4}} \quad (R_e \ (4000 - 10^6))$$

L = Length of pipe.

V = mean velocity of flow.

d = diameter of pipe.

(b) chezy's formula

The expression for loss of head due to friction

$$h_f = \frac{f'}{\rho g} \times \frac{P}{A} \times L \times V^2$$

h_f = loss of head due to friction

A = area of cross-section of pipe

P = wetted perimeter of pipe

V = Mean velocity of flow.

P = perimeter of pipe.

L = Length of pipe.

$\frac{A}{P} = \frac{\text{Area of flow}}{\text{perimeter}}$ is called hydraulic mean depth

$\frac{A}{P}$ = (hydraulic mean depth or hydraulic radius)

(A/P) is denoted by 'm'.

∴ hydraulic mean depth $m = A/P = \frac{\pi/4\, d^2}{\pi d} \{d/4\}$

$\frac{A}{P} = m$ or $\left(\frac{P}{A}\right) = 1/m$.

$$h_f = \frac{f'}{\rho g} \times L \times V^2 \times \frac{1}{m}$$

$$\Rightarrow V^2 = h_f \times \left(\frac{\rho g}{f'}\right) \times m \times \frac{1}{L}$$

$$\Rightarrow V = \sqrt{\frac{\rho g}{f'} \times m \times \left(\frac{h_f}{L}\right)}$$

$$\boxed{V = \sqrt{\frac{\rho g}{f'}} \times \sqrt{m \frac{h_f}{L}}}$$

where $\sqrt{\frac{\rho g}{f'}} = C$ (C = chezy's constant)

$$\frac{h_f}{L} = i$$

$$\therefore \boxed{V = C \times \sqrt{m \times i}}$$

This is known as chezy's formula.

$\boxed{m = d/4}$

Q) Find the head lost due to friction in a pipe of diameter 300mm and length 50 m through which water is flowing at a velocity of 3m/s using
(i) Darcy's formulae
(ii) chezy's formulae. [Data $\nu = 0.01$ stoke)

$d = 300mm = 0.30m.$
$L = 50m.$ $\nu = 0.01$ stoke $= 0.01 \times 10^{-4}\ m^2/s$.
$v = 3m/s.$
$C = 60.$

$$Re = \frac{Vd}{\nu} = \frac{3 \times 0.30}{0.01 \times 10^{-4}} = 9 \times 10^5.$$

$$f = \frac{0.079}{Re^{1/4}} = \frac{0.079}{(9 \times 10^5)^{1/4}} = 0.00256.$$

$$(i)\ h_f = \frac{4 \times f \times L \times v^2}{d \times 2g}$$ (Darcy's formulae)

$$= \frac{4 \times 0.00256 \times 50 \times 3^2}{0.3 \times 2 \times 9.81}$$

$$h_f = 0.7828\ m\ (Ans)$$

(ii) chezy's formulae.

$$V = C\sqrt{mi}$$

$C = 60.,\quad m = d/4 = \frac{0.3}{4} = 0.075m.$

$$V = C \times \sqrt{mi}$$

$$\Rightarrow 3 = 60 \times \sqrt{0.075 \times \frac{h_f}{L}}$$

$$\Rightarrow \left(\frac{3}{60}\right)^2 = 0.075 \times \frac{h_f}{L}$$

$$\Rightarrow \frac{h_f}{L} = \left(\frac{3}{60}\right)^2 \times \frac{1}{0.075}$$

$$\Rightarrow h_f = \left(\frac{3}{60}\right)^2 \times \frac{1}{0.075} \times 50 = 1.665\ m.\ (Ans)$$

Q) Find the diameter of pipe of length 2000 when the rate of flow of water through the pipe is 200 liters/sec and head loss due to friction is 4m.

C = 50

Ans $L = 2000 m.$

$Q = 200$ litre/s $= 0.2 \, m^3/s.$

$h_f = 4m.$

$C = 50.$

$$V = \frac{\text{discharge}}{\text{Area}} = \frac{0.2}{(\frac{\pi}{4} d^2)}$$

$$V = C \times \sqrt{mi}$$

$$= 50 \times \sqrt{\frac{d}{4} \times \frac{h_f}{L}}$$

$$\frac{0.2}{\frac{\pi}{4} d^2} = 50 \times \sqrt{\frac{d}{4} \times \frac{4}{2000}}$$

$$\Rightarrow \frac{0.2}{\frac{\pi}{4} d^2 \times 50} = \sqrt{\frac{d}{4} \times \frac{4}{2000}}$$

$$\Rightarrow \left(\frac{0.2 \times 4}{\pi d^2 \times 50}\right)^2 = \frac{d}{2000}$$

$$\Rightarrow \frac{(0.2)^2 \times (4)^2}{\pi^2 \times d^4 \times (50)^2} = \frac{d}{2000}$$

$$\Rightarrow \frac{(0.2)^2 \times 16 \times 2000}{\pi^2 \times (50)^2} = d^5$$

$$\Rightarrow d = \sqrt[5]{0.0518} = 0.553 m = 553 mm \text{ (Ans)}$$

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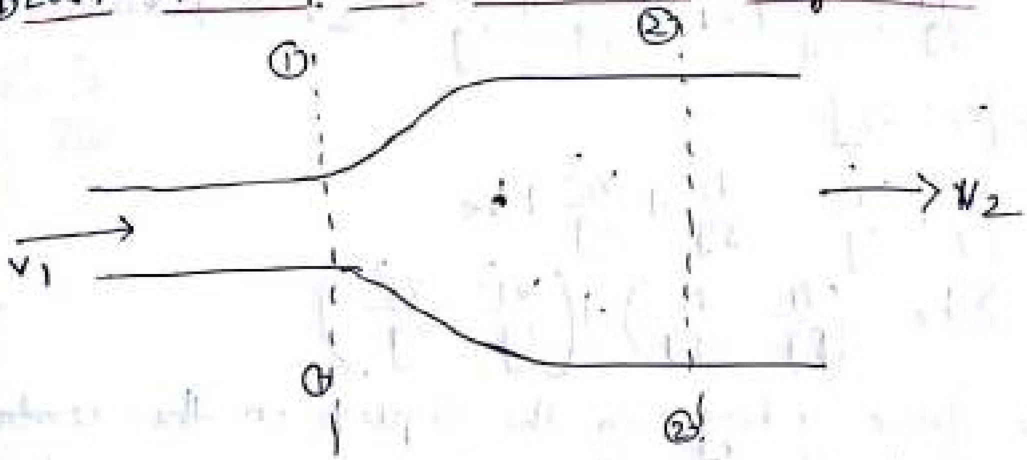
Minor Energy Losses :-

The loss of energy due to friction in pipe is known as major loss while the loss of energy due to change of velocity of the fluid is called minor loss of energy.

① Loss of head due to sudden enlargement



Consider a liquid flowing through a pipe which has sudden enlargement as shown in above figure. Consider two sections ①-① and ②-② before and after enlargement.

P_1 = pressure intensity at section ①-①

V_1 = velocity of flow at section ①-①

a_1 = area of pipe at section ①-①.

P_2 = pressure intensity at section ②-②.

V_2 = velocity of flow at section ②-②

a_2 = area of pipe at section ②-②.

→ Due to sudden change in diameter of pipe from D_1 to D_2, the liquid flowing from the smaller pipe is not able to follow the change of boundary. Thus the flow separates from the boundary and turbulent eddies are formed.

The loss of energy takes place due to forma[tion]
of these eddies.

p' = pressure intensity of the liquid eddies.

h_e = Loss of Head due to sudden enlargement.

Applying Bernoulli's equation

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + \text{head loss}$$

$\Rightarrow$ $\boxed{z_1 = z_2}$

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + h_e$$

$$\Rightarrow h_e = \left(\frac{p_1}{\rho g} - \frac{p_2}{\rho g}\right) + \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right)$$

→ The force acting on the liquid in the control volume in the direction of flow is given by

$$\boxed{F_x = p_1 A_1 + p'(A_2 - A_1) - p_2 A_2}$$

→ $\underline{p' = p_1}$

$$F_x = p_1 A_1 + p_1 (A_2 - A_1) - p_2 A_2 = p_1 A_2 - p_2 A_2$$

$$\boxed{F_x = A_2 (p_1 - p_2)}$$

Momentum of liquid in section 1-1 $= \rho A_1 V_1^2$.

momentum of liquid at section 2-2 $= \rho A_2 V_2^2$

change in momentum $= \rho A_2 V_2^2 - \rho A_1 V_1^2$

continuity equation $\boxed{A_1 V_1 = A_2 V_2}$

$$\boxed{A_1 = \frac{A_2 V_2}{V_1}}$$

Change in momentum/sec $= \rho A_2 V_2^2 - \rho \times A_1 V_1^2$

$$= \rho A_2 V_2^2 - \rho \times \frac{A_2 V_2}{V_1} \times V_1^2$$

$$= \rho A_2 V_2^2 - \rho A_2 V_1 V_2$$

$$= \rho A_2 (V_2^2 - V_1 V_2)$$

Net force acting on control volume in the direction of flow must be equal to the rate of change of momentum :

$$(P_1 - P_2) A_2 = \rho A_2 (V_2^2 - V_1 V_2)$$

$$\Rightarrow \frac{P_2 - P_2}{\rho} = V_2^2 - V_1 V_2$$

$$\Rightarrow \boxed{\frac{P_1 - P_2}{\rho g} = \frac{V_2^2 - V_1 V_2}{g}}$$

$$\therefore h_e = \left(\frac{P_1}{\rho g} - \frac{P_2}{\rho g}\right) + \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right)$$

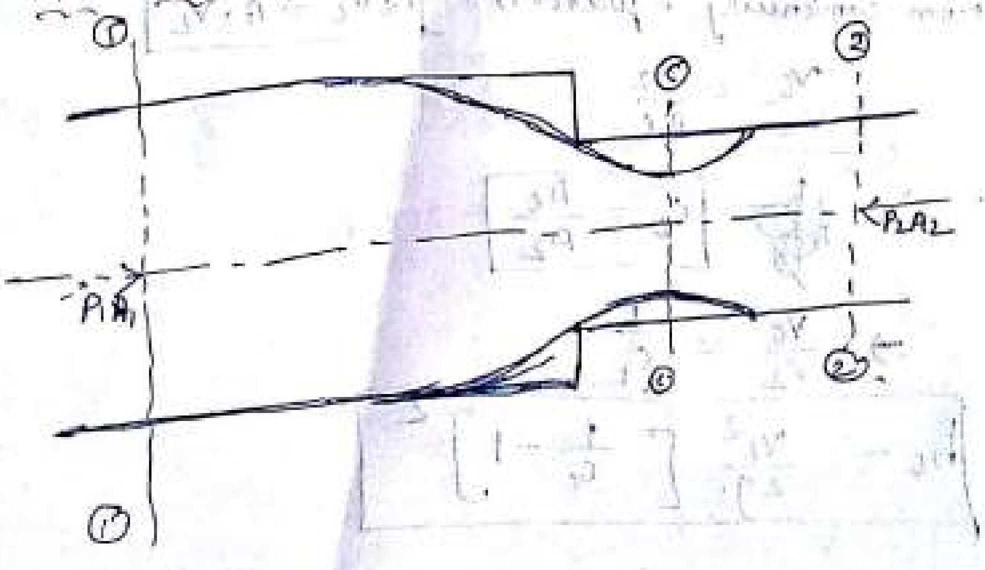
$$= \frac{V_2^2 - V_1 V_2}{g} + \frac{V_1^2}{2g} - \frac{V_2^2}{2g}$$

$$= \frac{2V_2^2 - 2V_1 V_2 + V_1^2 - V_2^2}{2g}$$

$$= \frac{V_2^2 + V_1^2 - 2V_1 V_2}{2g}$$

$$\boxed{h_e = \frac{(V_1 - V_2)^2}{2g}}$$

Loss of Head due to sudden Contraction :-



→ consider a liquid flowing in a pipe which has a sudden contraction in area as shown in fig.

→ consider two section (1-1) and (2-2) before and after contraction.

→ As the liquid goes from a large pipe to a small pipe, the area of flow goes on decreasing and becomes minimum at section (c-c). This section is called as vena contracta.

→ After section c-c, a sudden enlargement takes place. The loss of head due to sudden contraction is actually due to sudden enlargement from vena contracta to smaller pipe.

Let A_c = Area of flow at section c-c.
v_c = velocity of flow at section c-c.
A_2 = Area of flow at section 2-2.
v_2 = velocity of flow at section 2-2.
h_c = Loss of head due to sudden contraction.

$$h_c = \frac{(v_c - v_2)^2}{2g}$$

$$= \frac{v_2^2}{2g}\left[\frac{v_c}{v_2} - 1\right]^2$$

from continuity equation $A_c V_c = A_2 V_2$

$$\frac{V_c}{V_2} = \frac{A_2}{A_c}$$

$$\Rightarrow C_c = \frac{A_c}{A_2}$$

$$\Rightarrow \frac{V_c}{V_2} = \frac{1}{C_c}$$

$$h_c = \frac{V_2^2}{2g}\left[\frac{1}{C_c} - 1\right]^2$$

where $K = \left(\frac{1}{C_c} - 1\right)^2$

$$\boxed{h_c = \frac{K v_2^2}{2g}}$$

$C_c = 0.62$

So, $K = \left(\frac{1}{0.62} - 1\right)^2 = 0.375$

$$\boxed{h_c = 0.375 \frac{v_2^2}{2g}}$$

If the C_c value is not given then

$$\boxed{h_c = 0.5 \frac{v_2^2}{2g}}$$

Q) Find the loss of head when the pipe of diameter 200mm is suddenly enlarged to a diameter of 400mm. The rate of flow of water through the pipe is 250 litre/sec.

$D_1 = 200mm = 0.2 m$

$D_2 = 400 mm = 0.4 m.$

$A_1 = \pi/4 \, D_1^2 = \pi/4 \times (0.2)^2 = 0.03141 m^2$

$A_2 = \pi/4 \, D_2^2 = \pi/4 \times (0.4)^2 = 0.12564 m^2$

$Q = 250 litre/s = 0.25 m^3/s$

$v_1 = Q/A_1 = 7.96 m/s$

$v_2 = Q/A_2 = 1.99 m/s$

$h_e = \frac{(v_1 - v_2)^2}{2g} = \frac{(7.96 - 1.99)^2}{2 \times 9.81}$

$= 1.816$ m of water. (Ans)

3) Loss of Head at the Entrance of pipe :

This is the loss of energy which occurs when a liquid enters a pipe which is connected to large tank.

$$h_i = 0.5 \frac{v^2}{2g}$$

v = velocity of liquid in pipe.

4) Loss of Head at the Exit of pipe :-

This is loss of head due to velocity of liquid at the outlet of pipe. It is denoted as h_o

$$h_o = \frac{v^2}{2g}$$

v = velocity of liquid at outlet of pipe.

5) Loss of head due to Bend in pipe :-

When there is bend in pipe, the velocity of flow changes due to which formation of eddies takes place.

$$h_b = \frac{Kv^2}{2g}$$

h_b = loss of head due to bend.
v = velocity of flow.
K = coefficient of bend.

6) Loss of Head in various pipe fittings :-

This is the loss of head in various pipe fittings. It is expressed as

$$\frac{Kv^2}{2g}$$

V = velocity of flow
K = coefficient of pipe fitting

HYDRAULIC GRADIENT LINE :-

It is defined as the line which gives the sum of pressure head (P/w) and datum head (z) of a flowing fluid in a pipe with respect to some reference line.

→ It is briefly written as H.G.L (Hydraulic gradient Line)

TOTAL ENERGY LINE :-

It is defined as the line which gives the sum of pressure head, datum head and kinetic head of a flowing fluid in a pipe with respect to some reference line.

→ It is briefly written as T.E.L (Total Energy Line).

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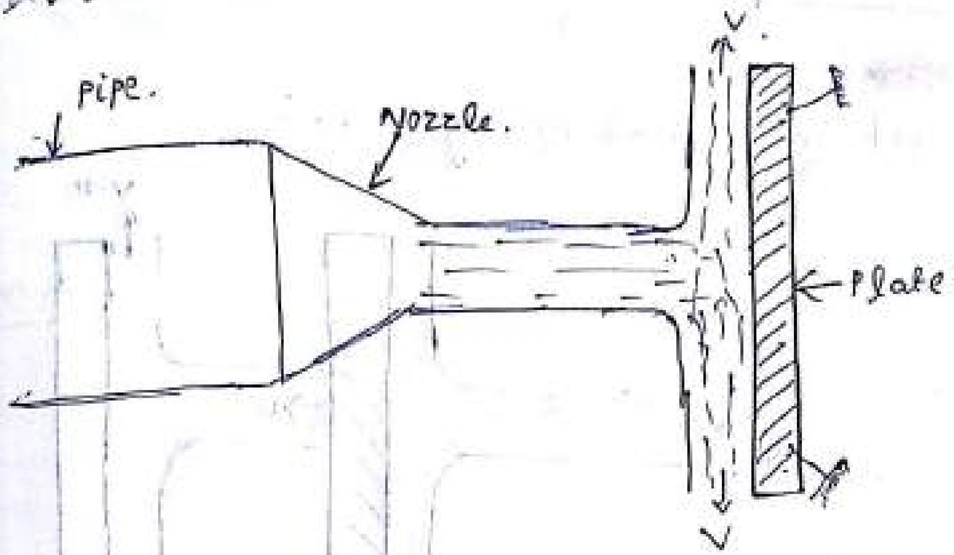
IMPACT OF JET (CHAPTER-7)

Impact of jet on a fixed vertical flat plate



→ consider a jet of water coming out from the nozzle, strikes a flat vertical plate.

V = velocity of the jet

d = diameter of the jet

a = area of crossection of jet $= \frac{\pi}{4} d^2$

→ The jet after striking the plate, will move along the plate. But the plate is at right angles to the jet. Hence the jet after striking will get deflected through 90°.

→ After striking the component of the velocity of jet in the direction of jet is zero.

The force exerted by the jet on the plate in the direction of jet

F_x = Rate of change of momentum in direction of force

$= \frac{\text{Initial momentum} - \text{final momentum}}{\text{Time}}$

$= \frac{(\text{Mass} \times \text{initial velocity}) - (\text{Mass} \times \text{Final velocity})}{\text{Time}}$

$= \frac{\text{Mass}}{\text{Time}} (\text{initial velocity} - \text{Final velocity})$

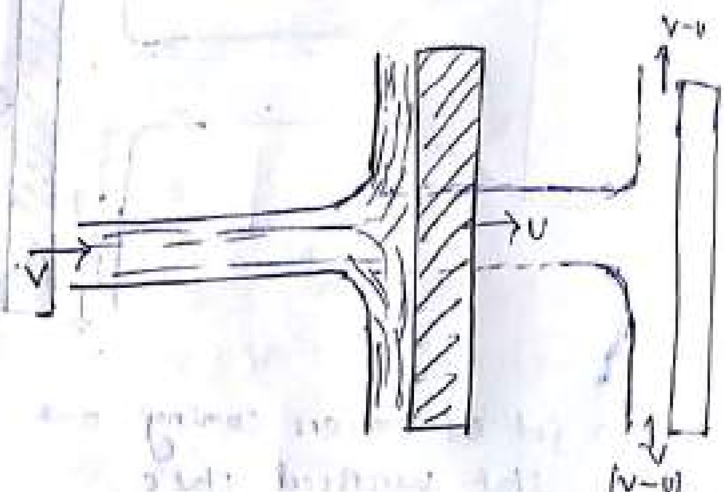
$= \frac{\text{Mass}}{\text{time}} (V - 0)$

$F_x = \rho a v (v - 0)$. $\left[\text{mass/sec} = \rho \times a v\right]$

$$\boxed{F_x = \rho a v^2}$$

~~Force on Plate~~

Impact of jet on vertical moving plate :-



→ v = velocity of jet
a = area of cross-section of the jet
u = velocity of flat plate.

→ In this case, the jet does not strike the plate with a velocity v, but it strikes with a relative velocity.

→ The relative velocity is equal to the difference of absolute velocity of jet of water and the velocity of plate.

→ The relative velocity = $(v - u)$

→ Mass of water striking the plate per sec =
$\rho \times$ Area of jet $\times$ velocity with which jet strikes the plate
$= \rho a (v - u)$.

→ Force exerted by the jet on the moving plate in the direction of jet

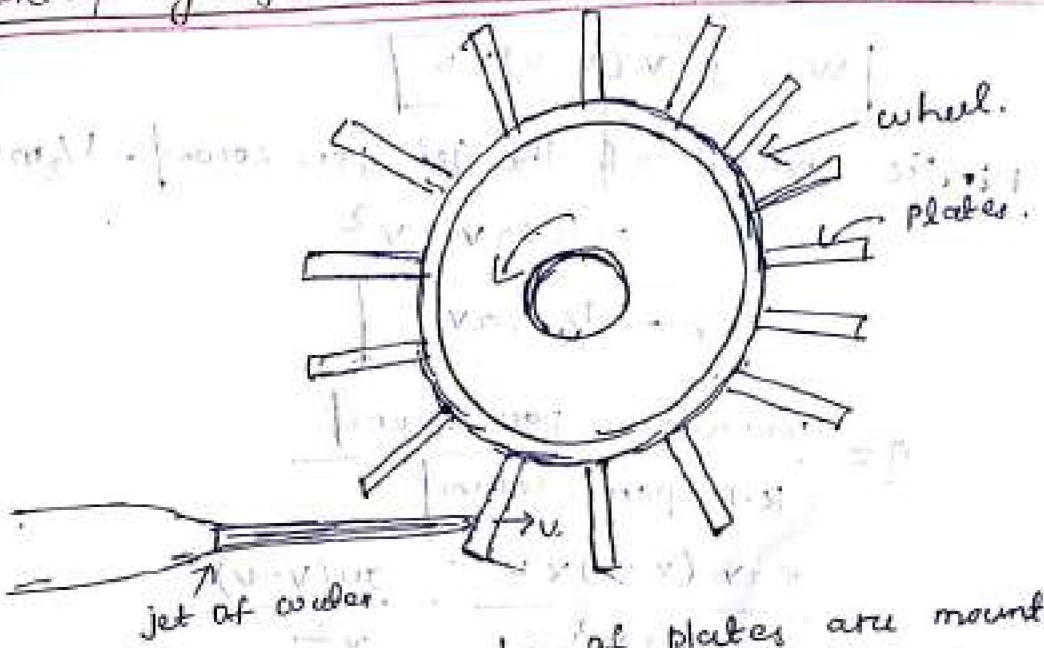
F_x = Mass of water $\times$ (initial velocity − final velocity)
$= \rho a (v - u) \left[(v - u) - 0\right]$.

$$\boxed{F_x = \rho a (v - u)^2}$$

→ The work will be done by the jet on the plate, as plate is moving.

$$\text{workdone} = \text{Force} \times \text{velocity}$$
$$= F_x \times U$$
$$\boxed{W = \rho a (V-U)^2 \times U}$$

Force exerted by a jet of water on a series of vanes



→ In actual practice, a large number of plates are mounted on the circumference of a wheel at a fixed distance apart.

→ The jet strikes a plate and due to the force exerted by the jet on the plate, the wheel starts moving.

V = velocity of jet.

d = diameter of jet.

a = cross-sectional area of jet $= \pi/4 \, d^2$

u = velocity of vane.

→ Mass of water per second striking the series of plates $= \rho a V$.

→ jet strikes the plate with a velocity $= (V-U)$

→ The force exerted by the jet in the direction of motion of plate

F_x = Mass × (initial velocity − final velocity)

$= \rho a V[(V-u)-0]$

$$\boxed{F_x = \rho a V(V-u)}$$

workdone = Force × ~~Distance~~ velocity

$= F_x \times u$

$$\boxed{W = \rho a V(V-u) \times u}$$

Kinetic energy of the jet per second $= \frac{1}{2} m V^2$

$= \frac{1}{2} \rho a V \times V^2$

$$\boxed{KE = \frac{1}{2} \rho a V^3}$$

$$\eta = \frac{\text{workdone per second}}{\text{K.E per second}}$$

$$= \frac{\rho a V (V-u) \times u}{\frac{1}{2} \rho a V^3} = \frac{2u(V-u)}{V^2}$$

$$\boxed{\eta = \frac{2u(V-u)}{V^2}}$$

condition for Maximum Efficiency :-

$$\frac{d\eta}{du} = 0$$

$$\Rightarrow \frac{d}{du}\left[\left(\frac{2u(V-u)}{V^2}\right)\right] = 0$$

$$\Rightarrow \frac{d}{du}\left(\frac{2uV - 2u^2}{V^2}\right) = 0$$

$$\Rightarrow \frac{2V - 2 \times 2u}{V^2} = 0$$

$$\Rightarrow 2V - 4u = 0$$

$$\Rightarrow V = 2u \Rightarrow \boxed{u = V/2}$$

Maximum efficiency

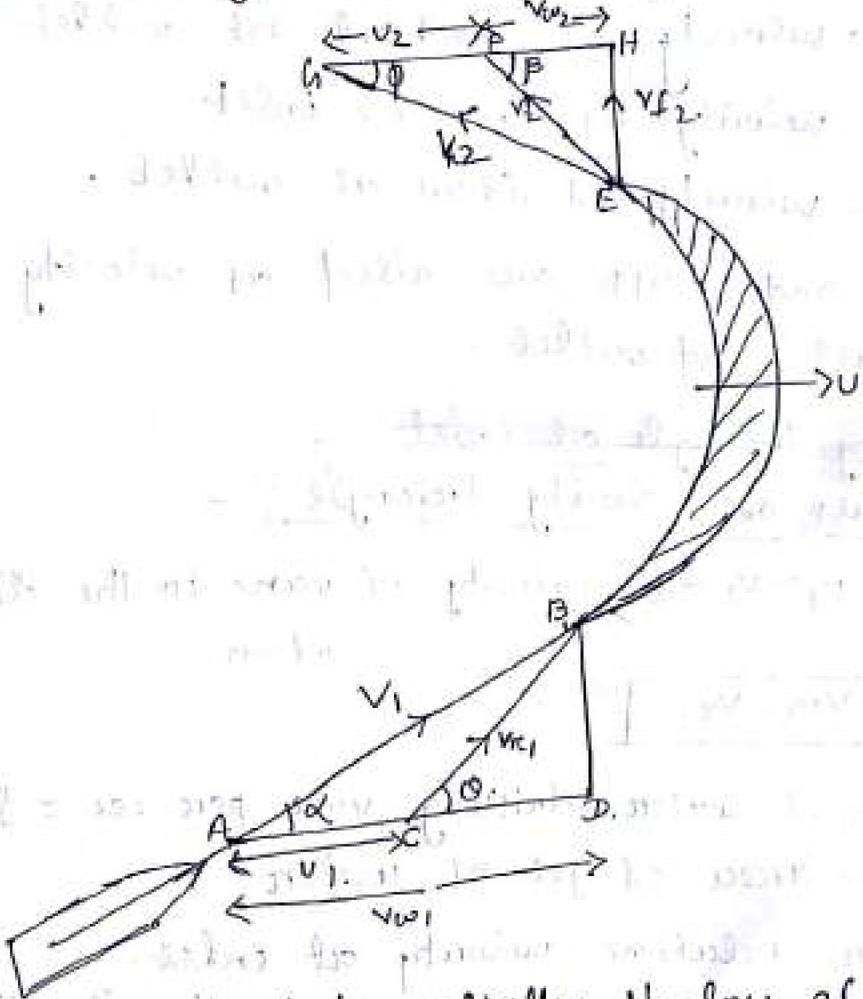
$$\eta_{max} = \frac{2v(V-v)}{V^2}$$

$$= \frac{2v(2v-v)}{(2v)^2}$$

$$= \frac{2v \times v}{4v^2} = \frac{1}{2} = 50\%$$

$$\boxed{\eta_{max} = 50\%}$$

Impact on a moving curved plate :-



→ As the jet strikes tangentially, the loss of energy due to impact of the jet will be zero. as the plate is moving, the velocity with which jet of water strikes is equal to the relative velocity of the jet with respect to the plate.

V_1 = velocity of the jet at inlet

u_1 = velocity of vane at inlet

V_{r_1} = relative velocity of jet and plate at inlet.

α = blade angle (inlet)

θ = vane angle (inlet).

V_2 = velocity of jet at outlet.

u_2 = velocity of vane at outlet.

V_{r_2} = relative velocity of jet at outlet.

β = blade angle at outlet.

ϕ = vane angle at outlet.

V_{w_1} = velocity of whirl at inlet

V_{w_2} = velocity of whirl at outlet

V_{f_1} = velocity of flow at inlet

V_{f_2} = velocity of flow at outlet.

ABD and EGH are called as velocity triangles at inlet and outlet.

~~velocity triangle at inlet~~ :-

Analysis of velocity triangle :-

$u_1 = u_2 = v$ = velocity of vane in the direction of motion.

$$\boxed{V_{r_1} = V_{r_2}}$$

→ Mass of water striking vane per sec = $\rho a V_{r_1}$

a = area of jet of water.

V_{r_1} = relative velocity at inlet.

→ force exerted by the jet in the direction of moti

$$\boxed{F_x = \rho a V_{r_1} (V_{w_1} + V_{w_2})}$$

If $\beta = 90°$, $V_{w_2} = 0$

$$\boxed{F_x = \rho a V_{r_1} \times V_{w_1}}$$

→ β is obtuse angle

$$\boxed{F_x = \rho a V_{r_1} [V_{w_1} - V_{w_2}]}$$

Thus in general F_x can be written as

$$\boxed{F_x = \rho a V_{r_1} [V_{w_1} \pm V_{w_2}]}$$

→ workdone per second on the vane by jet

$= F_x \times U$

$$W = \rho a V_{r_1} [V_{w_1} \pm V_{w_2}] \times U$$

efficiency of jet :-

$$\eta = \frac{\text{output}}{\text{Input}}$$

$$= \frac{\text{workdone per second on the vane}}{K.E}$$

$$= \frac{\rho a V_{r_1} (V_{w_1} \pm V_{w_2}] \times U}{\frac{1}{2} m V_1^2}$$

$$= \frac{\rho a V_{r_1} (V_{w_1} \pm V_{w_2}) \times U}{\frac{1}{2} \times \rho a V_{r_1} \times V_1^2}$$

$$= \frac{(V_{w_1} \pm V_{w_2}) \times U}{\frac{1}{2} \times V_1^2}$$

$$\eta = \frac{2U (V_{w_1} \pm V_{w_2})}{V_1^2}$$

1. Answer All the Questions. (2×10)

(a) State the composition of HSS Tool.

(b) Define depth of cut.

(c) List the operations carried out in a lathe.

(d) What are the types of grinder?

(e) Define drilling & boring.

(f) What is super finishing?

(g) What is the function of Ram?

(h) Define Abrasive.

(i) Define grinding.

(j) What is broaching?

2. Answer Any Six Question.

(a) What are the characteristics of tool material? (5×6)

(b) Differentiate between Capstan & Turret Lathe.

(c) Explain working of slotter.

(d) Describe the properties of coolant & lubricant

(e) Explain the specification of grinding wheel.

(f) With neat block diagram show different component of shaper m/c.

(g) Explain cutting action of a Reamer.

3. Draw three views of a single point cutting tool & explain the cutting Angles. (10)

4. Explain the working of an Universal dividing head. (10)

5. Explain the Quick Return mechanism of a shaper machine. (10

6. Describe the composition, properties & use of Various cutting tool material. (10)

7. With neat sketch explain the clamping device of a Planner. (10)

IV SEM - MECH ENGG

TH-2 : MANUFACTURING TECHNOLOGY

FULLMARK- 80 TIME- 3 HOURS

ANSWER ANY FIVE QUESTION INCLUDING Q. NO 1 & 2.

1. ANSWER ALL THE QUESTIONS. (2×10)
(a) Define Abrasive.
(b) what is the function of ram in sloter?
(c) Name the different type of milling machine.
(d) what are the composition of Carbon steel?
(e) Write four main parts of Lathe.
(f) Define the multiple tool holder.
(g) why coolants are used?
(h) Write four clamping device of a planner m/c.
(i) Differentiate between orthogonal & oblique cutting.
(j) Define Indexing.

2. ANSWER ANY SIX QUESTION. (5X6)
(a) Explain the working of Radial drilling machine.
(b) Explain the method of Taper-Turning operation.
(c) Difference between upmilling & Down milling.
(d) Explain cutting Action of a hacksaw blade.
(e) Explain the Automatic table feed mechanism of a shaper m/c.
(f) Explain the working of Centreless grinder.
(g) Draw the diagram of an Universal milling machine & show it's all part.

3. Show & Explain different parts of Capstan Lathe. (10)

4. Explain single point cutting tool Nomenclature. (10)

5. Explain the Quick Return mechanism of a shaper. (10)

6. Explain the manufacturing Process of grinding wheel. (10)

7. How we make a hexagonal Nut & bolt? Explain in detail. (10)

IV SEM - MECH ENGG.
TH-2: MANUFACTURING TECHNOLOGY

FULL MARK - 80 TIME - 3 HOURS

ANSWER ANY FIVE QUESTION INCLUDING Q.NO 1 & 2

1. ANSWER ALL THE QUESTIONS. (2×10)
(a) Name various cutting tool material.
(b) State the operations which may performed on a Lathe.
(c) Why chucks are used?
(d) Name different types of drilling machine?
(e) Define coolant.
(f) What is centreless grinding?
(g) Define Depth of cut.
(h) State the specification of shaper.
(i) What do you mean by surface finishing?
(j) Neccessity of broaching.

2. ANSWER ANY SIX QUESTION. (5×5)
(a) List various hand tools & discuss their cutting action.
(b) Explain different methods of taper turning.
(c) Draw the sketch of capstan & turret lathe with Nomenclature.
(d) Describe the main parts of a slotting machine (Any three).
(e) Explain the specification of grinding wheels.
(f) Draw a simple dividing head & explain it's working.
(g) State the properties & uses of any one cutting tool material.

3. Explain with a neat sketch the geometry of a Turning tool. (10)
4. Describe the desirable properties of coolant & Lubricant. (10)
5. With a neat sketch explain Quick return mechanism of a shaper. (10)
6. Explain cutting Action of a Reamer & chisel. (10)
7. Difference between shaper & planner machine (10).

Drilling Machine

(i) Drilling is an operation through which holes are produce in solid metals.

(ii) The process of making hole is done by the help of a tool which is known as drill tool.

(iii) In drilling operation it is not possible to produce a perfectly true hole with accurate dimensions and surface finish. So, it can be considered as roughing operations.

Q-1 classify drilling machines.

Ans Classification of drilling machine :-

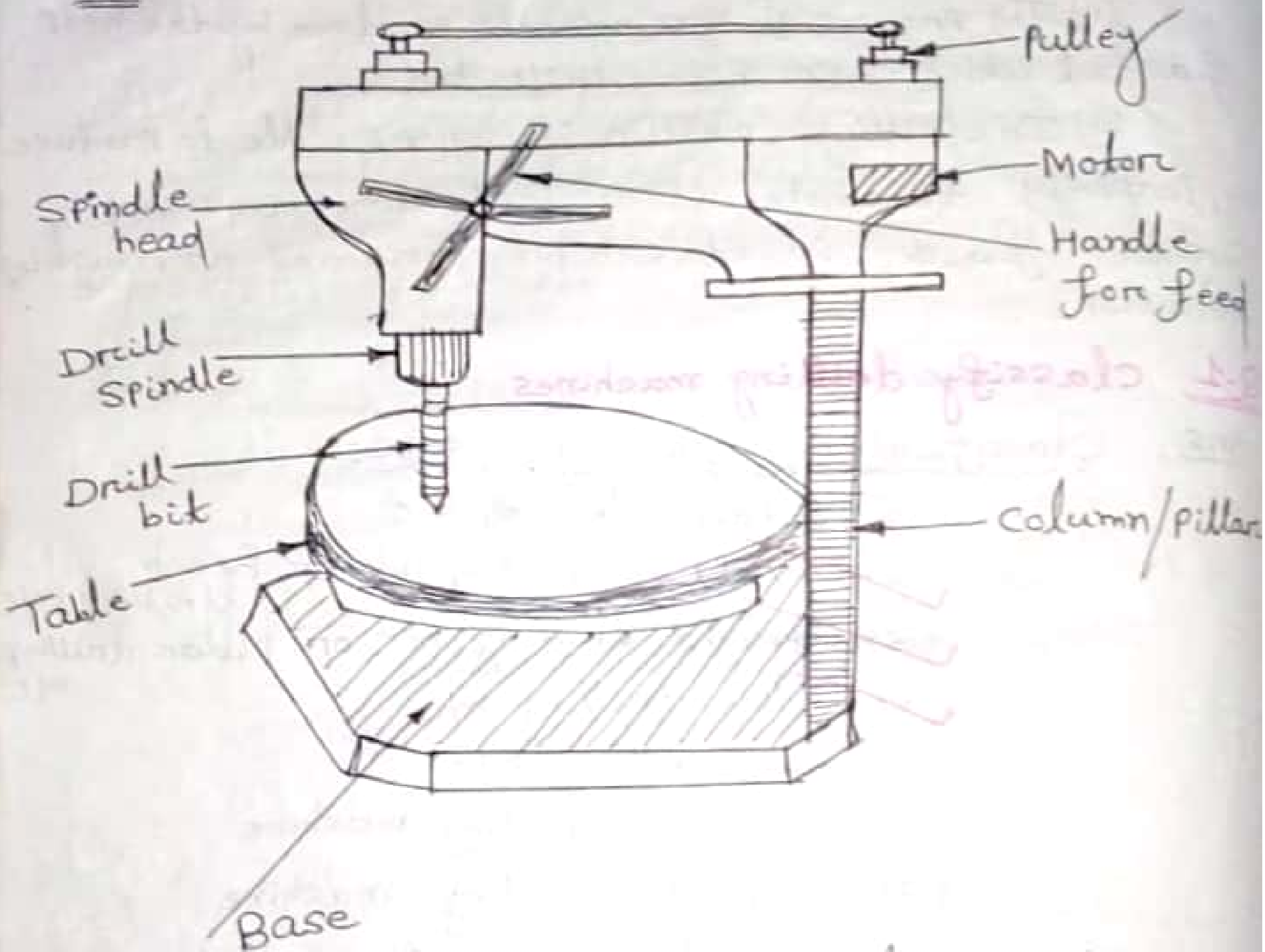
(1) Portable drilling m/c
(2) Sensitive drilling m/c or Bench drilling m/c
(3) Upright drilling m/c or pillar drilling m/c
(4) Radial drilling m/c
(5) Gang drilling m/c
(6) Automatic drilling machine
(7) Deep hole drilling machine
(8) Multiple spindle drilling m/c

Note In our syllabus, there are only 3 type of drilling machine is to be studied.

(a) Sensitive or Bench drilling m/c
(b) upright or pillar drilling m/c
(c) Radial drilling machine

Q-2 Explain the construction & working of Bench drilling m/c.

Ans



* It is a light, simple bench type machine used for light duty working.
* The machine can hold drills up to 12.5 mm. diameter.

The major components of bench type drilling m/c are
(1) Base (2) Column (3) Table
(4) Drill spindle
(5) Drill bit.

Construction Parts

Base:- The base provided support and rigidity to the entire structure of the machine. It is made of cast iron & having a fixed table over it.

Column:-

(i) The column or pillar is a supporting structure for the table, spindle head and other part of the machine

(ii) The column carries a swivelling table.

(iii) At the top of the column is provided with a motor which act as a drive mechanism for the system.

Table:-

(i) The table of the drilling m/c supports the workpiece and other clamping devices like drill jigs

(ii) By loosing the table clamping handle the table can be adjusted up & down on the column with respect to the drill.

Drill spindle:-

(i) The various mechanism of the spindle head powered by the help of motor through belt & pulleys.

(ii) The top of the column is provided with V-belt running over two pulleys.

(iii) one of these pulleys mounted over the motor shaft & other is mounted on the spindle head.

(iv) No gears are used in this drive arrangement

(v) Vertical movement of the spindle is given through the feed handle. by (rack & pinion arrangement

Drill bit:-

(i) Various types of drill bit can be used for drilling purpose according to the requirement.

(ii) Generally Twist drill are used for drilling operation. It made from HSS & High carbon Steel.

Working Principle

(i) When the switch is on of motor, the motor shaft starts revolving.

(ii) Then the power is transmitted through the V-belt which is mounted on the pulley to the other pulley which is mounted on the spindle head.

(iii) Thus the spindle starts rotating & the drill tool also rotates. by the help of the handle we can give feed.

(iv) The handle is mounted on the pinion shaft which is connected to a rack which moves longitudinally.

(v) Different spindle speeds can be obtained by shifting the V-belt to the different pairs of driving & driven pulleys.

(vi) while the motor rotates on the same speed.

(vii) There is no arrangement of automatic feed in this machine.

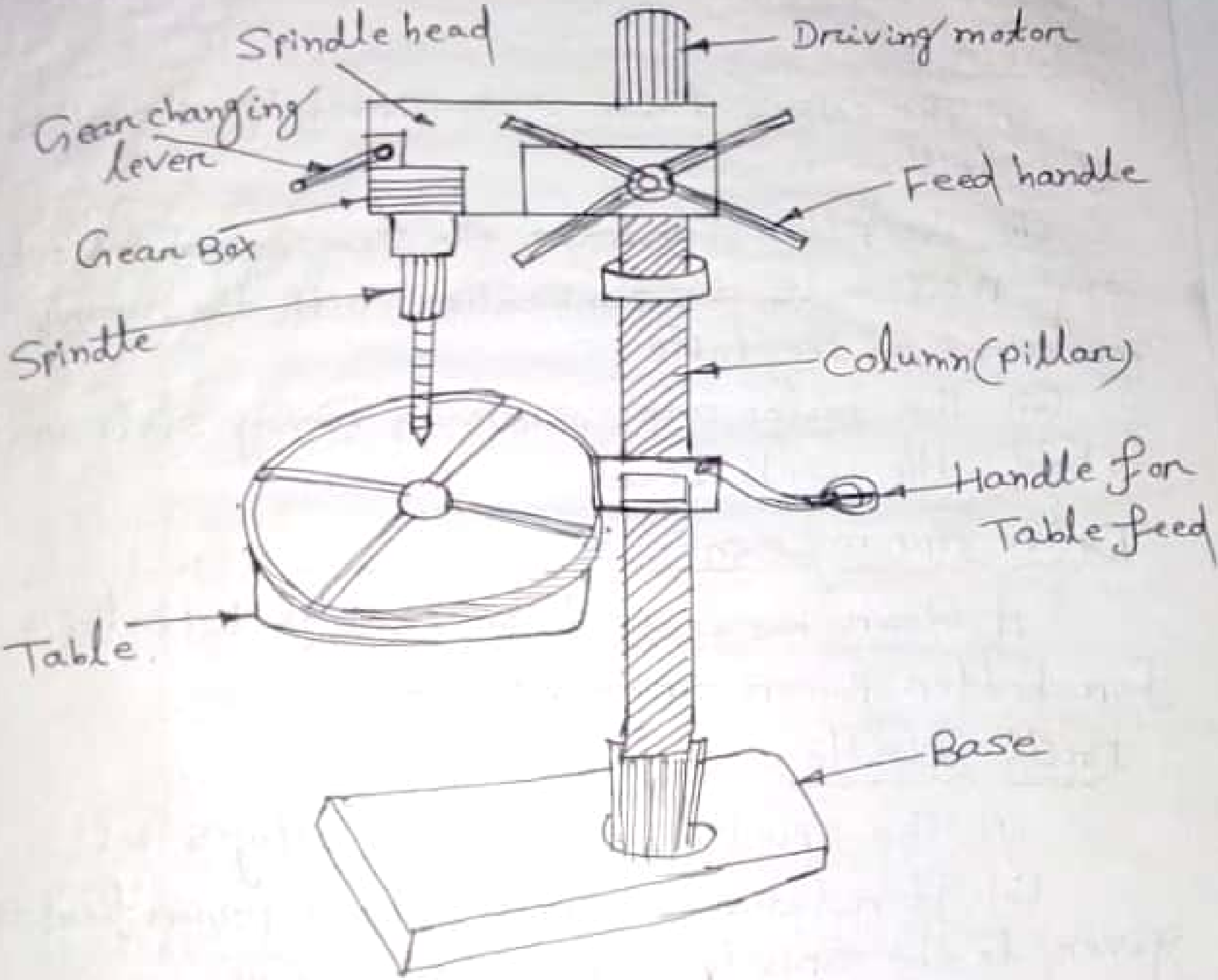
Q-3 With a neat sketch explain the function of pillar drilling machine.

Ans (i) The pillar drilling m/c is used for heavy work and has back gearing arrangement as lathe.

(ii) It is coming under up-right drilling machine.

(iii) It especially differs from a Sensitive drilling machine in it's weight, rigidity, Power feed and wide range of spindle speed.

(iv) It can give speed ranging from 75 to 3500 r.p.m. So, obtain this speed range here gear box is used instead of belt arrangement.



It consist of following parts.

(1) Base
(2) Pillar
(3) Table
(4) Spindle
(5) Drill bit
(6) Drive Arrangement.

Base:- The base of pillar drilling machine is made of heavy casting supports the pillar & spindle head.

Pillar/column:- The pillar is a hollow pipe of casting made of cast iron. ~~The~~ It rest from the base & supports the spindle head & table. Here rack & pinion gear present. So, that the table can be raise or lower depending upon the work piece retuirement.

Table:-

(i) The work table is supported by the pillar of a drilling machine.

(ii) The pillar facilates the swinging of table to any position & in combination with the rotary movement of the table.

(iii) The tables are generally having slots on it to hold the work piece.

Drive Arrangement:-

A Gear box is used instead of belt drive for better power transmission.

Drill Spindle:-

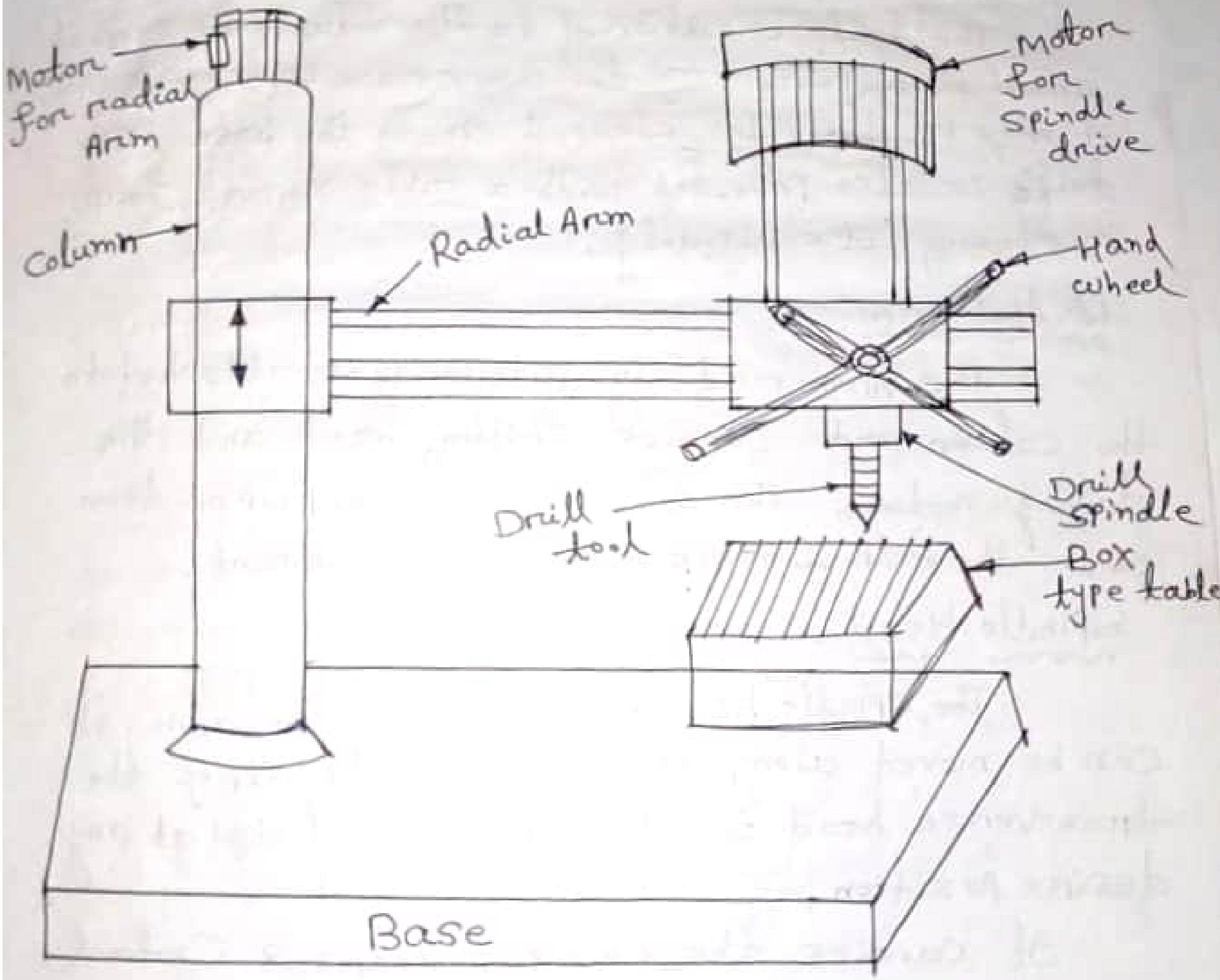
(i) The spindle is made of alloy steel.

(ii) It rotates the drill & here power feed is given to the spindle for heaviour work.

(iii) It has driven mechanism for changing speeds & feeds and thus a large no. of drill spindles are available to drill different kinds of Job.

Q-4 With block diagram explain the construction & working of a radial drilling machine.

Ans The radial drilling machine is used for too large and heavy drill hole.



Base:-

(i) The base is made box type of cast iron
(ii) The base carries the column & it may be bolted on bench with the base.
(iii) The base must be strong enough to give sufficient rigidity & support to the whole structure & other parts.

Column:-

The column is cylindrical & used to support the radial arm. It is made highly rigid and perfectly round in cross-section.

Table:-

The table is attached to the column to support small workpiece. If the workpiece is very large, it may be directly clamped on to the base. The table is also provided with a table support for increasing it's rigidity.

Radial Arm:-

The Arm radially outward is attached to the column and carries drilling head and the driving motor. The Arm can be moved up or down with the help of rack & pinion arrangement.

Spindle Head:-

The spindle Head is mounted on the arm. It can be moved along the arm with the help of the transverse head wheel and can be locked at any desire position.

It carries the changes gears & control for spindle speed & feed.

Working operation

(i) A separate motor is provided for elevating lowering the radial arm and can also be swing round the column to any desire angle.

(ii) Clamping levers are provided for locking the arm at desire height. The spindle head is mounted on the arm which can slide horizontal on the radial arm.

(iii) These adjustment of the arm & drilling head permit the operator & locate the drill quickly any point of the work.

(iv) Powerful drives are geared directly into the head of the machine and a wide range of power feed are available.

Q-5 Write the basic Principle of Boring.

Ans It is the Process of enlarging a hole that has already been drilled.

* Boring is used to achieve greater accuracy of the diameter of a hole.

Example This process is to used in large & heavy Parts such as engine frames, steam engine cylinder etc.

Q-6 Difference between Boring and drilling.

Ans Boring :-

(i) It is the Process of enlarging a hole that is already in the material. This hole made by drilling.

(ii) Boring concerns the internal diameter and the surface of a hole rather than the depth of the hole.

(iii) Boring is done using a boring bar; which is a heavy metal bar with the tool fixed at the end.

Drilling

(i) Drilling is the cutting process of a material using a specially designed rotating cutting tool called a drill bit.

(ii) The holes are produced by the drilling are always cylindrical in drilling process is simple.

(iii) The drill bit is rotated by a drill and pressed against the material, where the tip of the drill bits cuts away the layers of material. By continually pressing against the material, a hole of a desire length can be created.

BROACHING

Q-1 Define Broaching.

Ans It is a method of removing metal by pushing or pulling a cutting tool called a broach which cuts in fixed path.

* The tool may be pulled or pushed through the surfaces to be finished.

* Surface finished by broaching may be flat or contoured and may be either internal or external.

* A broach is a multiple edges cutting tool that has successively higher cutting edges along the length of the tool.

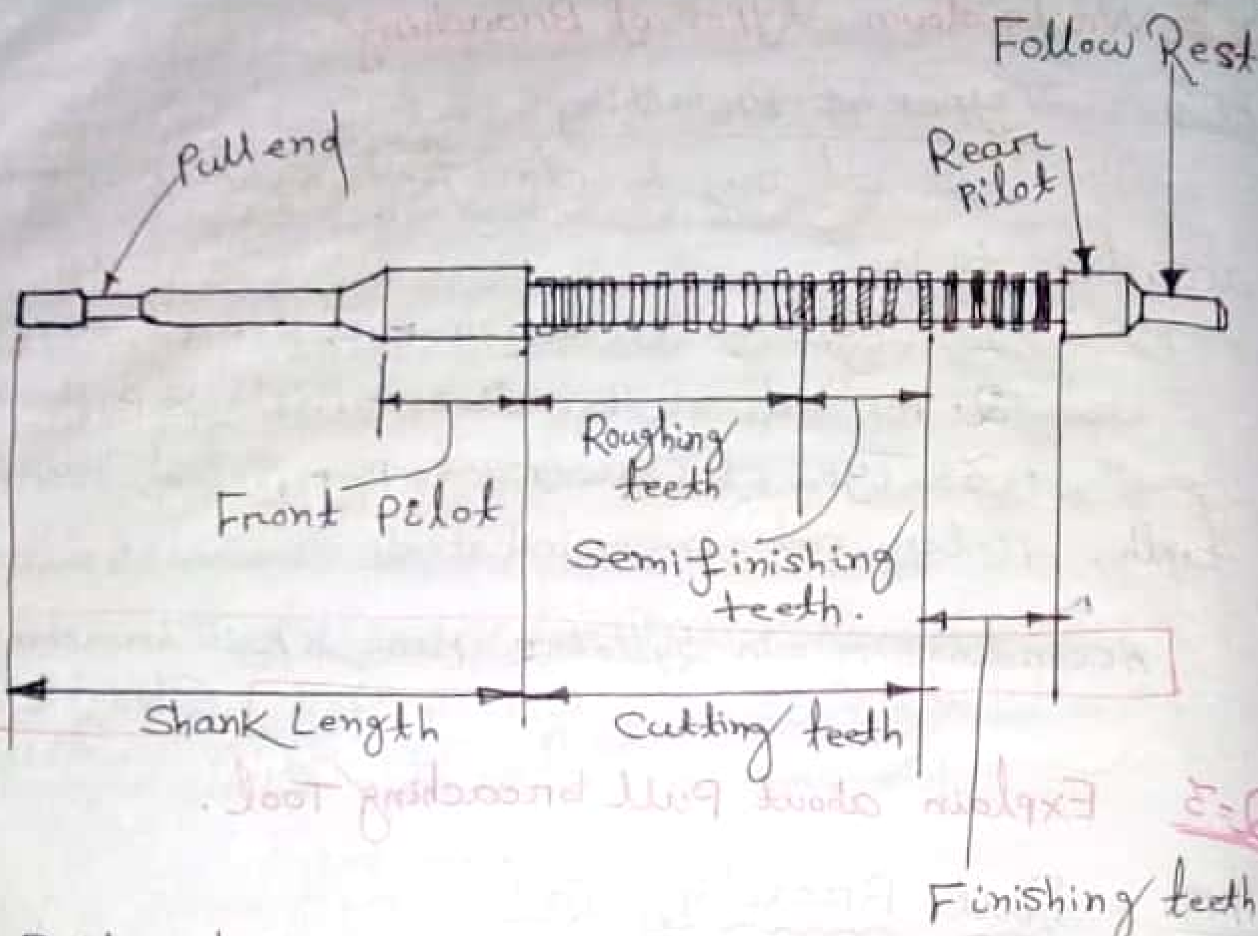
Q-2 Write down types of Braaching.

Ans Types of Broaching
It may be classified in various ways according to :-
1. Type of operation → Internal & external
2. Method of operation → Push & pull
3. Type of Construction → solid, overlapping tooth, rotor cut, inserted tooth.

According to our Syllabus push & pull breaching Study.

Q-3 Explain about Pull broaching Tool.

Ans Pull Broaching Tool
(i) In Pull broach; the tool is entirely in tension & long slender broaches are possible, having a large no. of teeth.
(ii) In pull broaching methods, the work is held stationary and the broach is pulled through the work. Broaches are held in a special head. pull broaching is used mostly for internal broaching but it can do some surface broaching.
(iii) Ordinary cut broaches for machining previously drilled or bored holes consist of different elements, which are discussed below.



Pull end:-

This is designed to permit engagement of the broach with the broaching machine through the use of a puller ~~head~~ head.

Front pilot

This centres the broach in the hole before the teeth begins to cut.

Roughing & Semi-finished teeth

They Remove most of the stock in the hole.

Finishing Teeth:-

They are for sizing the hole and must have the shape required the finished hole.

Rear Pilot & Follow Rest

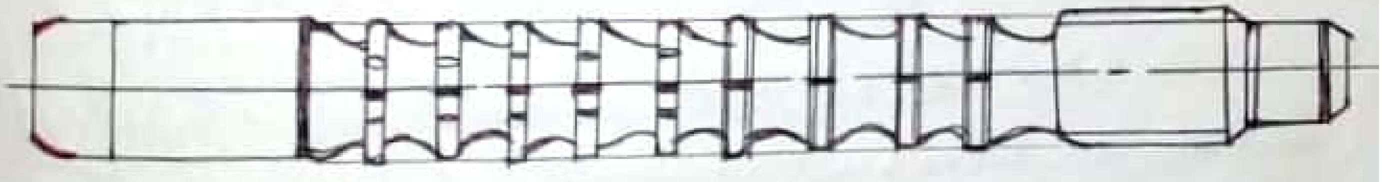
They support the broach after the last tooth leaves the hole.

* Push Broaching:-

(i) A push broach is one that is designed to be pushed through the workpiece by special press or push broaching machining. Because of the tendency to bend under compressive loads, the push broach must be short which means, less material can be removed for each pass of the tool.

(ii) In this broaching, the work is held stationary and the broach is pushed through the work.

(iii) Hand & hydraulic arbor presses are popular for push broaching. This methods is used mostly for sizing holes and cutting keyways.



(Figure of push Broach)

Q-4 What are the advantages of Broaching?

Ans <u>Advantages</u>

(1) Rate of Production is very high. With properly applied broaches, fixtures and machined, more pieces can be turned out per hour by broaching than by any other means.

(2) Little skill is required to perform a broaching operation.

(3) High Accuracy and a high class of Surface finish is possible.

(4) Both roughing and finishing cuts are completed in one pass of the tool.

(5) The process can be used for either internal or external Surface finishing.

(6) Any form that can be reproduced on a broaching can be machined.

<u>Broaching Application</u>

Broaches are used for high Production and for finishing high Surfaces.

Q-1 Define Sureface finishing.

Ans Super finishing is the proper function and service life at a machine part depending upon the quality of it's surface that is it's surface finish.

⇒ Various basic operations like turning, boring, drilling, milling, shaping etc. are used to produce various parts.

⇒ These parts are accurate in size but they don't carry a very high degree of surface finish for which the service life of the parts decreases.

⇒ So, to obtain highly finish surface various operations are performed as :- Lapping, Honing, Super finish, Grinding operation etc.

Q-2 Define Superfinishing.

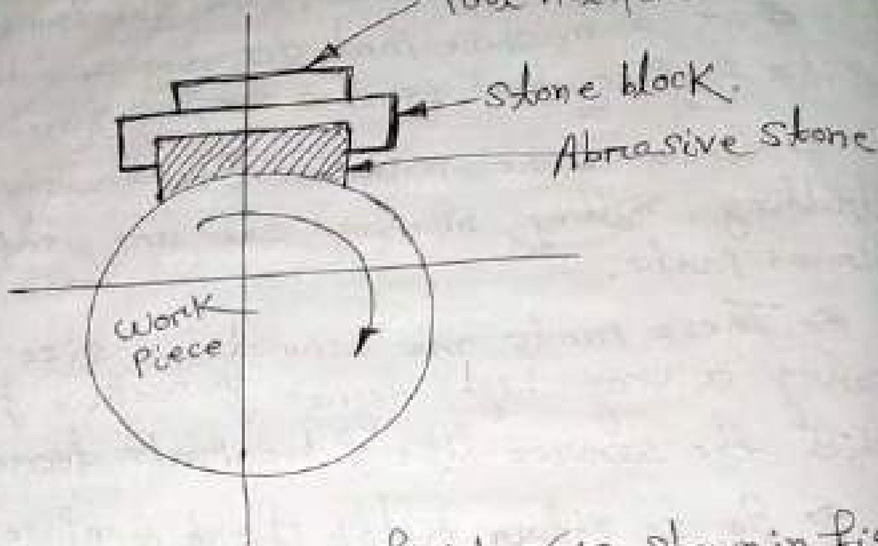
Ans (i) It is a process generally used for achieving high degree surface finish on the components. Removing the scratches or various marks from the work piece.

(ii) It is a not primarily dimension changing process but mainly used for high quality surface finish on the workpiece.

(iii) In this process very less amount of metal is removed which ranges from 0.0025 mm to 0.005 mm.

Q-3 Explain Principle of Superfinishing.

Ans



(i) The principle of super finishing is shown in fig. Here the face of abrasive stone is given the shape of the workpiece to be super finished.

(ii) The Abrassive stone block is held in a suitable tool holder & the whole arrangement is placed on the work surface.

(iii) The work piece is rotated at very slow speed. As the work rotated, the abrassive stone block reciprocates forward & backward at a rapid rate with rubbing of the stone. As a result super finishing surface is obtained.

Q-4 Description about Lapping.

Ans (i) Lapping is a Process employed for improving the Surface finish by reducing roughness, weavingness and other irregularities on the Surface.

(ii) It should be used only where geometrical accuracy is vital with surface finish.

(iii) The material to be selected for making lapping tools are soft cast iron, copper, brass, Lead etc.

(iv) Sometimes abrasive particles are also used. These particles are natural and artificial abrasive particles.

(v) Aluminium oxide (Al_2O_3), silicon Carbid & diamonds are used for lapping materials.

1. Answer All the Questions. (2×10)

(a) State the composition of HSS Tool.

(b) Define depth of cut.

(c) List the operations carried out in a lathe.

(d) What are the types of grinder?

(e) Define drilling & boring.

(f) What is super finishing?

(g) What is the function of Ram?

(h) Define Abrasive.

(i) Define grinding.

(j) What is broaching?

2. Answer Any Six Question. (5×6)

(a) What are the characteristics of tool material?

(b) Differentiate between Capstan & Turret Lathe.

(c) Explain working of slotter.

(d) Describe the properties of coolant & lubricant.

(e) Explain the specification of grinding wheel.

(f) With neat block diagram show different component of shaper m/c.

(g) Explain cutting action of a Reamer.

3. Draw three views of a single point cutting tool & explain the cutting Angles. (10)

4. Explain the working of an Universal dividing head. (10)

5. Explain the Quick Return mechanism of a shaper machine. (10

6. Describe the composition, properties & use of various cutting tool material. (10)

7. With neat sketch explain the clamping device of a Planner. (10)

IV SEM - MECH ENGG

TH-2 : MANUFACTURING TECHNOLOGY

FULLMARK- 80 TIME- 3 HOURS

ANSWER ANY FIVE QUESTION INCLUDING Q.NO 1&2.

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(a) Define Abrasive.
(b) what is the function of ram in sloter?
(c) Name the different type of milling machine.
(d) what are the composition of Carbon steel?
(e) Write four main parts of Lathe.
(f) Define the multiple tool holder.
(g) why coolants are used?
(h) Write four clamping device of a planner m/c.
(i) Differentiate between orthogonal & oblique cutting.
(j) Define Indexing.

2. ANSWER ANY SIX QUESTION. (5X6)

(a) Explain the working of Radial drilling machine.
(b) Explain the method of Taper-Turning operation.
(c) Difference between upmilling & Down milling.
(d) Explain cutting Action of a hacksaw blade.
(e) Explain the Automatic table feed mechanism of a shaper m/c.
(f) Explain the working of Centreless grinder.
(g) Draw the diagram of an Universal milling machine & show it's all part.

3. Show & Explain different parts of Capstan Lathe. (10)

4. Explain single point cutting tool Nomenclature. (10)

5. Explain the Quick Return mechanism of a shaper. (10)

6. Explain the manufacturing Process of grinding wheel. (10)

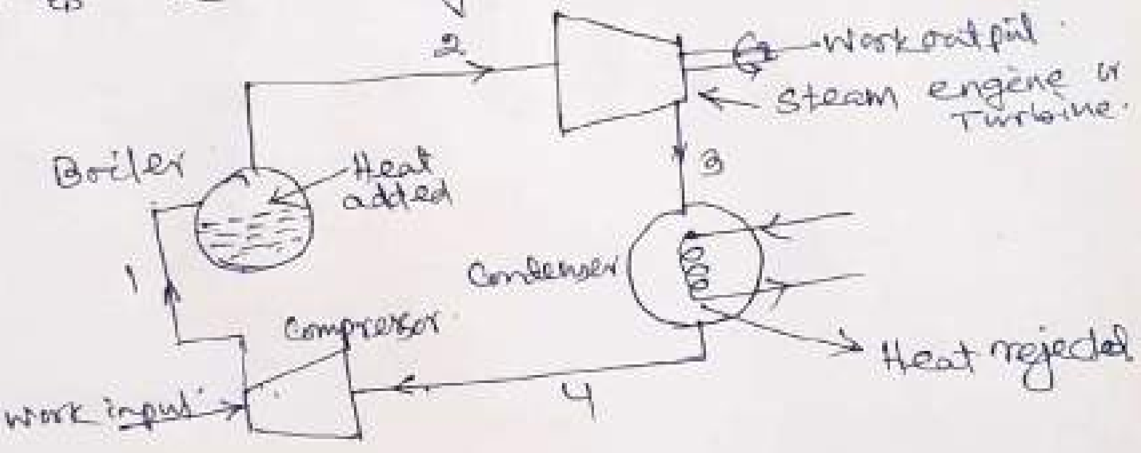
7. How we make a hexagonal Nut & bolt? Explain in detail. (10)

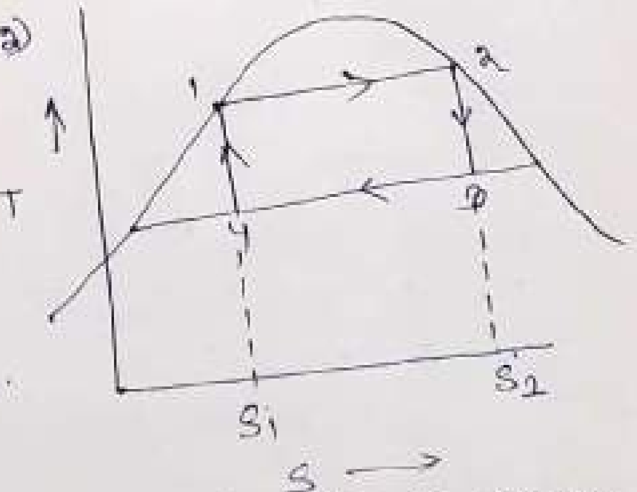
CHAPTER-5 [STEAM POWER CYCLE]

5.1 CARNOT CYCLE WITH VAPOUR.

Carnot cycle consists of 4 processes as below.
(i) Constant temp. heat addition (Expansion)
(ii) Isentropic expansion.
(iii) Constant temp. heat rejection (Compression)
(iv) Isentropic compression.

All the above processes can be assumed to be carried out in a thermal power plant where steam is the working substance.





Constant temp heat addition (1→2)

Heat is added in the boiler at boiler pressure from saturated liquid condition to the dry saturation stage.
So, total heat added
$= h_2 - h_1 = h_{g_2} - h_{f_1} = h_{fg}$.

Isentropic Expansion

The dry steam gets expanded in steam engine or turbine to condition 3 (wet steam at condenser pr.)
As no heat is supplied or rejected during this process the expansion is assumed isentropic. So treated as isentropic. But actually this process is polytropic process - (2→3)

Constant temp. heat rejection. $(h_3 - h_4)$

(3→4). The wet steam at point 3 rejects heat to cooling water in condenser at constant saturation temp. corresponding to condenser pressure upto point 4 (wet).

Isentropic compression (4→1)

The wet steam at point 4 is compressed isentropically in a compressor till it returns back to original state-1.

5.2

Total heat absorbed during the cycle $= h_2 - h_1 = h_g - h_f$

$= T_1 (s_2 - s_1)$.

Total heat rejected $= h_3 - h_4 =$

$= T_2 (s_3 - s_4)$

Workdone during the cycle = Heat absorbed — Heat rejected

$= T_1 (s_2 - s_1) - T_2 (s_3 - s_4)$

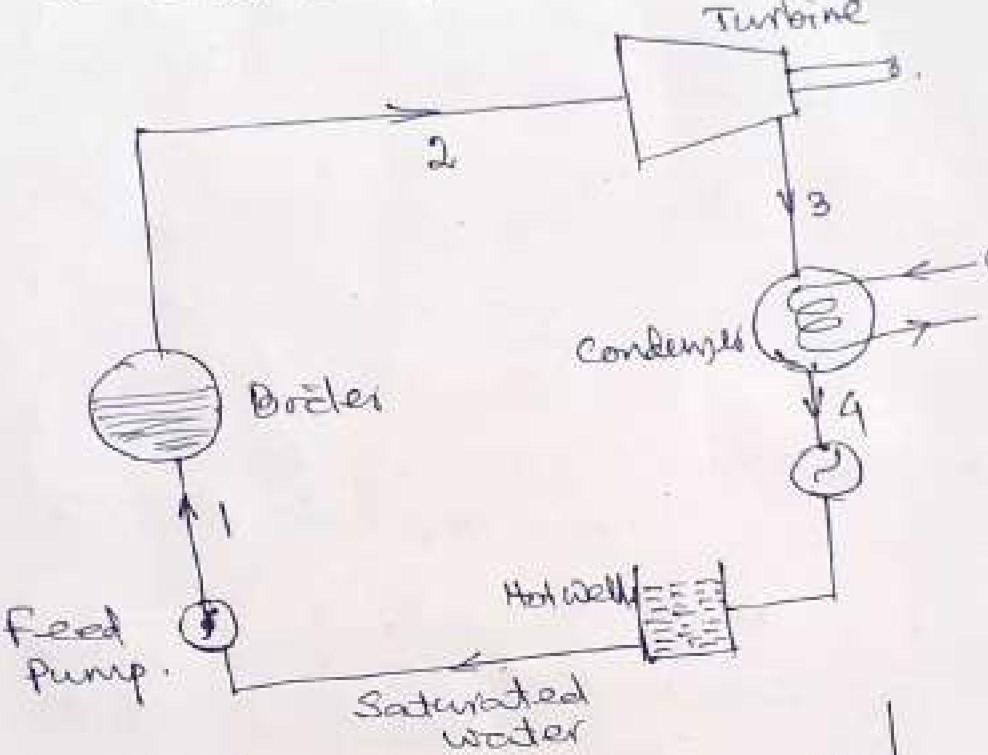
As $(s_2 - s_1) = (s_3 - s_4)$ $\quad = (s_2 - s_1)(T_1 - T_2)$

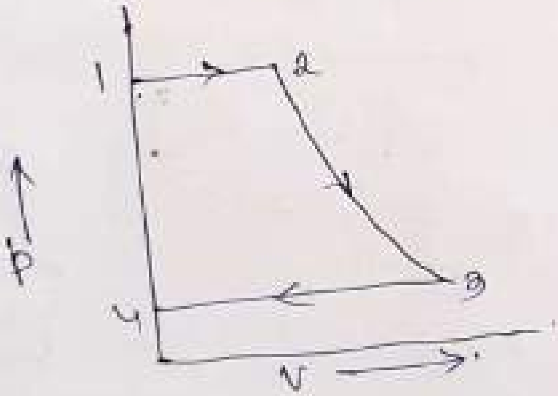
$$\eta_{carnot} = \frac{\text{Workdone}}{\text{Heat absorbed}} = \frac{(s_2 - s_1)(T_1 - T_2)}{T_1 (s_2 - s_1)} = \frac{T_1 - T_2}{T_1}$$

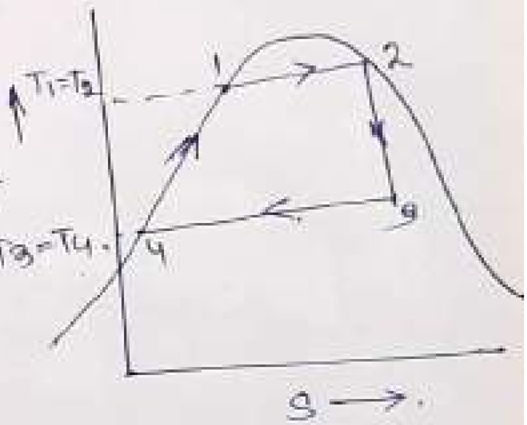
As ideal conditions can not be achieved, it is impossible to think of Carnot cycle operating on vapour. However, this cycle will give us maximum efficiency but can not be taken as a standard cycle for operation of all vapour cycles.

5.3 RANKINE CYCLE

5.3.1. This cycle is an ideal cycle for comparing the performance of steam plants. It is the modified form of the Carnot cycle where two isothermal processes are replaced by two const. pressure processes (i.e. boiler pressure & condenser pressure).







Process 1-2

Heat addition at constant boiler pressure.

$$(h_2 - h_1) = h_{fg} = h_{g_2} - h_{f_1}$$

Process 2-3.

Expansion of steam at constant entropy. pressure decreases from boiler pressure to condenser pressure. final condition of steam is wet at low condenser pressure.

Process 3-4

Heat rejection to the cooling water in condenser (constant Pressure device). The ultimate condition is saturated water at condenser pressure.

Heat rejected = $x\, h_{fg_3}$

Process 4-1

Compression of saturation water (pumping) from condenser pressure to boiler pressure.

Let $h_{f_1} = h_{f_2}$ = Enthalpy of water at point 1 corresponding to boiler pressure

$h_{f_3} - h_{f_4}$ = Enthalpy of water at point 4 corresponding to condenser pressure

5.3.2

Heat absorbed during warming operation or pump work

$= h_{f_1} - h_{f_4} = h_{f_2} - h_{f_3} = W_p$.

Heat absorbed during the cycle

= Heat absorbed during process (1-2) + Heat absorbed during warming operation

$= h_{fg_2} + W_p = h_{fg_2} + h_{f_2} - h_{f_3}$

$= \boxed{h_2 - h_{f_3}}$

Heat rejected during the cycle.

$= h_3 - h_{f_4}$

$= h_{f_3} + x_3 h_{fg_3} - h_{f_4} = \boxed{x_3 \cdot h_{fg_3}}$

So, Workdone during the cycle

= Heat absorbed − Heat rejected

$= (h_2 - h_{f_3}) - x_3 \cdot h_{fg_3}$

$= h_2 - (h_{f_3} + x_3 \cdot h_{fg_3})$

$= \boxed{h_2 - h_3}$

$$\text{Rankine efficiency} = \frac{\text{Workdone}}{\text{Heat absorbed}} = \boxed{\frac{h_2 - h_3}{h_2 - h_{f_3}}}$$

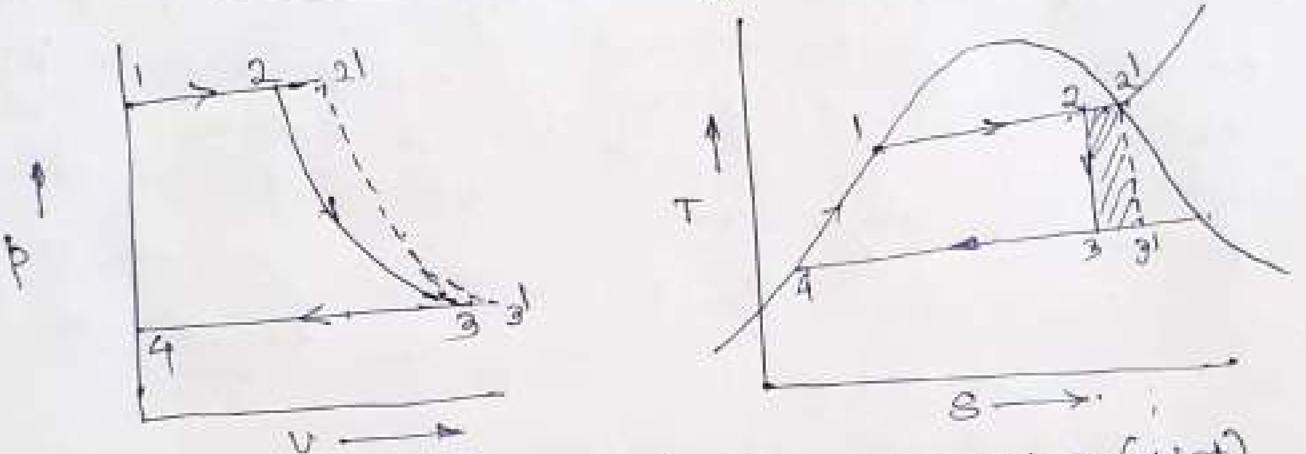
5.3.3 EFFECT OF VARIOUS END CONDITIONS ON RANKINE CYCLE

There may be two types of end Conditions that can be encountered in the rankine cycle

(i) The Condition of steam entering the turbine is wet.

(ii) The Conditions of steam entering the turbine is superheated.

1st Case: Wet steam entering turbine



If wet steam enters turbine at point 2 (wet) the condition of steam leaving turbine will be Point 3 instead of pt. 3' as shown before.

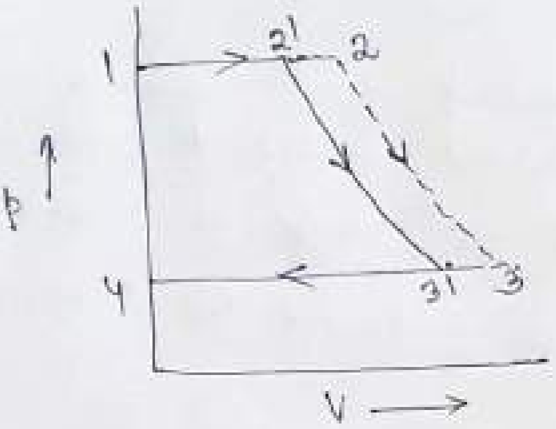
Now the workdone decreases by area 2-2'-3'-3. while amount of heat absorption also decreases from $(h_2' - h_4)$ to $(h_2 - h_4)$

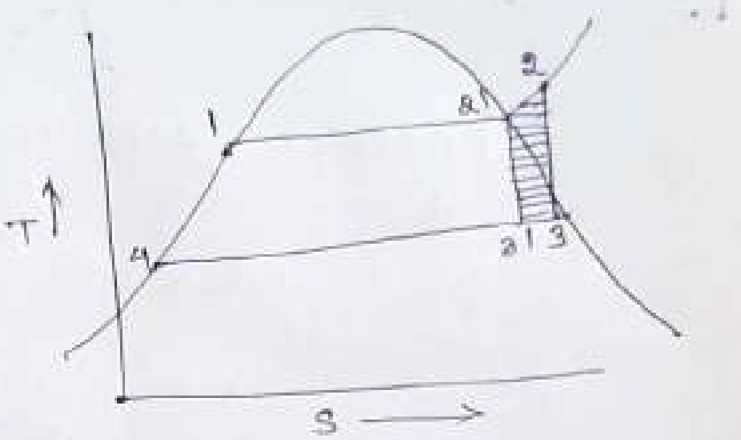
Hence, Rankine efficiency (more or less) remains same as value of workdone as well as heat absorption (both) decreases.

$$\eta_{rankine} = \frac{(h_2 - h_3)}{(h_2 - h_4)}.$$

As wet steam entering turbine contains liquid particles (water) it may cause erosion of turbine blades moving at very high speed.

2nd Case-





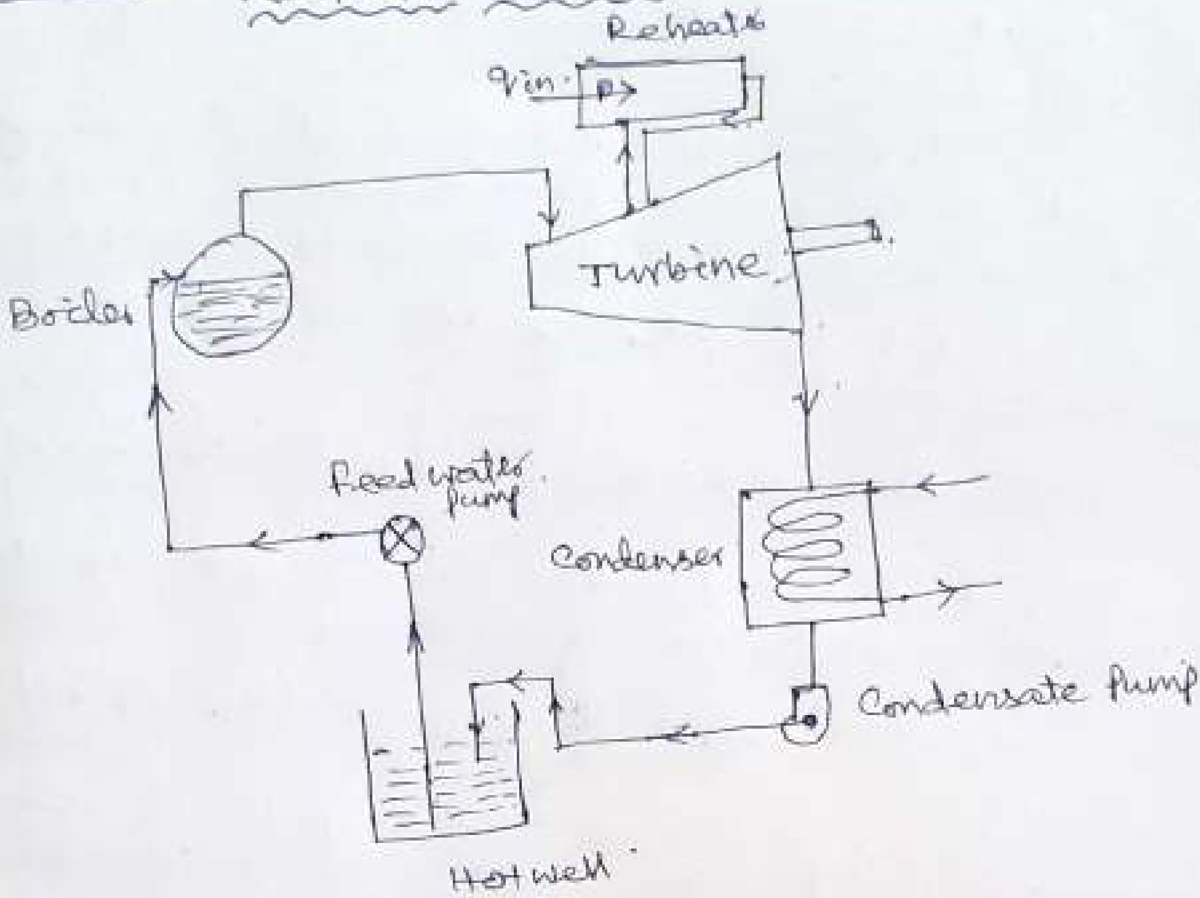
If superheated steam at condition (2) entered turbine instead of dry steam (2'), the workdone increases by Area 2-3-3'-2' while heat absorption also increases by $(h_2 - h_2')$. But due to pressure curve moving upward the workdone increases proportionately more than the heat absorption.

Therefore, Rankine efficiency will be more in comparision to that of dry steam admission to turbine.

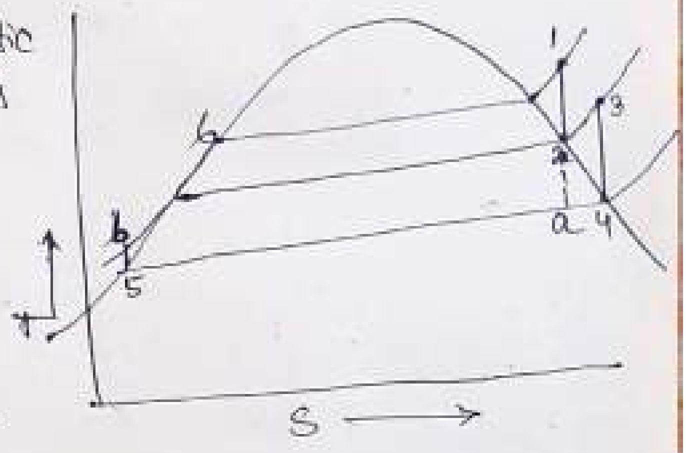
$$\eta_{Rankine} = \frac{(h_2 - h_3)}{(h_2 - h_4)}$$

Further, the expanded steam from turbine may be slightly wet as mentioned above or dry or slightly superheated to meet some technical difficulties.

5.3.4 REHEAT CYCLE



Above fig. shows the diagrammatic lay out of thermal power plant ~~with~~ for reheat cycle.



Heat is supplied to the system in the boiler represented by the process (b-6-1) on T-S diagram.

$$q_{in}\ (\text{boiler}) = (h_1 - h_b)\ \text{kJ/kg}$$

The steam from the boiler is led to the turbine where it is expanded isentropically from pressure p_1 to p_2. The work output from the system for 1st stage of expansion

$$W_1\ (\text{turbine}) = (h_1 - h_2)\ \text{kJ/kg}$$

At point 2 the steam is extracted from the turbine & led to reheater where heat is supplied and the condition of steam changed to superheated i.e. point 2 to point 3.

If reheating is not done and the steam is further expanded in the turbine as shown by process 1-2-a, the last stage of turbine will contain very wet steam.

The maxm. limit of moisture normally prescribed for the steam in the turbine blades is 10% because water particles cause blade erosion. This is avoided by adopting an intermediate reheater.

Heat added into system in reheater $= (h_3 - h_2)$ KJ/kg

The steam from reheater at condition (3) gets expanded in 2nd stage of turbine to condition 4

So Work output W_2 (turbine) $= (h_3 - h_4)$ KJ/kg

Now, steam from the turbine passes on to the Condenser where its latent heat is extracted by circulating cooling water

So, Heat removed from the system $= (h_4 - h_5)$

The saturated water at pt. 5 is extracted by condensate pump and fed to the hot well from where the water is pumped to the boiler by the feed pump.

Thus, total work input to the system

$W_p = W_p'$ (Condensate pump) $+ W_p''$ (Feed pump)

$= (h_6 - h_5)$ KJ.

Net work output $= W_1 + W_2 - W_p$

$= (h_1 - h_2) + (h_3 - h_4) - (h_6 - h_5)$

Net heat supplied $= q_{in}$ (boiler) $+ q_{in}$ (Reheater)

$= (h_1 - h_6) + (h_3 - h_2)$

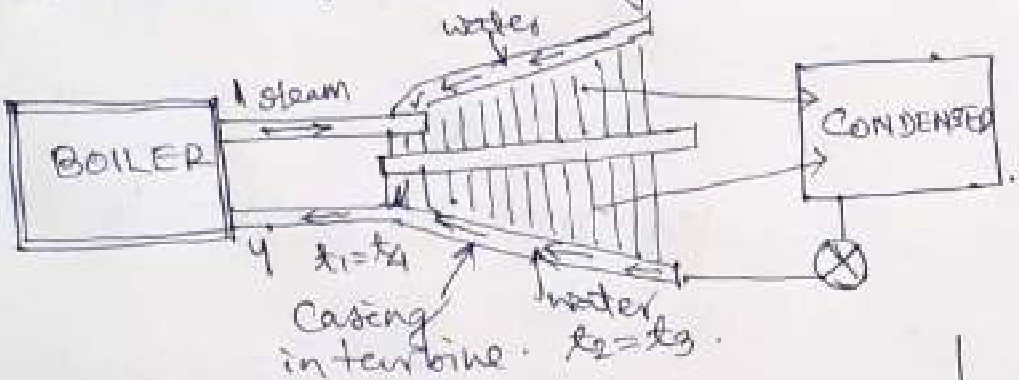
$$\eta_{reheat\ cycle} = \frac{W_{net}}{q_{in}} = \frac{(h_1 - h_2) + (h_3 - h_4) - (h_6 - h_5)}{(h_1 - h_6) + (h_3 - h_2)}$$

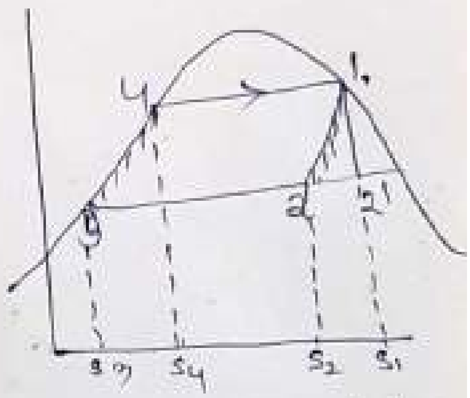
REGENERATIVE CYCLE

In the Rankine cycle, the Condensate at a fairly low temp. is pumped to the boiler, also same in Reheat cycle. Thus, there is irreversible mixing of Cold condensate with hot boiler water. This results in loss of cycle efficiency.

If methods are adopted so that the feed water from hot well is heated reversibly by interchange of heat within the System, the cycle efficiency will be improved & this method of heating is called Regenerative feed heating. & the cycle is Regenerative cycle.

Such a cycle can have theoritical limit of thermal efficiency as high as that of Carnot cycle.





Steam at Condition-1 passes to turbine & goes to the Condenser at state point 2. If the expansion would be isentropic, the process would have been 1-2'.

But in the regenerative cycle, it is assumed that, the Condensate after being pumped to boiler pressure is passed through the hollow casing surrounding the turbine rotor in opposite direction. Thus, feed water (Condensate) gradually gains heat and dry saturated which enters which enters turbine gradually looses heat.

If we imagine the temp. of water & steam to be same on both sides of the perfectly conducting partition, it is reversible heat transfer.

Thus 1 kg of water is gradually heated along the path 3-4 & 1 kg of dry steam looses same amount of heat during expansion process 1-2.

Such a heat exchange within the system is called <u>regenerative heating</u> & the cycle with this is called <u>regenerative cycle</u>.

Now, Net heat supplied to the system in the boiler during process 4-1 = q_1

$$= q_1 = T_1 (s_1 - s_4)$$

Net heat rejected from the system $= q_2 = T_2 (s_2 - s_3)$

Therefor $W_{net} = q_1 - q_2$

$$= T_1 (s_1 - s_4) - T_2 (s_2 - s_3)$$

But $(s_1 - s_4) = (s_2 - s_3)$

[As heat added to condensate along 3-4 cancelles with heat rejected along proc. 1-2 the lines 1-2 & 3-4 are parallel & 4-1 is equal to intercept 3-2] i.e.

$$\Rightarrow W_{net} = (T_1 - T_2)(s_1 - s_4)$$

$$\eta_{regen. cycle} = \frac{W_{net}}{q_1} = \frac{(T_1 - T_2)(s_1 - s_4)}{T_1 (s_1 - s_4)} = \frac{T_1 - T_2}{T_1}$$

η approches efficiency of the Carnot cycle.

CHAPTER-6. HEAT TRANSFER

6.1 - MODES OF HEAT TRANSFER:-

Heat gets transfered from a source/region at high temperature to another source at low temp. (As per 1st law of Thermodynamics) passing through a medium.

There are 3 types of heat transfer namely (1) Conduction (2) Convection (3) Radiation.

Conduction

When heat gets transfered in a solid body from one particle to another particle in the direction of fall in temperature, it is called conduction.

Here, the particle maintains its mean position & vibrates thereby transmitting energy to adjacent particle.

Needs Medium
solid

CONVECTION

When heat gets transfered such that one particle of the body moves relative to other particles, it is called convection.

Needs Medium
Liquid / Gas

RADIATION

When heat gets transfered from a hot body to cold body moving in straight lines without affecting intervening medium, it is called Radiation.

Needs no medium

Here, heat can pass through still gaseous atmosphere or perfect vacuum

6.2:- FOURIER's LAW OF HEAT CONDUCTION

STATEMENT-

"The amount of heat flow through a body in unit time is directly proportional to the surface area of heat flow and temperature difference on the two faces of the body and inversely proportional to the thickness of the body through which it flows".

$$Q\,(\text{heat}) \propto A\ (\text{Area})$$
$$\propto dT\ (\text{Change in temp})$$
$$\propto \frac{1}{dx}\ (\text{Thickness})$$

Combining above.

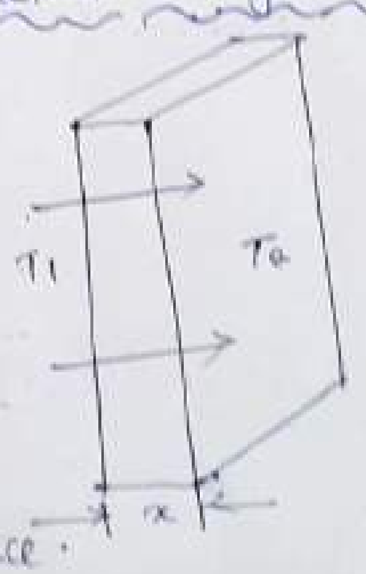
$$Q \propto A \cdot \frac{dT}{dx}$$

or,
$$\boxed{Q = K \cdot A \cdot \frac{dT}{dx}}$$

where K = Const. of proportionality
= Thermal Conductivity.

Heat transfer by conduction through a slab

Let T_1 = Temp. of Left face in K
T_2 = Temp of Right face in K
x = Thickness of the slab
A = Area of the slab
K = Thermal Conductivity
t = Time through which the heat flow has taken place.



As per Fourier's law,
$$Q = K \cdot A \cdot \frac{dT}{dx} = K \cdot A \cdot \frac{(T_1 - T_2)}{dx}$$

Now, the total amount of heat flow in time t

$$Q = \frac{KA(T_1 - T_2)t}{dx}$$

Thermal Conductivity

$$Q = \frac{KA(T_1 - T_2)t}{x}$$

If we substitute $A = 1m^2$, $(T_1 - T_2) = 1K$, $t = 1$ sec and $x = 1m$

then $Q = K$.

Thus, Thermal conductivity of a material is numerically equal to the quatity of heat which flows in one sec through a slab of the material of area $1m^2$ and thickness 1 m. when its faces differ in temperature by 1 K.

UNIT = $K = \frac{Q \cdot x}{A(T_1 - T_2)t}$ $\left[\frac{J \cdot m}{m^2 \cdot K \cdot Sec} = \frac{W}{m \cdot K} \right]$

$\frac{x}{K \cdot A}$ = Thermal Resistance.

$\frac{T_1 - T_2}{x} = \frac{dT}{dx}$ = Temperature Gradient.

6.3:- Newton's Law of Cooling

The rate of heat transfer by convection from a body to its sorrounding is directly proportional to the temperature difference and the surface area exposed.

$$Q_{convective} = h \cdot A \cdot (T - T_0) \cdot t$$

where h = Convective heat transfer Coefficient
A = Surface area (exposed) for heat transfer
T = Body temperature (Surface)
T_0 = sorrounding temperature.
t = time in sec.

UNIT - $h = \frac{Q}{A \cdot (T - T_0) \cdot t} \left[\frac{J}{m^2 \cdot K \cdot sec} = \frac{W}{m^2 \cdot K} \right]$

6.4 & 6.5 - RADIATION HEAT TRANSFER

Radiation is the energy emitted by matter in the form of electro-magnetic waves (photons) as a result of change in electronic configuration of atoms or molecules. Unlike conduction & convection, the transfer of energy by radiation requires no medium & energy transfer by radiation is fastest (same as speed of light.

STEFAN-BOLTZMAN'S LAW

The maximum rate of radiation that can be emitted from a surface at an absolute temperature depends upon its surface area & fourth power of surface temperature.

Let Q = Maxm. radiation
A = Surface area
& T_s = Surface area temp

Then $Q_{emit\,(maxm)} \propto A \cdot T_s^4$

w/ $$\boxed{Q = \sigma \cdot A \cdot T_s^4}$$

where σ = Stefan-Boltzman's Constant.
$= 5.67 \times 10^{-8}\ W/m^2 \cdot K^4$

The idealised surface that emits radiation at the maxm. rate is called a black-body ~~radiation~~ & radiation is called black body radiation.

The radiation emitted by all real surfaces is less than the radiation emitted by the blackbody at the same temperature.

$$Q_{max} = \varepsilon \cdot \sigma \cdot A \cdot T_s^4$$

where ε = emissivity of a surface.

A body receiving the radiations may absorb some of the radiation energy, reflect some of it and yet transmit some radiation energy.

Thus $Q_{(incident)} = Q_a + Q_r + Q_t$

$$\Rightarrow \frac{Q_i}{Q_i} = \frac{Q_a}{Q_i} + \frac{Q_r}{Q_i} + \frac{Q_t}{Q_i}$$

$$\Rightarrow 1 = \alpha + \beta + \nu$$

where α = absorptivity

β = reflectivity $\qquad \alpha + \beta + \gamma = 1$

γ = transmissivity.

ABSORPTIVITY:- It is the ratio of part of incident radiation absorbed by the surface to the total incident radiation. $\left(\frac{Q_a}{Q_i}\right)$

REFLECTIVITY:- It is the ratio of part of incident radiation reflected from the surface to the total incident radiation. $\left(\frac{Q_r}{Q_i}\right)$

TRANSMISSIVITY:- It is the ratio of part of incident radiation transmitted through the surface to the total incident radiation. $\left(\frac{Q_t}{Q_i}\right)$.

For solids Mostly $\alpha + \beta = 0$

Black Body $\beta = 0 \quad \gamma = 0 \quad \alpha = 1$

White body $\gamma = 0 \quad \alpha = 0 \quad \beta = 1$

Transparent body $\alpha = 0 \quad \beta = 0 \quad \gamma = 1$

Opaque body $\gamma = 0 \quad \alpha + \beta = 1$

KIRCHHOF'S LAW

The ratio of total emissive power of any body to the total emissive power of a black body is defined as emissivity or the absorptive power.

$$\frac{E}{E_b} = \epsilon = \alpha = \text{Absorptive power.}$$

MODEL TEST- 1

SEM- IV Branch- Mechanical

Th.4 Thermal Engg. - II

FULL MARK :- 80 TIME :- 3 hrs

Answer any five questions including Q. No. 1 & 2

1. Answer all questions. [2x10

(a) Define mechanical efficiency.

(b) Define specific fuel consumption.

(c) Write uses of compressed air.

(d) Define MEP.

(e) Define dryness fraction of steam.

(f) Differentiate between ~~steam~~ gas and vapour.

(g) What is draught?

(h) Represent carnot vapour power cycle in T-S & P-V diagram.

(i) What is thermal efficiency of carnot cycle.

(j) Define emissivity.

2. Answer any six questions. [5x6

(a) A gas engine has piston diameter of 200 mm and length of stroke 500 mm. Net effective pressure 5 bar. The engine makes 200 explosions per minute. Determine the mechanical efficiency of the engine, if its BP is 5 kW. Also determine piston speed of the engine.

(b) Mention 5 industrial use of compressed air.

(c) Determine the changes in properties for Isothermal nonflow process of gas.

(d) Differentiate betn firetube boiler and water tube boiler.

(e) Derive the efficiency of carnot vapour cycle.

(f) Explain various modes of heat transfer.

2) Define boiler. Classify and write various types of boiler.

3) A 4-cylinder, 2-stroke cycle petrol engine develops 30 kW at 2500 rpm. The mean effective pressure on each piston is 8 bar and mechanical efficiency is 80%. Calculate the diameter and stroke of each cylinder, if stroke to bore ratio is 1.5. Also calculate the fuel consumption of the engine, if brake thermal efficiency is 28%, calorific value of the fuel is 43900 KJ/kg. [10]

4) A two stage, single acting, reciprocating air compressor takes in air at 1 bar and 300 K. Air is discharged at 10 bar. The intermediate pressure is ideal for minimum work and perfect intercooling. The law of compression is $pv^{1.3}$ = constant. The rate of discharge is 0.1 kg/s. Calculate

(a) Power required to drive the compressor

(b) Saving in work in comparison with single-stage compression

(c) Isothermal efficiency

(d) Heat transferred in intercooler

Take R = 0.287 KJ/kgK cp = 1 KJ/kgK [10]

5) What is steam generator? Describe the various type of mounting and accessories used in boiler. [10]

6) Explain the Reheat Rankine cycle with P-V, T-S diagram. Also state the advantage of reheat cycle. [10]

7) (a) What is heat transfer? [2]

(b) Define blackbody radiation. Write notes on

(i) Emmisitivity

(ii) Absorptivity

(iii) Transmissivity

(iv) Kirchoff's law

MODEL TEST-2

SEM-IV Branch - Mechanical

Th-1 Thermal Engg - II

Full mark - 80 Time :- 3hours

Answer any FIVE questions including Qs. 1 & 2.

1) Answer All the questions. [2×10

(a) What is steam? Write its uses.

(b) Define Air-fuel ratio?

(c) Define relative efficiency of IC engine.

(d) Define free air delivered of reciprocating compressor.

(e) Define bore and stroke of reciprocating compressor.

(f) Represent the formation of steam in P-V & T-S diagram.

(g) Classify the boilers.

(h) What is boiler mounting and boiler accessories.

(i) What is the purpose of reheat in Rankine cycle.

(j) State Newton's law of cooling.

2. Answer any SIX questions. [5×6

(a) Explain various efficiencies involved in I.C. engine for the calculation of performance ~~measurement~~ parameters.

(b) ~~Ex~~ Describe the main parts of reciprocating air compressor.

(c) Explain the use of mollier chart for finding unknown properties of steam.

(d) Explain the working of Cochran boiler.

(e) A steam power plant operates on carnot cycle using dry steam at 18 bar. The exhaust takes place at 0.08 bar into condenser. The steam consumption is 20 kg/min. Calculate

(a) Power developed in the cycle

(b) efficiency of the cycle

(f) Define conduction. State the law governing this process with assumption ~~considered~~ considered.

(g) Determine the changes in properties for adiabatic process of gas.

3) In a test of a single cylinder, 4-stroke diesel engine, Indicated power = 30 kW, Brake power = 26 kW, Engine speed = 1000 rpm, BSFC = 0.35 kg/kWh, CV of fuel used = 43900 KJ/kg, calculate

(a) Indicated thermal efficiency

(b) Brake thermal efficiency

(c) mechanical efficiency

(d) specific fuel consumption

4) Stroke and bore of the cylinder of a single acting single stage reciprocating compressor are 250 mm and 150 mm respectively. Pressure and temperature at entry to compressor are 1 bar and 27°C respectively. If compressor runs at 100 RPM. Determine I.P. required to operate the compressor. Assume that compression follows the law $pv^{1.25} = C$ & pressure ratio as 10. Also calculate isothermal efficiency of cycle.

5) (a) Steam is being generated in a boiler under a pressure of 12 bar. Find the enthalpy and entropy of 5 kg of steam, when

(i) steam is wet having dryness fraction of 0.85

(ii) steam is superheated with temperature of 200°C. [5

(b) A quantity of gas has a volume of 0.5 m^3 pressure of 2 bar and temp^{r} of 200°C. If the gas is compressed isentropically until its volume becomes 0.1 m^3, find the

(i) temp^{r} at the end of compression

(ii) Work done

Assume $C_p = 1.005$ KJ/kgK, $C_v = 0.712$ KJ/kgK,

$R = 285$ J/kgK [5

6) Explain the regenerative cycle with P-V, T-S diagram. [10

7) Describe the parts and working principle of Babcock & Wilcox boiler. or what is boiler draught. Explain various methods [10

Properties of fluid

Dt-18.12.19

Chapter-1

Specific gravity = $\frac{\text{Density}}{\text{Specific gravity}} \times 100$

water = 1
Mercury = 13.6

Pressure in a liquid

$P = \rho g h$

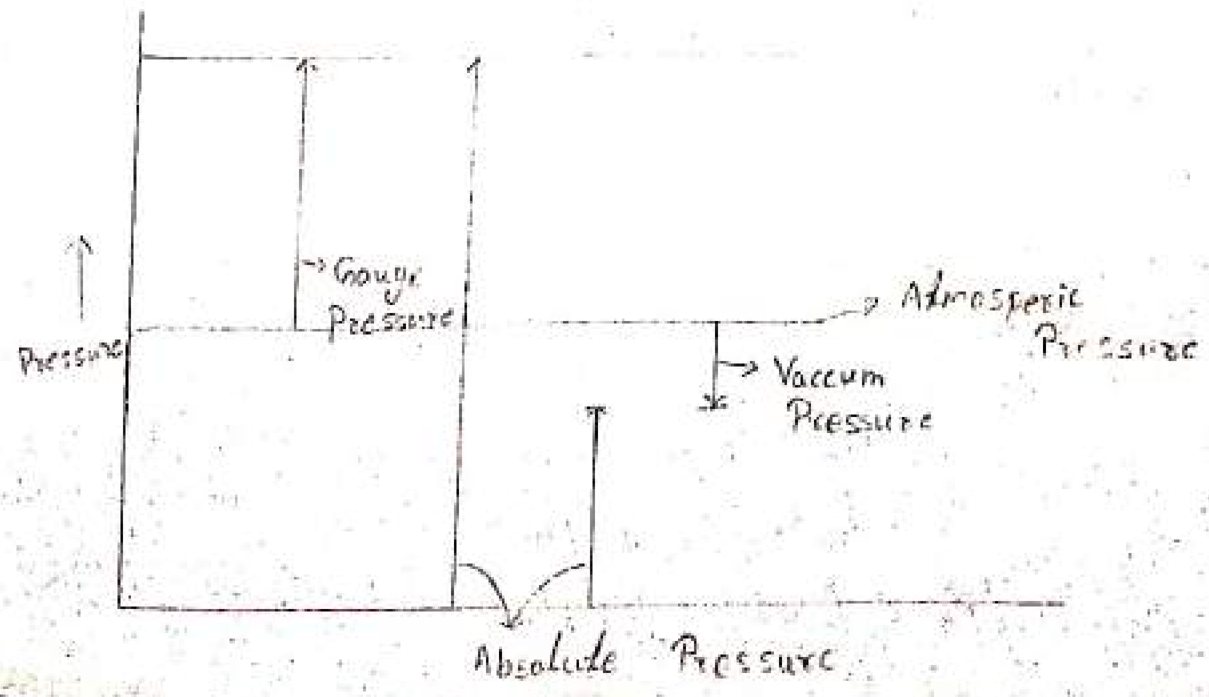
specific weight = $\frac{\text{weight}}{\text{unit volum}} = N/m^3$

Manometer

Dt 20.12.19

Simple manometer
- Piezometer
- simple U-tube manometer
- single coloumn manometer

Differential manometer
- Differential U-tube manometer
- Inverted U-tube manometer



$P_{abs} = P_{atm} + P_{gauge}$

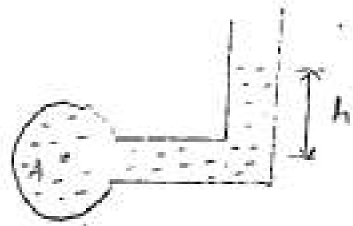
$P_{abs} = P_{atm} - P_{vaccume}$

(i) Piezometer

Dt - 23.12.2019

It is the simplest form of manometer it consist of a glass tube where one end is connected to the point where the pressure is to the measure and other end remain open to the atmospere

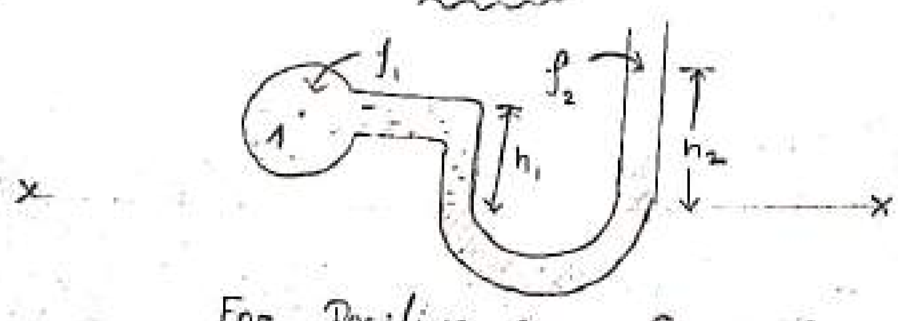
$$\boxed{P_A = \rho g h}$$



(ii) Simplest U-tube Manometer

It consist of a glass tube bend in U-shape here one end is connected to a point where the pressure is to be measured and other end remain open to the atmosphere in this type of manometer we can measured the pressure by balancing the two column of manometer. we take a liquid having specific gravity greater then the given liquid.

Case - 1

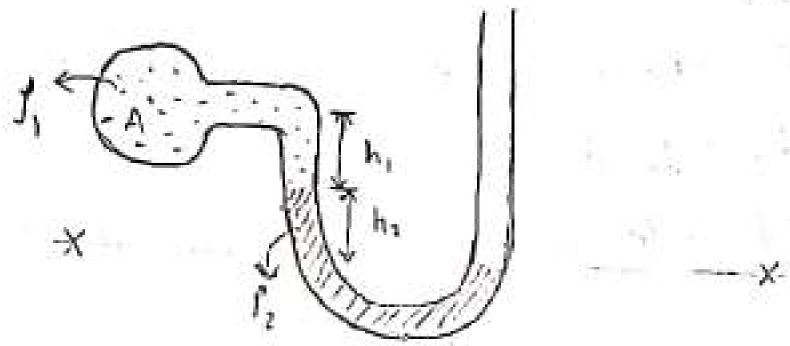


For Positive Gauge Pressure

$$P_A + \rho_1 g h_1 = \rho_2 g h_2$$

$$\Rightarrow P_A = \rho_2 g h_2 - \rho_1 g h_1$$

Case - 2



For Vacuum Pressure

$$P_A + \rho_1 g h_1 + \rho_2 g h_2 = 0$$

$$P_A = -(\rho_1 g h_1 + \rho_2 g h_2)$$

Let ρ_1 = density of the liquid whose pressure is to be measured

ρ_2 = density of heavy liquid

h_1 = rise of liquid in left limb

Case - 1

For gauge pressure

Total left side pressure is equal to

$P_A + \rho_1 g h_1$

Total right side pressure is equal to

$\rho_2 g h_2$

For free surface pressure is same at all the point so, left side pressure must be equal to right side pressure

$$P_A + \rho_1 g h_1 = \rho_2 g h_2$$

Case - II

For Vaccume Pressure

Total left side pressure is equal to

$P_A + \rho_1 g h_1 + \rho_2 g h_2$

Total right side pressure is equal to

0

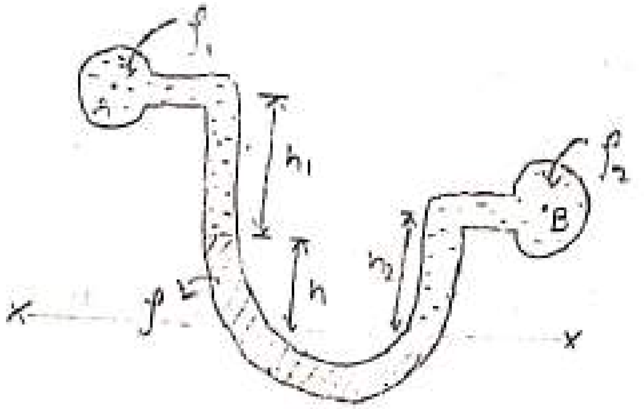
For free surface pressure is same at all the points. So, left side pressure must be equal with right side pressure.

$P_A + \rho_1 g h_1 + \rho_2 g h_2 = 0$

Dt - 07.01.2020

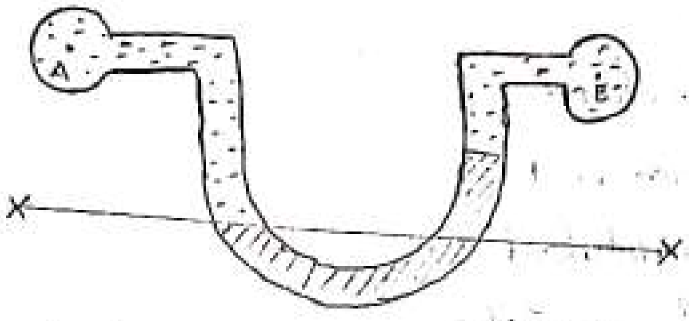
Differential U-tube manometer

It consist, it is used measure the difference of pressure in two points in a single pipe or in two different pipes.



$$P_A + \rho_1 g h_1 + \rho g h = P_B + \rho_2 g h_2$$

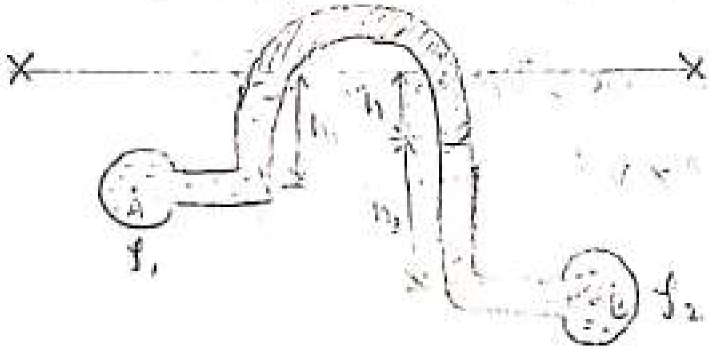
$$P_A - P_B = \rho_2 g h_2 - (\rho_1 g h_1 + \rho g h)$$



$$P_A + \rho_1 g h_1 = P_B + \rho_2 g h_2 + \rho g h$$

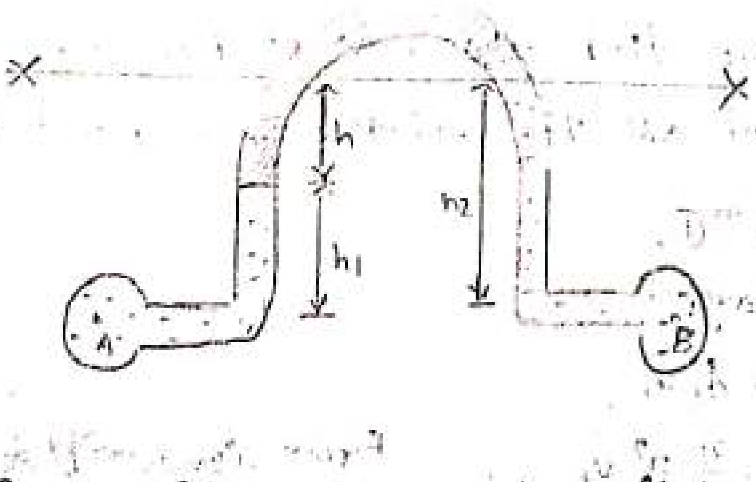
$$P_A - P_B = (\rho_2 g h_2 + \rho g h) - (\rho_1 g h_1)$$

Inverted U-tube manometer



$$P_A - \rho_1 g h_1 = P_B - \rho_2 g h_2 - \rho g h$$

$$P_A + P_B = \rho_1 g h_1 - (\rho_2 g h_2 + \rho g h)$$



$$P_A - \rho_1 g h_1 - \rho g h = P_B - \rho_2 g h_2$$

$$P_A + P_B = (\rho_1 g h_1 + \rho g h) - \rho_2 g h_2$$

Dt 10.01.2020

Types of Flow

① steady and unsteady
② Uniform and non uniform
③ Laminar and Turbulent
④ Rotational and Irrotational
⑤ Compressible and Incompressible
⑥ One, two and three dimentional

* All liquids are incompressible (ρ = const)
All gases are compressible ($\rho \neq$ const)

Rate of flow or Discharge (Q)

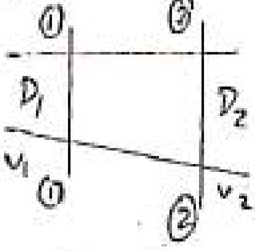
$$\boxed{Q = A \times V} \quad m^2\, m/s = \frac{m^3}{s}$$

$$\frac{m^3}{s} = 10^3 \times \frac{lit}{s}$$

It is the product of area and velocity. It is also known as volume rate of flow.

Continuity equation.

It state that the rate of flow or discharge is same at all the points. In a fluid flow



At sec^n ①,
Discharge

$Q_1 = A_1 V_1$

$= \frac{\pi}{4} D_1^2 v_1$

$Q_2 = A_2 V_2$

$= \frac{\pi}{4} D_2^2 V_2$

From continuity eq^n

$Q_1 = Q_2$

$$\boxed{A_1 V_1 = A_2 V_2}$$

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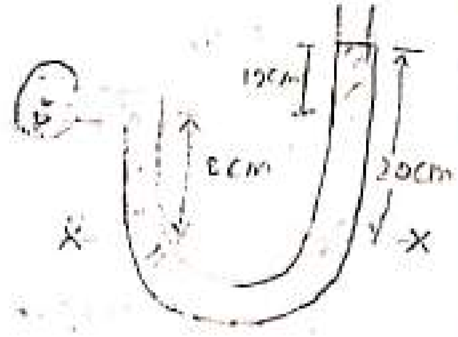
Q. The right limb of a simple U-tube manometer containing mercury is open to the atmosphere while the left limb is connected to a pipe in which a fluid of specific gravity is 0.9 is flowing. The center of the pipe is 12 cm below the level of mercury in the right limb. Find the pressure of fluid in the pipe if the difference of the mercury level in the two limbs is 20cm

Given



specific gravity$_1$ = 0.9

$\rho_1 = 0.9 \times 1000 = 900\ kg/m^3$

$h_1 = 8cm = 0.08\ m$

specific gravity$_2$ = 13.6

$\rho_2 = 13600\ kg/m^3$

$h_2 = 20\ cm = 0.2\ m$

$P + \rho_1 g h_1 = \rho_2 g h_2$

$P = \rho_2 g h_2 - \rho_1 g h_1$

$= (13600 \times 9.81 \times 0.2) - (900 \times 9.81 \times 0.08)$

$= 26683.2 - 706.32$

$= 25976.88$

$= 25977\ N/m^2$

Q A simple U-tube manometer containing mercury is connected to a pipe in which a fluid of sp. g = 0.8 and having vacuum pressure is flowing. The other end of the manometer is open to atmosper. Find the vacuum pressure in pipe. If the diffrance of mercury level in the two limb is 40 cm and the hight of fluid in the left from the center of pipe is 15 cm below.

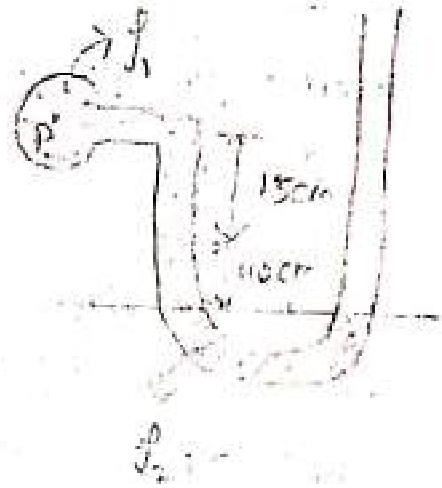
Given

$\rho_1 = 800\ kg/m^3$

$h_1 = 0.15\ m$

$\rho_2 = 13600 kg/m^3$

$h_2 = 0.4\ m$



$$P + \rho_1 g h_1 + \rho_2 g h_2 = 0$$

$$P = -[(800 \times 9.81 \times 0.15) + (13600 \times 9.81 \times 0.4)]$$

$$= -54543.6\ N/m^2$$

$$= -54544\ N/m^2$$

Dt 13.01.2020

Energies in a fluid flow (head):

① Pressure energy / head $\left(\frac{P}{\rho g}\right)$

② Kinetic / velocity energy / head

$$v = \sqrt{2gh} \Rightarrow v^2 = 2gh \Rightarrow \boxed{h = \frac{v^2}{2g}}$$

③ Datum / potential energy (z)

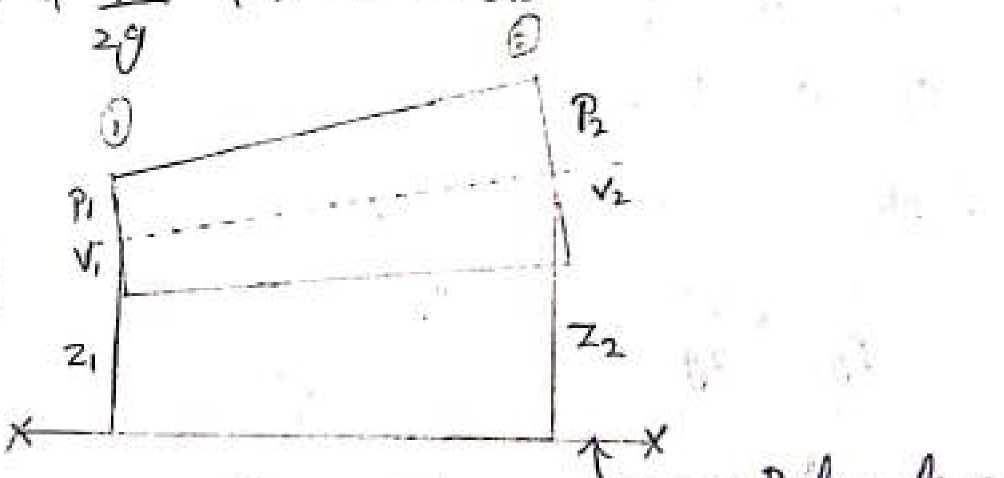
$$\text{Total energy} = \frac{P}{\rho g} + \frac{v^2}{2g} + z$$

Bernoulli's Theorm

It state that the total energy is same at all the points in a fluid flow.

$$\frac{P}{\rho g} + \frac{v^2}{2g} + z = \text{const}$$

Total energy at sec^n ①



$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

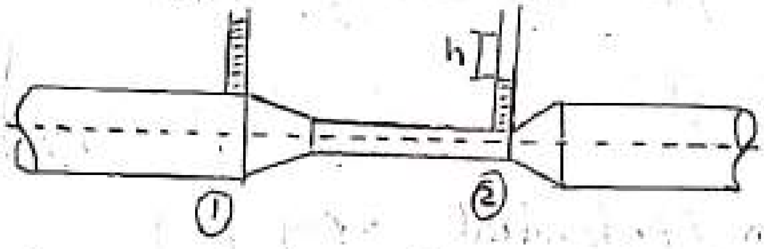
Practical application of Bernoulli's equation

① Venturimeter ② Orificemeter

③ Pitot tube

① Venturimeter

It is a device used to measure the rate of flow in a pipe it consist of one converging end & one diverging end and a throat.



Consider two section, section ① at pipe and section ② at throat. Let

d_1 = diameter of pipe at section ①

a_1 = area of pipe at section ①

$= \frac{\pi d_1^2}{4}$

P_1 = Pressure at section ①

V_1 = Velocity at section ①

d_2, a_2, P_2, V_2 = Corresponding value at sec^n ②

Applying Bernoulli's eq^n at sec^n ①

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

As the pipe is horizontal

$Z_1 = Z_2$

So,

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g}$$

$$\frac{P_1 - P_2}{\rho g} = \frac{V_2^2 - V_1^2}{2g}$$

$$h = \frac{V_2^2 - V_1^2}{2g} \qquad \text{Let } \frac{P_1 - P_2}{\rho g} = h$$

$$2gh = V_2^2 - V_1^2 \quad \text{——— (i)}$$

Now appling continuty eq^n at sec^n ① and ②

$$a_1 V_1 = a_2 V_2$$

$$V_1 = \frac{a_2 V_2}{a_1}$$

Now putting value of V_1 in eq^n (i)

$$2gh = V_2^2 - \left(\frac{a_2 V_2}{a_1}\right)^2$$

$$2gh = V_2^2 - \frac{a_2^2 V_2^2}{a_1^2}$$

$$2gh = V_2^2 \left(1 - \frac{a_2^2}{a_1^2}\right)$$

$$2gh = V_2^2 \left(\frac{a_1^2 - a_2^2}{a_1^2}\right)$$

$$V_2^2 = 2gh \left(\frac{a_1^2}{a_1^2 - a_2^2}\right)$$

$$V_2 = \sqrt{2gh \left(\frac{a_1^2}{a_1^2 - a_2^2}\right)}$$

$$V_2 = \sqrt{2gh}\left(\frac{a_1}{\sqrt{a_1^2 - a_2^2}}\right)$$

Now discharge

$$Q = a_2 V_2$$

$$= a_2 \times \sqrt{2gh}\left(\frac{a_1}{\sqrt{a_1^2 - a_2^2}}\right)$$

$$\boxed{Q = \sqrt{2gh}\ \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}}}$$

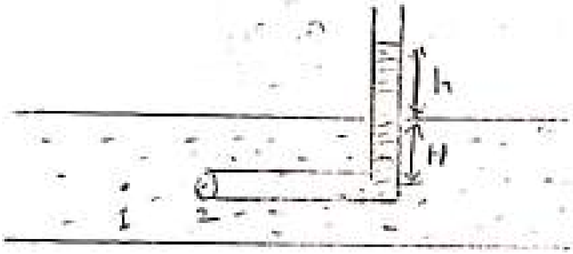
$$Q_{actul} = C_d \sqrt{2gh} \left(\frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \right)$$

where

C_d = Coeffiecent of discharge it's value is generaly taken as 0.98.

Pitot Tube

It is a device used to measure the rate of flow in a Pipe. It consist of a glass tube bend in as shown in the figure



Consider point 1 inside the pipe and point 2 just at the inlet of the pitot tube

h = Rise of liquid above the surface of pipe

H = Depth of pitot tube inside the liquid

Let

P_1 = Pressure at point one

V_1 = velocity at point one

P_2, V_2 = Corresponding value at point two

Now appling bernoulli's equation at point ① and ②

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

$$H + \frac{V_1^2}{2g} = H + h + 0$$

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$V_1^2 = 2gh$

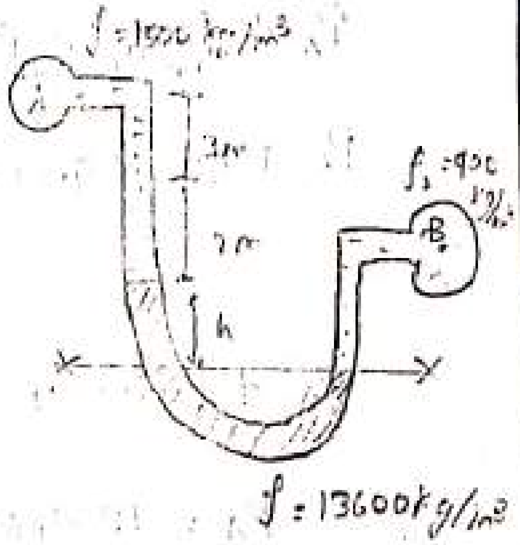
$V_1 = \sqrt{2gh}$

$V_{actual} = C_v \sqrt{2gh}$

C_v = coefficent of velocity.

Dt 14.01.2020

Q A differential manometer is connected at two point A and B of two pipes as shown in the figure the pipe A contain a liquid of specific gravity 1.5 while pipe B contain a liquid of specific gravity 0.9 the pressures at A and B are 1 kgf/cm² and 1.8 kgf/cm² find the differance in mercury level in the differential manometer



$P_A = 1 \text{ kgf/cm}^2$

$= 9.81 \times 10^4 \text{ N/m}^2$

$P_B = 1.8 \times 9.81 \times 10^4 \text{ N/m}^2$

$P_A + \rho_1 g h_1 + \rho g h = P_B + \rho_2 g h_2$

$9.81 \times 10^4 + 1500 \times 9.81 \times 5 + 13600 \times 9.81 \times h$

$= 1.8 \times 9.81 \times 10^4 + 900 \times 9.81 \times (2+h)$

$171675 + 133416h = 176580 + (8829(2+h))$

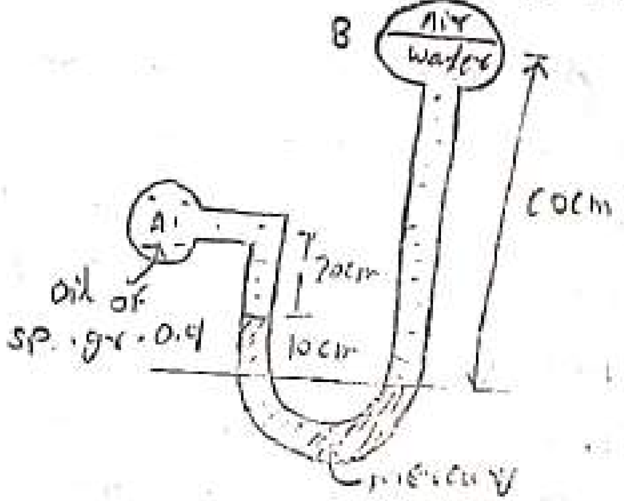
$133416h - 8829h = 176580 + 17658 - 171675$

$124587h = 22563$

$$h = \frac{22563}{124587}$$

$$= 0.18 \text{ m}$$

A differential manometer is connected at the point A and B as shown in the fig. At B air pressure is 9.81 N/cm² . Find the absolute pressure at A



$$P_A + \rho_1 g h_1 + \rho g h = P_B + \rho_2 g h_2$$

$$P_A + 900 \times 9.81 \times 0.2 + 13600 \times 9.81 \times 0.1$$

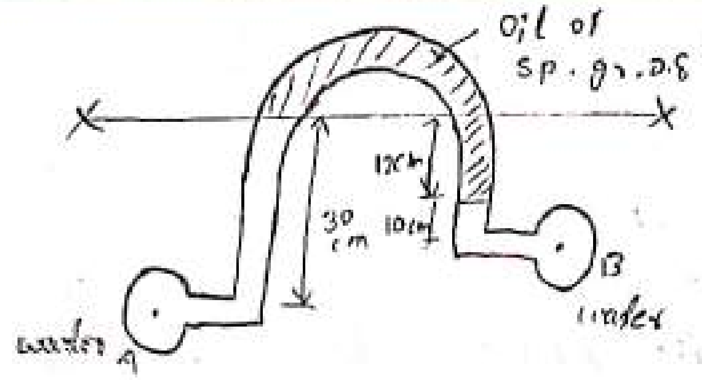
$$= 9.81 \times 10^4 + 1000 \times 9.81 \times 0.6$$

$$P_A + 15107.4 = 103986$$

$$P_A = 103986 - 15107.4$$

$$= 88878.6 \text{ N/m}^2.$$

Q water is flowing through two different pipe an inverted differential manometer having an oil of sp. gr. 0.8 is connected the pressure head in pipe A is 2m of water find the pressure in pipe B as shown in the fig.



$h = 2$

$h = \frac{P_A}{\rho g} \Rightarrow P_A = \rho g h$

$= 1000 \times 9.81 \times 2$

$= 19620 \ N/m^2$

$19620 - (1000 \times 9.81 \times 0.3) = P_B - (1000 \times 9.81 \times 0.1) - (800 \times 9.81 \times 0.12)$

$16677 = P_B - 1922.76$

$P_B = 16677 + 1922.76$

$= 18599.76 \ N/m^2$

Specific volume

It is defined as the ratio of the volume of a fluid to it's mass

$$sp.vol = \frac{\text{volume of fluid}}{\text{mass of fluid}}$$

$$= \frac{1}{\frac{\text{mass of fluid}}{\text{vol of fluid}}} = \frac{1}{\rho}$$

Viscosity

It is defined as the property of a fluid which offeres resistance to the moment of 1 layer of fluid to the adjusent layer of the fluid.

Dt:- 17.02.2020

Q The diameters of a pipe at the section 1 and 2 are 10cm and 15cm respectively. Find the discharge through the pipe if the velocity of the water flow through the pipe at section 1 is 5m/s determine also the velocity at section 2

Ans Given

$A_1 = \frac{\pi d^2}{4} = \frac{\pi \times (0.1)^2}{4} = 7.854 \times 10^{-3}$

$A_2 = \frac{\pi d^2}{4} = \frac{\pi \times (0.15)^2}{4} = 0.0176$

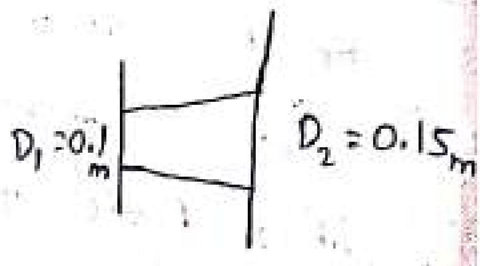
$V_1 = 5 \, m/s$

$Q = A_1 V_1$

$= 0.03927 \; m^3/s$

$Q = A_2 V_2$

$0.03927 = 0.0176 \times V_2$

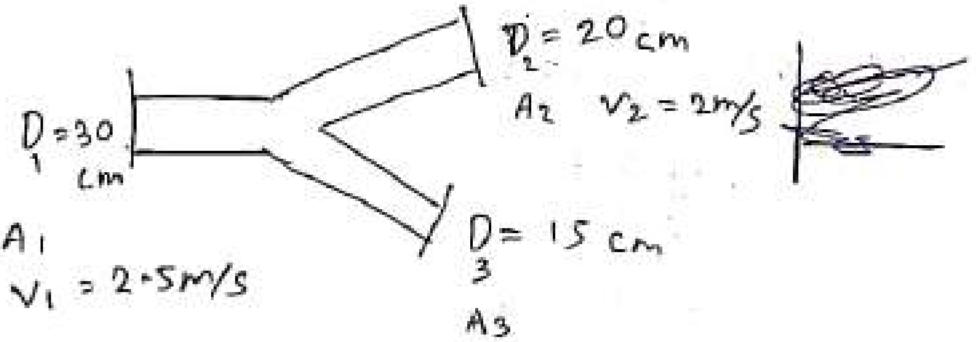


$V_2 = \frac{0.03927}{0.0176}$

$= 2.23125 \; m/s$

$= 2.23 m/s$

Q A 30 cm Diameter pipe conveying water branches into two pipe of diameter 20 cm and 15 cm respectively if the avarage velocity in 30 cm diameter pipe is 2.5 m/s find the discharge in this pipe also determine the velocity in 15 cm pipe ~~and~~ if the avarage velocity in 20 cm pipe is 2 m/s



$$A_1 = \frac{\pi d^2}{4} = \frac{\pi \times (0.3)^2}{4} = 0.0706 \text{ m}$$

$$A_2 = \frac{\pi d^2}{4} = \frac{\pi \times (0.2)^2}{4} = 0.0314 \text{ m}$$

$$A_3 = \frac{\pi d^2}{4} = \frac{\pi \times (0.15)^2}{4} = 0.0176 \text{ m}$$

$$Q_1 = A_1 V_1$$
$$= 0.0706 \times 2.5$$
$$= 0.1765 \text{ m}^3/\text{s}$$

$$Q_2 = A_2 V_2$$
$$= 0.0314 \times 2$$
$$= 0.0628 \text{ m}^3/\text{s}$$

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$Q_1 = Q_2 + A_3 V_3$

$0.1765 = 0.0628 + 0.0176 \times V_3$

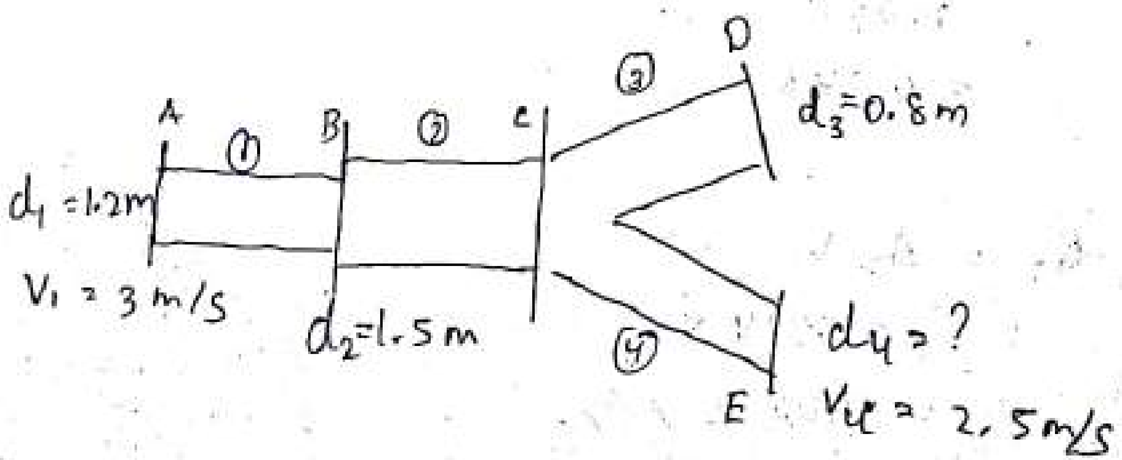
$0.0176 \times V_3 = 0.1765 - 0.0628$

$0.0176 \times V_3 = 0.1137$

$V_3 = \frac{0.1137}{0.0176}$

$= 6.46 \ m/s$

Q water flows through a pipe A B 1.2 m diameter at 3m/s and then passes through a pipe BC 1.5 m diameter at C the pipe branches. Branch CD is 0.8m in diameter and carries 1/3 of the flow in AB the flow velocity in branch CE is 2.5 m/s find the volume rate of flow in AB, the velocity in BC, the velocity in CD and diameter of 'DE'



$A_1 = \frac{\pi d^2}{4} = 1.1309\ m^2$

$A_2 = \frac{\pi d^2}{4} = 1.7671\ m^2$

$A_3 = \frac{\pi d^2}{4} = 0.5026\ m^2$

$Q_1 = A_1 V_1$

$= 3.3927\ m^3/s$

$\boxed{Q_1 = Q_2}$

$Q_2 = A_2 V_2$

$3.3927 = 1.7671 \times V_2$

$V_2 = \frac{3.3927}{1.7671}$

$= 1.9199\ m/s$

$Q_1 \times \frac{1}{3} = Q_3$

$Q_3 = \frac{3.3927}{3} = 1.1309\ m^3/s$

$Q_3 = A_3 V_3$

$1.1309 = 0.5026 \times V_3$

$V_3 = \frac{1.1309}{0.5026} = 2.25\ m/s$

$Q_2 = Q_3 + A_4 V_4$

$3.3927 = 1.1309 + A_4 \times 2.5$

$A_4 \times 2.5 = 3.3927 - 1.1304$

$A_4 = \frac{2.2618}{2.5}$

$= 0.90472 \ m^2$

$A_4 = \frac{\pi d^2}{4}$

$0.9 \times 4 = \pi d^2$

$\pi d^2 = 3.6$

$d^2 = \frac{3.6}{\pi}$

$d = \sqrt{1.1454}$

$= 1.0704 \ m$

Dt 21.01.2020

Q) water is flowing throughing a pipe of 5cm diameter under a pressure of 29.43 N/cm² and with mean velocity of 2 m/s find the total head or total energy per unit weight of water at a cross section which is 5m above the datum line

given

$P = 29.43 \ N/cm^2 = 29.43 \times 10^4 \ N/m^2$

$V = 2 \ m/s$ $\rho = 1000$

$Z = 5 \ m$

$$\frac{P}{\rho g} = \frac{29.43 \times 10^4}{1000 \times 9.81} = 30 \text{ m}$$

$$\frac{V^2}{2g} = \frac{(2)^2}{2 \times 9.81} = 0.2038 \text{ m}$$

$Z = 5$ m

Total head

$= 30 + 0.2038 + 5$

$= 35.2038$ M

Q A pipe through which water is flowing is having diameter 20cm and 10cm at the cross sections 1 and 2 respectively the velocity of water at section 1 is given 4 m/s find the velocity head at section 1 and 2 and also the rate of discharge..

$$A_1 = \frac{\pi d^2}{4} = \frac{\pi (0.2)^2}{4}$$

$= 0.0314$

$$A_2 = \frac{\pi d^2}{4} = \frac{\pi (0.1)^2}{4} = 7.8539 \times 10^{-3}$$

Scanned with CamScanner

$A_1 V_1 = A_2 V_2$

$0.0314 \times 4 = 7.853 \times 10^{-3} \times V_2$

$V_2 = \frac{0.0314 \times 4}{7.853 \times 10^{-3}}$

$= 15.99$

$= 16 \ m/s$

The rate of discharge

$Q = 0.1256 \ m^3/s$

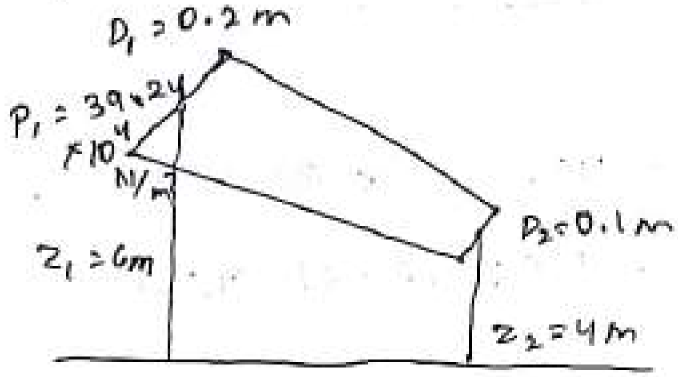
velocity head (1)

$\frac{v^2}{2g} = \frac{(4)^2}{2 \times 9.81} = 0.8015 \ m$

velocity head (2)

$\frac{v^2}{2g} = \frac{(16)^2}{2 \times 9.81} = 13.047 \ m$

Q The water is flowing through a pipe of diameters 20 cm and 10cm at section 1 and 2 respectively. The rate of flow through the pipe is 35 L/s the section 1 is 6m above the datum line and section 2 is 4m above the datum line. If the pressure at section 1 is 39.24 N/cm², find the intensity of pressure at section 2



$Q = 35\ lit/s$

$= 0.035\ m^3/s$

By appling Bernoulli's eq^n

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

By appling continuity eq^n

$Q = A_1 V_1 = A_2 V_2$

$$V_1 = \frac{Q}{A_1} = \frac{0.035}{\frac{\pi \times (0.2)^2}{4}} = 1.114\ m/s$$

$$V_2 = \frac{Q}{A_2} = \frac{0.035}{\frac{\pi \times (0.1)^2}{4}} = 4.456\ m/s$$

$$= \frac{39.24 \times 10^4}{1000 \times 9.81} + \frac{(1.114)^2}{2 \times 9.81} + 6 = 46.063$$

$$= \frac{P_2}{1000 \times 9.81} + \frac{(4.456)^2}{2 \times 9.81} + 4 = 5.012 + \frac{P_2}{9810}$$

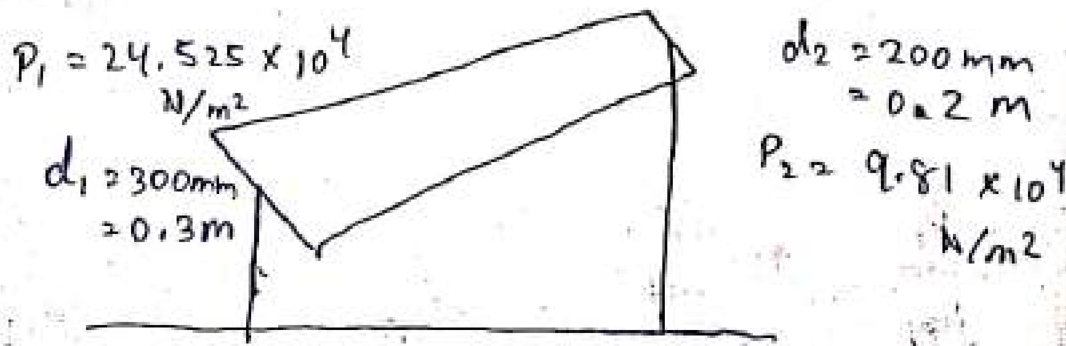
$$\frac{P_2}{9810} = 46.063 - 5.012$$

$$P_2 = 41.051 \times 9810$$

$$= 402710.31 \ N/m^2$$

$$= 40.271031 \ N/cm^2$$

Q water is flowing through a pipe having diameter 300 mm and 200 mm at the bottom and upper end respectively the intensity of pressure at the bottom end is 24.525 N/cm² and the pressure at the upper end is 9.81 N/cm² determine the difference in datum head if the rate of flow through pipe is 40 lit per sec



$$Q = 40 \ lit/s$$

$$= 0.04 \ m^3/s$$

$$V_1 = \frac{Q}{A_1}$$

$$= \frac{0.04}{\frac{\pi \times (0.3)^2}{4}} = 0.565 \text{ m/s}$$

$$V_2 = \frac{Q}{A_2}$$

$$= \frac{0.04}{\frac{\pi \times (0.2)^2}{4}} = 1.273 \text{ m/s}$$

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

$$\frac{24.525 \times 10^4}{1000 \times 9.81} + \frac{(0.565)^2}{2 \times 9.81} + z_1 = \frac{9.81 \times 10^4}{1000 \times 9.81} + \frac{(1.273)^2}{2 \times 9.81} + z_2$$

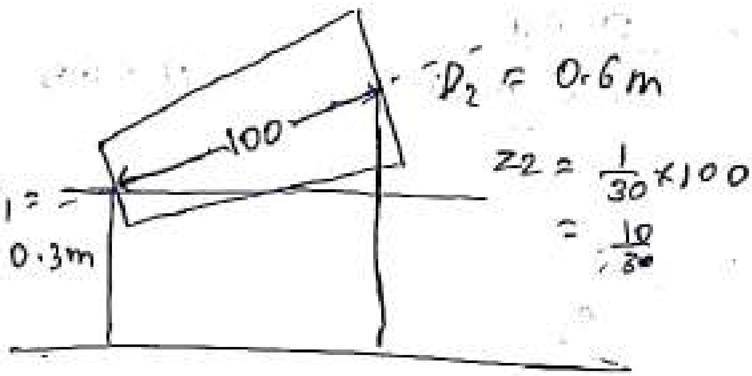
$$25.016 + z_1 = 10.082 + z_2$$

$$z_2 - z_1 = 25.016 - 10.085$$

$$= 14.931 \text{ m}$$

24.01.2020

water is flowing through a tapper pipe of length 100 m having diameters 600 mm at the upper and and 300 mm at the lower end at a rate of 50 lit/sec the pipe has a slope of 1 in 30 find the pressure at the lower end if the pressure at the higher level is 19.62 N/cm²



$Q = 0.05 m^3/s$

$P_2 = 19.62 \times 10^4$ $N m^{-2}$

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

$V_1 = \frac{Q}{A_1}$

$= \frac{0.05}{\frac{\pi (0.3)^2}{4}} = 0.7073$ N/m²

$V_2 = \frac{Q}{A_2}$

$= \frac{0.05}{\frac{\pi (0.6)^2}{4}} = 0.1768$ N/m²

$$\frac{P_1}{1000 \times 9.81} + \frac{(0.7073)^2}{2 \times 9.81} + 0$$

$$= \frac{P_1}{9810} + 0.0254$$

$$\frac{19.62 \times 10^4}{1000 \times 9.81} + \frac{(0.1768)^2}{2 \times 9.81} + \frac{10}{3}$$

$$= 23.3349$$

$$\Rightarrow \frac{P_1}{9810} = 23.3349 - 0.0254$$

$$\Rightarrow P_1 = 23.3349 - 0.0254 \times 9810$$

$$= 23.3095 \times 9810$$

$$= 228666.195$$

$$= 22.8666 \ N/cm^2$$

Value of H in Venturimeter

Case -I

If the differencial manometer contains a liquid heavier then the liquid flowing through the pipe

Let

S_h = Specific gravity of the heaver

S_o = Specific gravity of liquid flowing through the pipe

x = difference of heaver liquid column in U-tube

$$h = x\left[\frac{S_h}{S_o} - 1\right]$$

Case - II

Let S_L = Specific gravity of the light liquid

S_o = Specific gravity of liquid flowing through the pipe

x = difference of light liquid column in U-tube

$$h = x\left[1 - \frac{S_L}{S_0}\right]$$

Q A horizontal venturimeter with inlet and throat diameter 30 cm and 15 cm is used to measure the flow or water the reading of differencial manometer connected to the inlet and throat is 20 cm of mercury determine the rate of flow.

$C_d = 0.98$

$d_1 = 0.3\ m$

$d_2 = 0.15\ m$

$x = 0.2\ m$

$S_h = 13.6$

$S_0 = 1$

$$h = x\left[\frac{S_h}{S_0} - 1\right]$$

$$= 0.2\left[\frac{13.6}{1} - 1\right]$$

$$= 2.52\ m$$

$$Q_{act} = C_d \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$$

$$a_1 = \frac{\pi d_1^2}{4} = 0.0706\ m^2$$

$$a_2 = \frac{\pi d_2^2}{4} = 0.0176\ m^2$$

$$Q_{act} = 0.98 \frac{(0.0706)(0.0176)}{\sqrt{(0.0706)^2 - (0.0176)^2}} \sqrt{2 \times 9.81 \times 252}$$

$$= 0.1252 \; m^3/s$$

Q an oil of sp. gr = 0.8 is flowing through a venturi meter having a inlet diameter 20cm d_2 = 10 cm the oil mercury manometer shows a reading of 25 cm . calculate the discharge of oil through the horizontal venturimeter

$S_h = 13.6$

$S_o = 0.8$

$x = 0.25$

$d_1 = 0.20$

$d_2 = 0.1$

$$a_1 = \frac{\pi d_1^2}{4} = \frac{\pi \times (0.2)^2}{4} = 0.0314$$

$$a_2 = \frac{\pi d_2^2}{4} = \frac{\pi \times (0.1)^2}{4} = 7.85 \times 10^{-3}$$

$$h = x \left[\frac{S_h}{S_o} - 1\right]$$

$$= 0.25 \left[\frac{13.6}{0.8} - 1\right]$$

$$= 4$$

$$Q_{act} = 0.98 \times \frac{(0.0314)(7.85\times10^{-3})}{\sqrt{(0.0314)^2 - (7.85\times10^{-3})^2}} \times \sqrt{2\times9.81\times4}$$

$$= 0.0703 \ m^3/s$$

Dt 01.02.2020

Q A pitot static tube placed in the centre of 300mm pipe line has one oriphise pointing up strem and other ter to it the mean velocity in the pipe is 0.8 of the central velocity find the discharge through the pipe if the pressure diffrence between the two orifise is 60 mm of water take Cv = 0.98

Given

$d = 0.3m$ $C_v = 0.98$

$h = 0.06m$

$\bar{V} = 0.8 \times V$

$$V = C_v\sqrt{2gh}$$

$$V = 0.98\sqrt{2\times9.81\times0.06}$$

$$= 1.063 \ m/s$$

$$\bar{V} = 0.8\times V$$

$$= 0.8\times1.063$$

$$= 0.850 \ m/s$$

~~Ans~~

$Q = A\bar{V}$

$= \frac{\pi}{4} d^2 \times 0.850$

$= 0.07 \times 0.850$

$= 0.0595 \ m^3/s$

Q find the velocity of the flow of an oil through a pipe when the difference in mercury level in a differential manometer connected to the two tappings of the pitot tube is 100 mm taken Cv = 0.98 and specific gravity of oil is 0.8

Given

$x = 0.1 m$

$C_v = 0.98$

$S_h = 13.6$, $S_o = 0.8$

$h = x \left[\frac{S_h}{S_o} - 1 \right]$

$\boxed{h = 1.6} \ m$

$V = C_v \sqrt{2gh}$

$= 0.98 \times \sqrt{2 \times 9.81 \times 1.6}$

$= 5.4907 \ m/s$

Q A pitor tube is inserted in a pipe of 300mm diameter the static pressure in the pipe is 100mm of mercury (vacuum) the stagnation pressure at the center of the pipe recorded by the pitot tube is 0.981 N/cm² calculate the rate of flow of water through pipe if the mean velocity of flow is 0.85 times the central velocity taken Cv = 0.98

Given

$d = 300\ mm$

static pressure head $= -100$ mm of Hg

$= -0.1$ m of Hg

$= -0.1 \times 13.6$ m of water

$= -1.36$ m of water

stagnation pressure $= 0.981 \times 10^4\ N/m^2$

stagnation pressure head $= \frac{0.981 \times 10^4}{1000 \times 9.81} = 1\ m$

$h = 1 + 1.36$

$= 2.36\ m$

$\bar{V} = 0.85 \times V$

$= 5.6678\ m/s$

$V = C_v \sqrt{2gh}$

$= 0.98 \times \sqrt{2 \times 9.81 \times 2.36}$

$= 6.668\ m/s$

$Q = A \times \bar{V} = 0.0706 \times 5.6678$

= [illegible] $= 0.4\ m^3/s$

[illegible]

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Hydrostatics

Total pressure

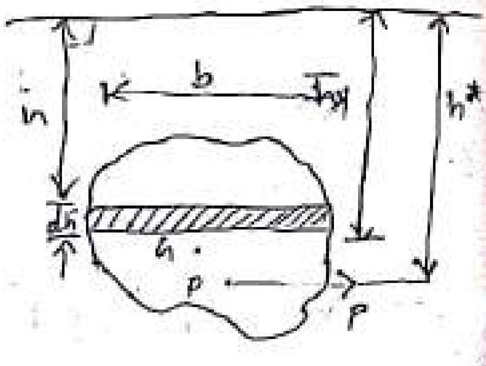
It is defined as the force exerted by a static fluid on a surface either plane or curved when the fluid comes in contact with the surface. This force always act normal to the surface.

Center of pressure

It is defined as the point of application of the total pressure on the surface

→ vertical plane surface submerged in a liquid

Consider a plane vertical surface of arbitrary shape immersed in a liquid



Let

A = total area of the surface

$\bar{h}$ = distance of G of the area from free surface of liquid

G = center of gravity of the plane surface

P = center of pressure

h^* = distance of center of pressure from the free surface of liquid.

Total pressure (P)

consider a strip of thickness 'dh' and width 'b' at a depth of 'h' from the free surface of liquid

pressure intensity on the strip

$$p = \rho g h$$

Area of the strip

$$dA = b \times dh.$$

Total pressure force on strip

$$dF = p \times dA$$
$$= \rho g h \times b \times dh$$

Integrating both side

$$F = \int dF$$
$$= \int \rho g h \times b \times dh$$
$$= \rho g \int b \times h \times dh$$

we know that

$$\int b \times h \times dh = \int h \times dA$$

= moment of the strip from the free surface

Total moment of the body from free surface

$$= \int h \times dA$$
$$= A\bar{h}$$

$$F = \rho g A \bar{h}$$

Dt 7.02.2020

Center of Pressure (h^*)

It is calculated by using the principle of moments. which state that the moment of the resultant force about an axis is equal to the sum of moments of the components about the same axis

moment of force dF acting on a strip about free surface of liquid

$= dF \times h$

$= \rho g h \times b \times dh \times h$

Sum of moments of all such forces about free surface of liquid

$$= \int \rho g h \times b \times d \times h$$

$$= \rho g \int b h . dh . h$$

$$= \rho g \int b h^2 dh$$

$$= \rho g \int h^2 dA$$

⇒ I_0 = moment of inertia of the surface about free surface of liquid

Sum of moment about free surface

$= \rho g I_o$

The moment of force F about free surface

$= F \times h^*$

According to principle of moments:

$\rho g I_o = F \times h^*$

$\Rightarrow \rho g A\bar{h} \times h^* = \rho g I_o$

$\Rightarrow h^* = \frac{\rho g I_o}{\rho g A\bar{h}}$

$$\boxed{h^* = \frac{I_o}{A\bar{h}}}$$

According to parallel axis theorem:

$I_o = I_a + A\bar{h}^2$

$h^* = \frac{I_o}{A\bar{h}}$

$= \frac{I_a + A\bar{h}^2}{A\bar{h}}$

$$\boxed{h^* = \frac{I_a}{A\bar{h}} + \bar{h}}$$

Rectangle

moment of inertia about base $\frac{bd^3}{3}$

moment of inertia about an axis passing through CG and parallel to base $\frac{bd^3}{12}$

Triangle

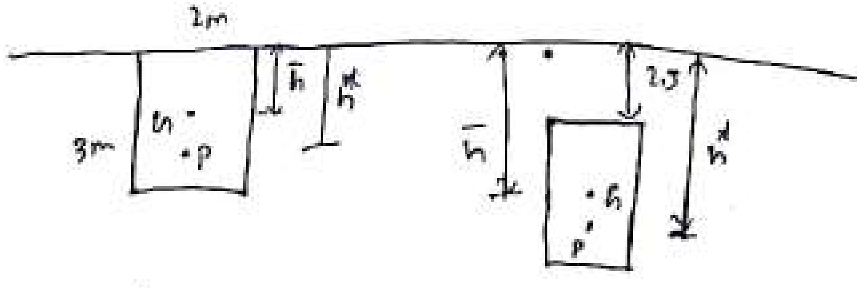
About base $= \frac{bh^3}{12}$

About Cg $= \frac{bh^3}{36}$

Circle $= \frac{\pi d^4}{64}$

Q A rectangular plain surface is 2m wide and 3 m depth it lies in vertical plan in water determine the total pressure and position of center of pressure on the plain surface when it upper edge is horizontal and ① coincides with water surface
② 2.5 m below the free water surface.

$\bar{h}$ = Distance of Cg from free surface



Case I   Case II

Case I   coincides with water surface

$F = \rho g A \bar{h}$

$= 1000 \times 9.81 \times 2 \times 3 \times 1.5$

$= 88290$ N

Case II

$$h^* = \frac{I_G}{A\bar{h}} + \bar{h}$$

$$F = \rho g A \bar{h}$$

$$= 1000 \times 9.81 \times 6 \times 4$$

$$= 235440 \text{ N}$$

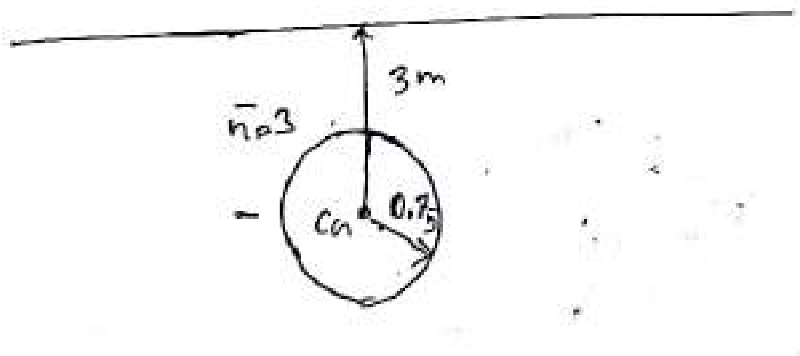
$$I_G = \frac{bd^3}{12}$$

$$= \frac{2 \times (3)^3}{12} = 4.5 \ m^4$$

$$h^* = \frac{4.5}{6 \times 4} + 4$$

$$h^* = 4.1875 \ m$$

Q Determine the total pressure on a circular plate of diameter 1.5 m which is placed vertically in water in such a way that the center of the plate is 3 m below the free surface of water find the position of center of pressure also



$$F = \rho g A \bar{h}$$

$$= 1000 \times 9.81 \times \frac{\pi}{4} d^2 \times 3$$

$$= 52007.102 \text{ N}$$

$$h^* = \frac{I_G}{A\bar{h}} + \bar{h}$$

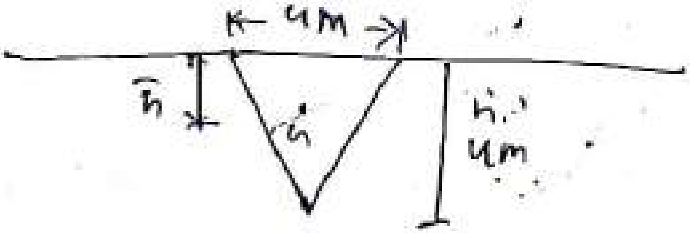
$$I_G = \frac{\pi d^4}{64}$$

$$= 0.2485 \ m^4$$

$$h^* = \frac{0.2485}{1.7671 \times 3} + 3$$

$$= 3.0468 \ m$$

Q Determine the total pressure and center of pressure on an isoscale triangle plate of base 4m and altitude 4m when it is immersed vertically on an oil of specific gravity 0.9 the base of the plate coinsides with the free surface of the oil



$$\bar{h} = \frac{h}{3} = \frac{4}{3} = 1.33 \ m$$

$F = \rho g A \bar{h}$

$= 0.9 \times 10^3 \times 9.81 \times \frac{1}{2} b \times h \times 1.33$

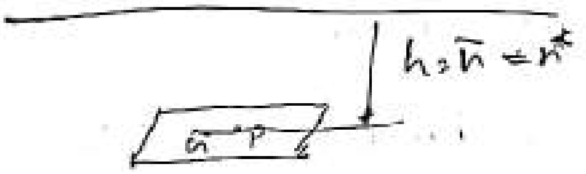
$= 93940.56$ N

$h^* = \frac{I_G}{A \bar{h}} + \bar{h}$

$I_G = \frac{bh^3}{36} = 7.11 \ m^4$

$h^* = \frac{7.11}{8 \times 1.33} + 1.33$

$= 1.998$ m



$F = \rho g A \bar{h}$

Dt 14.02.2020

Orifices and mouth piece

vena - contracta :

Orifices :

It is a small opening of any cross section (circular, triangular, rectangular, etc.) on the side or on the bottom of a tank through which a fluid is flowing.

mouth piece

It is a short length of a pipe which is two or three times of diameter in length fitted in a tank or vessel containg the fluid.

Classification of orifice

① Small orifice and large orifice

② circular , triangular or rectangular , etc

③ sharp edged orifice

bell mouth orifice

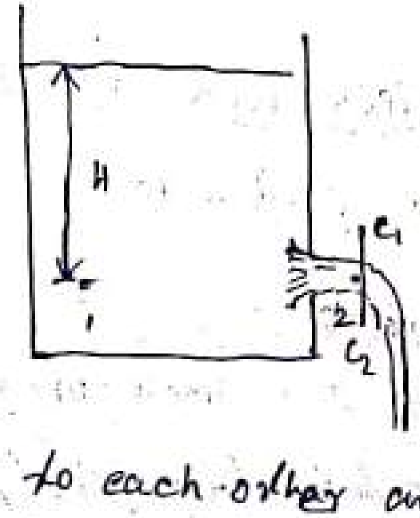
④ Free discharging orifice

Drowned or submerged orifice

Flow through an orifice

vena contracta

It a distance of $\frac{1}{2}$ of diameter of the orifice at this section the streamline are straight and parallel to each other and perpendicular to the plane of the orifice beyond this section the jet diverges and



it attracted in the downward direction due to gravity

consider two section 1 and 2 inside the tank and at the vena contracta respectively

Applying Bernoulli's eqⁿ at ① and ②

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

$$\Rightarrow \frac{P_1}{\rho g} + \frac{V_1^2}{2g} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} \quad (\text{as } Z_1 = Z_2)$$

$$\Rightarrow H + 0 = 0 + \frac{V_2^2}{2g}$$

$$\Rightarrow \boxed{V_2 = \sqrt{2gH}}$$

Imp **Hydrolic coefficient**

Coefficient of velocity

It is defined as the actual velocity of a jet of liquid at vena contracta and the theoretical velocity of the jet.

$$C_V = \frac{\text{Actual velocity}}{\text{Theoritical velocity}}$$

$$= \frac{V}{\sqrt{2gh}}$$

It is denoted by C_V and it's value varies from

0.95 to 0.99

Coefficent of contraction

It is defind as the ratio of the area of jet at vena contracta to the area of orifice

$$C_c = \frac{\text{Area of vena contracta}}{\text{Area of orifice}}$$

$$= \frac{a_c}{a}$$

The value of C_c varies from 0.61 - 0.69

Coefficent of discharge

It is defind as the ratio of actual discharge form an orifice to the therotical discharge from the orifice

$$C_d = \frac{\text{Actual discharge}}{\text{Therotical discharge}}$$

$$= \frac{\text{Actual area} \times \text{Actual velocity}}{\text{Therotical area} \times \text{therotical velocity}}$$

$$= C_c \times C_v$$

The value of C_d varies from 0.61 - 0.65

Q The head of water over an orifice of diameter 40mm is 10m find the actual discharge and actual velocity of the jet at vena contracta

$Cd = 0.6 \qquad Cv = 0.98$

Given

$D = 0.04\ m$

$H = 10\ m$

$a = \frac{\pi}{4}(D)^2$

$= 0.00125\ m^2$

Actual discharge

= Actual area × actual velocity

$V_2 = \sqrt{2gH}$

$= \sqrt{2 \times 9.81 \times 10}$

$= 14.007\ m/s$

$Cv = \frac{V}{\sqrt{2gH}}$

$V = Cv \times \sqrt{2gH}$

$= 0.98 \times 14.007$

$= 13.726\ m/s$

$Cd = \frac{a_c \times V_1}{a \times V_2}$

$$a_c = \frac{C_d \times a \times V_2}{V_1}$$

$$= \frac{0.6 \times 0.00125 \times 14.007}{13.726}$$

$$= 7.65 \times 10^{-4}$$

$$= 0.000765$$

$$C_d = \frac{\text{Actual discharge}}{0.0175}$$

Actual discharge $= 0.6 \times 0.0175$

$= 0.0105 \ m^3/s$

Q The head of water over the center of the orifice of diameter 20 mm is 1 m the actual discharge through the orifice is 0.85 Lit/s find the coefficient of dischare

$D = 20 \text{ mm} = 0.02$

$H = 1 \text{ m}$

Actual discharge $= 0.85 \times 10^{-3}$

$a = \frac{\pi}{4}(D)^2$

$= 3.141 \times 10^{-4} \ m^2$

$v_1 = \sqrt{2gH}$

$= \sqrt{2 \times 9.81 \times 1}$

$= 4.429 \ m/s$

Th. discharge $= 3.141 \times 10^{-4} \times 4.429$

$= 1.391 \times 10^{-3} \ m^3/s$

$$C_d = \frac{0.85 \times 10^{-3}}{1.391 \times 10^{-3}}$$

$= 0.611$

Dt 18.2.2020

Surface tension

It is defined as the tensile force acting on the surface of a liquid in contact with gas or on the surface between two immisible liquid such that the contant surface behave like a membrane

Surface tension on liquid droplets

Consider a small spherical droplet of a liquid of radius 'r'

Let σ = surface tension of the liquid

p = pressure intensity inside the droplet

d = diameter of droplet.

Tensile force due to surface tension is equal to

$\sigma \times \pi d$

Pressure force on the area = $p \times \frac{\pi}{4} d^2$

For equlibrium

$\sigma \times \pi d = p \times \frac{\pi}{4} d^2$

$p = \frac{4\sigma}{d}$

Surface tension on a hollow bubble

$2(\sigma \times \pi d) = p \times \frac{\pi}{4} d^2$

$\sigma \times \pi d = p \times \frac{\pi d^2}{8}$

$p = \frac{8\sigma}{d}$

Q The surface tension of water in contact in air at 20°C is 0.0725 N/m the pressure inside a droplet of water is 0.02 N/cm² greater then the outside pressure calculate the diameter of droplet of water

Give

$\sigma = 0.0725$

$P = 0.02 \times 10^4$

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$$d = \frac{4\sigma}{P}$$

$= 1.45 \times 10^{-3}$

$= 0.00145$ m

Q Find the surface tension in a soap bubble of 40mm diameter when the inside pressure is 2.5 N/m² above atmospheric pressure

Give

$p = 2.5 N/m^2$

$d = 40 mm = 0.04 m$

$$\sigma = \frac{pd}{8}$$

$= 0.0125$ N/m

Q The pressure outside the droplet of water of diameter 0.04mm is 10.32 N/cm². Calculate the pressure within the droplet if surface tension is 0.0725 N/m

Give

$d = 0.04 mm = 4 \times 10^{-6}$ m

$p = 10.32 N/cm^2 = 10.32 \times 10^4 N/m^2$

$\sigma = 0.0725 N/m$

$$P_s = \frac{4\sigma}{d} = 72500$$

$P_T = P_s + P$

$= 175700$ (wrong)

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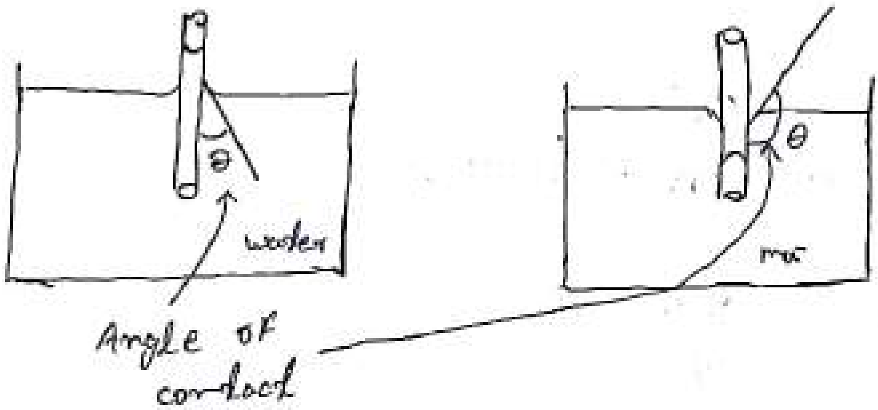
Dt 28.02.2020

Capillarity

It is defined as a phenomenon of rise or fall of a liquid surface in a small tube relative to the adjusent generally level of liquid when the tube is held vertically in the liquid



Expression for capillarity rise

$$h = \frac{4\sigma}{\rho g d}$$

Expression for capillary fail

$$h = \frac{4\sigma\cos\theta}{\rho g d}$$

where

h = hight of the liquid in the tube

σ = surface tension of liquid

θ = angle of contact between liquid of glass tube

Q Calculate the capillary rise in a glass tube of 2.5 mm diameter when immersed vertically in

① water

② mercury

Take surface tension 0.0725 N/m for water and 0.052 N/m for mercury. Angle of contact is 130°

Ans

Given

$d = 2.5\ mm = 0.0025$ $\theta = 130^\circ$

$\sigma = 0.0725$ water

$\sigma = 0.052$ mercury

water	mercury
$h = \frac{4\sigma}{\rho g d}$	$h = \frac{4\sigma\cos\theta}{\rho g d}$
$= 0.011\ m$	$= -0.0004\ m$

Q Calculate the capillary effect in a glass tube of 4 mm diameter when immersed in water and mercury the values of water and mercury with air are 0.073575 N/m and 0.51 N/m respectively the angle of contact for mercury is 130° take density of water 998 kg/m³

Q The capillary rise in a glass tube is not to exceed 0.2 mm of water determine its minimum size given that surface tension of water in contact with air is 0.0725 N/m

$$d = \frac{4\sigma}{\rho g h}$$

$$= 1.47$$

Newtons law of viscosity

It state that the shear stress in a ~~fluid~~ fluid element layer is directly proportional to shear strain

$$\tau \propto \frac{du}{dy}$$

$$\tau = \mu \frac{du}{dy}$$

μ = viscosity

τ = shear stress

ideal fluid:

A fluid which is incompressible and is having no viscosity is known as ideal fluid

Real fluid

A fluid which pos viscosity is known as real fluid

Newtonian fluid

obeys Newtons law of fluid

Non Newtonian fluid

A plate 0.025 mm distance from a fixed plate move at 60 cm/s and required a force of 2 N/area to maintain its speed. Determine the fluid viscosity between the plate

$dy = 0.025 \text{ mm} = 2.5 \times 10^{-5}$

$du = (60 - 0) = 60 \text{ cm/s} = 0.6 \text{m}$

$\tau = 2 \text{ N/m}^2$

$\mu = \frac{du}{dy} \times \frac{}{\tau}$

$= 12000 \quad \text{N sec/m}^2$

Dyen sec/cm^2

1 Dyen sec per cm^2 is equal to 1 poise

1 Poise $= \frac{1}{10}$ N sec/m^2

1 centipoise $= \frac{1}{100}$ poise

Kinematic viscosity

It is defined as the ratio between dynamic viscosity and density of fluid

$$\nu = \frac{\mu}{\rho}$$

Unit SI unit m^2/sec

CGS unit $cm^2/sec = 1$ Stoke

$\frac{du}{dy}$ is known as velocity gradient

Find the kinematic viscosity of an oil having density 9.81 kg/m3 the shear stress at a point in oil is 0.2452 N/m2 and velocity gradient at that point is 0.2/sec

$$\nu = \frac{\mu}{\rho}$$

$$\mu = \frac{dy}{du} =$$

$$= \frac{1}{0.2} \times 0.2452$$

$$= 1.226 \text{ N sec/m}^2$$

$$\nu = \frac{1.226}{9.81 \times 10^3}$$

$$= 0.1249 \times 10^{-3} \text{ m}^2\text{/sec}$$

$$= 0.1249 \times 10^{-3} \times 10^4 \text{ cm}^2\text{/sec}$$

$$= 1.249$$

Notches and weirs

Dt 3.03.2020

Notch

It is a device used for measuring the rate of flow of a liquid through a small channel or tank

* It may be defined as an opening in the side of a tank or a small channel in such a way that the liquid surface in the tank or channel is below the top edge of the opening

weir

It is a concrit or masonary structure placed in an open channel over with the flow occures.

* It is generally in the form of vertical wall with a sharp edge at the top runing all the way across the open channel.

classification of Notch and weire

→ According to shape of opening

1. Rectangluar notch
2. Triangular notch
3. Trapezoidal notch
4. stepped notch

According to the effect of sides on the nappe

① notch with end contraction

② notch with out end contraction or ~~suppresed~~ suppressed notch

According to the shape of opening

① Rectangular weir

② Triangular weir

③ Trapezoidal weir (Cipolletty weir)

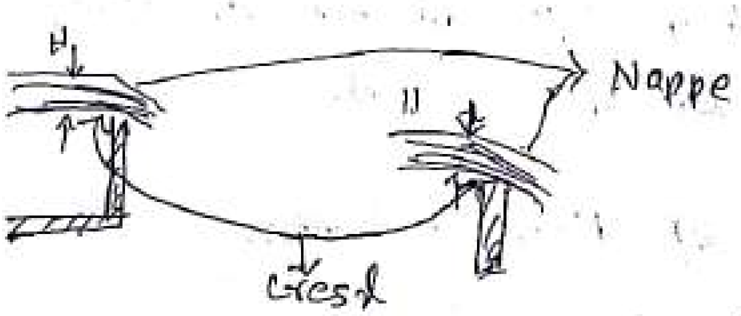
According to the shape of the crest

① Sharp crested weir

② Broad crested weir

③ narrow crested weir

④ ogee shaped weir



Discharge over a rectangular notch or weir

$$Q = \frac{2}{3} C_d L \sqrt{2g} (H)^{3/2}$$

L = Length of the notch or weir

H = height or head of water over the crest.

Q) Find the discharge of water flowing over a rectangular notch of 2m length when the constant head over the notch is 300 mm take cd = 0.6

$Q = \frac{2}{3}(0.6) \times 2 \times \sqrt{2 \times 9.81}\,(0.3\,m)^{3/2}$

$= 0.5822\ m^3/s$

Q) The head of water over a rectangular notch is 900 mm the discharge is 300 lit/sec find the length of the notch cd = 0.62

$Q = 300\ m^3/sec$

$H = 0.9$

$Q = 5.042\,L$

$L = 0.191\ m$

Q) Determine the height of a rectangular weir of length 6m to be build across a rectangular channel the maximum depth of water on the up stream side of the weir is 1.8 m and discharge is 2000 lit per sec take cd = 0.6

Given

$L = 6\,m$

$H + h = 1.8\,m \Rightarrow h = 1.8 + H$

$$2 = \frac{2}{3} \times 0.6 \times 8 \sqrt{2 \times 9.81} (H)^{\frac{3}{2}}$$

$$(H)^{\frac{3}{2}} = \frac{2}{10.630}$$

$$H = (0.1881)^{\frac{2}{3}}$$

$$= 0.328 \text{ m}$$

$$h = 1.8 - H$$

$$= 1.8 - 0.328$$

$$= 1.472 \text{ m}$$

Discharge over a triangular notch or weirs

$$\boxed{Q = \frac{8}{15} C_d \tan\frac{\theta}{2} \sqrt{2g} (H)^{5/2}}$$

Q1) Find the discharge over a triangular notch of angle 60° when the head over V notch is 0.3 m, $C_d = 0.6$

$$Q = \frac{8}{15} 0.6 \times \tan\left(\frac{60}{2}\right) \sqrt{2 \times 9.81} \times (0.3)^{5/2}$$

$$= 0.0403 \text{ m}^3/\text{s}$$

Q water flows over a rectangular wire 1m wide At a depth of 150mm and after work passes through a triangular right angle weir taking cd for rectangular and triangular as 0.62 and 0.59 respectively value find the depth over the triangular weir

Given

L = 1m ▭

H = 0.15 ▭

cd = 0.62 ▭

cd = 0.59 △

$$Q = \frac{2}{3} cd \times L \cdot \sqrt{2g} \, (H)^{\frac{3}{2}}$$

$$= 0.1063 \, m^3/s$$

$$Q = \frac{8}{15} cd \sqrt{2g} \, (H)^{\frac{5}{2}}$$

$$0.1063 = 1.3937 \, (H)^{\frac{5}{2}}$$

$$H = (0.0762)^{\frac{2}{5}}$$

$$= 0.357 \text{ m}$$

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Dt 6.03.2020

Flow through pipes

Loss of energy in pipes

when a fluid is flowing through a pipe the fluid expances some resistance due to which some of the energy of fluid is lost

Loss of energy or head due to friction

Darcy - weisbach formula

$$h_f = \frac{4fLV^2}{d \cdot 2g}$$

where

h_f = Loss of head due to friction

L = Length of pipe

V = mean velocity of flow

d = diameter of pipe

f = coefficent of friction which is a function of reynold number

$$f = \frac{16}{R_e} \quad (R_e < 2000)$$

$$f = \frac{0.079}{R_e^{1/4}} \quad (4000 < R_e < 10^6)$$

Chezy's formula

$$V = C\sqrt{mi}$$

where

c = chezy's constant

m = hydrolic mean depth

$$m = \frac{A}{P} = \frac{\frac{\pi}{4}d^2}{\pi d} = \frac{d}{4}$$

It is defined as the ratio of area of flow to the wetted perimeter.

i = loss of head per unit length of pipe

$$= \frac{h_f}{L}$$

v = mean velocity

Q Find the head lost due to friction in a pipe of diameter 300 mm and length 50 meter through which water is flowing at a velocity of 3m/s using ① Darcy formula

② chezy's formula for which C = 60

Take viscosity of water = 0.01 stock

$$Re = \frac{V \times d}{\nu}$$

where V = velocity

ν = viscocity

d = diameter

Given

$d = 0.3$ m

$L = 50$m

$v = 3$m/s

$\nu = 0.01$ stock $= 0.01\ cm^2/s = 0.01 \times 10^{-4}\ m^2/s$

① $C = 60$

$Re = \frac{V \times d}{\nu}$

$= 900000$

$f = \frac{0.079}{Re^{1/4}} = 2.56 \times 10^{-3}$

$h_f = \frac{4 f L V^2}{d \cdot 2g}$

$= 0.764$ m

② $m = \frac{d}{4}$

$= \frac{0.3}{4}$

$= 0.075$ m

$V = C\sqrt{mi}$

$V = C\sqrt{m \times \frac{h_f}{L}}$

$$v = 16.431\sqrt{\frac{hf}{L}}$$

$$3 = 16.431\frac{\sqrt{hf}}{\sqrt{50}}$$

$$3 = 16.431\frac{\sqrt{hf}}{7.071}$$

$$\sqrt{hf} = \frac{3}{16.431} \times 7.071$$

$$hf = (1.291)^2$$

$$= 1.66\ m$$

Q find the diameter of pipe of length 2000 m when the rate of flow of water through the pipe is 200 lit/sec and the head lost due to friction is 4 m take the value of C = 50

Given

$L = 2000\ m$

$Q = 200\ lit/sec \quad \frac{200}{1000} = 0.2\ m/sec$

$= A.V = \frac{\pi}{4} d^2 \times V$

$= V = \frac{0.2}{\frac{\pi}{4} d^2}$

$$\frac{0.256}{d^2} = 50\sqrt{0.25d \times 2 \times 10^{-3}}$$

$$= 1.118\sqrt{d}$$

$$\frac{1}{d^2} = \frac{1.118\sqrt{d}}{0.256}$$

$$= 4.367\sqrt{d}$$

$$\frac{1}{d^2}$$

$$\frac{1}{d^4} = 19.070689\, d$$

$$d^5 = \frac{1}{19.070689}$$

$$d = \sqrt[5]{0.0524}^{\,1/5}$$

$$= 0.554 \text{ m}$$

A crude oil of kinematic viscosity 0.4 stoke is flowing through a pipe of diameter 300 mm at the rate of 300 lit/sec. Find the head lost due to friction for a length of 50 m of the pipe

ν = 0.4 stoke = 0.4×10^{-4} m²/s

d = 300 mm = 0.3 m

Q = 300 lit/sec = 0.3 m/sec

L = 50 m

solution

$Q = A \times V$

$= \frac{\pi}{4} d^2 \times V$

$$0.3 = \frac{\pi}{4} \times (0.3)^2 \times V$$

$$V = 4.24 \text{ m/s}$$

$$Re = \frac{V \times d}{\nu}$$

$$= 31800$$

$$f = \frac{0.079}{Re^{1/4}}$$

$$= 5.91 \times 10^{-3}$$

$$h_f = \frac{4fLV^2}{d \cdot 2g}$$

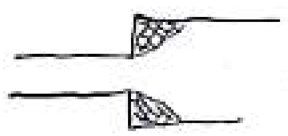
$$= 3.857 \text{ m}$$

Dt 13.03.20

minor energy lose

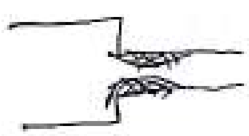
① Loss of head due to sudden enlargement

$$h_e = \frac{(v_1 - v_2)^2}{2g}$$



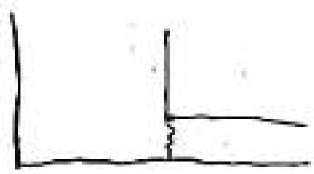
② Loss of head due to sudden contraction.

$$h_c = 0.5 \frac{v_2^2}{2g}$$



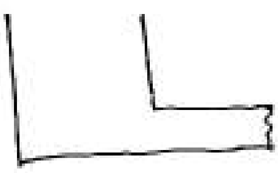
③ Loss of head at the entrance of a pipe

$$h_i = 0.5 \frac{v^2}{2g}$$



④ Loss of head at the exit of a pipe

$$h_o = \frac{v^2}{2g}$$



Q1 Determine the rate of flow of water through a pipe of diameter 20 cm and length 50 m when 1 end of the pipe is connected to a tank and other end of the pipe is open to the atmospher the pipe is horizontal and hight of water in the tank is 4m above the centero of the pipe. concider all minor losse and take $f = 0.009$ in the darcy formula

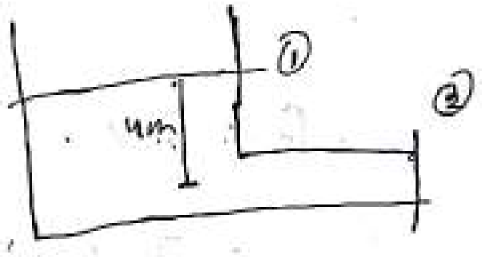
Given

$d = 0.2\,m$

$L = 50\,m$

$H = 4\,m$

$f = 0.009$



Taking two section at first in the starting of water in the tank and other is at the pipe end

Applying Bernoulli's eqn at section ① and ②

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + \text{All losses.}$$

$$\Rightarrow \frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + h_i + h_f$$

$$\Rightarrow 0 + 0 + 4 = 0 + \frac{v_2^2}{2g} + 0 + 0.5\frac{v_2^2}{2g} + \frac{4fLv^2}{2g}$$

$$4 = \frac{v_2^2}{2g} + \frac{0.5\,v_2^2}{2g} + \frac{4fLv^2}{2g}$$

$$v_2^2 + 0.5v_2^2 + 4fLv_2^2 = 78.48$$

$$v_2^2 + 0.5v_2^2 + 1.8\,v_2^2 = 78.48$$

$$3.3\,v_2^2 = 78.48$$

$$v_2^2 = \frac{78.48}{3.3} = 23.7818$$

$V_2 = \sqrt{283.7818}$

$= 4.8766$ m/s (2.4)

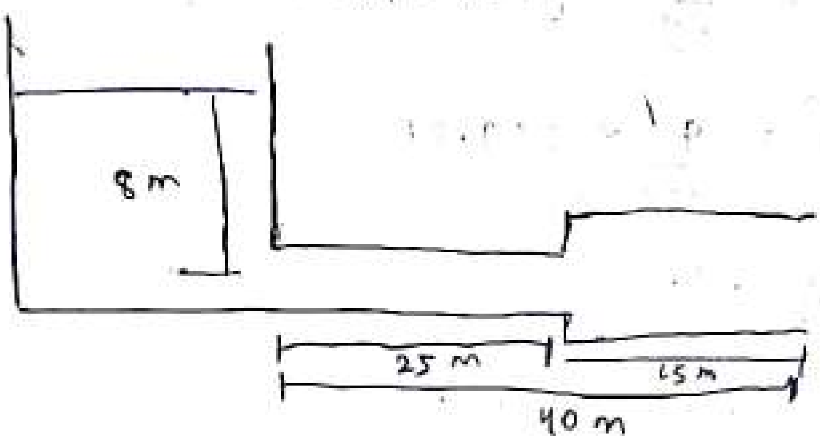
$Q = A \times V$

$= \frac{\pi}{4} d^2 \times V$

$= \frac{\pi}{4} \times (0.2)^2 \times 4.8766$

$= 0.15$ (0.075)

Q A horizontal pipe line 40 m long is connected to a water tank at one end and discharges freely into the atmosphere at the other end for the first 25 m of it's length from the tank the pipe is 150 mm diameter and it's diameter is suddly enlarge to 300 mm the hight of water in the tank is 8 m above the center of the pipe. considering all losses of head which occure determine the rate of flow. take f = 0.01 for both section of pipe.



Appling bernoulli's eq^n of section ① and ②

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + h_i + h_{f_1} + h_E + h_{f_2}$$

$$z_1 = \frac{V_2^2}{2g} + \frac{0.5 V_1^2}{2g} + \frac{(V_1 - V_2)^2}{2g} + \frac{4fLV_1^2}{d_1 \cdot 2g} + \frac{4fLV_2^2}{d_2 \cdot 2g}$$

$$8 = \frac{V_2^2}{2g} + \frac{0.5(4V_2)^2}{2g} + \frac{4fL(4V_2)^2}{d_1\, 2g} + \frac{(3V_2)^2}{2g} + \frac{4fLV_2^2}{d_2 g h}$$

$A_1 V_1 = A_2 V_2$

$0.017 V_1 = 0.070 V_2$

$V_1 = \frac{0.070}{0.017} V_2$

$V_1 = 4.011\ V_2$

$$8 = \frac{V_2^2}{2g}\left(1 + 0.5(4)^2 + \frac{4fL\,16}{d_1} + 9 + \frac{4fL}{d_2}\right.$$

$$8 = \frac{V_2^2}{2g}(126.667)$$

$$V_2^2 = \frac{8 \times 2 \times 9.81}{126.667}$$

$$V_2 = \sqrt{1.239}$$

$$= 1.113 \text{ m}^2/\text{s}$$

$$Q = A_2 V_2$$

$$= 0.0786 \text{ m}^3/\text{s}$$

▶ 11.5 HYDRAULIC GRADIENT AND TOTAL ENERGY LINE

The concept of hydraulic gradient line and total energy line is very useful in the study of flow of fluids through pipes. They are defined as :

11.5.1 Hydraulic Gradient Line. It is defined as the line which gives the sum of pressure head $\left(\frac{p}{w}\right)$ and datum head (z) of a flowing fluid in a pipe with respect to some reference line or it is the line which is obtained by joining the top of all vertical ordinates, showing the pressure head (p/w) of a flowing fluid in a pipe from the centre of the pipe. It is briefly written as H.G.L. (Hydraulic Gradient Line).

11.5.2 Total Energy Line. It is defined as the line which gives the sum of pressure head, datum head and kinetic head of a flowing fluid in a pipe with respect to some reference line. It is also defined as the line which is obtained by joining the tops of all vertical ordinates showing the sum of pressure head and kinetic head from the centre of the pipe. It is briefly written as T.E.L. (Total Energy Line).

Problem 11.22 *For the problem 11.16, draw the Hydraulic Gradient Line (H.G.L.) and Total Energy Line (T.E.L.).*

Solution. Given :

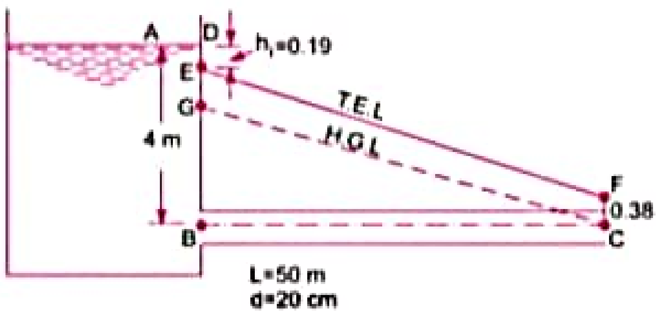
$$L = 50 \text{ m}, d = 200 \text{ mm} = 0.2 \text{ m}$$

$$H = 4 \text{ m}, f = .009$$

Velocity, V through pipe is calculated in problem 11.16 and its value is $V = 2.734$ m/s

Now, h_i = Head lost at entrance of pipe

$$= 0.5 \frac{V^2}{2g} + \frac{0.5 \times 2.734^2}{2 \times 9.81} = 0.19 \text{ m}$$



$$= \frac{4 \times f \times L \times V^2}{d \times 2g} = \frac{4 \times 0.009 \times 50 \times (2.734)^2}{0.2 \times 2 \times 9.81} = 3.428 \text{ m.}$$

(*a*) **Total Energy Line (T.E.L.).** Consider three points, *A*, *B* and *C* on the free surface of water in the tank, at the inlet of the pipe and at the outlet of the pipe respectively as shown in Fig. 11.8. Let us find total energy at these points, taking the centre of pipe as reference line.

1. Total energy at $A = \frac{p}{\rho g} + \frac{V^2}{2g} + z = 0 + 0 + 4.0 = 4$ m
2. Total energy at B = Total energy at $A - h_i = 4.0 - 0.19 = 3.81$ m
3. Total energy at $C = \frac{p_c}{\rho g} + \frac{V_c^2}{2g} + z_c = 0 + \frac{V^2}{2g} + 0 = \frac{2.734^2}{2 \times 9.81} = 0.38$ m.

Hence total energy line will coincide with free surface of water in the tank. At the inlet of the pipe, it will decrease by h_i (= 0.19 m) from free surface and at outlet of pipe total energy is 0.38 m. Hence in Fig. 11.8,

(*i*) Point *D* represents total energy at *A*

(*ii*) Point *E*, where $DE = h_i$, represents total energy at inlet of the pipe

(*iii*) Point *F*, where $CF = 0.38$ represents total energy at outlet of pipe.

Join *D* to *E* and *E* to *F*. Then *DEF* represents the total energy line.

(*b*) **Hydraulic Gradient Line (H.G.L.).** H.G.L. gives the sum of $(p/w + z)$ with reference to the datum-line. Hence hydraulic gradient line is obtained by subtracting $\frac{V^2}{2g}$ from total energy line. At outlet of the pipe, total energy $= \frac{V^2}{2g}$. By subtracting $\frac{V^2}{2g}$ from total energy at this point, we shall get point *C*, which lies on the centre line of pipe. From *C*, draw a line *CG* parallel to *EF*. Then *CG* represents the hydraulic gradient line.

Problem 11.23 *For the problem 11.17, draw the hydraulic gradient and total energy line.*

Solution. Refer to problem 11.17.

Given: $L_1 = 25$ m, $d_1 = 0.15$ m

$L_2 = 15$ m, $d_2 = 0.3$ m, $f = .01$, $H = 8$ m

The velocity V_2 as calculated in problem 11.17 is

$$V_2 = 1.113 \text{ m/s}$$

$$V_1 = 4V_2 = 4 \times 1.113 = 4.452 \text{ m/s}$$

The various head losses are $h_i = 0.5 \times \frac{V_1^2}{2g} = \frac{0.5 \times 4.452^2}{2 \times 9.81} = 0.50$ m

$$h_{f_1} = \frac{4f \times L_1 \times V_1^2}{d_1 \times 2g} = \frac{4 \times .01 \times 25 \times (4.452)^2}{0.15 \times 2 \times 9.81} = 6.73 \text{ m}$$

$$h_e = \frac{(V_1 - V_2)^2}{2g} = \frac{(4.452 - 1.11)^2}{2 \times 9.81} = 0.568 \text{ m}$$

$$h_{f_2} = \frac{4 \times f \times L_2 \times V_2^2}{d_2 \times 2g} = \frac{4 \times .01 \times 15 \times (1.113)^2}{0.3 \times 2 \times 9.81} = 0.126 \text{ m}$$

$$h_o = \frac{V_2^2}{2g} = \frac{1.113^2}{2 \times 9.81} = 0.063 \text{ m}$$

Also $$V_1^2/2g = \frac{4.452^2}{2 \times 9.81} = 1.0 \text{ m.}$$

Total Energy Line

(*i*) Point *A* lies on free surface of water.

(*ii*) Take $AB = h_i = 0.5$ m.

(*iii*) From *B*, draw a horizontal line. Take *BL* equal to the length of pipe, *i.e.*, L_1. From *L* draw a vertical line downward.

(*iv*) Cut the line $LC = h_{f_1} = 6.73$ m.

(*v*) Join the point *B* to *C*. From *C*, take a line *CD* vertically downward equal to $h_e = 0.568$ m.

(*vi*) From *D*, draw *DM* horizontal and from point *F* which is lying on the centre of the pipe, draw a vertical line in the upward direction, meeting at *M*. From *M*, take a distance $ME = h_{f_2} = 0.126$. Join *DE*.

Then line *ABCDE* represents the total energy line.

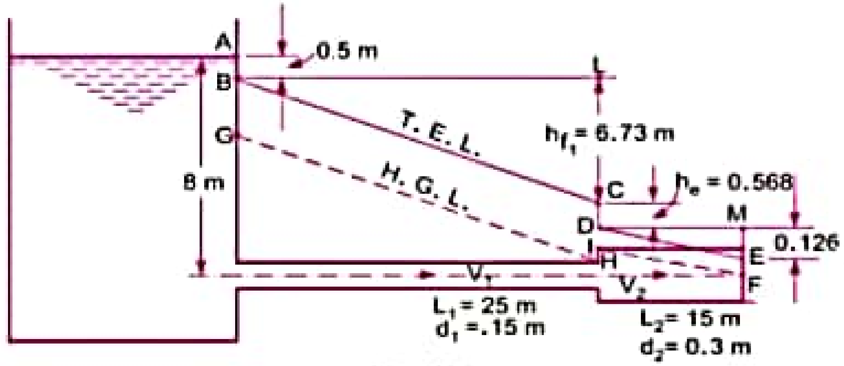


Fig. 11.9

Hydraulic Gradient Line (H.G.L.)

(*i*) From *B*, take $BG = \frac{V_1^2}{2g} = 1.0$ m.

(*ii*) Draw the line *GH* parallel to the line *BC*.

(*iii*) From *F*, draw a line *FI* parallel to the line *ED*.

(*iv*) Join the point *H* and *I*.

Then the line *GHIF* represents the hydraulic gradient line (H.G.L.).

Problem 11.24 *For Problem 11.18, draw the hydraulic gradient and total energy line.*

Solution. Refer to Problem 11.18.

Given : $d = 300$ mm $= 0.3$ m

$L = 400$ m, $Q = 300$ litres/s $= 0.3$ m³/s

$f = .008$

Let $\quad H_1 = 50$ m. But $H_1 - H_2 = 40.537$ m (Calculated in Problem 11.18)

$\therefore \quad H_2 = 50 - 40.537 = 9.463$ m.

The calculated losses are :

(i) $h_i = 0.459$ m $\quad$ (ii) $h_{f_1} = 39.16$ m

(iii) $h_o = 0.918$ m

(a) T.E.L.

(i) Point A is on the free surface of water in 1st tank. From A, take $AB = h_i = 0.459$ m.

(ii) Draw a horizontal line BF. Take BF equal to the length of pipe. From F, draw a vertical line in the downward direction. Cut $FC = h_{f_1} = 39.16$ m.

(iii) Join BC. From C take $CD = h_0 = 0.918$ m. The point D should coincide with free surface of water in 2nd tank. Then line $ABCD$ is the total energy line.

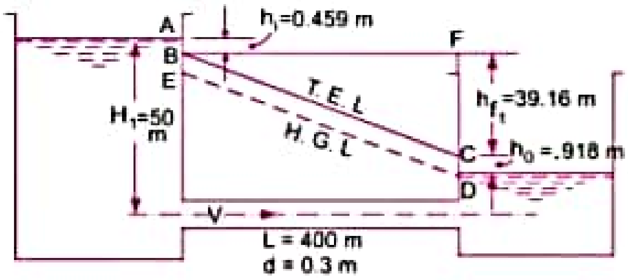


Fig. 11.10

(b) H.G.L. From D, draw a line DE parallel to line BC. Then DE is the H.G.L.

Or

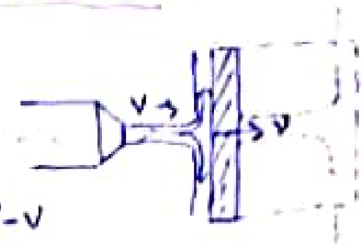
From B, take $BE = \dfrac{V^2}{2g} = 0.918$ m and from E draw a line ED parallel to BC. The point D should coincide with free surface of water in the 2nd tank. Then line ED represents the H.G.L.

(c) IMPACT OF JET ON A MOVING FLAT PLATE (VERTICAL)

Let, V = velocity of the jet

v = velocity of the plate

Velocity of the jet relative to the plate = V−v



We may consider as though the plate is at rest & that the jet is moving with a velocity (V−v) relative to the plate.

∴ Force exerted by the jet on the plate

$$F = \rho a (V-v)^2 \text{ Newton}$$

In this case, since the point of application of the force moves, work is done by the jet.

Workdone by the jet on the plate per second

$$= Fv = \rho a (V-v)^2 v \text{ Nm/s or, Joule/sec.}$$

(d) IMPACT OF JET ON A MOVING FLAT PLATE (INCLINED)

Let the velocity of the jet & the vane be V & v in the same direction. Let the angle between the jet & the plate be θ. In this case mass of liquid striking the plate per second = $\rho a(V-v)$

Relative velocity normal to the plate before impact

$$= (V-v)\sin\theta$$

Relative velocity normal to the plate after impact

$$= 0$$

∴ Force exerted by the jet normal to the plate

$$F = \rho a (V-v)[(V-v)\sin\theta - 0]$$

$$\Rightarrow F = \rho a (V-v)^2 \sin\theta \text{ Newton}$$

This force F acting normal to the plate can be resolved into components F_x & F_y in the direction of motion of plate & perpendicular to the direction of motion of the plate.

$F_x = \rho a (V-v)^2 \sin^2\theta$ & $F_y = \rho a (V-v)^2 \sin\theta\cos\theta$

∴ workdone by jet per second $= F_x v = \rho a (V-v)^2 v \sin^2\theta$.

∴ Force exerted by the jet normal to the plate

F = mass striking the plate /sec × Change in velocity normal to the plate

$= M(V\sin\theta - 0) = \rho a V \cdot V\sin\theta$

$\Rightarrow$ $\boxed{F = \rho a V^2 \sin\theta}$ Newton.

* In the above two cases the workdone by the jet on the plate is zero since the point of application of the force doesn't move.

4th sem
Mech. Engg
FM & HM

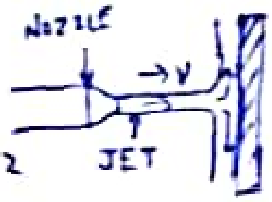
Impact of Jet

Notes by
P. Mahapatra
PTGF, GP, Balangir

Introduction to Jet → A jet of water issuing from a nozzle has a velocity & hence it possesses a K.E.. If this jet strikes a plate then it is said to have an impact on the plate. The jet will exert a force on the plate which it strikes. This force is called dynamic force exerted by the jet. This force is due to the change in momentum of the jet as a consequence of the impact. This force is equal to the rate of change of momentum. i.e. mass striking/sec × change in velocity.

Impact of jet on a Stationary Flat plate (vertical)

Consider a jet of water impinging normally on a flat plate at rest.



Let, a = Cross-sectional area of the jet in m^2

V = velocity of the jet in m/s

M = Mass of water striking the plate per second.

∴ $M = \rho a V$ kg/sec.

where, ρ = density of water in kg/m3

Force exerted by the jet on the plate

F = Change in momentum per second

= mass striking the plate/sec × change in velocity

$= M(V-0) = MV = \rho aV.V$

$$\Rightarrow \boxed{F = \rho a V^2} \text{ Newton}$$

Impact of jet on a Stationary Flat Plate (inclined)

Let, θ = Angle between jet & plate

Velocity component normal to the plate before impact $= V\sin\theta$

Velocity component normal to the plate after impact $= 0$.

17.2.2 Force Exerted by a Jet on Stationary Curved Plate

(A) Jet strikes the curved plate at the centre. Let a jet of water strikes a fixed curved plate at the centre as shown in Fig. 17.3. The jet after striking the plate, comes out with the same velocity if the plate is smooth and there is no loss of energy due to impact of the jet, in the tangential direction of the curved plate. The velocity at outlet of the plate can be resolved into two components, one in the direction of jet and other perpendicular to the direction of the jet.

Component of velocity in the direction of jet = $-V \cos \theta$.

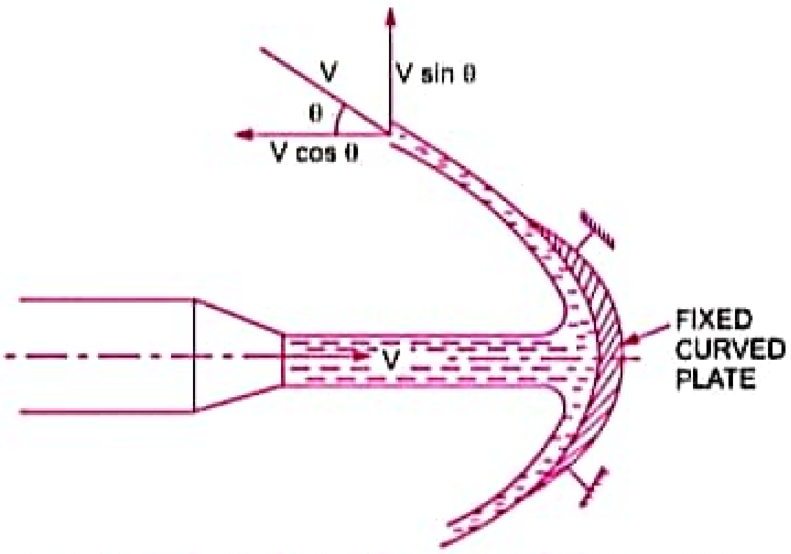


Fig. 17.3 *Jet striking a fixed curved plate at centre.*

(–ve sign is taken as the velocity at outlet is in the opposite direction of the jet of water coming out from nozzle).

Component of velocity perpendicular to the jet = $V \sin \theta$

Force exerted by the jet in the direction of jet,

$$F_x = \text{Mass per sec} \times [V_{1x} - V_{2x}]$$

where V_{1x} = Initial velocity in the direction of jet = V

V_{2x} = Final velocity in the direction of jet = $-V \cos \theta$

$\therefore \qquad F_x = \rho aV[V - (-V\cos\theta)] = \rho aV[V + V\cos\theta]$

$$= \rho aV^2[1 + \cos\theta] \qquad ...(17.5)$$

Similarly, $\qquad F_y$ = Mass per sec × $[V_{1y} - V_{2y}]$

where $\quad V_{1y}$ = Initial velocity in the direction of $y = 0$

V_{2y} = Final velocity in the direction of $y = V\sin\theta$

$$\therefore \qquad F_y = \rho aV[0 - V\sin\theta] = -\rho aV^2\sin\theta \qquad ...(17.6)$$

–ve sign means that force is acting in the downward direction. In this case the angle of deflection of the jet $= (180° - \theta)$ ...[17.6 (A)]

(B) Jet strikes the curved plate at one end tangentially when the plate is symmetrical. Let the jet strikes the curved fixed plate at one end tangentially as shown in Fig. 17.4. Let the curved plate is symmetrical about x-axis. Then the angle made by the tangents at the two ends of the plate will be same.

Let $\quad V$ = Velocity of jet of water,

θ = Angle made by jet with x-axis at inlet tip of the curved plate.

If the plate is smooth and loss of energy due to impact is zero, then the velocity of water at the outlet tip of the curved plate will be equal to V. The forces exerted by the jet of water in the directions of x and y are

$$F_x = (\text{mass/sec}) \times [V_{1x} - V_{2x}]$$
$$= \rho aV[V\cos\theta - (-V\cos\theta)]$$
$$= \rho aV[V\cos\theta + V\cos\theta]$$
$$= 2\rho aV^2\cos\theta \qquad ...(17.7)$$
$$F_y = \rho aV[V_{1y} - V_{2y}]$$
$$= \rho aV[V\sin\theta - V\sin\theta] = 0$$

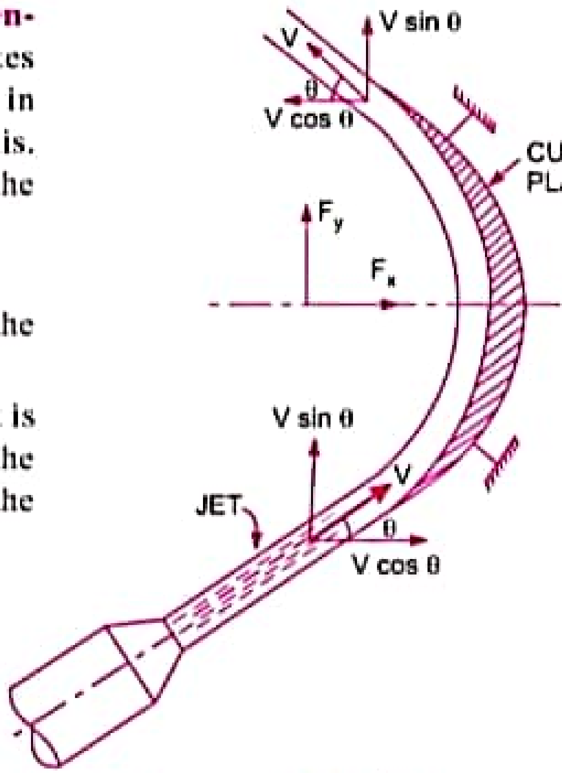


Fig. 17.4 *Jet striking curved fixed plate at one end.*

(C) Jet strikes the curved plate at one end tangentially when the plate is unsymmetrical. When the curved plate is unsymmetrical about x-axis, then angle made by the tangents drawn at the inlet and outlet tips of the plate with x-axis will be different.

Let $\qquad \theta$ = angle made by tangent at inlet tip with x-axis,

ϕ = angle made by tangent at outlet tip with x-axis.

The two components of the velocity at inlet are

$$V_{1x} = V\cos\theta \text{ and } V_{1y} = V\sin\theta$$

The two components of the velocity at outlet are

$$V_{2x} = -V\cos\phi \text{ and } V_{2y} = V\sin\phi$$

$\therefore$ The forces exerted by the jet of water in the directions of x and

$$F_x = \rho aV[V_{1x} - V_{2x}] = \rho aV[V\cos\theta - (-$$
$$= \rho aV[V\cos\theta + V\cos\phi] = \rho aV^2[\cos\theta + \cos\phi] \qquad ...(17.8)$$
$$F_y = \rho aV[V_{1y} - V_{2y}] = \rho aV[V\sin\theta - V\sin\phi]$$
$$= \rho aV^2[\sin\theta - \sin\phi]. \qquad ...(17.9)$$

Today's Topics:

1. Capstan and Turret Lathe:
2. Capstan and Turret Lathe Working:
3. Capstan and Turret Lathe Advantages:
4. Bar Feeding Mechanism in Capstan and Turret Lathe:
5. Tools used in Capstan and Turret Lathe:
6. Self-opening Die Head:
7. Difference Between Capstan and Turret Lathe Machine:

Capstan and Turret Lathe:

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A **capstan and turret lathe is a production lathe**. It is used to manufacture any number of identical pieces in the minimum time.

These lathes were first developed in the **United States of America** by **Pratt and Whitney** in 1960.

Capstan lathe is one of the types of **semi-automatic lathe**.

In semi-automatic lathes machining operations are done automatically.

Functions other than machining like loading and unloading of a job, the positioning of tools coolant operations are done manually.

The turret head is mounted on the ram fitted with turret slides longitudinally on the saddle.

Turret head has a **hexagonal block having six faces** with a bore for mounting six or more than six tools at a time.

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In the case of a **Capstan Lathe**, **the hexagonal turret is mounted on a short slide or ram** which again fitted with a saddle.

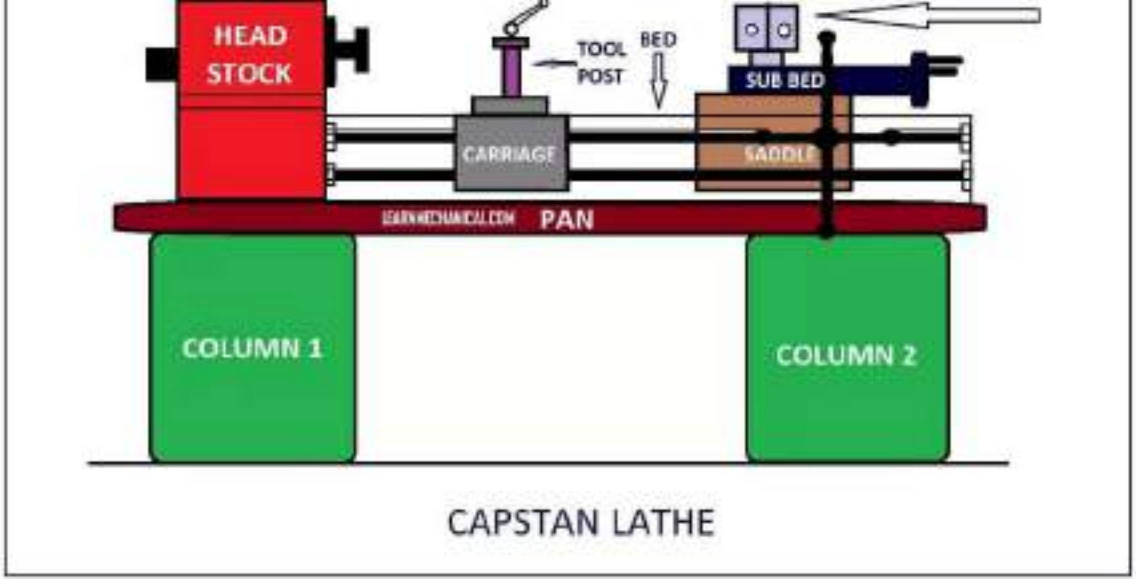
The saddle can be move accordingly throughout the bed ways and can be fixed to the bed if necessary.

It is specially used for bar type jobs.

But in the case of **Turret Lathe**, the **hexagonal turret directly mounted on the saddle.** The saddle can be move through the bed ways.

Turret lathe is generally used for chucking type work.

Schematic Diagram of a Capstan Lathe:



SCHEMATIC DIAGRAM OF CAPSTAN LATHE

Schematic Diagram of a Turret Lathe:

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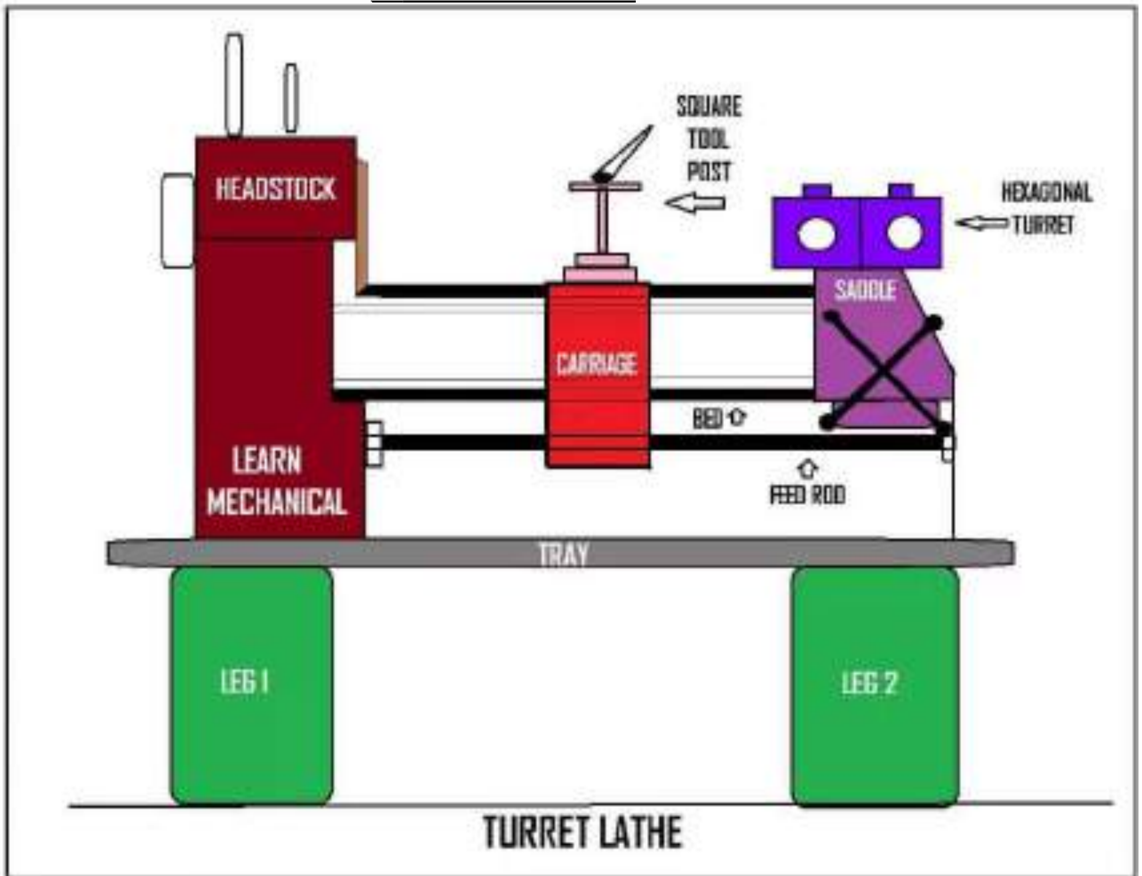

SCHEMATIC DIAGRAM OF TURRET LATHE

Capstan and Turret Lathe Working:

The workpiece is held in collet or chucks which are actuated **hydraulically or pneumatically.**

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According to the sequence of operation, the tool is moved with the help of a turret head.

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The Parting tool is mounted in an inverted position on the rear end of the turret.

After completing each operation the turret head is moved back to its initial position which indexes the tools automatically.

Capstan and Turret Lathe Advantages:

The advantages of Capstan and Turret Lathe is the following:

The rate of production is higher

Different ranges of speeds are obtained.

A number of tools can be accommodated.

Chucking of larger workpieces can be done.

Operators of less skill are required hence lowers the labor cost.

Higher rigidity so can withstand heavy loads.

Bar Feeding Mechanism in Capstan and Turret Lathe:

In the **bar feeding mechanism**, the bar is pushed after the chuck is released without stopping the **Lathe Machine**

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We use this mechanism for minimizing the setting time.

The bar is passed through the pedestal bushing, bar holding chuck, headstock spindle, and the collet chuck.

The **collet chuck** is screwed on the headstock spindle and holding the feed bar and also helps the bar to rotates as per spindle speed.

Bar holding chuck rotates within the sliding block with the rotation of the feeding bar.

Also, you can see a rope and a deadweight in this mechanism.

One side of the rope is attached with the sliding block with the help of pin and another side of rope passes through 2 different pulleys and then connecting with a deadweight at its end.

So now when the collet chuck released by the lever the dead weight tends to move in the downward direction, due to this it exerts thrust on the bar holding chuck and feed the bar until it touches the workshop.

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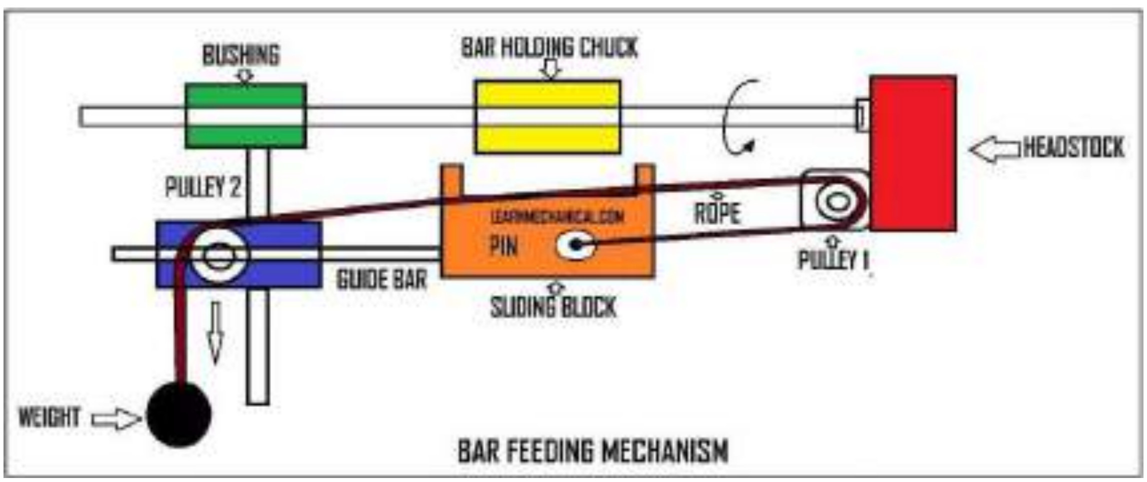
As we already have seen that Capstan Lathe is best for bar types jobs that's why we are generally seeing Bar Feeding Mechanism on Capstan Lathe.



BAR FEEDING MECHANISM IN CAPSTAN LATHE

Tools used in Capstan and Turret Lathe:

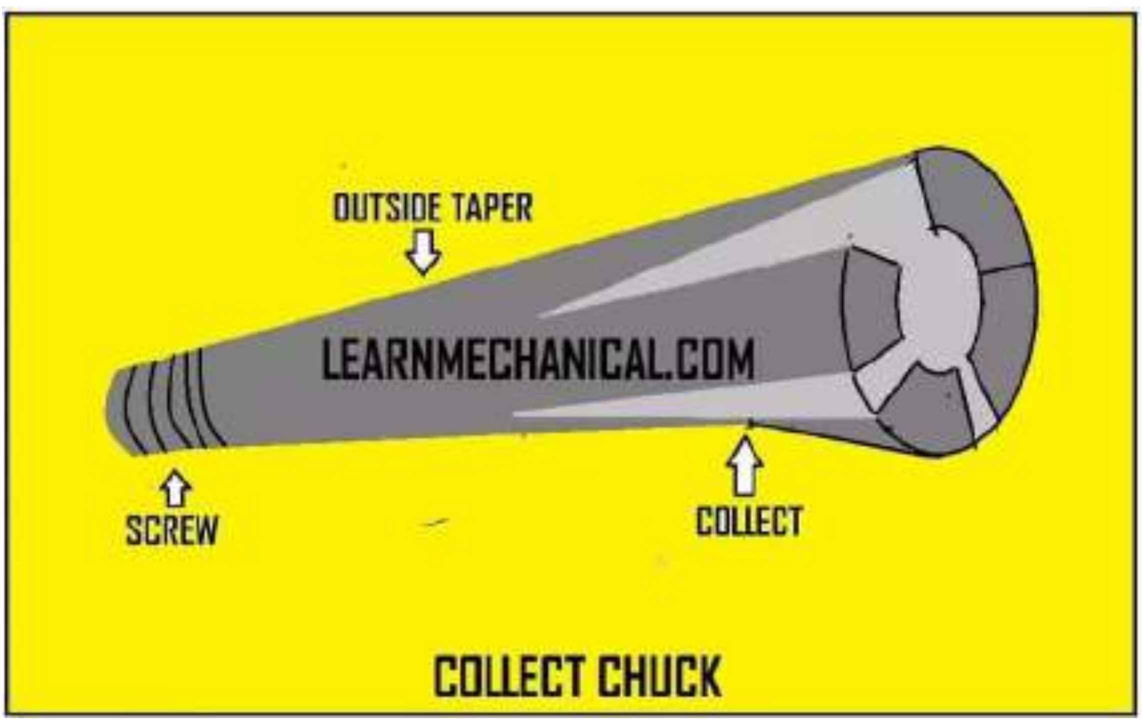
Collect Chuck:

This is **used for griping or you can holding any small bars in Capstan and Turret Lathe** (Mainly when we do Mass production).

The size of collet chucks is different corresponding to the bar sizes.

The jaws of the collet chuck are gripped the workpiece by its springing nature.

It is a thin steel brass bushing having slots on the outer side throughout its length.



How a Collect Chuck looks like

Roller Box Steady Turning tool

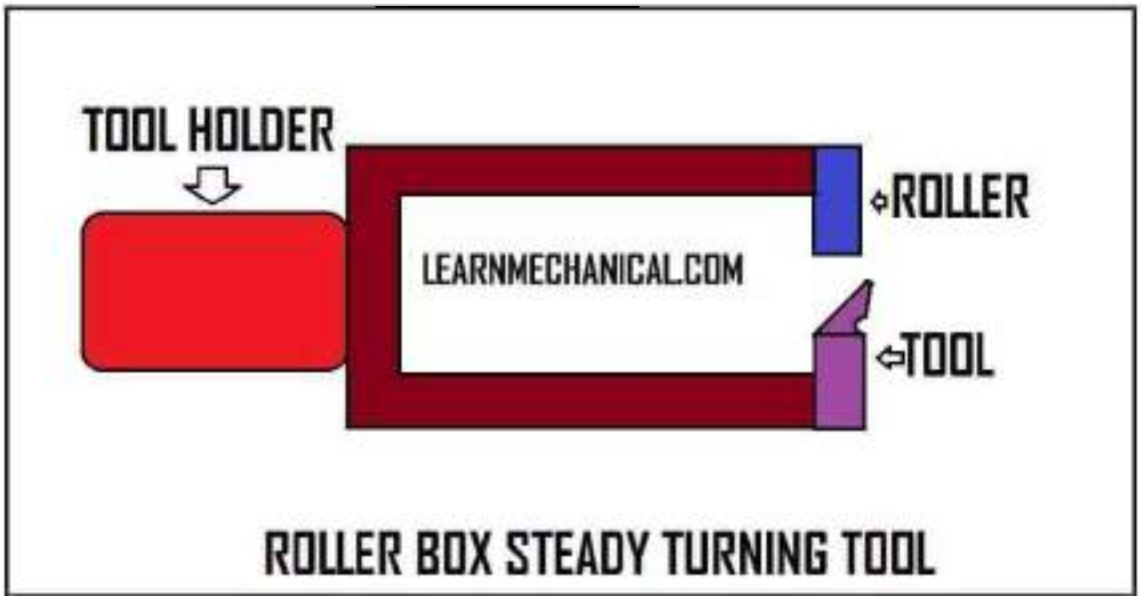
This type of tool is **used on bar work and when a considerable amount of stock is to be removed from the job.**

Roller box consists of the backrest or traveling two roller steadies that can be adjusted as per requirement.

A single point cutting tool is present in front of two rollers and gives rigidity to the workpiece.

Due to this rigid support, depth of cut, turning, etc. can be performed very smoothly.

This is a costly tool only used in mass production.



ROLLER BOX STEADY TURNING TOOL USED IN CAPSTAN AND TURRET LATHE

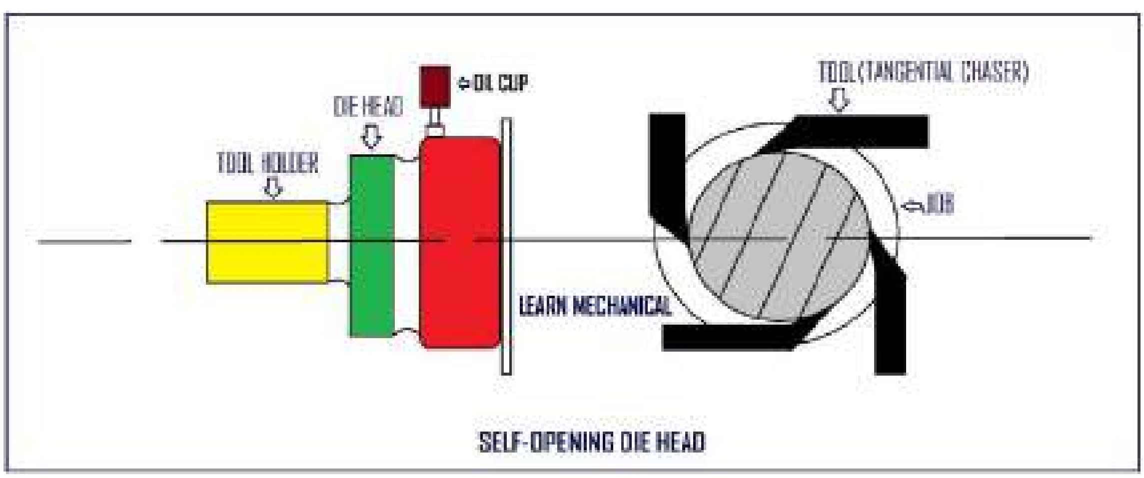
Self-opening Die Head:

This tool is **used especially for cutting external threads.**

The pitch of the cutting edges is determined according to the required thread pitch to be cut.

Chasers may be triangular, tangential, and circular types.

The function of the self-opening die is it opened automatically when the tool travel is stopped after the screw cutting operation.



Difference Between Capstan and Turret Lathe Machine:

Difference Between Capstan and Turret Lathe Machine:

Capstan Lathe	Turret Lathe
In capstan lathe, the turret tool head is mounted over the ram and that is mounted over the saddle.	In turret lathe, the turret tool head is mounted over the saddle like a single unit.
For providing feed to the tool, ram is moved.	For providing feed to the tool, a saddle is moved.
Capstan lathe is a Lightweight machine.	Turret Lathe is a Lightweight machine.
The turret head cannot be moved in the lateral direction of the bed.	The turret head can be moved crosswise i.e. in the lateral direction of bed in some turret lathe.
In capstan lathe, the collet is used to gripping the Job.	In turret lathe, power Jaw chuck is used to gripping the Job.
Capstan lathe is usually horizontal lathes.	Turret lathes are available in horizontal and vertical lathes.
Because of no saddle displacement, Movement of turret tool head over the longitudinal direction of bed is small along with the ram.	Turret tool head moves along with the saddle over the entire bed in the longitudinal direction.

For indexing turret tool head, the handwheel of the ram is reversed and turret tool index automatically.	For indexing turret tool head, a turret is rotated manually after releasing clamping lever.
Capstan lathe working operations are faster because of lighter in construction.	Turret lathe working operations are slower because of heavier in constructions.
Capstan lathe used for shorter workpiece because of limited ram movement.	Turret lathe used for longer workpiece because of saddle movement along the bed.
In Capstan lathe used for machining workpiece up to 60 mm diameter.	In Turret lathe used for machining workpiece up to 120 mm in diameter.
Heavy cuts on the workpiece cannot be given because of non-rigid construction.	Heavy cuts on the workpiece can be given because of the rigid construction of the machine.

Let's see the difference between Capstan and Turret Lathe from the Engine Lathe:

ENGINE LATHE	CAPSTAN AND TURRET LATHE
The direction of rotation is mostly anti-clockwise	It can rotate in both directions.

Required less power as these machines are design for doing a single operation at a time.	Requied 4-5 times more power because of handaling 2-3 operations at a time.
Less number of spindle speed available in these types of lathe	The vast amount of spindle speeds are available
Setting and machining time is higher.	Setting and machining time for mass production is very less, as its handle sevaral operation at a time.
The skilled operator needed.	Semi-skilled operators can be run the machine
The lead screw present in these types of lathe is long	Lead screw is not present but short threads can be easily cut by chaser.
Any type of taper turning can be done by this machine	Only short length taper can be done with the help of the form tool.

Summary:

What is capstan and turret lathe?

A capstan and turret lathe is a production lathe. It is used to manufacture any number of identical pieces in the minimum time.

These lathes were first developed in the United States of America by Pratt and Whitney in 1960.

What is the working principle of Capstan and Turret lathe?

In these types of a lathe, the workpiece is held in collet or chucks which are actuated hydraulically or pneumatically. All the needed tools are held in the respective holes on the turret head. According to the sequence of operation, the tool is moved with the help of a turret head.

What are the advantages of Capstan and Turret Lathe?

The advantages of Capstan and Turret Lathe is the following:

The rate of production is higher

Different ranges of speeds are obtained.

A number of tools can be accommodated.

Chucking of larger workpieces can be done.

Operators of less skill are required hence lowers the labor cost.

Higher rigidity so can withstand heavy loads.

Conclusion:

As we saw in this article that these machines are the modification of an Engine Lath, also there is no long lead screw in this type of lathe.

Capstan and turret lathes are now used vastly in the Manufacturing tool to produce mass products.

Start

So that is all about **Capstan and Turret Lathe**, feel free to ask your question in the comment box or you can use our Discussion Board to ask your doubts.

And also don’t forget to share our articles on your social handles.

You may be interested to read these articles:

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Shaper Machine: Definition, Working, Types, Operations, Specification, Advantages, Disadvantages, and Application (With PDF)

In Manufacturing Technology

Table of Contents

Hello, readers in today's article, we will learn **how a shaper machine works also we learn about the parts, types, operations, specification, advantages disadvantages, and applications of a shaper machine**.

So let's start with the definition of shaper machine.

Shaper Machine Definition:

The **Shaper** is a reciprocating type of machine tool basically used to produce Horizontal, Vertical or Inclined flat surfaces by means of straight-line reciprocating single-point cutting tools similar to those which is used in lathe operation.

The flat surface produced may be horizontal, vertical or inclined at an angle

Working Principle of Shaper Machine:

A **shaper machine is working on the following principle**:

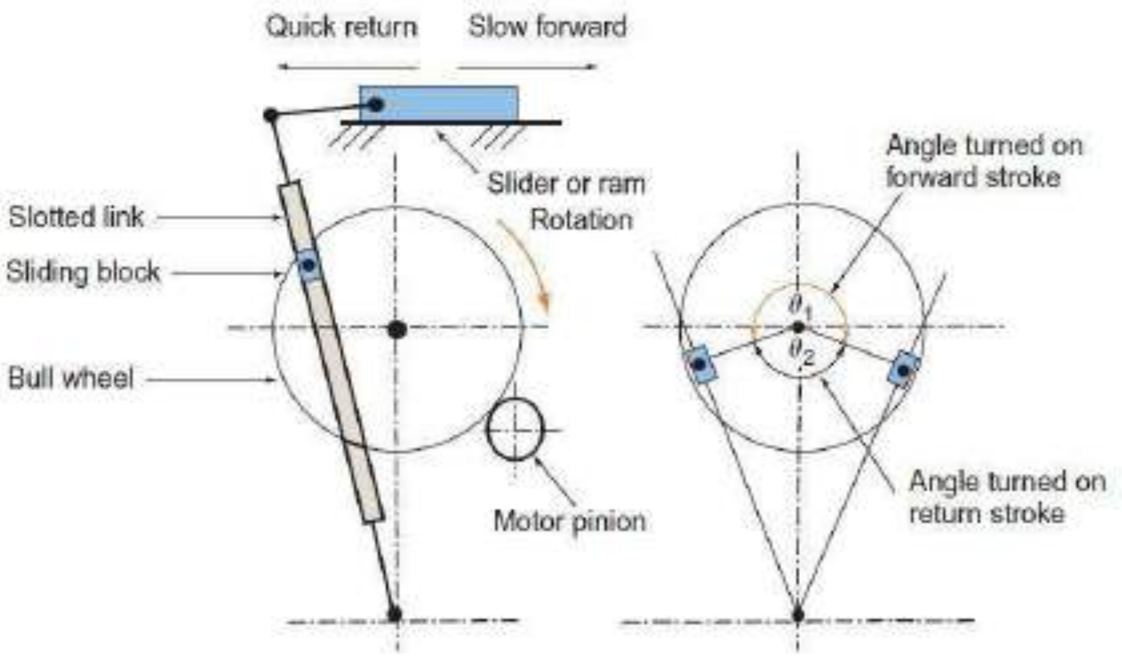
- A shaper machine holds the Single point cutting tool in ram and workpiece is fixed over the table.
- The ram holding the tool reciprocates over the workpiece and metal is cut during the forward stroke called a cutting stroke and
- No metal is cut during its return stroke is called an Idle stroke.
- The feed is given at the end of the cutting stroke.
- Generally, the cutting stroke is carried out at slow speed and the idle stroke is carried at high speed with the help of quick return mechanism.

In the shaper machine, there is another mechanism called **Quick return Motion Mechanism**.

So what happens in quick return motion mechanism is,

In the forward stroke, the Slider moves fast and removing the material from the workpiece.

Whereas in the return stroke, the Slider moves faster than the forward stroke that means Quick return, it takes less time to return, called a return stroke.



Quick return motion mechanism of shaper machine

Quick return mechanism's animation video:

Types of Shaper Machine:

Based on the type of driving mechanism types of shaper machines.

- Crank type (Example: Quick return Motion Mechanism)

- Geared type shaper
- Hydraulic type (I mentioned the **working principle of hydraulic shaper machine** below in this article)

Based on ram travel types of shaper machines.

- Horizontal Shaper
- Vertical Shaper

Based on the table design types of shaper machines.

- Standard or Plain Shaper
- Universal shaper

Standard or Plain Shaper:

In this machine, the table has only two motion: crosswise in the horizontal plane and vertical movement (up and down).

The table is not provided with a swiveling motion.

Universal shaper:

This machine is similar to plain shaper except that the table can be tilted at a various angle, making it possible to inclined flat surfaces.

The table can be swiveled about 360 degrees about a central axis parallel to the cutting stroke direction and also perpendicular to it, that is, around two horizontal axes.

The table also has a movement in the horizontal plane and vertical direction (up and down) as in plain shaper.

A universal Shaper Machine (Source: AliBaba.com)

Based on cutting stroke types of shaper machines.

- Push type shaper machine
- Draw type shaper machine

Operations Performed on Shaper Machine:

There are **4-types of operations performed in a shaper machine**, and those are:

- Horizontal cutting
- Vertical cutting
- Inclined cutting
- Irregular cutting

Horizontal cutting:

Horizontal surfaces are machined by moving the work mounted on the machine table at a cross direction with respect to the ram movement.

The clapper box can be set vertical or slightly inclined towards the uncut surface.

This arrangement enables the tool to lift automatically during the return stroke. The tool will not drag on the machined surface.

Vertical cutting:

A vertical cut is made while machining the end of a workpiece, squaring up a block or machining a shoulder.

The feed is given to the tool by rotating the down feed screw of the vertical slide.

The table is not moved vertically for this purpose.

The apron is swiveled away from the vertical surface being machined.

Inclined cutting:

An angular cut is done at any angle other than a right angle to the horizontal or to the vertical plane.

The work is set on the table and the vertical slide of the tooth head is swiveled to the required angle either towards the left or towards right from the vertical position.

Irregular cutting:

A round nose tool is used for this operation.

For a shallow cut the apron may be set vertical but if the curve is quite sharp, the apron in swiveled towards the right or left away from the surface to be cut.

Parts of a Shaper Machine with Function:

Base:

The Base is designed to take the entire load of the machine tool and it is bolted to the floor of the shop.

This is made of grey cast iron to resist vibration and to take the compressive load.

Column:

The column is a Box like casting made up of cast iron and mounted on a base.

It is provided with accurately machined guideways on the top on which the ram reciprocates.

The guideways are also provided on the front vertical face for the movement of cross rail. The column encloses the ram driving mechanism.

Cross rail:

The cross rail is mounted on the ground vertical guideways of the column.

It consists of two parallel guideways on its top perpendicular to the ram axis is called as a saddle to move the table in crosswise direction by means of a feed screw.

The table can be raised or lowered to accommodate different sizes of the job by rotating elevating screw which causes the cross rail to slide up and down on the vertical face of the column.

Saddle:

It is mounted on the cross rail to hold the table firmly on its top.

The crosswise movement of the saddle causes the table to move crosswise direction by rotating the crossfeed screw.

Table:

It is mounted on the **saddle**.

It can be moved crosswise by rotating crossfeed rod and vertically by rotating the elevating screw.

The table is a box-like casting with accurately machined top and side surfaces. These surfaces having t-slots for clamping the work.

In Universal shaper, the table may be swiveled on a horizontal axis and its upper part may be tilted up or down.

In heavy Shaper, the front face of the table is supported by adjustable table support to give more rigidity.

Ram:

It is a reciprocating member of the shaper which holds the tool and the reciprocates on the guideways on the top of the column by means of quick return motion mechanism.

It houses the screwed shaft for altering the position of the RAM with respect to the work. The RAM is in semi-cylindrical form and heavily ribbed inside to make it more rigid.

Tool Head:

The tool head holds the cutting tool firmly and provides both vertical and angular movement to the tool with the help of down feed screw handle.

The head allows the tool to have an automatic relief during the return stroke.

The vertical slide of a tool head consists of a swivel base which is graduated in degrees. So, the vertical slide can set at any angle with the work surface.

The amount of feed or depth of cut may be adjusted by a micrometer dial on top of the down feed screw.

A tool head again consists of:

- Apron
- Clapper box and clapper block

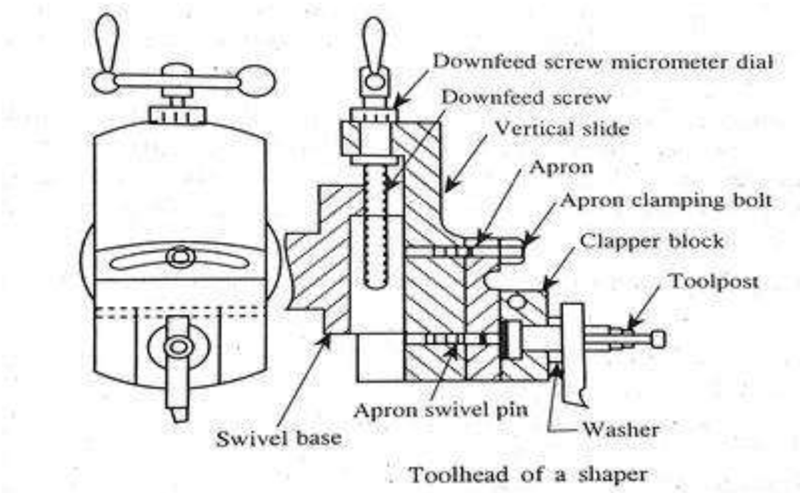
Apron consisting of clapper box and tool post is clamped on the vertical slide by the screw.

The **apron** Can be swiveled upon the apron swivel pin towards left or right.

The **clapper box** houses the **clapper block** by means of a hinge pin.

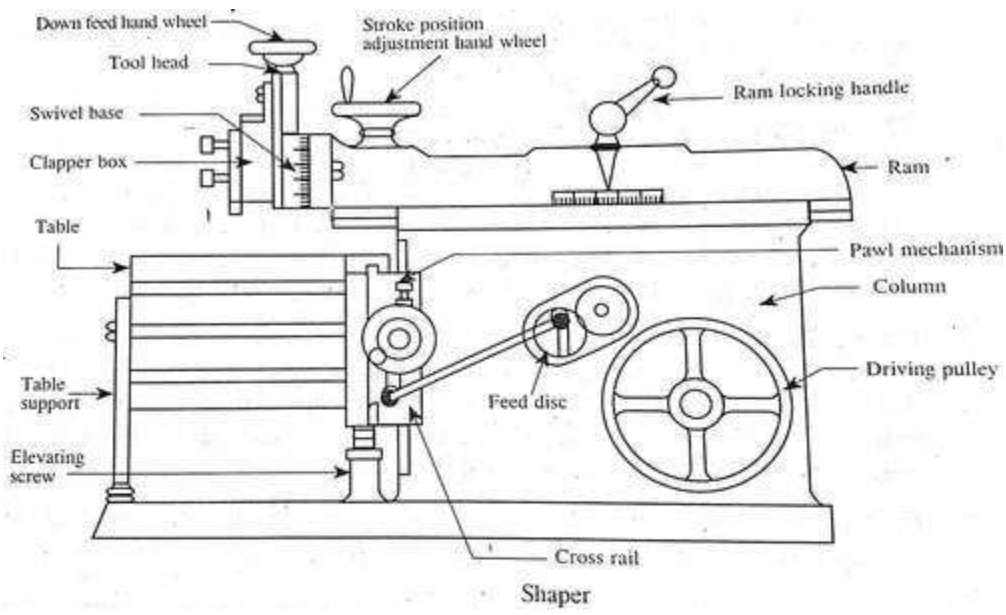
The **tool post** is mounted on the **clapper block**.

During forwarding cutting stroke the clapper block keeps the rigid support to the tool by fitting securely into clapper box and while returning stroke the tools slide over the work by lifting, the block out of clapper boxes shown in the above figure



Detailed diagram of tool head with parts

The below diagram is shown is a principal part of the Shaper Machine:



Specification of Shaper Machine:

The specification of shaper machine depends upon the following:

- The maximum length of stroke ram.
- Types of the drive (Crank, Gear and Hydraulic type)
- Power input of the machine
- Floor space required to establish the machine
- Weight of the machine in tonne.
- Feed
- Cutting to return stroke ratio.
- Angular movement of the table.

Advantages of Shaper Machine:

- The single point tool used which is inexpensive or we can say low tooling cost.
- The cutting stroke having a definite stopping point.
- The work can be held easily in the shaper machine.
- The set up is very quick and easy and also can be readily changed from one job to another job.

Disadvantages of Shaper Machine:

- By nature, it is a slow machine because of its straight-line forward and returns strokes the single point cutting tool requires Several strokes to complete a work. (They are slow)
- The cutting speed is not usually very high speeds of reciprocating motion due to high inertia force developed in the motion of the units and components of the machine.

Applications of Shaper Machine:

- To generate straight and flat surfaces.
- Smooth rough surfaces.
- Make internal splines.
- Make gear teeth.
- To make dovetail slides.
- Make key ways in pullies or gears.
- Machining of die, punches, straight and curved slots.

Hydraulic Shaper Mechanism in Shaper Machine:

In **hydraulic shaper machine**, a constant speed motor drives a hydraulic pump which delivers oil at a constant pressure to the line.

A regulating valve admits oil under pressure to each end on the piston alternately.

At the same time allowing oil from the opposite end of the piston to return to the reservoir.

The piston is pushed by the oil and being connected to ram by piston rod, pushes the ram carrying the tool.

The admission of oil to each end of the piston, alternately, is accomplished with the help of trip dogs and pilot valves.

As the ram moves and complete its stroke (Forward and Return) a trip dog will trip the pilot valve which operates the regulating valve.

The regulating valve will admit the oil to the other side of the piston and the motion of the ram will get reversed.

It is clear that the length of the ram stroke will depend upon the position of trip dogs.

The length of the ram stroke can be changed by unclamping and moving the trip dogs to the desired position.

A hydraulic shaper looks like this:

Hydraulic Shaper Machine (Source: IndiaMart)

Video lecture on Shaping Machine if you wish you can check this video for brief knowledge:

Conclusion:

So today we completed the Shaping machine topic, we discuss definition, parts, working, types, application, advantages, disadvantages, and specifications of a Shaper Machine, hope you understand the whole concept. In case you wanna read this type of article on the lathe machine tool and drilling machine you can check these article for that “Lathe Machine Tool: Definition, Parts, Types and Operations” & “Drilling Machine: Definition, Parts, Types, and Operations“

If you have any queries or doubts about the Shaper machine, you can ask me in the comment section or we have a dedicated Q&A platform for you where you directly post your question: **Click here to post your question**, and also you can **join our facebook group**. I will love to hear from you and glad to help you. Till then enjoy rest your day. Cheers

TABLE DRIVE MECHANISM

A planer driving mechanism provides the longitudinal to and fro motion of the planer worktable. The following methods are employed for the said purpose.

(a) Open and cross belt drive (b) Gear drive (c) Reversible motor drive

(a) Open and cross belt drive:

Two belts, one open and one crossed operate on loose and tight pulleys. Crossed belt is used for forward or cutting stroke and the open belt for return motion. The crossed belt making a greater arc of contact on the pulley is considered better for driving the table on the cutting stroke.

There are two tight pulleys and two loose pulleys. Larger tight pulley - Cutting stroke and smaller tight pulley - quicker return stroke.

Crossed belt drive mechanism permits operation of the gear train in such a manner that the table will travel slowly on the cutting stroke and travel faster on the return stroke. Pulleys keyed to the drive pinion shaft are called tight pulleys and those which turn freely on the shaft are called loose pulleys. During cutting stroke the crossed belt is on the tight pulley, the open belt is on the loose pulley and the position is reverse during the return stroke.

DRIVE MECHANISM

For obtaining continuous forward and return motion of the planer table both the open and crossed belts run continually and are shifted back and forth by the belt shifter which is linked to the reverse lever. Trip dogs are provided, one each at both ends of the planer table. At the end of each stroke, the trip dog meets against the reverse lever, actuates the belt shifter and thus the table movement is reversed

Reversible motor drive:

The reciprocating motion of the planer table is obtained by driving through a worm on to a rack attached to the length of the underside of the table. The reversal of the drive is obtained by reversing the motor itself either by field or phase changing. Commonly used on modern planers as it provides a wider range of table speeds and a better control. Most planers are driven direct by a coupled motor in place of the old method of open and crossed belt drive.

MAJOR COMPONENTS AND THEIR FUNCTIONS:

BED:

- The bed of a planer is a box-like casting having cross ribs. It is very large in size and heavy in weight and it supports the column and all other moving parts of the machine.
- The bed is made slightly longer than twice the length of the table so that the full length of the table may be moved on it.
- The gearing arrangement and hydraulic cylinder for driving the table housed under the bed.

TABLE:

- The planer table is a heavy rectangular casting and is made of good quality cast iron.
- It is driven by hydraulic cylinder or by gear pinion driving and a rack which is fastened under the centre of the table.
- Motor driving pinion is reverse type with variable speed.
- Upper side of the table has T slots to clamp the work piece.

COLUMN:

- The housings also called columns or uprights are rigid box-like vertical structures placed on each side of the bed and are fastened to the sides of the bed.
- It will handle heavy load without deflection.

CROSS RAIL:

- It is mounted on vertical guide ways of column and slides up and down.
- Handled by hand or by power operated screw
- The Crossrail has screws for vertical and crossfeed of the toolheads and a screw for elevating the rail. These screws rotated either by hand or by power.

- This is necessary to generate a flat horizontal surface on a workpiece because the tool follows the pat on the Crossrail during crossfeed.
- The two elevating screws in the two housing are rotated by an equal amount to keep the Crossrail horizontal in any position.
- The front face of the cross rail is accurately machined to provide a guide surface for the tool head saddle.

TOOL HEAD:

- It's generally holds the tool firmly.
- Tool post is connected with the tool head, so that in return stroke tool will be raised and also it saves cutting edge.

Milling

Introduction

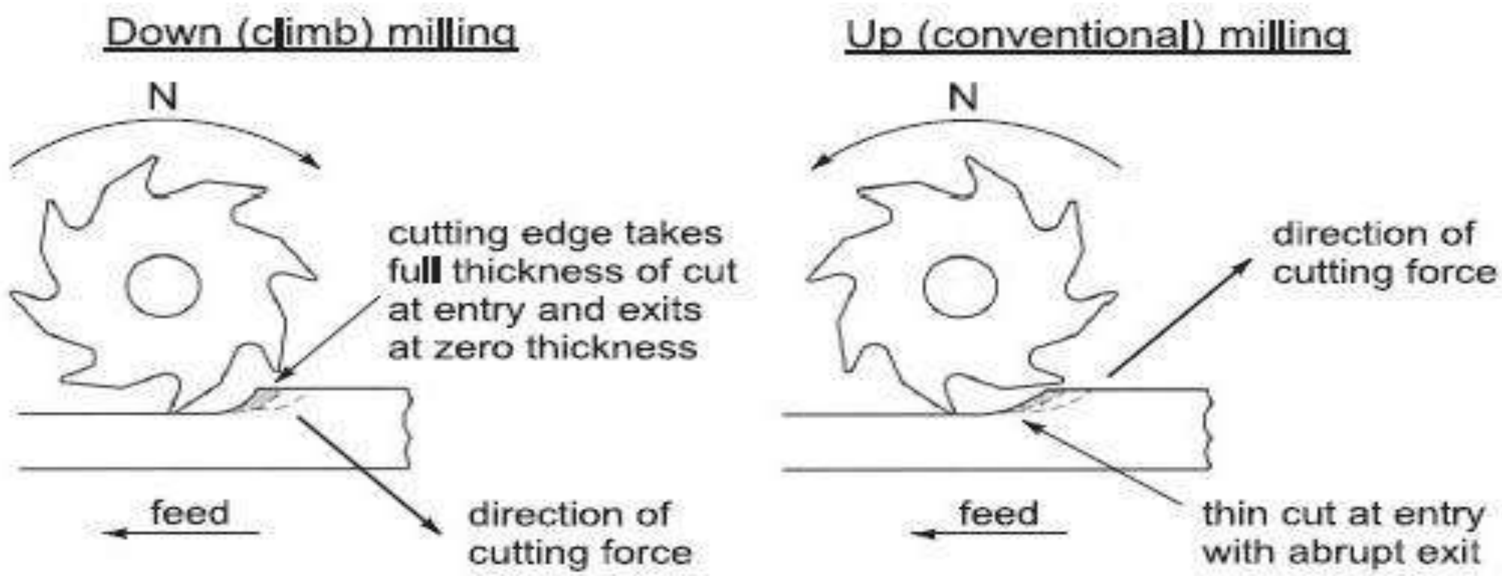
- Milling is the process of machining flat, curved, or irregular surfaces by feeding the work piece against a rotating cutter containing a number of cutting edges. The usual Mill consists basically of a motor driven spindle, which mounts and revolves the milling cutter, and a reciprocating adjustable worktable, which mounts and feeds the work piece.
- Milling machines are basically classified as vertical or horizontal. These machines are also classified as knee-type, ram-type, manufacturing or bed type, and planer-type. Most milling machines have self-contained electric drive motors, coolant systems, variable spindle speeds, and power-operated table feeds

- Milling is a process of producing flat and complex shapes with the use of multi-tooth cutting tool, which is called a milling cutter and the cutting edges are called teeth.
- The axis of rotation of the cutting tool is perpendicular to the direction of feed, either parallel or perpendicular to the machined surface. The machine tool that traditionally performs this operation is called milling machine.
- Milling is an interrupted cutting operation in which the teeth of the milling cutter enter and exit the work during each revolution. This interrupted cutting action subjects the teeth to a cycle of impact force and thermal shock on every rotation. The tool material and cutter geometry must be designed to withstand these conditions. Cutting fluids are essential for most milling operations.

Manufacturing Technology

Types of milling

- There are two basic types of milling
- *Down* (*climb*) milling, when the cutter rotation is in the same direction as the motion of the work piece being fed.
- *up* (*conventional*) milling, in which the work piece is moving towards the cutter, opposing the cutter direction of rotation



Two types of peripheral milling. Note the change in the cutting force direction.

Comparison of Up and Down Milling

- Down milling, the cutting force is directed into the work table, which allows thinner work parts to be machined. Better surface finish is obtained but the stress load on the teeth is abrupt, which may damage the cutter.
- Up milling, the cutting force tends to lift the work piece. The work conditions for the cutter are more favorable. Because the cutter does not start to cut when it makes contact (cutting at zero cut is impossible), the surface has a natural waviness.

Milling Operations

Milling of Flat Surfaces

Peripheral Milling

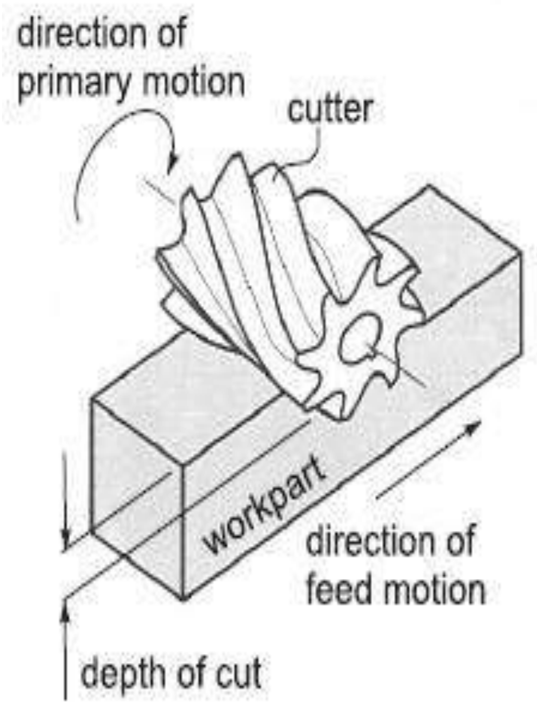
- In *peripheral milling*, also called *plain milling*, the axis of the cutter is parallel to the surface being machined, and the operation is performed by cutting edges on the outside periphery of the cutter. The primary motion is the rotation of the cutter. The feed is imparted to the work piece.
- In peripheral milling the axis of the cutter rotation is parallel to the work surface to be machined.

Types of Peripheral Milling

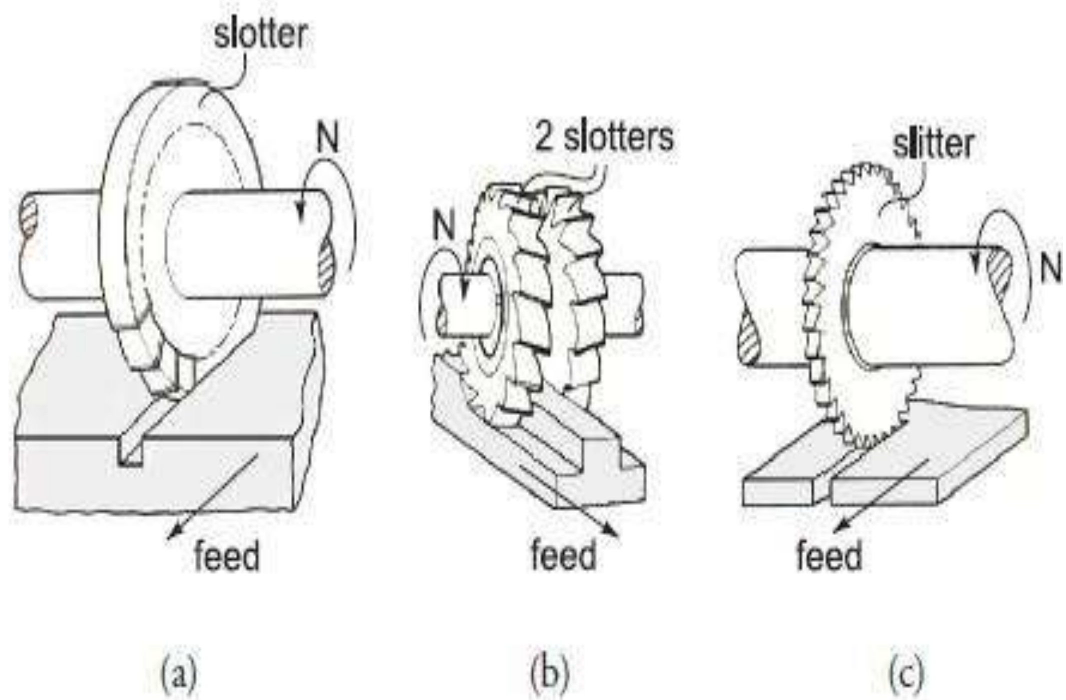
- Slab milling
  - The basic form of peripheral milling in which the cutter width extends beyond the work piece on both sides
- Slotting
  - *Slotting*, also called *slot milling*, in which the width of the cutter, usually called *slotter*, is less than the work piece width.
  - The slotter has teeth on the periphery and over the both end faces. When only the one-side face teeth are engaged, the operations is known as the *side milling*, in which the cutter machines the side of the work piece

- Straddle milling
  - *Straddle milling*, which is the same as side milling where cutting takes place on both sides of the work.
  - In straddle milling, two slotters mounted on an arbor work together;
  - When the slotter is very thin, the operation called *slitting* can be used to mill narrow slots (slits) or to cut a work part in two.
  - The slitting cutter (*slitter*) is narrower than the slotter and has teeth only on the periphery.

Peripheral Milling

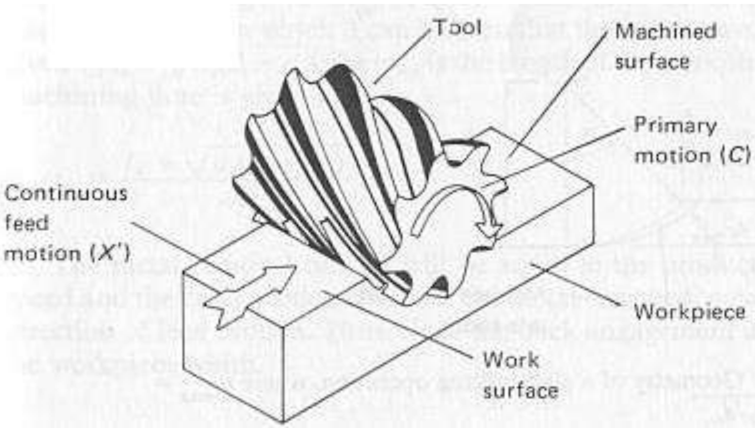


Peripheral slab milling operation.

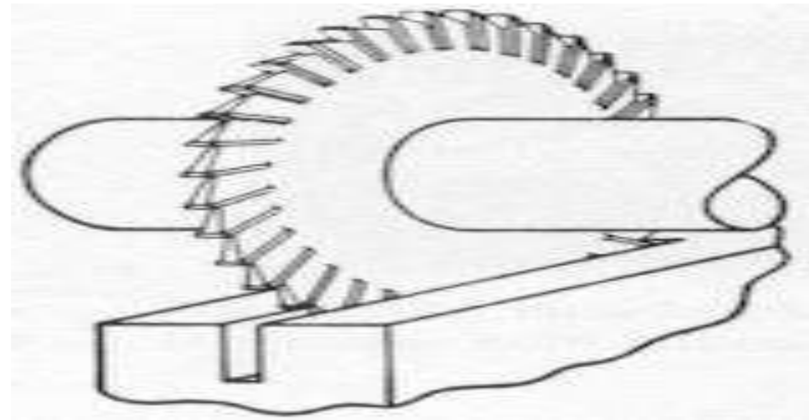


Peripheral milling operations with narrow cutters: (a) slotting, (b) straddle milling, and (c) slitting.

Peripheral Milling



A



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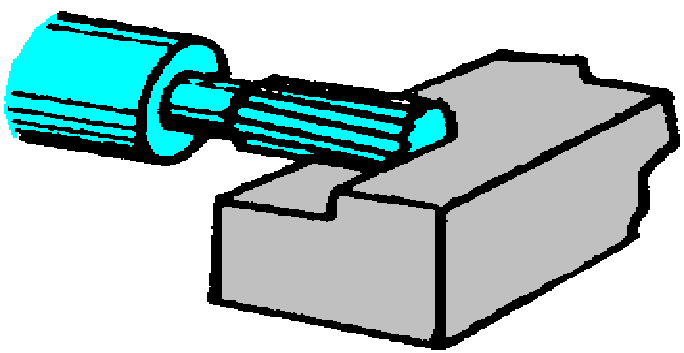

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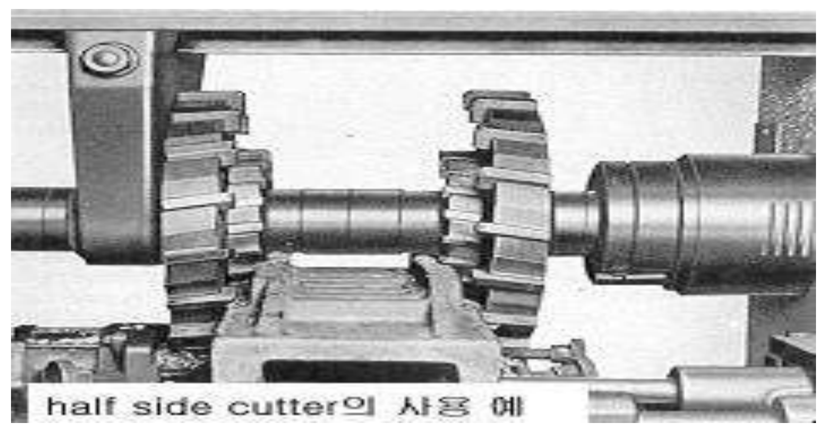


D

A. Slab milling , B. Slot milling , C. Side milling , D. Straddle milling

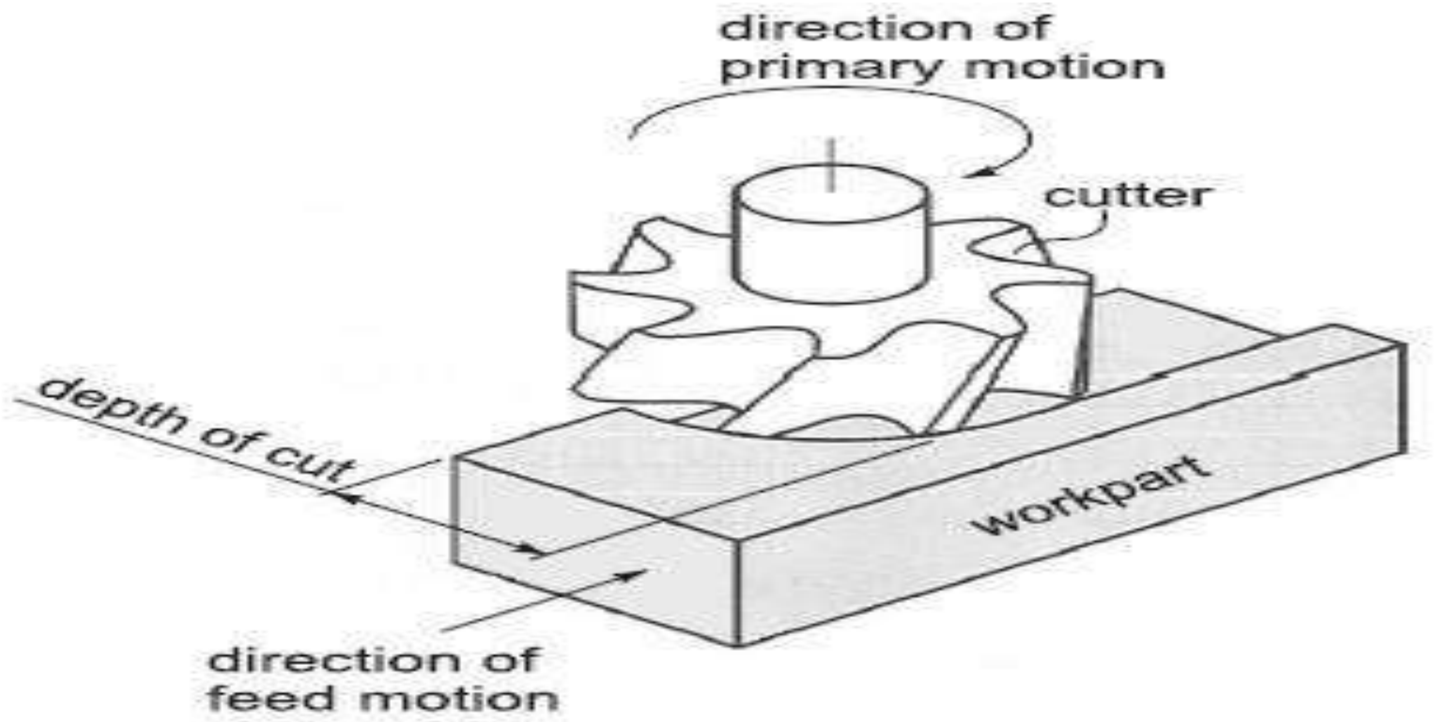
Advantages of peripheral milling

- More stable holding of the cutter. There is less variation in the arbor torque
- Lower power requirements.
- Better surface finish.

Face milling

- In *face milling*, cutter is perpendicular to the machined surface. The cutter axis is vertical, but in the newer CNC machines it often is horizontal. In face milling, machining is performed by teeth on both the end and periphery of the face-milling cutter.
- Face milling is usually applied for rough machining of large surfaces. Surface finish is worse than in peripheral milling, and feed marks are inevitable. One advantage of the face milling is the high production rate because the cutter diameter is large and as a result the material removal rate is high. Face milling with large diameter cutters requires significant machine power.
- In Face milling the axis of the cutter rotation is perpendicular to the work surface to be machined.

Face milling



Partial face milling operation. The face-milling cutter machines only one side of the workpiece.

End milling

- In *end milling*, the cutter, called *end mill*, has a diameter less than the work piece width. The end mill has helical cutting edges carried over onto the cylindrical cutter surface are used to produce pockets, closed or end key slots, etc.

End milling operation used to cut a pocket in an aluminum work part.

Milling of Complex Surfaces

- Milling is one of the few machining operations, which are capable of machining complex *two*- and *three-dimensional surfaces*, typical for dies, molds, cams, etc. Complex surfaces can be machined either by means of the cutter path (*profile milling* and *surface contouring*), or the cutter shape (*form milling*).

Form milling

- In form milling, the cutting edges of the peripheral cutter (called *form cutter*) have a special profile that is imparted to the work piece. Cutters with various profiles are available to cut different two-dimensional surfaces. One important application of form milling is gear manufacturing

Types of Form Milling

Profile milling

- In profile milling, the conventional end mill is used to cut the outside or inside periphery of a flat part. The end mill works with its peripheral teeth and is fed along a curvilinear path equidistant from the surface profile.

Surface contouring

- The end mill, which is used in surface contouring has a hemispherical end and is called *ball-end mill*. The ball-end mill is fed back and forth across the work piece along a curvilinear path at close intervals to produce complex three-dimensional surfaces.
- Similar to profile milling, surface contouring require relatively simple cutting tool but advanced, usually computer-controlled feed control system.

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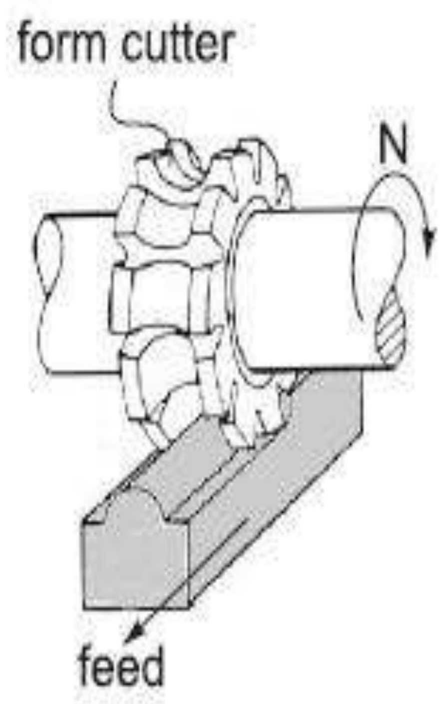
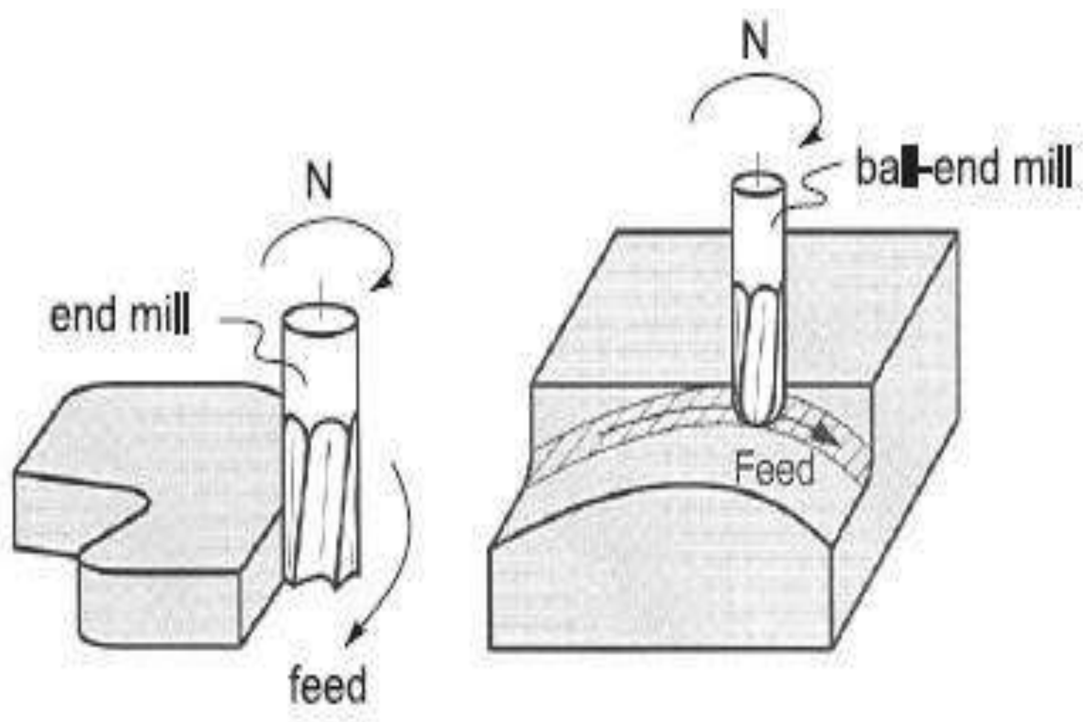
Form Milling



Form milling of two-dimensional surface.



(*Left*) Profile milling of a cam, and (*Right*) Surface contouring of a complex three-dimensional surface.

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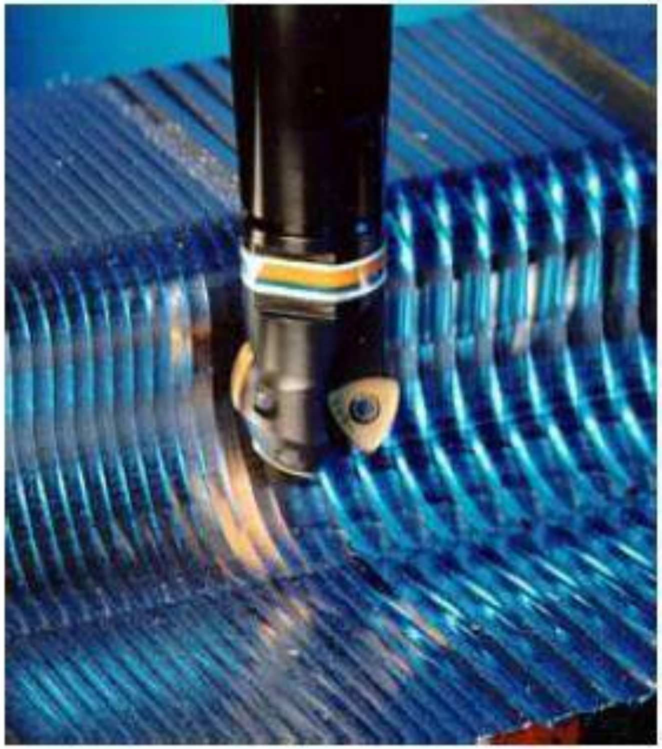
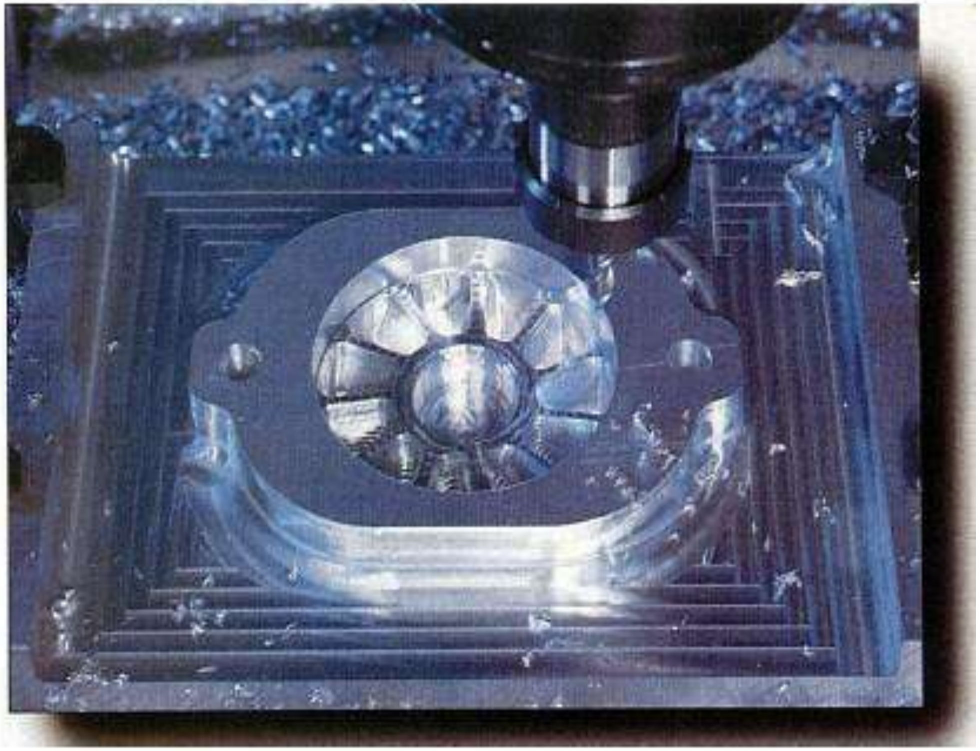
Surface contouring



Close-up view of a hemispherical ball-end mill with indexed carbide inserts used for rough cutting of a three-dimensional surface.



Surface contouring of die cavity. The cutter used is a high-speed steel ball-end mill.

Milling machines

- The conventional milling machines provide a primary rotating motion for the cutter held in the spindle, and a linear feed motion for the work piece, which is fastened onto the worktable.
- Milling machines for machining of complex shapes usually provide both a rotating primary motion and a curvilinear feed motion for the cutter in the spindle with a stationary work piece.

Milling Machine Types

- Various machine designs are available for various milling operations. In this section we discuss only the most popular ones, classified into the following types
  - **Column-and-knee milling machines**
  - **Bed type milling machines**
  - **Machining centers**

Other Classifications

According to nature of purposes of use

- General Purpose Milling Machine
  - Conventional milling machines, e.g Up and down milling machines
- Single Purpose Milling Machine
  - Thread, cam milling machines and slitting machine
- Special Purpose Milling Machine
  - Mass production machines, e.g., duplicating mills, die sinkers, thread milling etc.

According to configuration and motion of the work-holding table / bed

Knee type

- small and medium duty machines the table with the job/work travels over the bed (guides) in horizontal (X) and transverse (Y) directions and the bed with the table and job on it moves vertically (Z) up and down.

Bed type

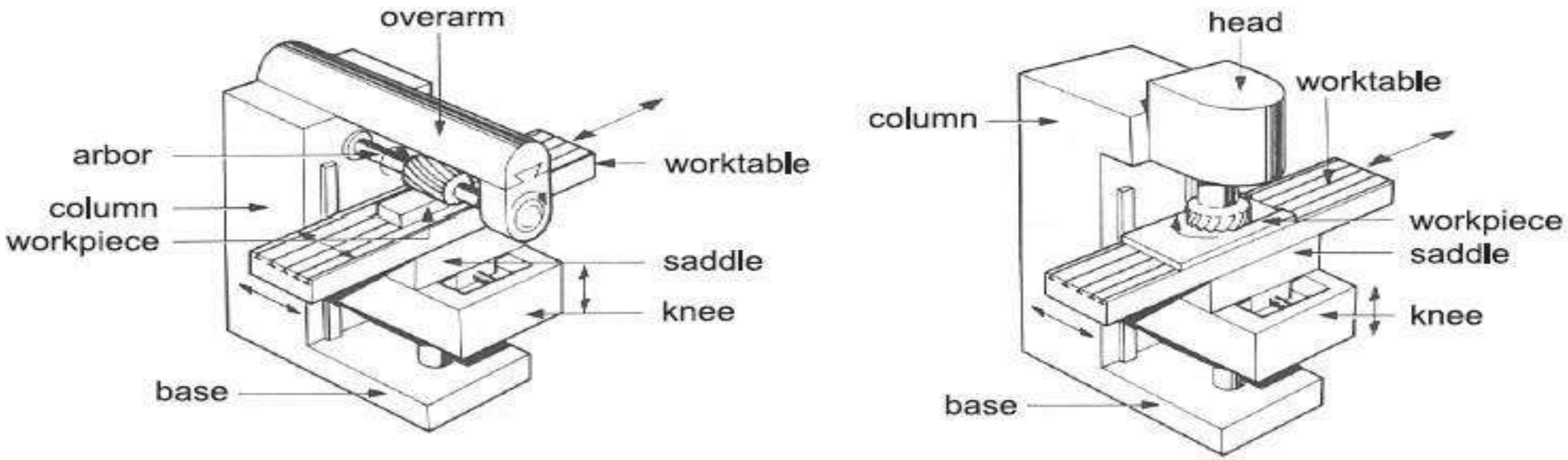
- Usually of larger size and capacity; the vertical feed is given to the milling head instead of the knee type bed

According to the orientation of the spindle

- Horizontal Milling Machine
  - Horizontal spindle Feed
- Vertical milling machine
  - Vertical Spindle Feed
- Universal milling machine
  - Both Horizontal and Vertical spindle Feed

Column-and-knee milling machines

- The *column-and-knee milling machines* are the basic machine tool for milling. The name comes from the fact that this machine has two principal components, a *column* that supports the spindle, and a *knee* that supports the work table.
- There are two different types of column-and-knee milling machines according to position of the spindle axis
  - Horizontal &Vertical.



Two basic types of column-and-knee milling machines, (*Left*) horizontal, and (*Right*) vertical.

Manufacturing Technology

Bed type machines

- In bed type milling machines, the worktable is mounted directly on the bed that replaces the knee. This ensures greater rigidity, thus permitting heavier cutting conditions and higher productivity. This machines are designed for mass production.
- Single-spindle bed machines are called *simplex mills* and are available in either horizontal or vertical models. *Duplex mills* have two spindle heads, and *triplex mills* add a third spindle mounted vertically over the bed to further increase machining capability.

Portal planer mill for heavy machining of large workparts.

Manufacturing Technology

Machining centers

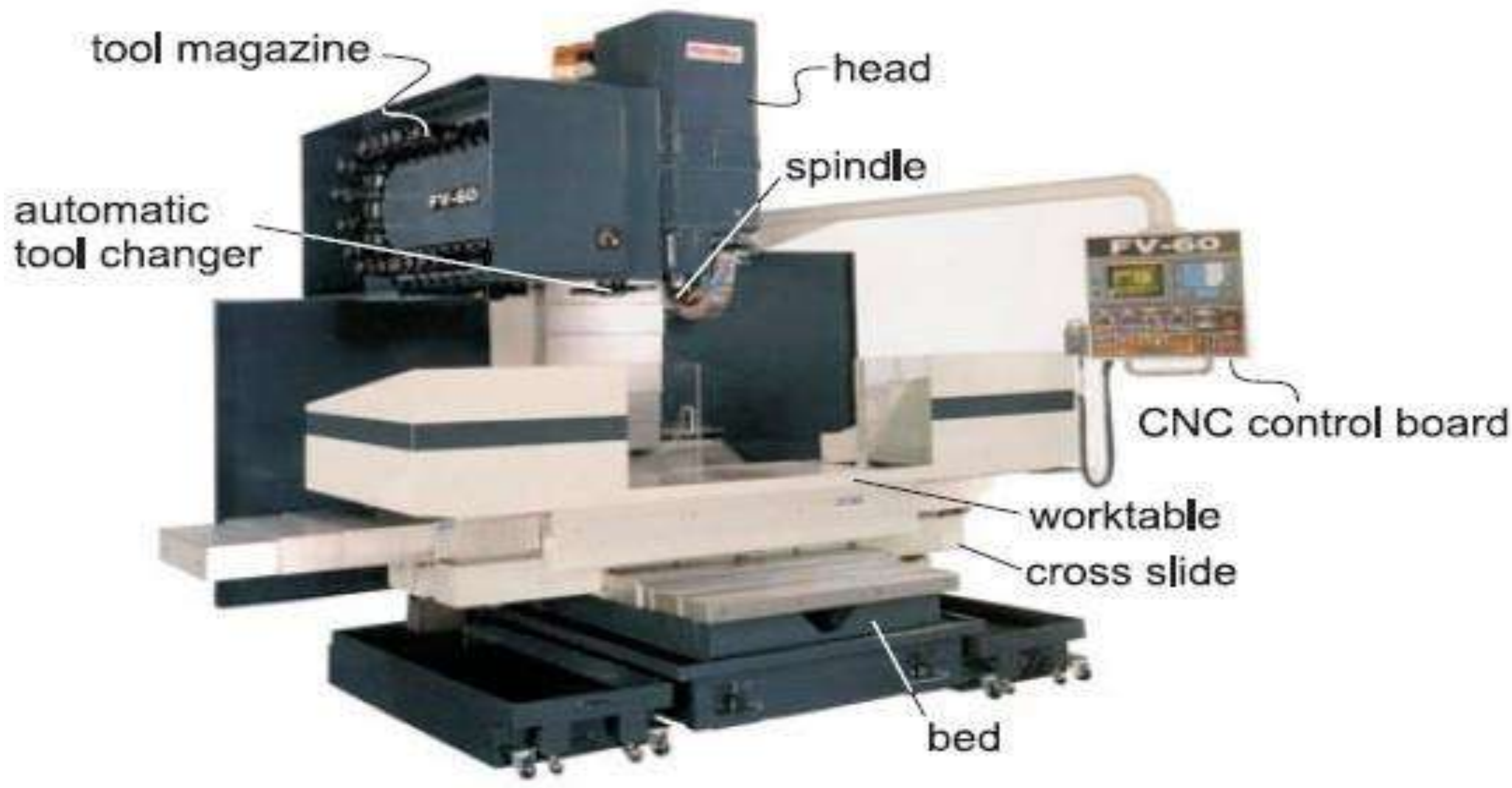
- A machining center is a highly automated machine tool capable of performing multiple machining operations under CNC control.

The features that make a machining center unique include the following

- Tool storage unit called *tool magazine* that can hold up to 120 different cutting tools.
- *Automatic tool changer*, which is used to exchange cutting tools between the tool magazine and machining center spindle when required. The tool changer is controlled by the CNC program.
- *Automatic work part positioning*. Many of machining centers are equipped with a rotary worktable, which precisely position the part at some angle relative to the spindle. It permits the cutter to perform machining on four sides of the part.

Manufacturing Technology

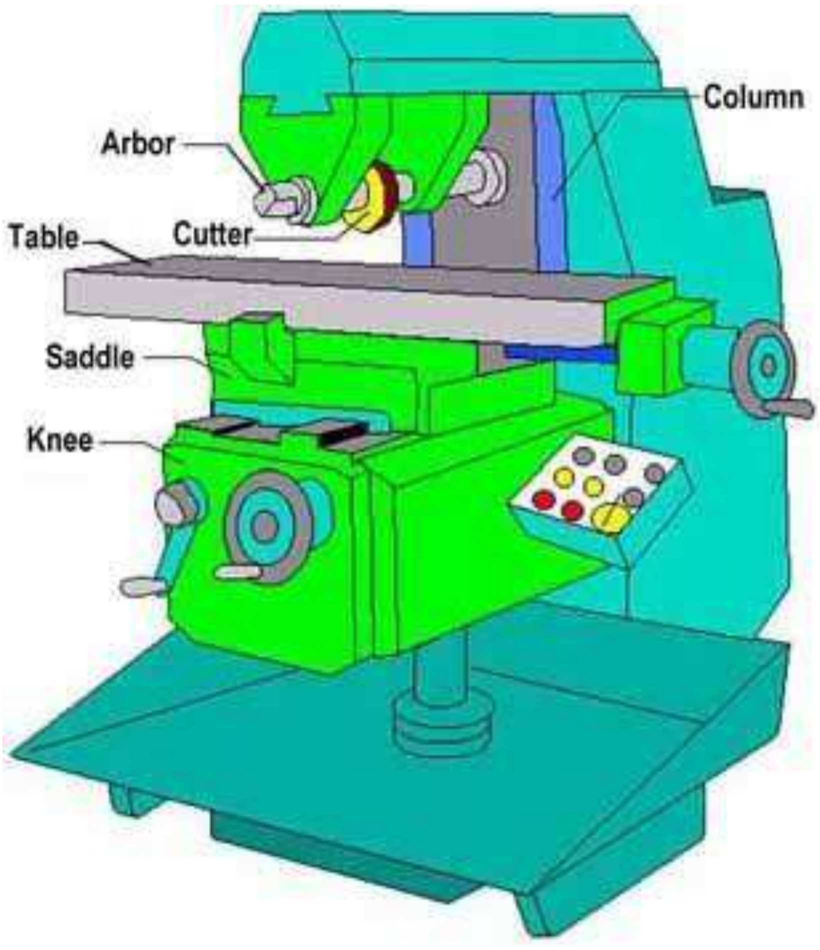
Machining center

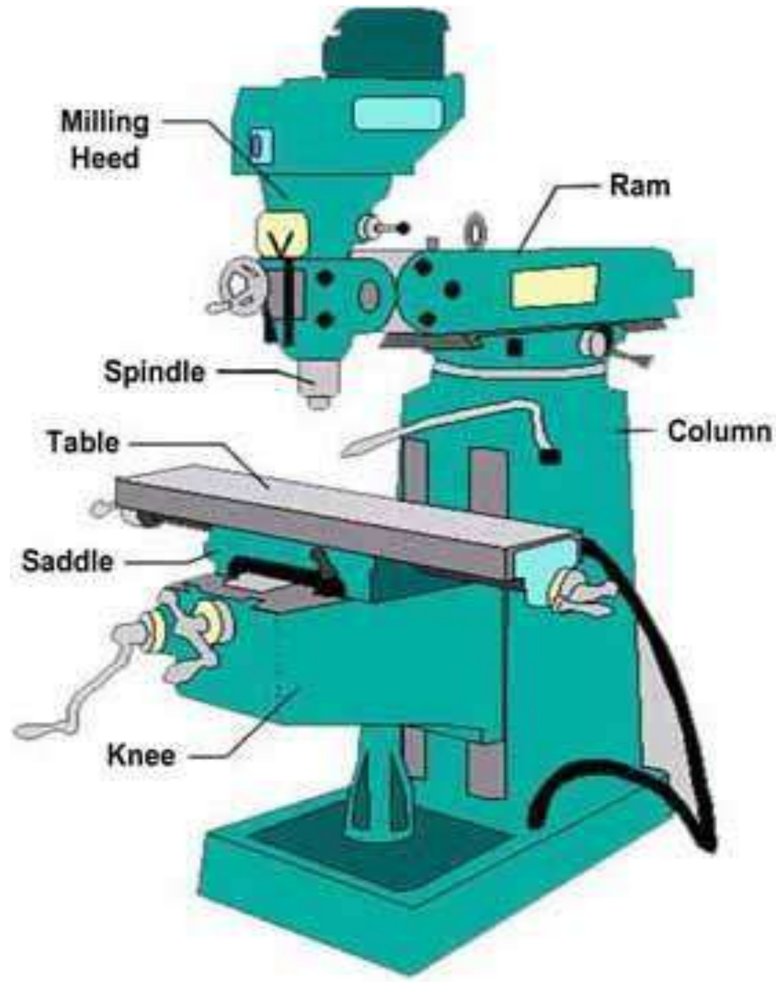


Universal machining center.

Manufacturing Technology

- Milling Machine Specifications



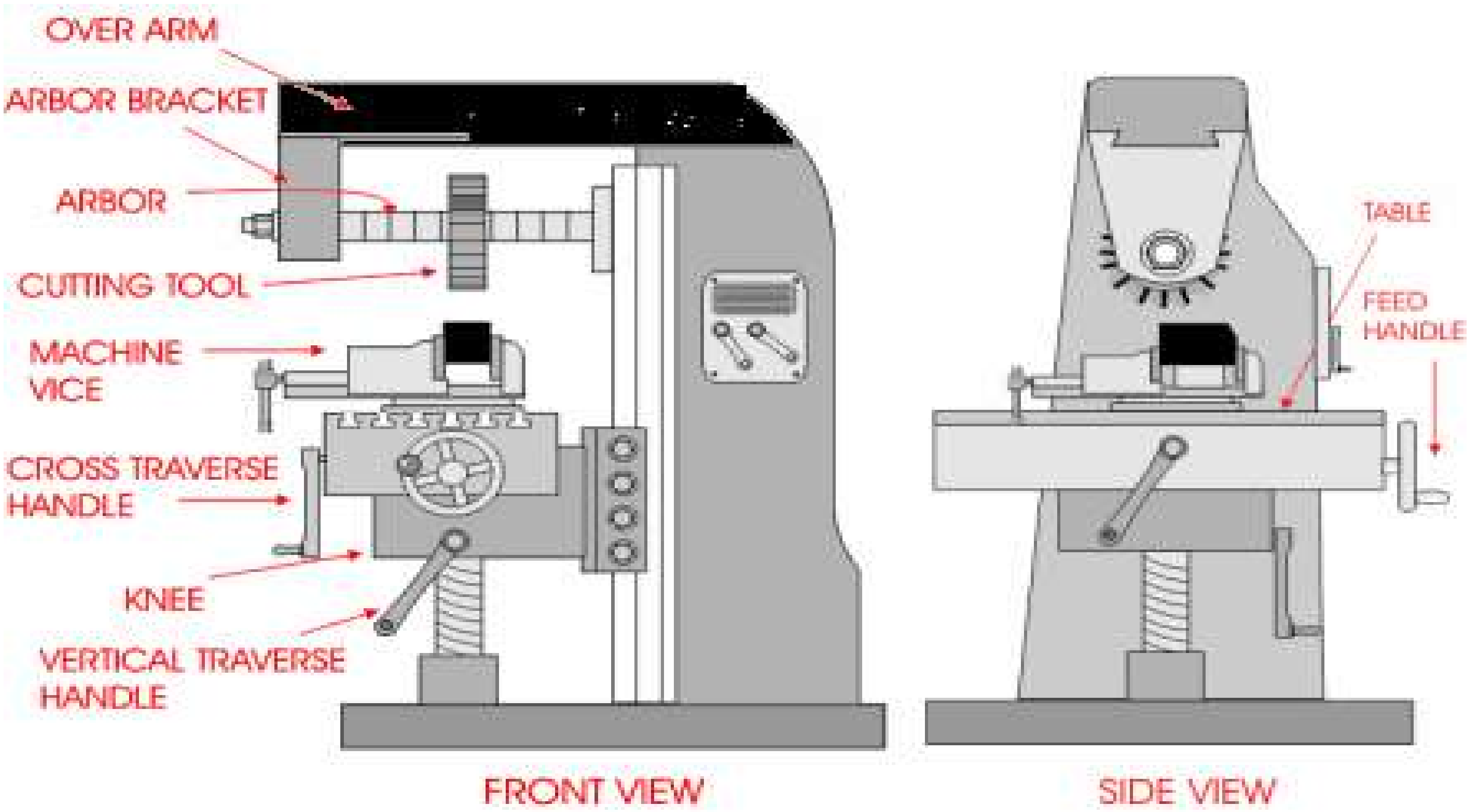


Horizontal Milling Machine

Vertical Milling Machine

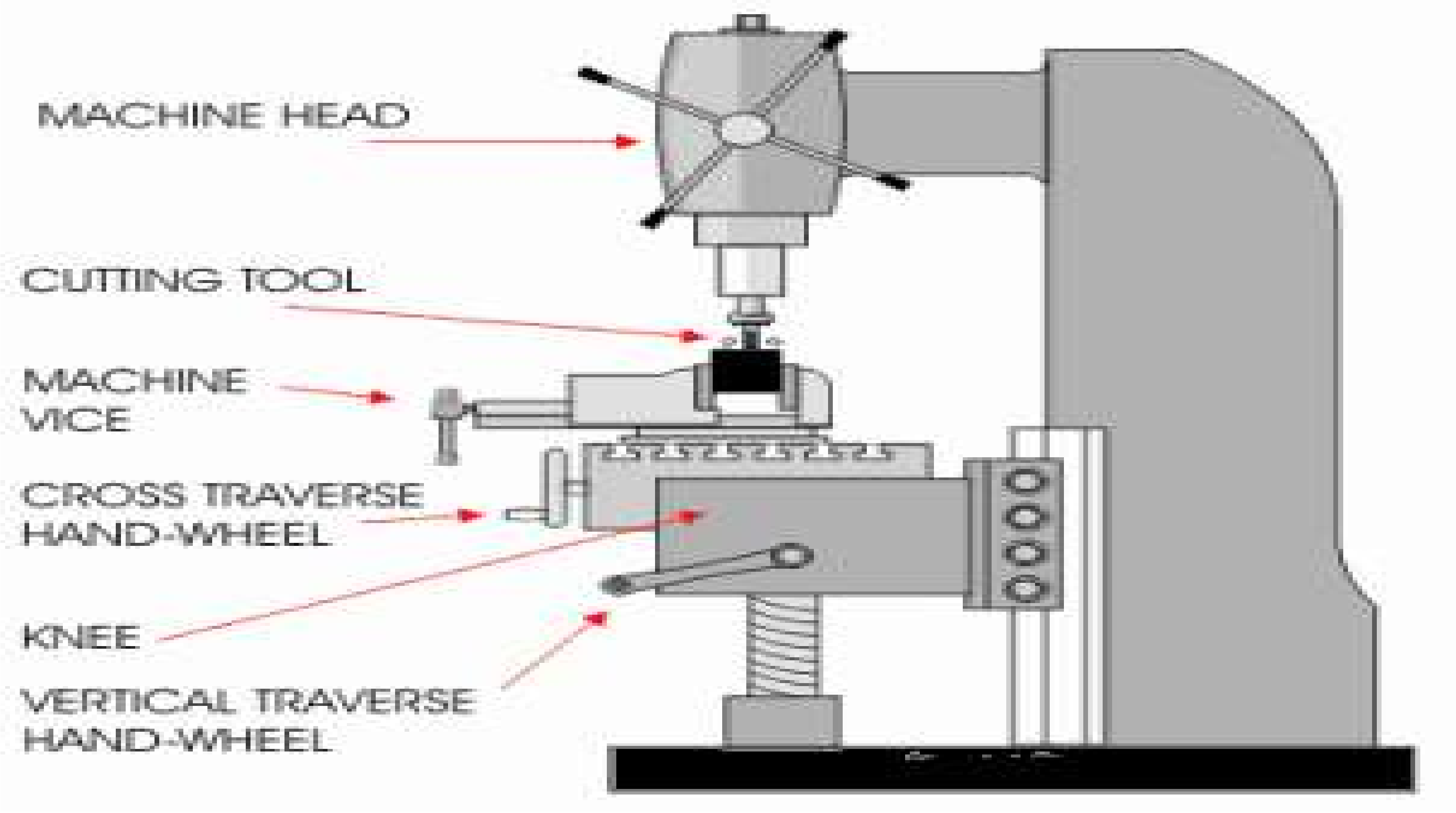
Manufacturing Technology

- Milling Machine Specifications



Manufacturing Technology

- Milling Machine Specifications



Milling cutters

Classification of milling cutters according to their design

- *HSS cutters:* Many cutters like end mills, slitting cutters, slab cutters, angular cutters, form cutters, etc., are made from high-speed steel (HSS).
- *Brazed cutters*: Very limited number of cutters (mainly face mills) are made with brazed carbide inserts. This design is largely replaced by mechanically attached cutters.
- *Mechanically attached cutters:* The vast majority of cutters are in this category. Carbide inserts are either clamped or pin locked to the body of the milling cutter.

Milling Cutter Nomenclature

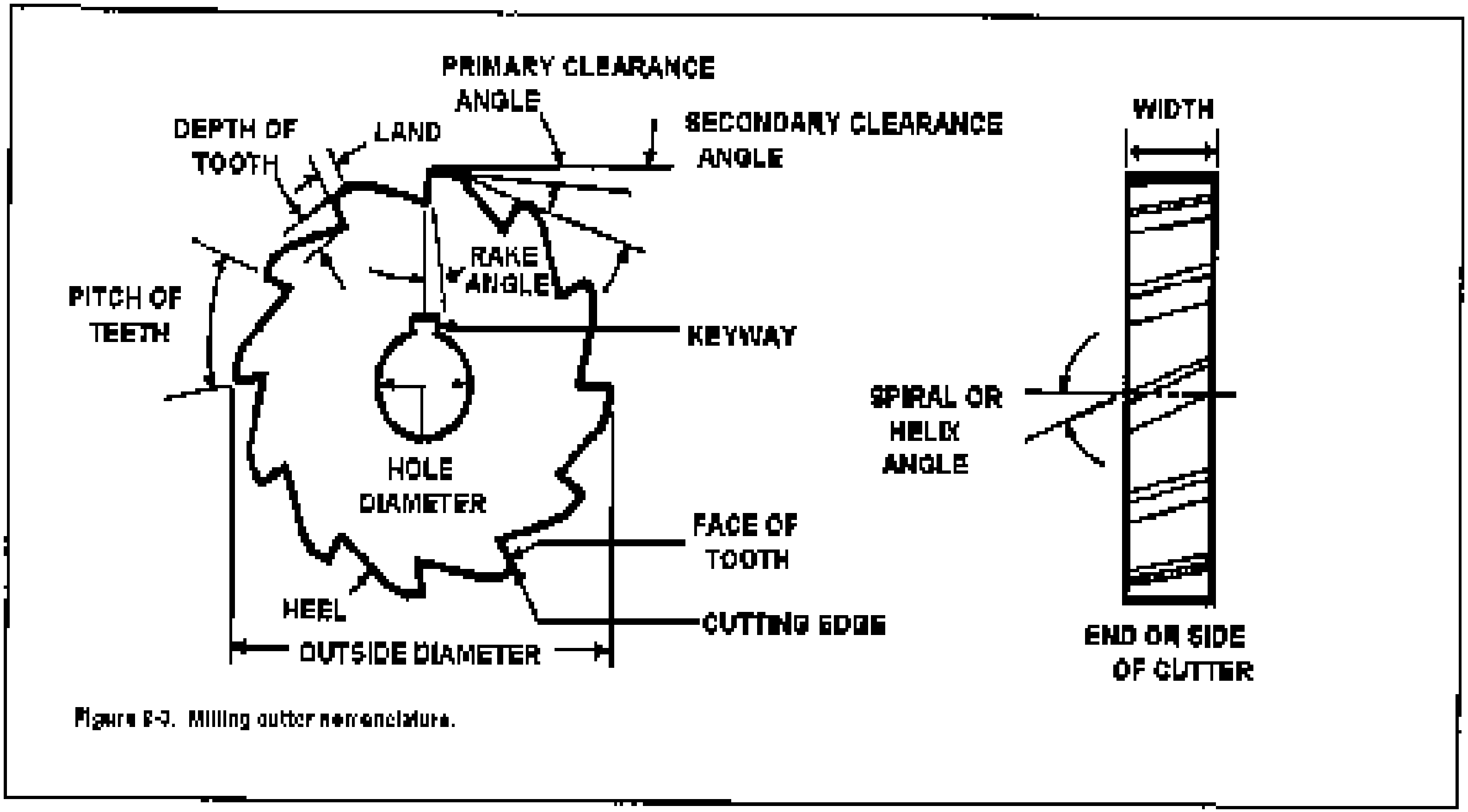


Figure 8-3. Milling cutter nomenclature.

Milling Cutter Nomenclature

- The pitch refers to the angular distance between like or adjacent teeth.
- The pitch is determined by the number of teeth. The tooth face is the forward facing surface of the tooth that forms the cutting edge.
- The cutting edge is the angle on each tooth that performs the cutting.
- The land is the narrow surface behind the cutting edge on each tooth.
- The rake angle is the angle formed between the face of the tooth and the centerline of the cutter. The rake angle defines the cutting edge and provides a path for chips that are cut from the workpiece.
- The primary clearance angle is the angle of the land of each tooth measured from a line tangent to the centerline of the cutter at the cutting edge. This angle prevents each tooth from rubbing against the workpiece after it makes its cut.

Milling Cutter Nomenclature

- This angle defines the land of each tooth and provides additional clearance for passage of cutting oil and chips.
- The hole diameter determines the size of the arbor necessary to mount the milling cutter.
- Plain milling cutters that are more than 3/4 inch in width are usually made with spiral or helical teeth. A plain spiral-tooth milling cutter produces a better and smoother finish and requires less power to operate. A plain helical-tooth milling cutter is especially desirable when milling an uneven surface or one with holes in it.

Classification of milling cutters associated with the various milling operations

Profile sharpened cutters

- surfaces are not related with the tool shape
  - Slab or plain milling cutter : straight or helical fluted
  - Side milling cutters – single side or both sided type
  - Slotting cutter
  - Slitting or parting tools
  - End milling cutters – with straight or taper shank
  - Face milling cutters

Form relieved cutters

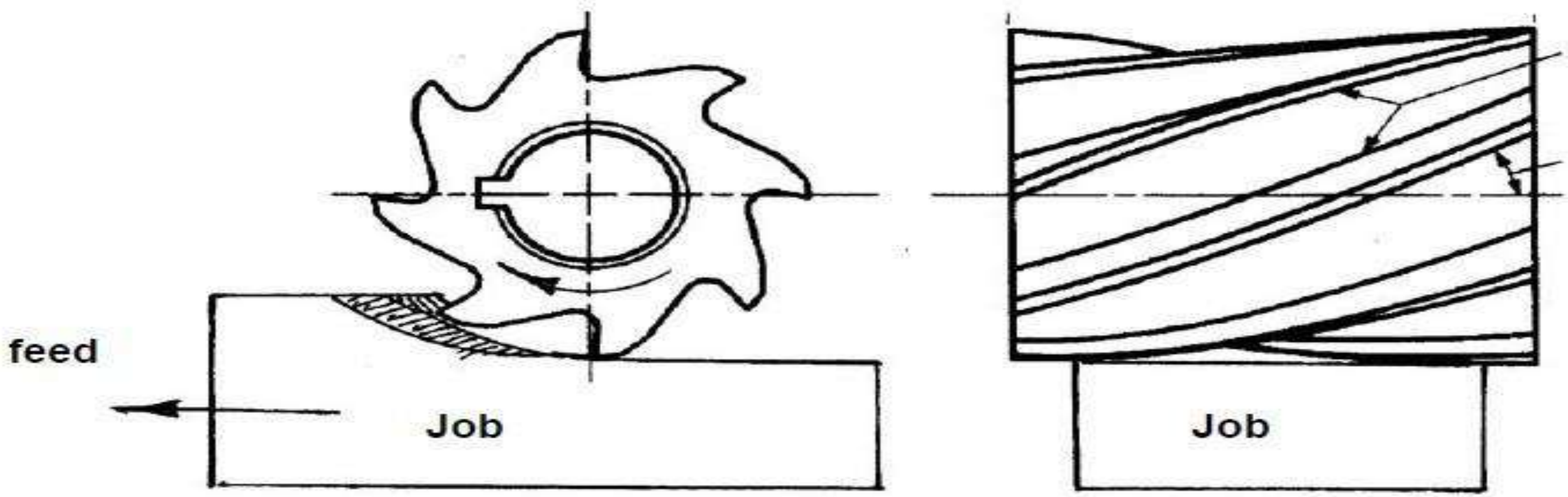
- Where the job profile becomes the replica of the tool-form
  - Form cutters
  - Gear (teeth) milling cutters
  - Spline shaft cutters
  - Tool form cutters
  - T-slot cutters
  - Thread milling cutter

Profile sharpened cutters

- The profile sharpened cutters are inherently used for making flat surfaces or surface bounded by a number of flat surfaces only.

Slab or Plain milling cutters

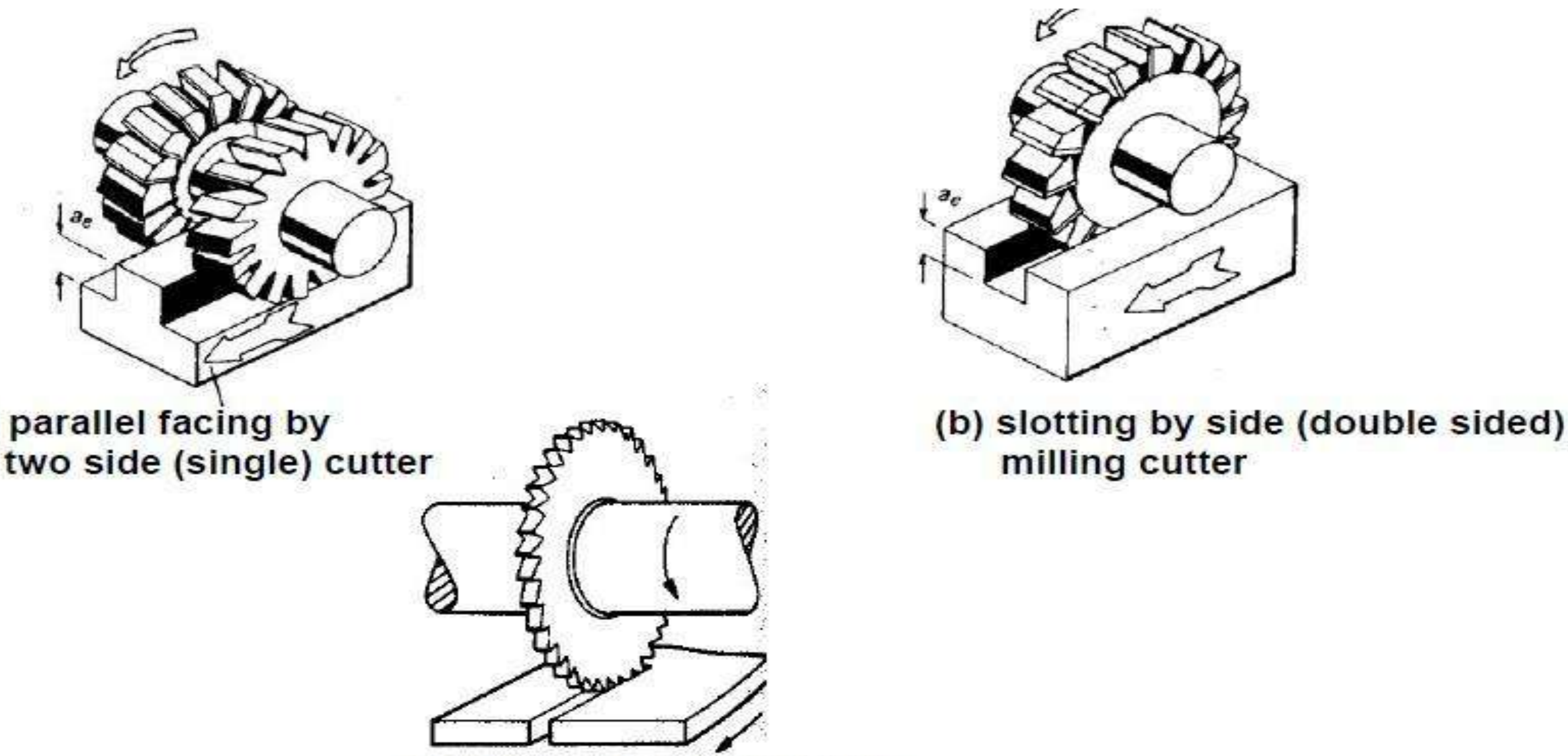
- Plain milling cutters are hollow straight HSS cylinder of 40 to 80 mm outer diameter having 4 to 16 straight or helical equi-spaced flutes or cutting edges and are used in horizontal arbour to machine flat surface



Machining flat surface by slab milling Cutter

Side and slot milling cutters

- These arbour mounted disc type cutters have a large number of cutting teeth at equal spacing on the periphery.



(a) parallel facing by two side (single) cutter

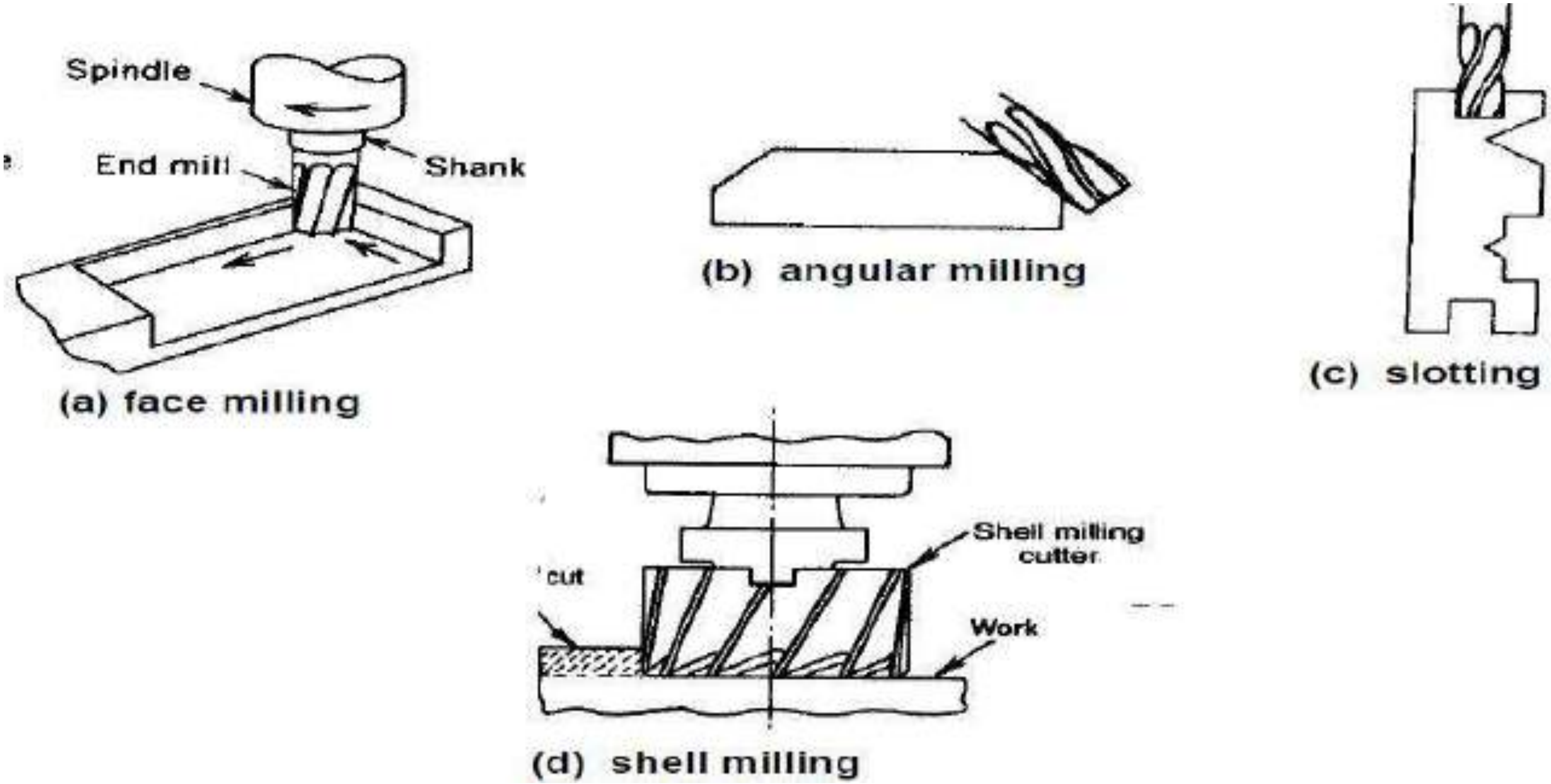
(b) slotting by side (double sided) milling cutter

(c) Parting by slitting saw

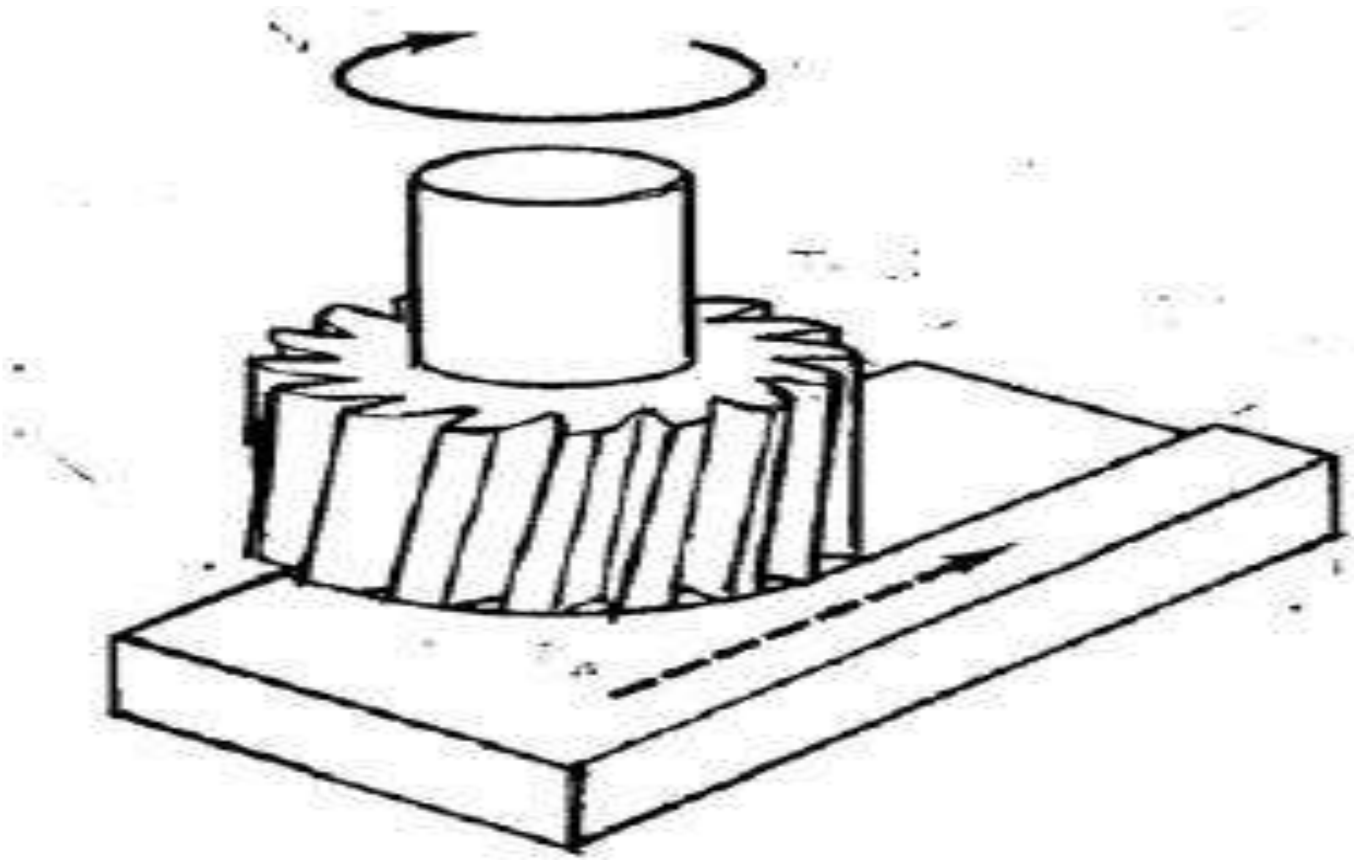
Side milling cutters

End milling cutters

- The end milling cutter, also called an end mill, has teeth on the end as well as the periphery

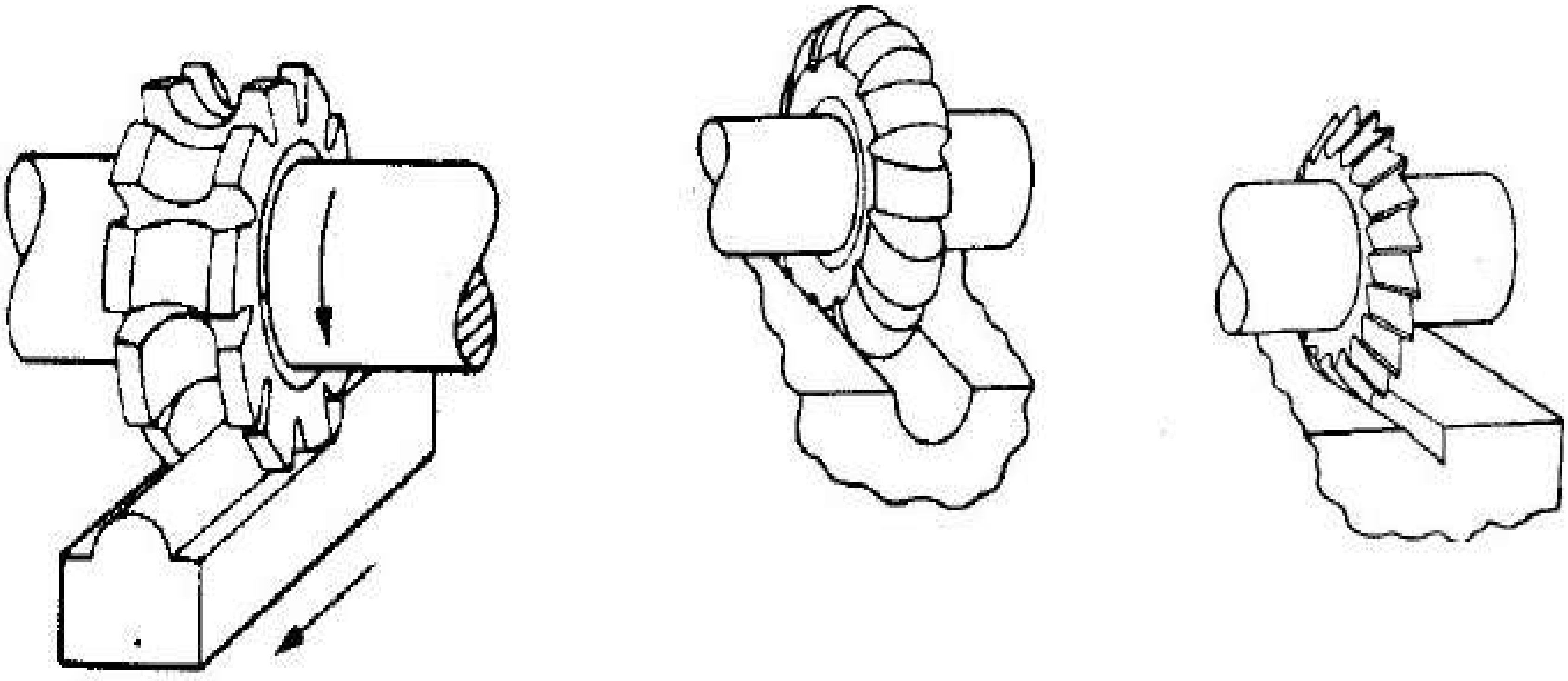


Face milling cutter

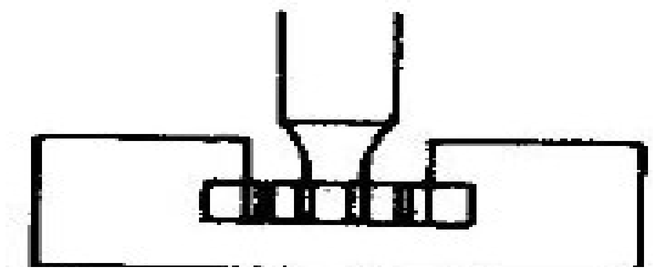


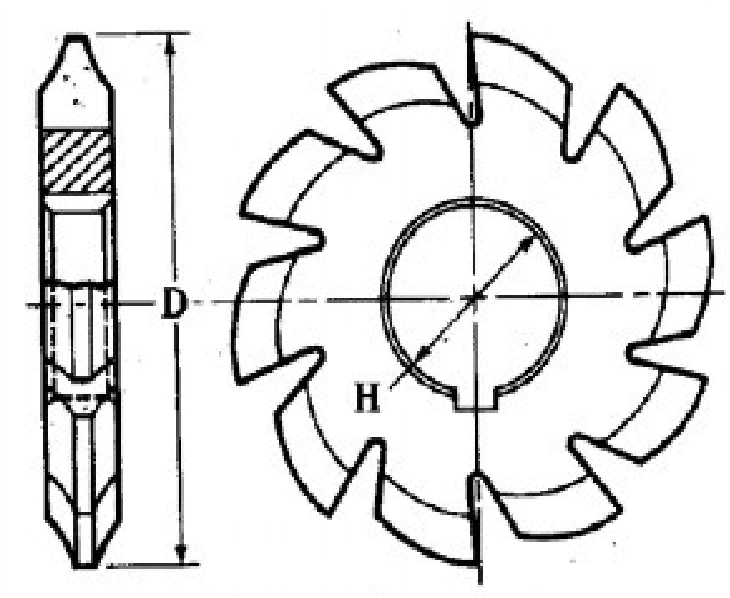
Form relieved cutters

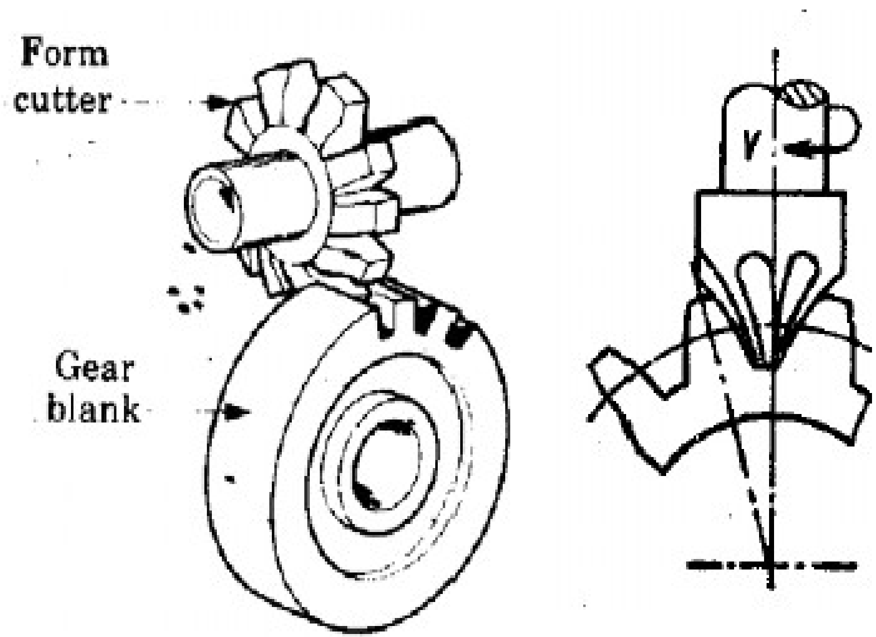
- Form of the tool is exactly replica of the job-profile to be made
- Clearance or flank surfaces of the teeth are spiral shaped instead of flat
- Used for making 2-D and 3-D contour surfaces



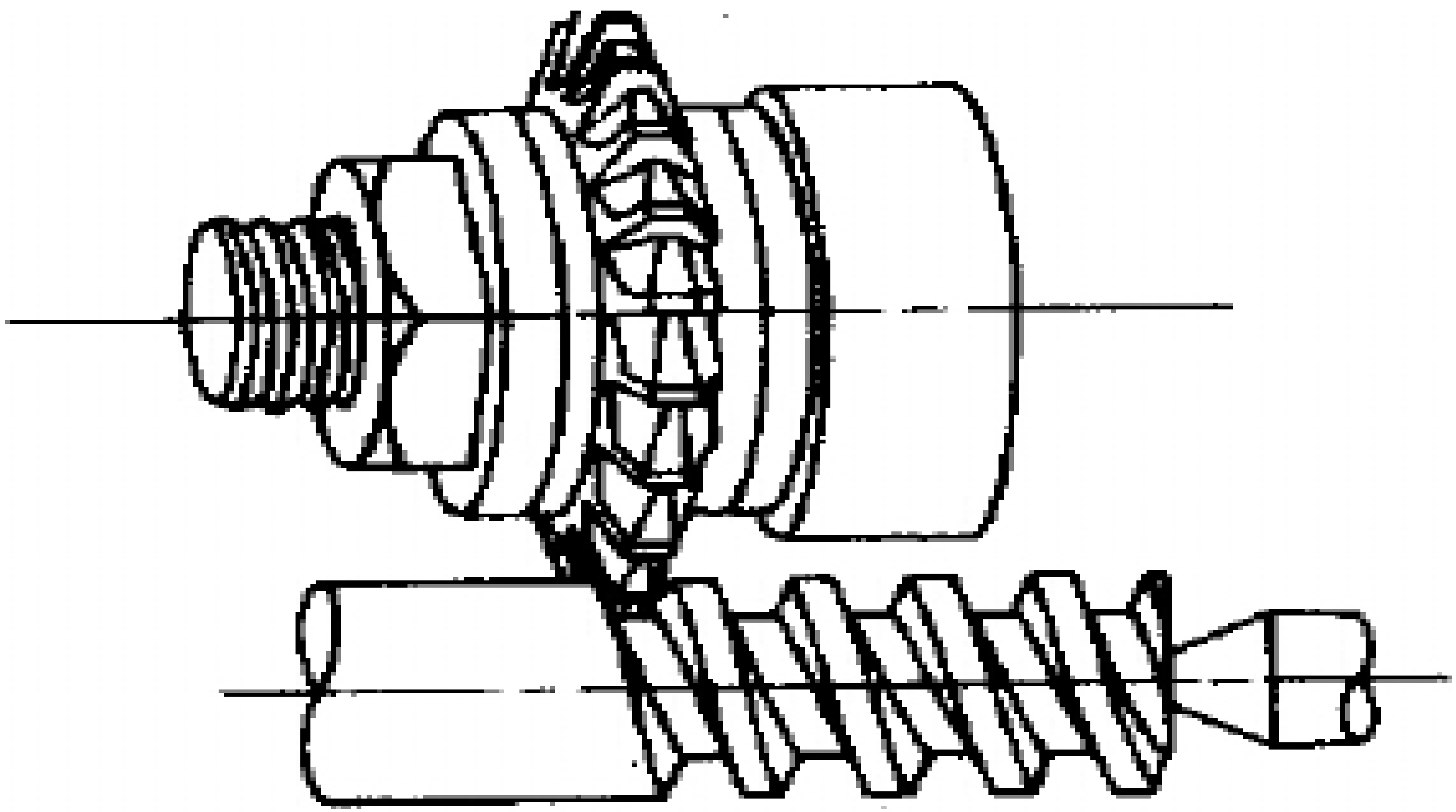
T-slot & Gear milling cutters







Thread milling cutter

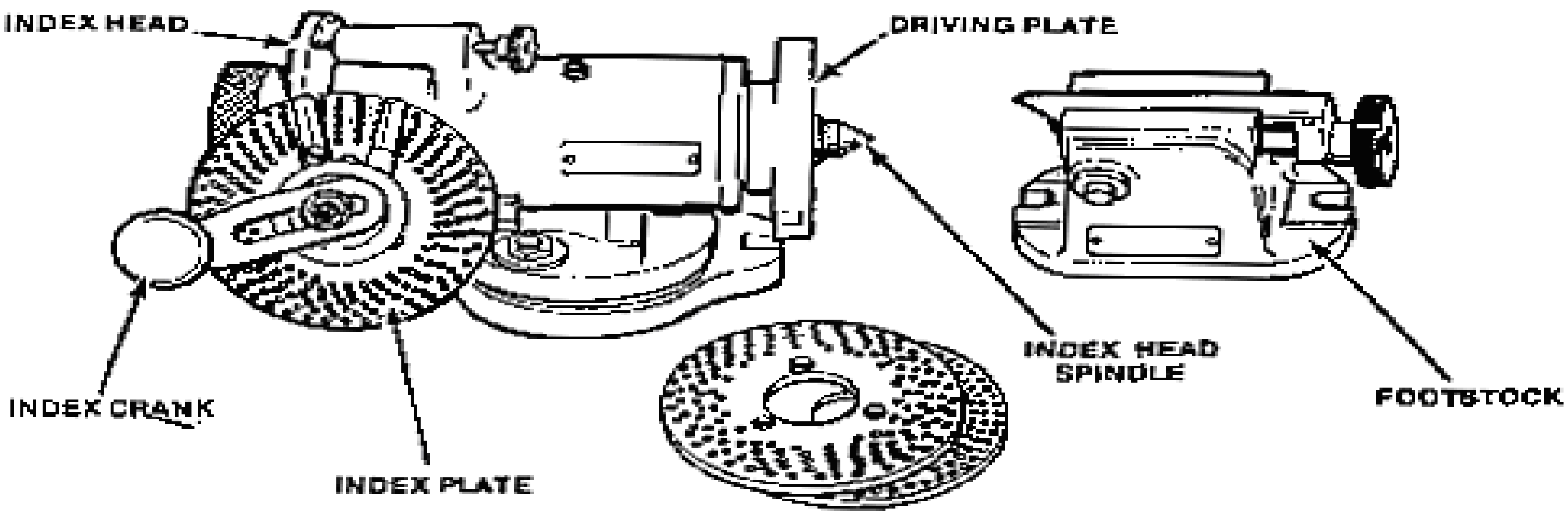


Indexing

- Indexing is the process of evenly dividing the circumference of a circular work piece into equally spaced divisions, such as in cutting gear teeth, cutting splines, milling grooves in reamers and taps, and spacing holes on a circle.
- The index head of the indexing fixture is used for this purpose.

Index Head

- The index head of the indexing fixture (Figure) contains an indexing mechanism which is used to control the rotation of the index head spindle to space or divide a work piece accurately. A simple indexing mechanism consists of a 40-tooth worm wheel fastened to the index head spindle, a single-cut worm, a crank for turning the worm shaft, and an index plate and sector. Since there are 40 teeth in the worm wheel, one turn of the index crank causes the worm, and consequently, the index head spindle to make 1/40 of a turn; so 40 turns of the index crank revolve the spindle one full turn.

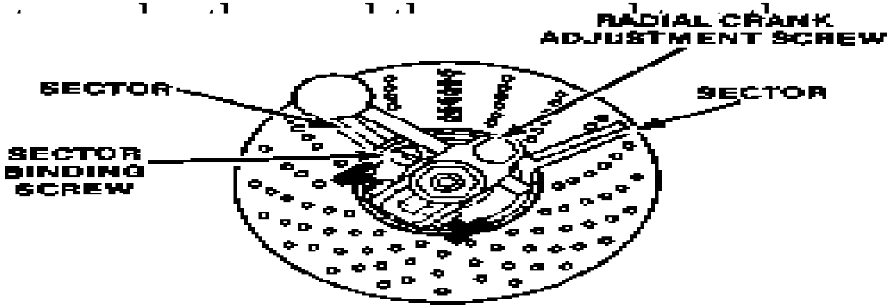


Index Plate

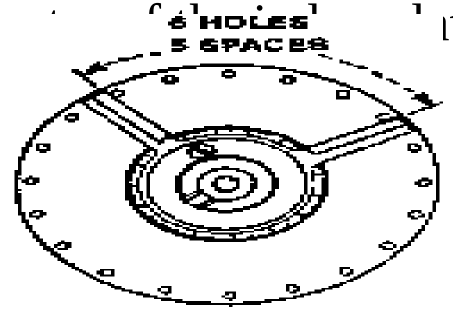
- The indexing plate (Figure) is a round plate with a series of six or more circles of equally spaced holes; the index pin on the crank can be inserted in any hole in any circle. With the interchangeable plates regularly furnished with most index heads, the spacing necessary for most gears, bolt heads, milling cutters, splines, and so forth can be obtained.

Sector

- The sector (Figure) indicates the next hole in which the pin is to be inserted and makes it unnecessary to count holes when moving the index crank after each cut. It consists of two radial, beveled arms which can be set at any angle [illegible] …te.



INDEX PLATE
WITH CRANK
AND SECTOR



OPERATION OF
SECTOR

Index Plate Types

- **Brown and Sharpe type consists of 3 plates of 6 circles each drilled as follows:**
  - **Plate I - 15, 16, 17, 18, 19, 20 holes**
  - **Plate 2 - 21, 23, 27, 29, 31, 33 holes**
  - **Plate 3 - 37, 39, 41, 43, 47, 49 holes**
- **Cincinnati type consists of one plate drilled on both sides with circles divided as follows:**
  - **First side - 24, 25, 28, 30, 34, 37, 38, 39, 41, 42, 43 holes**
  - **Second side - 46, 47, 49, 51, 53, 54, 57, 58, 59, 62, 66 holes**

Indexing Methods

Simple Indexing or Plain Indexing

- In simple or plain indexing, an index plate selected for the particular application, is fitted on the worm shaft and locked through a locking pin’
- To index the work through any required angle, the index crank pin is withdrawn from the hole of the index plate than the work is indexed through the required angle by turning the index crank through a calculated number of whole revolutions and holes on one of the hole circles, after which the index pin is relocated in the required hole
- If the number of turns that the crank must be rotated for each indexing can be found from the formula
  - $N = 40 / Z$
  - Where
  - Z - No of divisions or indexings needed on the work
  - 40 – No of teeth on the worm wheel attached to the indexing plate, since 40 turns of the index crank will turn the spindle to one full turn

- Suppose it is desired to mill a gear with eight equally spaced teeth. l/8th of 40 or 5 turns (Since 40 turns of the index crank will turn the spindle one full turn) of the crank after each cut, will space the gear for 8 teeth. If it is desired to space equally for 10 teeth, 1/10 of 40 or 4 turns would produce the correct spacing.
- The same principle applies whether or not the divisions required divide equally into 40. For example, if it is desired to index for 16 divisions, 16 divided into 40 equals 2 8/16 turns. i.e for each indexing we need two complete rotations of the crank plus 8 more holes on the 16 hole circle of plate 1(**Plate I - 15, 16, 17, 18, 19, 20 holes)**

Direct Indexing

- In direct indexing, the index plate is directly mounted on the dividing head spindle (no worm shaft or wheel)
- While indexing, the index crank pin is withdrawn from the hole of the index plate than the pin is engaged directly after the work and the indexing plate are rotated to the desire number of holes
- In this method fractions of a complete turn of the spindle are limited to those available with the index plate
- Direct indexing is accomplished by an additional index plate fastened to the index head spindle. A stationary plunger in the index head fits the holes in this index plate. By moving this plate by hand to index directly, the spindle and the work piece rotate an equal distance. Direct index plates usually have 24 holes and offer a quick means of milling squares, hexagons, taps, and so forth. Any number of divisions which is a factor of 24 can be indexed quickly and conveniently by the direct indexing method.

Differential Indexing

- Sometimes, a number of divisions is required which cannot be obtained by simple indexing with the index plates regularly supplied. To obtain these divisions, a differential index head is used. The index crank is connected to the worm shaft by a train of gears instead of a direct coupling as with simple indexing. The selection of these gears involves calculations similar to those used in calculating change gear ratio for lathe thread cutting.
- Gear Ratio I = 40/K (K – Z)

  Where

  - K – a number very nearly equal to Z
  - For example if the value of Z is 53, the value of K is 50

Indexing in Degrees

- Work pieces can be indexed in degrees as well as fractions of a turn with the usual index head. There are 360 degrees in a complete circle and one turn of the index crank revolves the spindle 1/40 or 9 degrees. Therefore, 1/9 turn of the crank rotates the spindle 1 degree. Work pieces can therefore be indexed in degrees by using a circle of holes divisible by 9. For example, moving the crank 2 spaces on an 18-hole circle, 3 spaces on a 27-hole circle, or 4 spaces on a 36-hole circle will rotate the spindle 1 degree.
- Smaller crank movements further subdivide the circle: moving 1 space on an 18-hole circle turns the spindle 1/2 degree (30 minutes), 1 space on a 27-hole circle turns the spindle 1/3 degree (20 minutes), and so forth.

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Indexing Head:

The index head of the indexing fixture contains an indexing mechanism which is used to control the rotation of the index head spindle to space or divide a workpiece accurately. A simple indexing mechanism consists of 4o teeth worm wheel fastened to the index head spindle, a single cut worm, a crank for turning the worm shaft and index plate and sector. Since there are 40 teeth in worm wheel, one turn of the index crank causes the worm and consequently, the index head spindle to make 1/40 of turn , so that 40 turns of the index crank revolve the spindle one full turn.

Index Plate:

The indexing plate is a round plate with a series of six or more circles of equally spaced holes, the index pin on the crank can be inserted in any desired hole in any circle. With interchangeable plate regularly furnished with most index heads, the spacing is necessary for most gears, bolt heads, milling cutters, splines etc.

Index Plate Types
Brown and Sharpe type
Consists of 3 plates of 6 circles each drilled as follows:

Plate I - 15, 16, 17, 18, 19, 20 holes
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Cincinnati type
Consists of one plate drilled on both sides with circles
Divided as follows:
First side - 24, 25, 28, 30, 34, 37, 38, 39, 41, 42, 43 holes
Second side - 46, 47, 49, 51, 53, 54, 57, 58, 59, 62, 66 holes

Sector:

The sector indicates the next hole in which the pin is to be inserted and makes it unnecessary to count holes when moving the index crank after each cut. It consists of two radial, beveled arms which can be set at any angle.

Simple Indexing Head:

Simple indexing is also called as 9 indexing. It is more accurate and has a large range of indexing than rapid indexing. For indexing, the dividing head spindle is turned by the index crank. The worm shaft carrying the crank has a single-threaded worm which meshes with worm gear having 40 teeth, 40 turns of the crank are necessary to rotate the index head spindle through one revolution. Therefore, one complete turn of the index crank will cause the worm wheel to make 1/40 of a revolution. To facilitate indexing to the fraction of a turn, an Index plate is used to cover practically all numbers. The Index plate with a circle of holes manufactured by the brown and sharp company is:

Plate No 1- 15, 16, 17,18,19,20

Plate No 2- 21, 23, 27,29,31,33

Plate No 3- 37, 39, 41,43,47,49

[Index crank movement *OR* Number of crank rotation = 40/N]
Where N = number of divisions required on the work.

Angular Indexing Head:

The angular indexing is the Process of dividing the periphery of work in angular measurements. There are 360 degrees in a circle, and then the index crank is rotated by 40 number of revolution and the spindle rotates through 1 complete Revolution or by 360 degrees, one complete turn off the crank will cause the spindle and the work to rotate through 360/40=9 degrees. When a result is a whole number, the index crank is rotated through the full calculated number. If the result is a fraction and a whole number, the part of the revolution of the crank after turning the whole number is calculated by multiplying is suitable for numbers to the numerator and denominator of the fraction, defecation to make the denominator of the fraction is equal to the number of holes in the index plate circle and the now numerator number for holes to be moved by the index Crank.

[Index crank movement *OR* Number of crank rotation = Indexing angle required/9]
Where N = number of divisions required on the work.

Compound Indexing Head:

In Compound indexing, there are two separate movements of the index crank in two different hole circles of one index plate to get the crank movement. In Compound indexing, there are two separate movements of the index crank in two different hole circles of one index plate to get the crank movement. The index plate is held stationary by Lock pin head which engages with one of the whole circle of the index place from the back. For indexing , the crankpin is rotated by the required number of the spaces in one of the holes of the circle of the index plate and then the pin is engaged with the plate. The second index movement is done by removing the real lock pin and the rotating the plate together with the index crank forward or backward through the calculated number of spaces of another hole circle, and the lock pin is engaged.

STEP 1 : Convert that division into two fractions like example 77= 11 * 7

STEP 2 : Select the hole circle number based on the number of division like example

11 * 7

(11 * 3) (7 * 3)

(33) (21)

STEP 3 : Solve equation and find hole circle number and hole no. by Trial and error method

X/21 (+/-) Y/33 = 40 / 77

Differential Indexing Head:

Sometimes, a number of divisions is required which cannot be obtained by simple indexing with the index plates regularly supplied. To obtain these divisions, a differential index head is used. The index crank is connected to the worm shaft by a train of gears instead of a direct coupling as with simple indexing. The selection of these gears involves calculations similar to those used in calculating change gear ratio for lathe thread cutting.

STEP 1 : Select the nearest value such a way that it is divisible by 40

STEP 2 **: 40/N' + 1/N (a.b/c.d) = 40/N'**

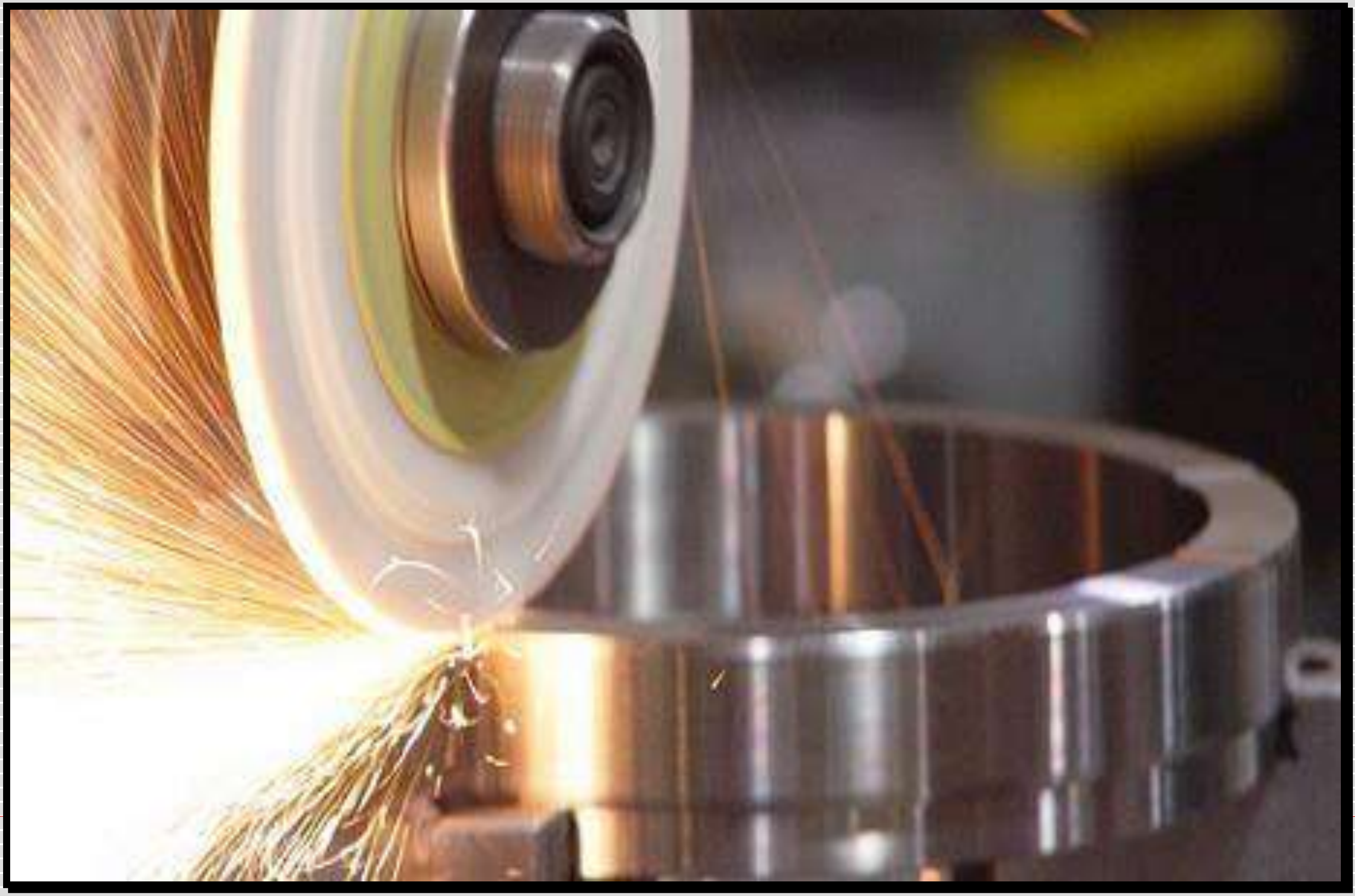
N = Given divisible number in the question

N' = Nearest divisible no. that will be divisible by 40

INTRODUCTION TO GRINDING PROCESS

- **It is the only economical method of cutting hard material like hardened steel.**
- **It produces very smooth surface , suitable for bearing surface.**
- **Surface pressure is minimum in grinding. It is suitable for light work,which will spring away from the cutting tool in the other machining processes.**

Grinding operation

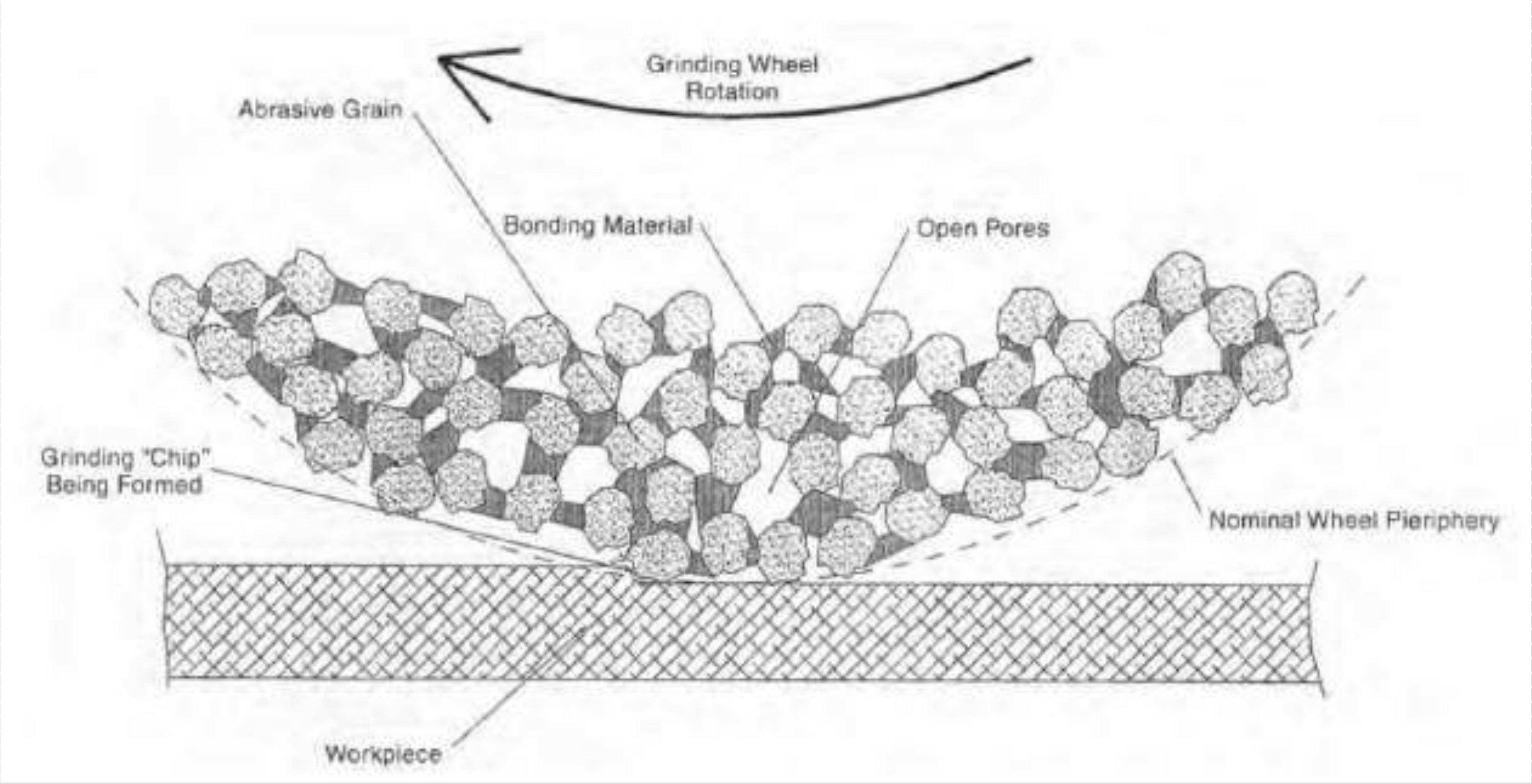


Types of grinding operation

1. Ruff or precision Grinding
   a) Snagging
   b) Off-hand
2. Precision Grinding
   a) Surface grinding
   b) Cylindrical grinding
   c) Center less grinding
   d) Form and profile grinding
   e) Plunge cut grinding

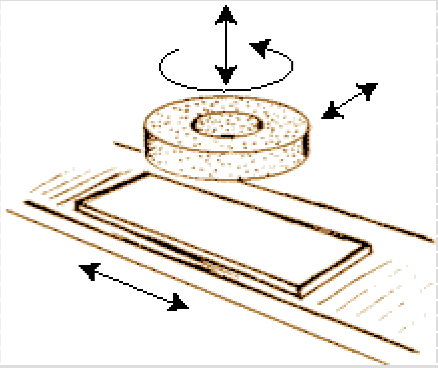
Grinding Process

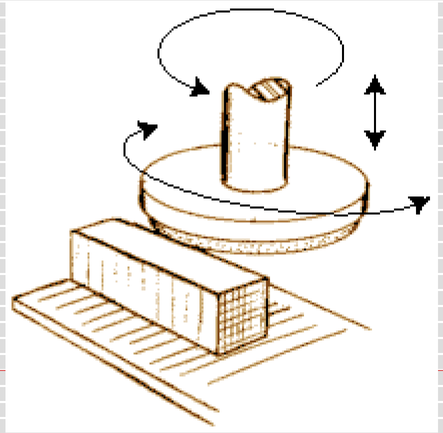
Grinding is an abrasive machining process that uses a grinding wheel as the cutting tool.

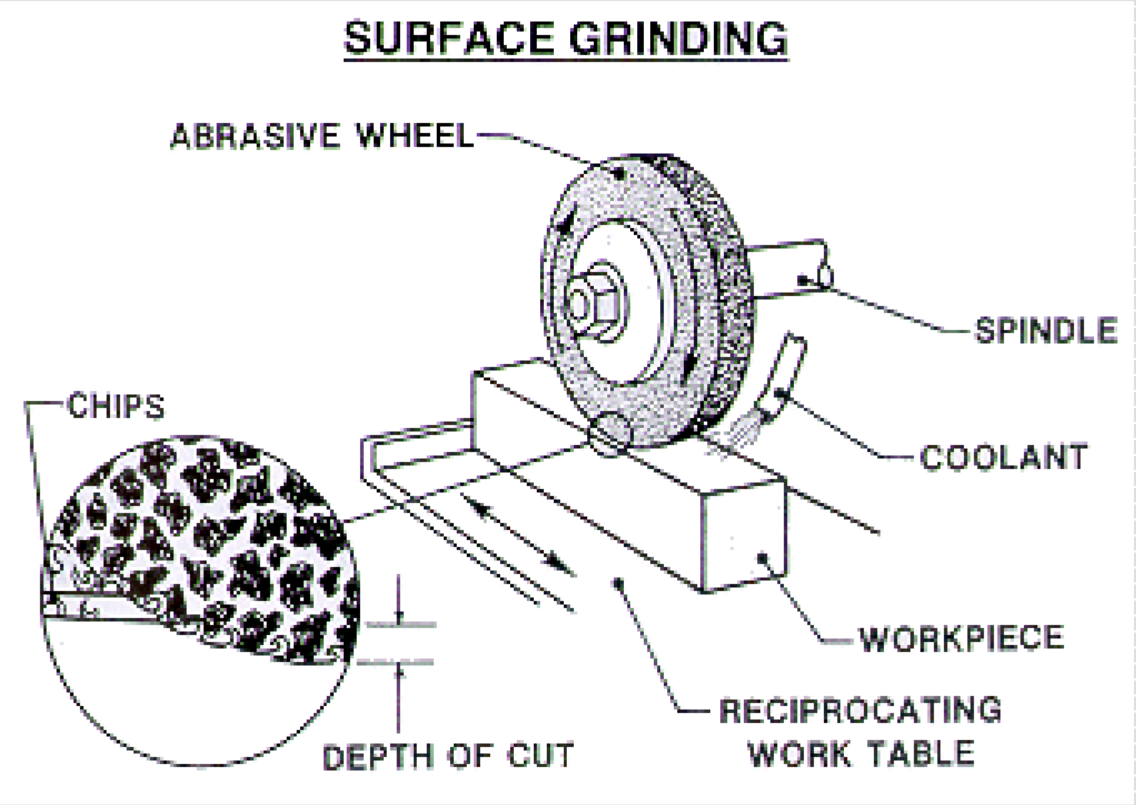


Surface Grinding

Surface grinding uses a rotating abrasive wheel to remove material, creating a flat surface.



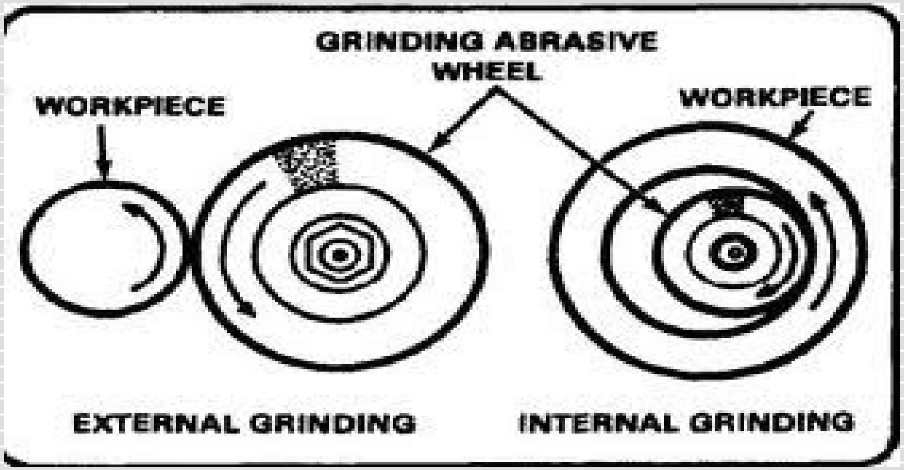




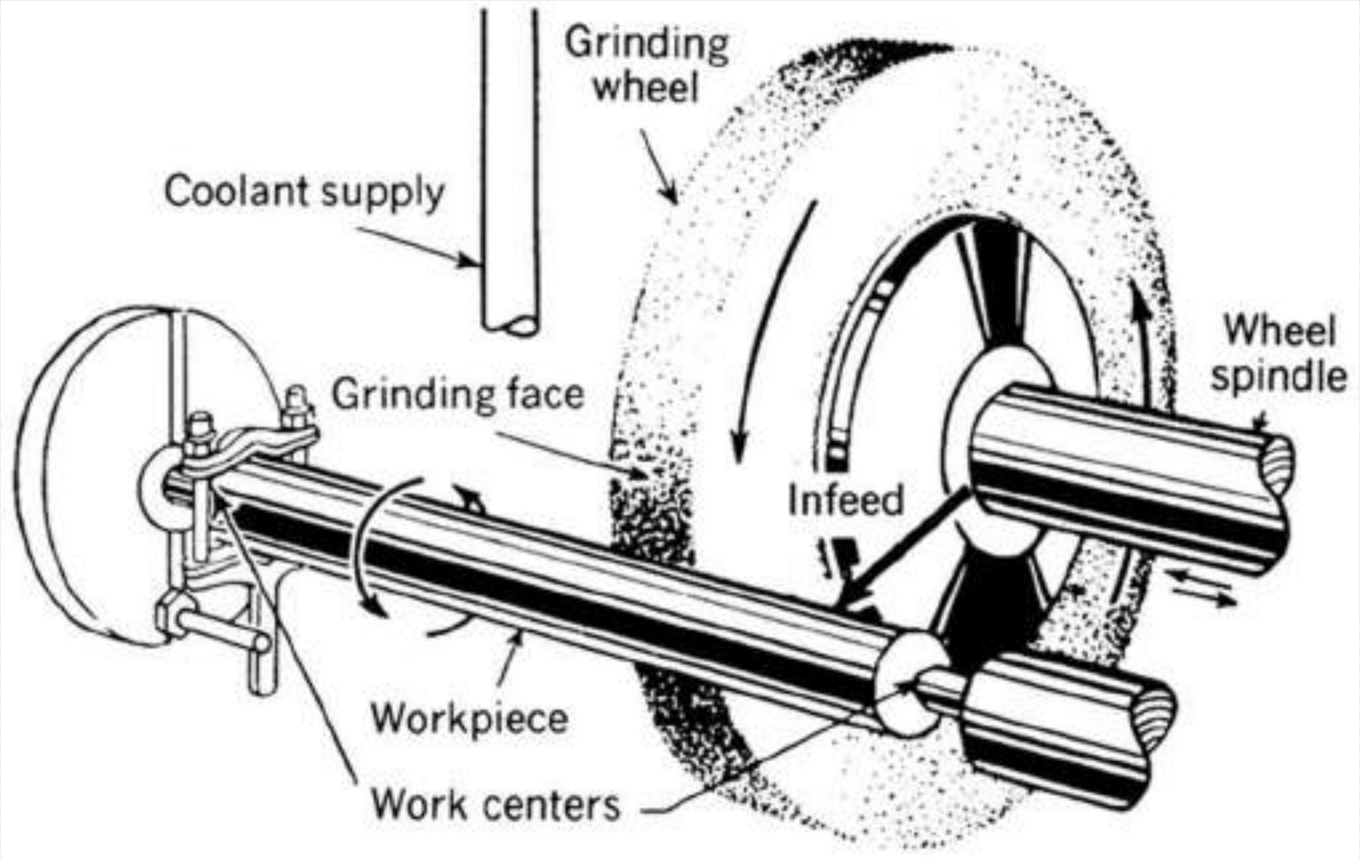
Cylindrical Grinding

Cylindrical grinding (also called center-type grinding) is used to grind the cylindrical surfaces and shoulders of the workpiece.

1. External cylindrical grinding
2. Internal cylindrical grinding

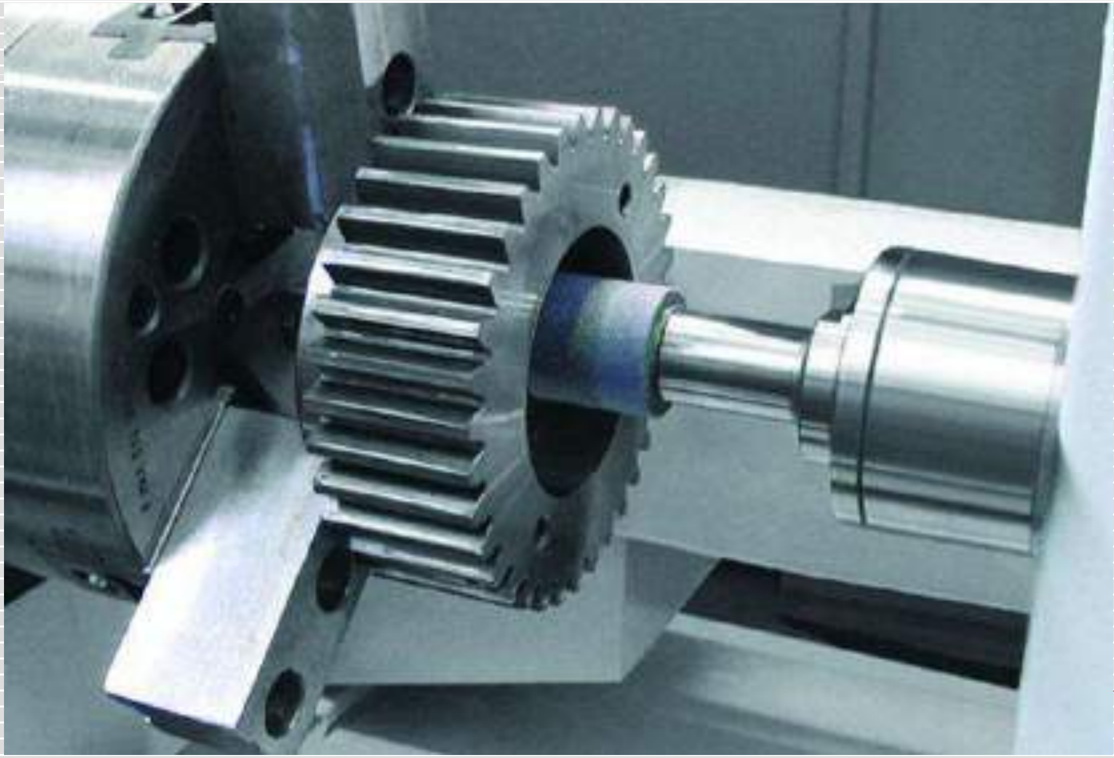


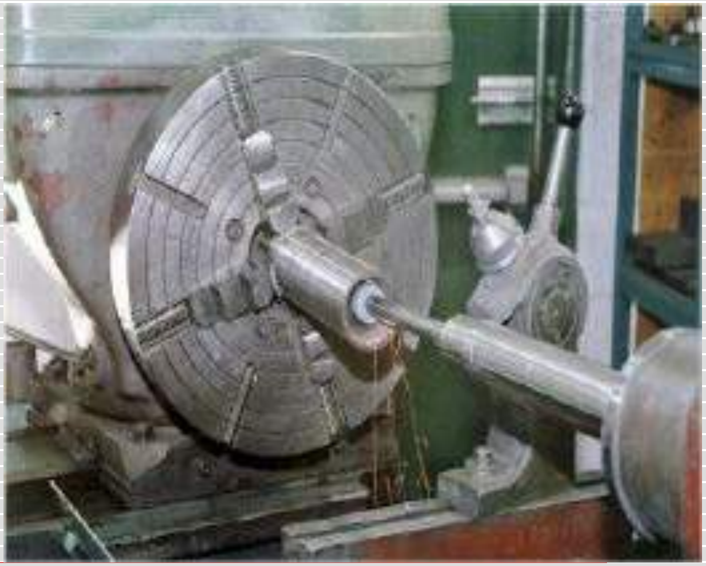
External cylindrical grinding



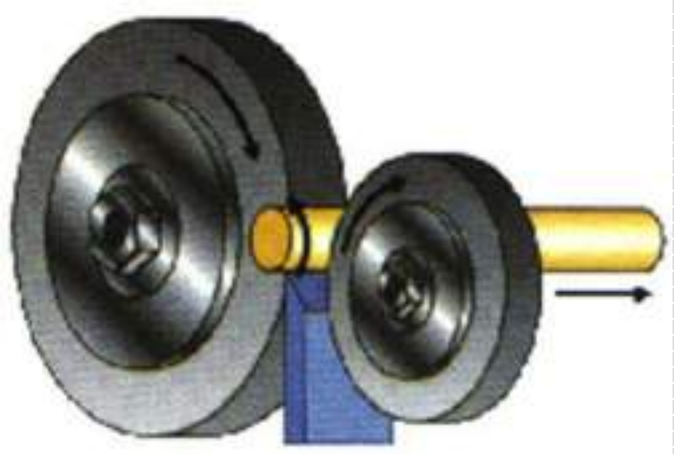
Internal cylindrical grinding

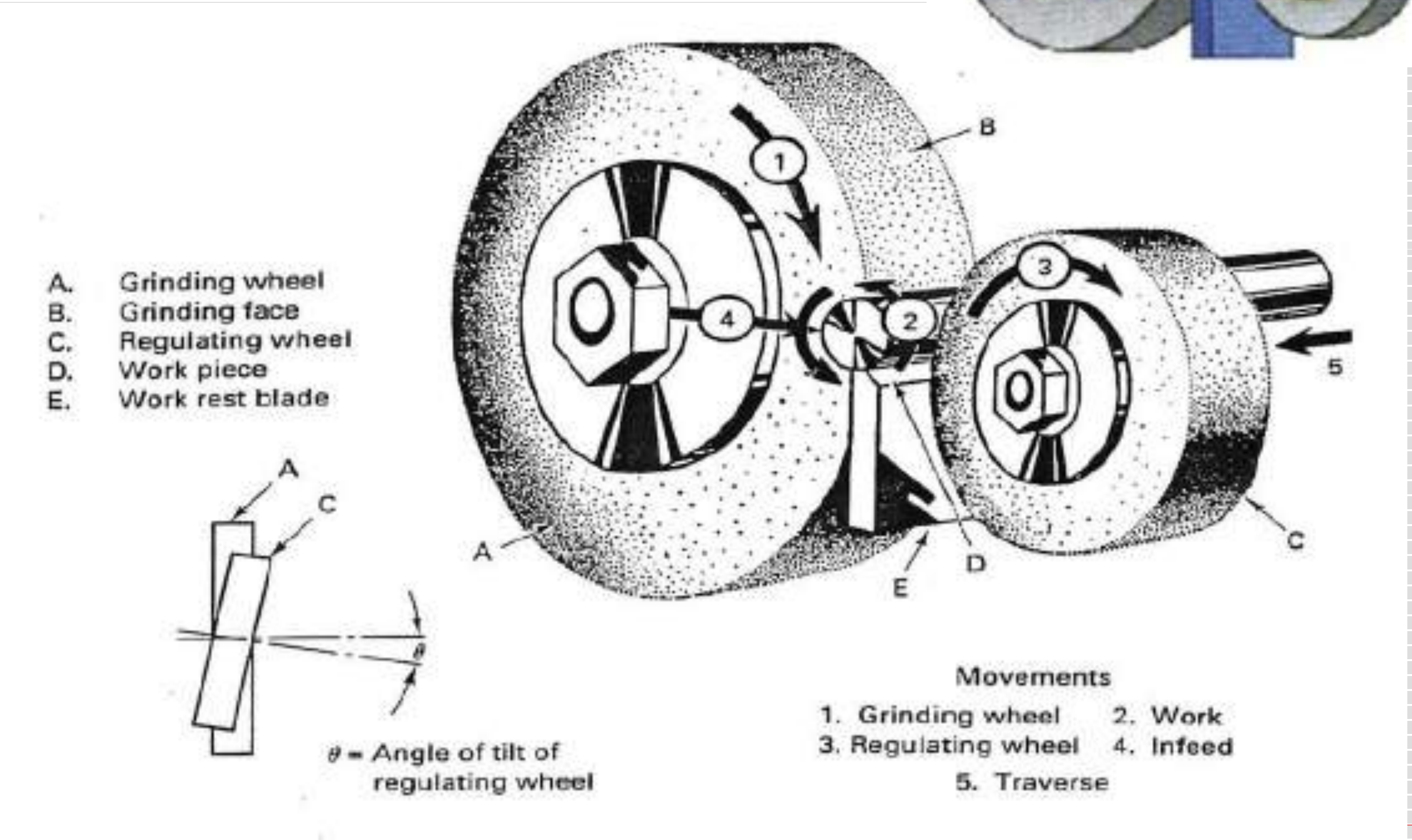
Internal grinding is used to grind the internal diameter of the workpiece. Tapered holes can be ground with the use of internal grinders that can swivel on the horizontal.





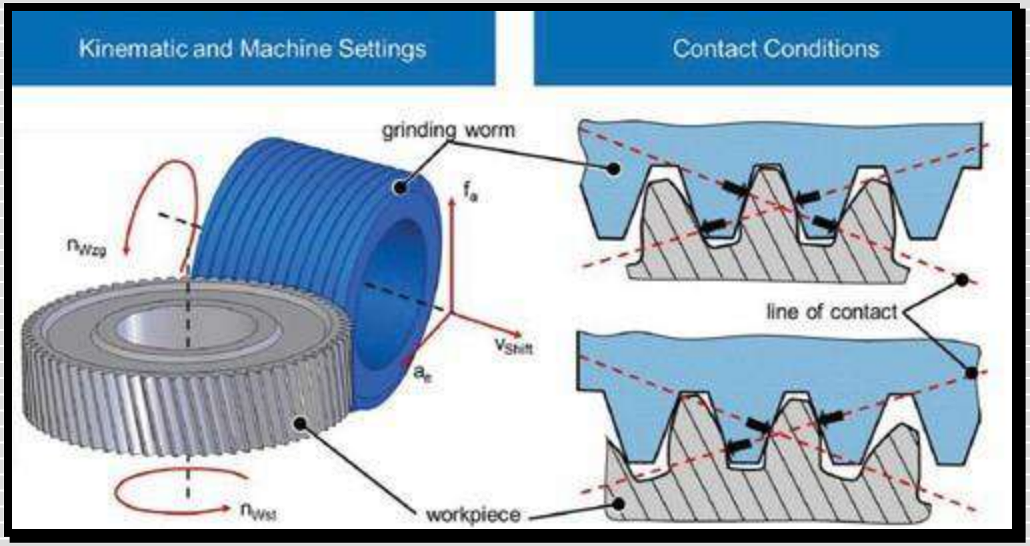
Centerless grinding





Form and profile grinding

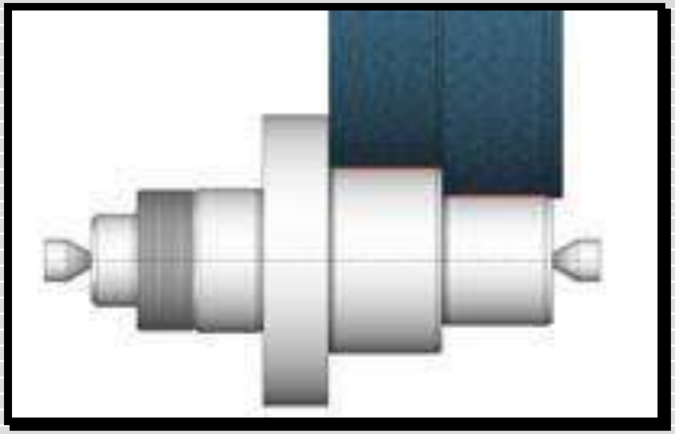
Form grinding is a specialized type of cylindrical grinding where the grinding wheel has the exact shape of the final product. The grinding wheel does not traverse the workpiece.



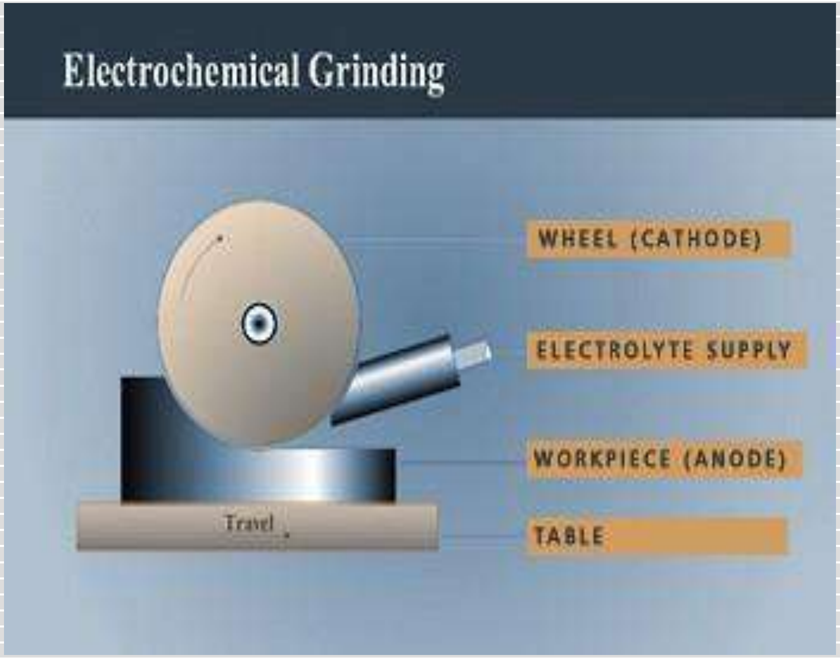
Plunge cut grinding

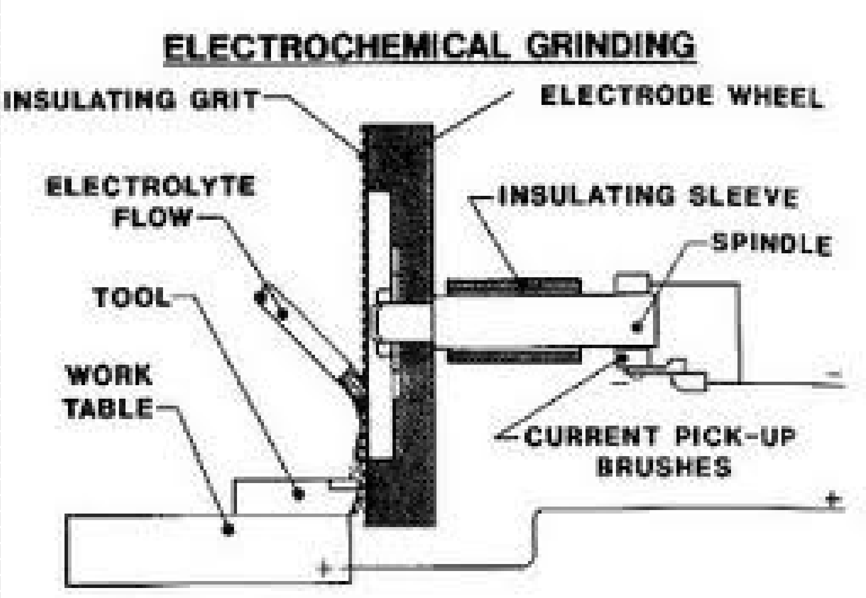
Infeed (Plunge) Grinding is used to grind workpieces which have projections or shoulders, multiple diameters or other irregular shapes which preclude the use of through feed grinding.

For example :- Grinding of crank shaft.



Electrochemical grinding





Electrochemical grinding

- The wheels and workpiece are electrically conductive.
- Wheels used last for many grindings - typically 90% of the metal is removed by electrolysis and 10% from the abrasive grinding wheel.
- Capable of producing smooth edges without the burrs caused by mechanical grinding.
- Does not produce appreciable heat that would distort workpiece.
- Decomposes the workpiece and deposits them into the electrolyte solution. The most common electrolytes are sodium chloride and sodium nitrate at concentrations of 2 lbs. per gallon

SIGNIFICANCE OF GRINDING OPERATIONS:

- Grinding is a material removal and surface generation process used for shape and finish components made up of metals and other materials.
- The surface obtained through grinding is 10 times better than any other machining like turning or milling.

MANUFACTURING OF GRINDING WHEELS:

A **grinding wheel** is a wheel composed of an abrasive compound and used for various grinding (abrasive cutting) and abrasive machining operations. Such wheels are used in grinding machines.

The wheels are generally made from a composite material consisting of coarse-particle aggregate pressed and bonded together by a cementing matrix (called the *bond* in grinding wheel terminology) to form a solid, circular shape. Various profiles and cross sections are available depending on the intended usage for the wheel. They may also be made from a solid steel or aluminum disc with particles bonded to the surface. Today most grinding wheels are artificial composites made with artificial aggregates, but the history of grinding wheels began with natural composite stones, such as those used for millstones.

The manufacture of these wheels is a precise and tightly controlled process, due not only to the inherent safety risks of a spinning disc, but also the composition and uniformity required to prevent that disc from exploding due to the high stresses produced on rotation.

Grinding wheels are consumables, although the life span can vary widely depending on the use case, from less than a day to many years. As the wheel cuts, it periodically releases individual grains of abrasive, typically because they grow dull and the increased drag pulls them out of the bond. Fresh grains are exposed in this wear process, which begin the next cycle. The rate of wear in this process is usually very predictable for a given application, and is necessary for good performance.

Selection of Grinding Wheels:

The proper selection of grinding wheels is very important for getting good results (i.e. obtaining better finish and at the same time having more life of the wheel). In order to meet all these requirements, the various elements that influence the process must be considered.

Selection mainly depends upon the following factors:

(a) Constant factors.

(b) Variable factors.

Constant factors include:

(i) Work material. It should be remembered that for grinding a soft material, hard wheel should be used and vice versa,

(ii) Amount and rate of stock removal,

(iii) Area of contact between work and wheel.

(iv) Condition of grinding machine. A softer grade of wheel is used on robust and heavy machine,

(v) Finish and accuracy required on the job.

Variable factors include:

(i) Wheel speed,

(ii) Work speed,

(iii) Condition of grinding machine (state of the wheel spindle bearing),

iv) Skill of operator (personal factors).

From above it is obvious that several factors are to be considered for the proper selection of the right wheel. The different wheels are constituted by different combinations of abrasive materials, grain size, type of bond, hardness of bond, structure etc. Thus the difficulty in choosing right wheel for any particular job can be gauged from the fact that more than 10,000 different combinations are obtainable in one wheel.

Work Material:

It will influence the following elements:

(a) Abrasive material,

(b) Grain size of grit number (mesh number),

(c) Grade (strength of bond),

(d) Structure.

(a) Abrasive:

This choice of right abrasive is to some extent determined by the type of material only to be ground, which will decide whether the abrasive is Silicon Carbide (SiC) or Aluminium Oxide (Al_2O_3) as these are most commonly used abrasives in different varieties. SiC is the best suited abrasive for brittle and hard materials like grey cast iron castings, chilled iron, tungsten carbide, hard steels, stone, porcelain and other ceramic substances.

SiC is also recommended for low tensile strength material such as non-ferrous metals, bronze, brass, copper, aluminium and plastic materials, $A1_20_3$ is better for tough materials having high tensile strength like mild steel, alloy steel, high speed annealed malleable iron, tough bronze, wrought iron, etc.

(b) Grain Size:

For softer materials, it is a general practice to use coarse grain size and for harder materials, fine grains. Coarser grain is used for high rate of stock removal. Fine grain is used if the work size or the work surface finish is important. Grain size is determined by the mesh number by which it is retained when passed through a series of meshes in a vibrating sieve.

(c) Grade:

The hard materials and materials having high strength offer more resistance to wheel while grinding operation is performed. Thus if hard grade of wheel is used then wheel will get blunt soon and the grinding will not be good. Therefore, for better results on such materials, the abrasive particles should break and fall quickly so that new sharp faces of the particles do the work and they never get blunt.

For softer materials, high or harder grade, i.e. good bond is used. The grading is done by capital alphabets, the first alphabets being used for softer grade and last ones for harder grade.

(d) Structure:

This represents the void between the abrasives and is influenced by the work material. In the case of harder materials the chips are of small size and also the rate of metal removal is low. Thus a small reservoir is needed to remove the chips from the hard material, and the dense structure is desirable for it.

For softer materials, the open structure is prescribed as the rate of metal removal is high and size of chips is also big. The structure is denoted by numbers from 1 to 15.

Amount and Rate of Stock Removal:

It does not influence the abrasive material but the

(a) Grain size,

(b) Grade,

(c) Structure.

For fast removal of metal, coarse gain size is required and vice versa. As regards grade, soft grade is used for fast removal of metal, of course at the cost of wheel life. With softer grade, the abrasive particles fall off quickly and wheel keeps on sharpening, thus removing more quantity of material. Also in order that metal may be removed at faster rate, more space is required for chip removal and hence open structure is desirable for fast removal of metal and vice versa.

Area of Contact:

It mainly influences grade and to some extent grain size also. When the area of contact in grinding operation is large, total grinding pressure is distributed over a larger area and the pressure per unit area is less and hence a softer wheel is needed for it. Thus for internal grinding where arc of contact is more, softer wheel is used and for external grinding, harder wheel.

Condition of Grinding Machine:

Heavy rigid machines demand the softer grade of wheel than the light machines. If condition of grinding machine is such as to cause vibration, harder grade is used compared to one where complete freedom from vibrations is there.

Finish and Accuracy Required:

For high degree of accuracy and fine finish requirement, small sized grain wheels should be used.

Variable Factors:

i. Wheel Speed and Work Speed:

These are the most predominant factors and about 70% of the complaints can be improved by proper selection of work and wheel speed e.g. if one gets burnt surface then speed of the wheel may be reduced. If there is excess wheel wear, it indicates that either wheel is running too slow or the work too fast.

Wheel speed affects the grade to a considerable extent and for higher wheel speed, soft wheel (soft grade) should be used. Wheel speed depends upon type of grinding operation e.g. external or internal grinding or parting off operation. Work speed depends upon type of work, type of grinding and finish required. It also affects the grade, and for higher work speed it is desirable to use harder wheel and vice versa.

ii. Condition of Grinding:

(By condition of grinding we mean whether the grinding is done in wet conditions or dry conditions.) In dry conditions with hard wheel the heat generation is more and thus soft wheel is required and vice versa.

iii. Skill of Operator:

An unskilled worker can’t handle soft wheels and he is likely to break them. Thus unskilled worker should be allowed to work only in those conditions which require a hard wheel.

Selection of Grinding Wheels for Thread Grinding and Tool Sharpening:

The factors influencing the type of abrasive for thread grinding wheels are the material of workpiece, its hardness, pitch and profile of the threads. Al_2O_3 wheel is preferred for most of the applications. For grinding titanium, SiC wheel is used and for grinding carbide and ceramic materials, diamond wheel is used. Finer grit size is used for finer pitch.

If fine grit it used then harder wheel is employed. For high precision thread grinding, and where lead errors in pre-cut threads are to the corrected, vitrified bond wheels are used which are more rigid also. Resinoid bond wheels are very flexible and can remove stock rapidly. However, these can't correct the lead errors in pre-cut threads because of their flexibility.

For tool sharpening, Al_2O_3 wheels are used for H.S.S; silicon carbide wheels are used for carbide-tipped tools. The operation of lapping and fine finish is done by diamond wheel. CBN wheel is well suited for grinding a variety of difficult to machine tool steels. Other considerations are same as for general grinding applications.

Selection of Grinding Wheel According to I.S. Specifications:

Various elements are put in systematic manner as follows:

Compulsory Elements:

Following have to be mentioned in all the wheels:

(1) Abrasive,

(2) Grain size,

(3) Grade,

(4) Type of Bond.

Optional Elements are:

(1) Prefix,

(2) Structure,

(3) Suffix.

Abrasive:

These are denoted by:

A—for Al_2O_3, C—for SiC

WA—for white Al_2O_3, GC—for green grit SiC.

The last two are sometimes put under prefix also.

Grain Size:

It is denoted by grit number.

The various numbers for different types of grain size are given below:

Coarse grain: 8, 10, 12, 14, 16, 24

Medium grain: 30, 36, 46, 54, 60

Fine grain: 80, 100, 120, 150,180

Very fine grain: 220, 240, 280, 320, 400,500,600.

For all types of grinding higher limit is upto 180. The grit number above 200 is recommended for lapping operation etc.

Grade:

The following classification is employed for grade:

A—E: Very soft,

G—K: Soft, L—

O: Medium, P—

S: Hard, T—Z:

Very hard. **Type**

of Bond:

The following notations are followed:

V—Vitrified,

B—Resinoid, BF—

Resinoid reinforced R—

Rubber,

RF—Rubber reinforced

E—Shellac,

S—Silicate, Mg—

Magnesia **Prefix:**

It denotes manufacturer symbol for exact nature of abrasive e.g. GC. Here G is prefix and C stands for silicon carbide.

This varies from manufacturer to manufacturer and they have their own code numbers. Sometimes mixture of two varieties may also be used in abrasives.

Structure:

It is denoted by number from 1 to 15. 1—

8: Dense structure

9—15: Open structure.

Suffix:

It is manufacturer's own identification mark (trade secret) and depends upon the process and type of manufacturer.

GRINDING MACHINE

Introduction

- A **grinding machine,** often shortened to **grinder,** is any of various power tools or machine tools used for grinding, which is a type of machining using an abrasive wheel as the cutting tool. Each grain of abrasive on the wheel's surface cuts a small chip from the work piece via shear deformation.

- Grinding is used to finish work pieces that must show high surface quality (e.g., low surface roughness) and high accuracy of shape and dimension. As the accuracy in dimensions in grinding is on the order of 0.000025 mm, in most applications it tends to be a finishing operation and removes comparatively little metal, about to 0.50 mm depth. However, there are some roughing applications in which grinding removes high volumes of metal quite rapidly. Thus, grinding is a diverse field.

- The grinding machine consists of a bed with a fixture to guide and hold the work piece, and a power-driven grinding wheel spinning at the required speed. The speed is determined by the wheel's diameter and manufacturer's rating. The user can control the grinding head to travel across a fixed work piece, or the work piece can be moved while the grind head stays in a fixed position.

- Fine control of the grinding head or tables position is possible using a vernier calibrated hand wheel, or using the features of numerical controls.

- Grinding machines remove material from the work piece by abrasion, which can generate substantial amounts of heat. To cool the work piece so that it does not overheat and go outside its tolerance, grinding machines incorporate a coolant. The coolant also benefits the machinist as the heat generated may cause burns. In high-precision grinding machines (most cylindrical and surface grinders), the final grinding stages are usually set up so that they remove about 200 nm (less than 1/10000 in) per pass - this generates so little heat that even with no coolant, the temperature rise is negligible. '

Types of Grinding Machine

- Belt grinder
- Bench grinder
- Cylindrical grinder
- Surface grinder
- Tool and cutter grinder
- Jig grinder
- Gear grinder

Belt grinder

- Belt grinder, which is usually used as a machining method to process metals and other materials, with the aid of coated abrasives. Sanding is the machining of wood; grinding is the common name for machining metals. Belt grinding is a versatile process suitable for all kind of applications like finishing, deburring, and stock removal.

Bench grinder

- Bench grinder, which usually has two wheels of different grain sizes for roughing and finishing operations and is secured to a workbench or floor stand. Its uses include shaping tool bits or various tools that need to be made or repaired. Bench grinders are manually operated.

Cylindrical grinder

- Cylindrical grinder, which includes both the types that use centers and the **centerless** types. A cylindrical grinder may have multiple grinding wheels. The work piece is rotated and fed past the wheel(s) to form a cylinder. It is used to make precision rods, tubes, bearing races, bushings, and many other parts.

Surface grinder

- Surface grinder which includes the **wash grinder.** A surface grinder has a "head" which is lowered, and the work piece is moved back and forth past the grinding wheel on a table that has a permanent magnet for use with magnetic stock. Surface grinders can be manually operated or have CNC controls. Rotary surface grinders or commonly known as "Blanchard" style grinders, the grinding head rotates and the table usually magnetic but can be vacuum or fixture, rotates in the opposite direction, this type machine removes large amounts of material and grinds flat surfaces with noted spiral grind marks. Used to make and sharpen; burn-outs, metal stamping die sets, flat shear blades, fixture bases or any flat and parallel surfaces.

Tool and cutter grinder

- Tool and cutter grinder and the D-bit grinder. These usually can perform the minor function of the drill bit grinder, or other specialist tool room grinding operations.

Jig grinder

- Jig grinder, which as the name implies, has a variety of uses when finishing jigs, dies, and fixtures. Its primary function is in the realm of grinding holes and pins. It can also be used for complex surface grinding to finish work started on a mill.

Gear grinder

- Gear grinder, which is usually employed as the final machining process when manufacturing a high-precision gear. The primary function of these machines is to remove the remaining few thousandths of an inch of material left by other manufacturing methods (such as gashing or hobbing).

Examples of Bonded Abrasives

Fig: A variety of bonded abrasive used in abrasive machining processes

Common Grinding Wheels

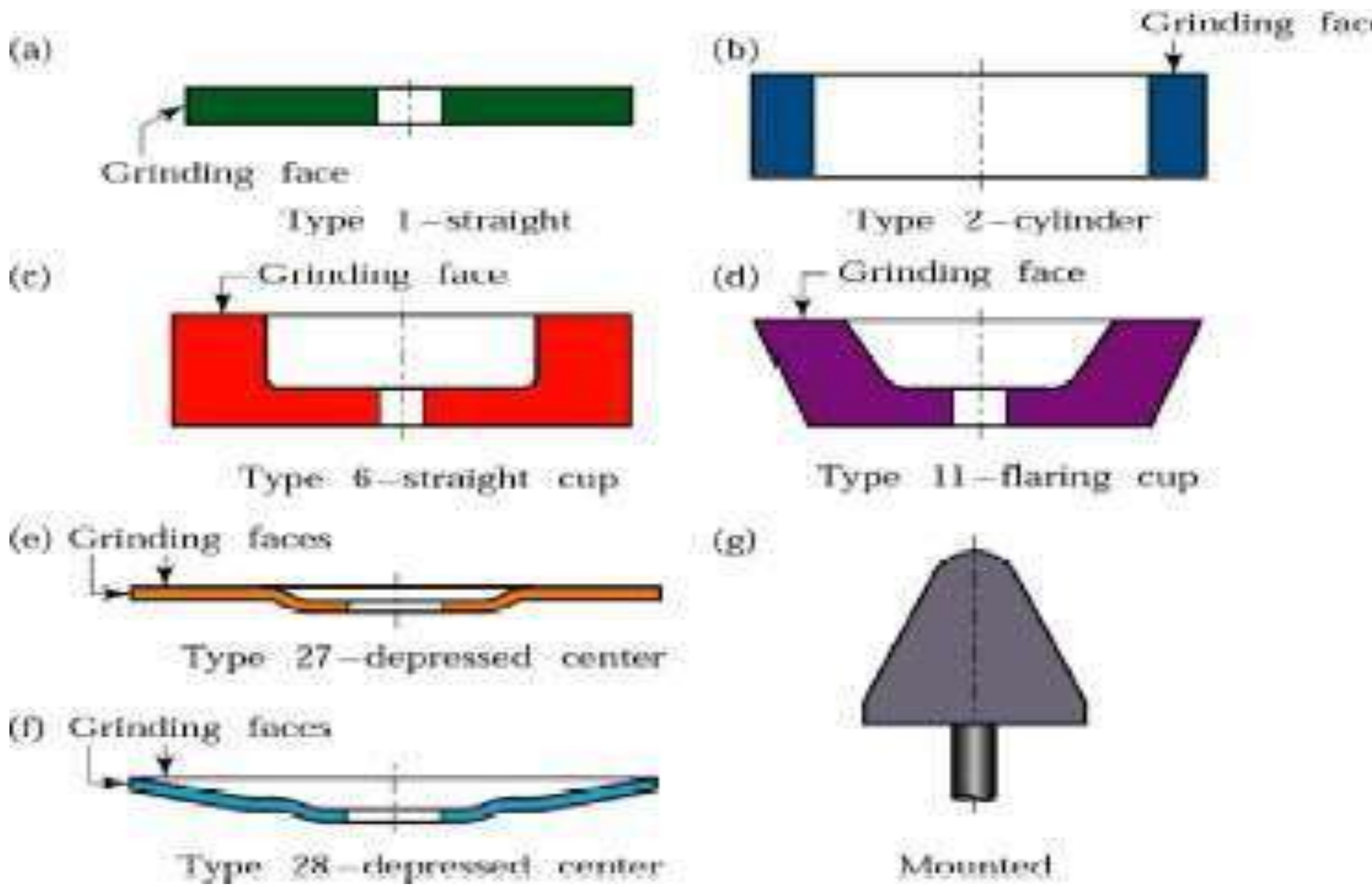


Fig: Common Type of Grinding Wheels made with conventional abrasives. Note that each wheel has a specific grinding face; grinding on other surfaces is improper and unsafe

GRINDING WHEEL SPECIFICATONS

PRESENTATION BY:-

YASHRAJ V. PATIL

DEFINITION:-

- A grinding wheel is a multitooth cutter made up of many hard particles known as abrasives which have been crushed to leave sharped edges for machining.
- Every grinding wheel has two constituents:

i. abrasive used for cutting.

ii. bond that holds abrasive grains.

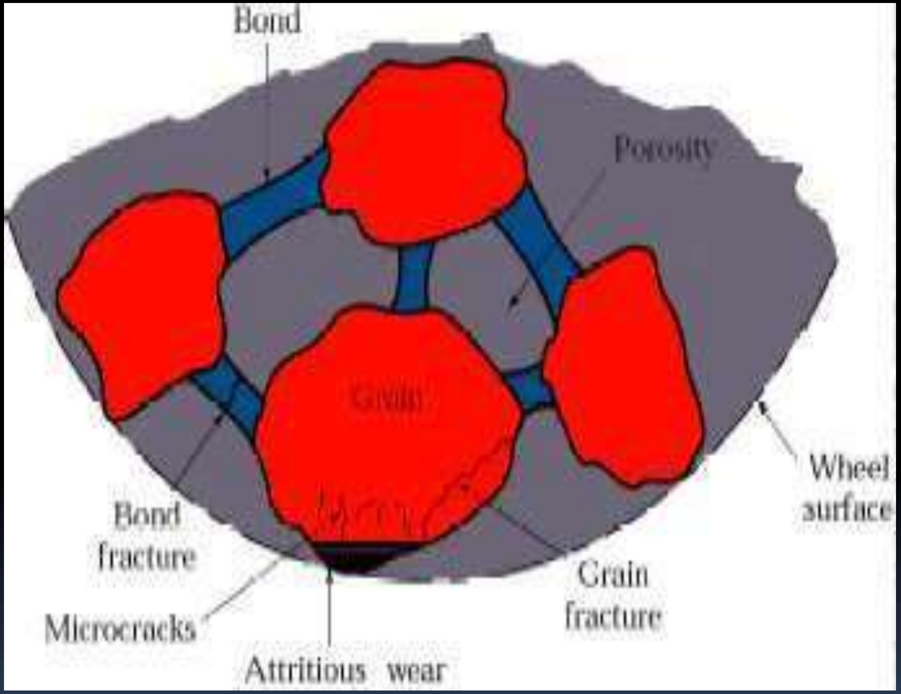
BASIC FUNCTIONS OF A GRINDING WHEEL:-

- Removal of stock
- Generation of cylindrical, flat and curved surfaces
- Production of highly finished surfaces
- Cutting off operations
- Production of sharp edges and points.

CONSTRUCTION OF GRINDING WHEEL:-

Grinding wheel consists of-

i. Abrasives
ii. Bond
iii. Grit/grain size
iv. Grade
v. Structure of wheels



ABRASIVES:-

- An abrasive is a hard and tough substance, having sharp edges. It cuts or wears away materials softer than itself.
- Important properties of abrasives are penetration hardness, fracture resistance and wear resistance.

TYPES OF ABRASIVES:-

- Natural abrasives- they are obtained from nature. Natural abrasives are sand stone, emergy/corundum, diamond and garnet.
- Artificial/synthetic abrasives- they are manufactured to have well defined and controlled properties of hardness, roughness and type of structure. Artificial o synthetic abrasives are silicon carbide(SiC), aluminium OXIDE(AL_2O_3)

BOND : -

- The bond is an adhesive substance which cements or holds the abrasive grains together to form a grinding wheel.
- Depending upon the application, bond imparts the qualities of hardness or softness to the grinding wheel.
- The choice or selection of the bond depends upon the accuracy, the required surface finish and the nature of grinding operation.

SR. NO.	NAME OF BOND	CHARACTERISTICS	DESIGNATION
1.	Vitrified bond	Good strength and high porosity	V
2.	Silicate bond	Waterproof, used for large diameter wheels. Grinding of fine edge tools, etc.	S
3.	Shellac bond	Thin wheels, high elasticity, not suitable for heavy duty application.	E
4.	Resinoid bond	Rough grinding, high speed grinding.	B
5.	Rubber bond	Thin wheels, fine finishing and polishing e.g. ball bearing races.	R
6.	Oxychloride bond	Disc grinders, less brittle.	O

GRIT/GRAIN SIZE:-

- Size of grain grit is determined by sorting or grading the material by passing through screens with the no. of meshes per linear inch.
- The grain size influences stock removal rate and the generated surface finish.
- The selection of grain size is determined by-
  i. Nature of grinding operation
  ii. Material to be grinded
  iii. Material removal rate
  iv. Surface finish required

SR. NO.	SIZE	TYPE	APPLICATIONS
1.	10,12,14,16,20,24	Coarse	Rapid material removal
2.	30,36,46,54,60	Medium	Stock removal and finish both
3.	80,100,120,150,180	Fine	Less stock removal, high surface finish
4.	220,240,280,320,400,500, 600	Very fine	Very high surface finish, grinding hard materials

GRADE OF THE WHEEL:-

- Structure of the grinding wheel represents to the grain spacing or the manner in which the abrasive grains are distributed throughout the wheel.
- The entire volume is occupied by abrasive grains, bonding material and pores.
- The primary purpose of structure is to provide chip clearance and it may be open medium or dense.

SR. NO.	TYPE	DESIGNATION	APPLICATION
1.	Dense	1,2,3,4	Cutting and snagging, hard and brittle materials
2.	Medium	5,6,7,8	90% grinding wheels
3.	Open	9,10,11,12,13,14	Soft, tough, ductile materials e.g. ball bearings, brass, bronze

WHEEL SHAPES AND SIZES:-

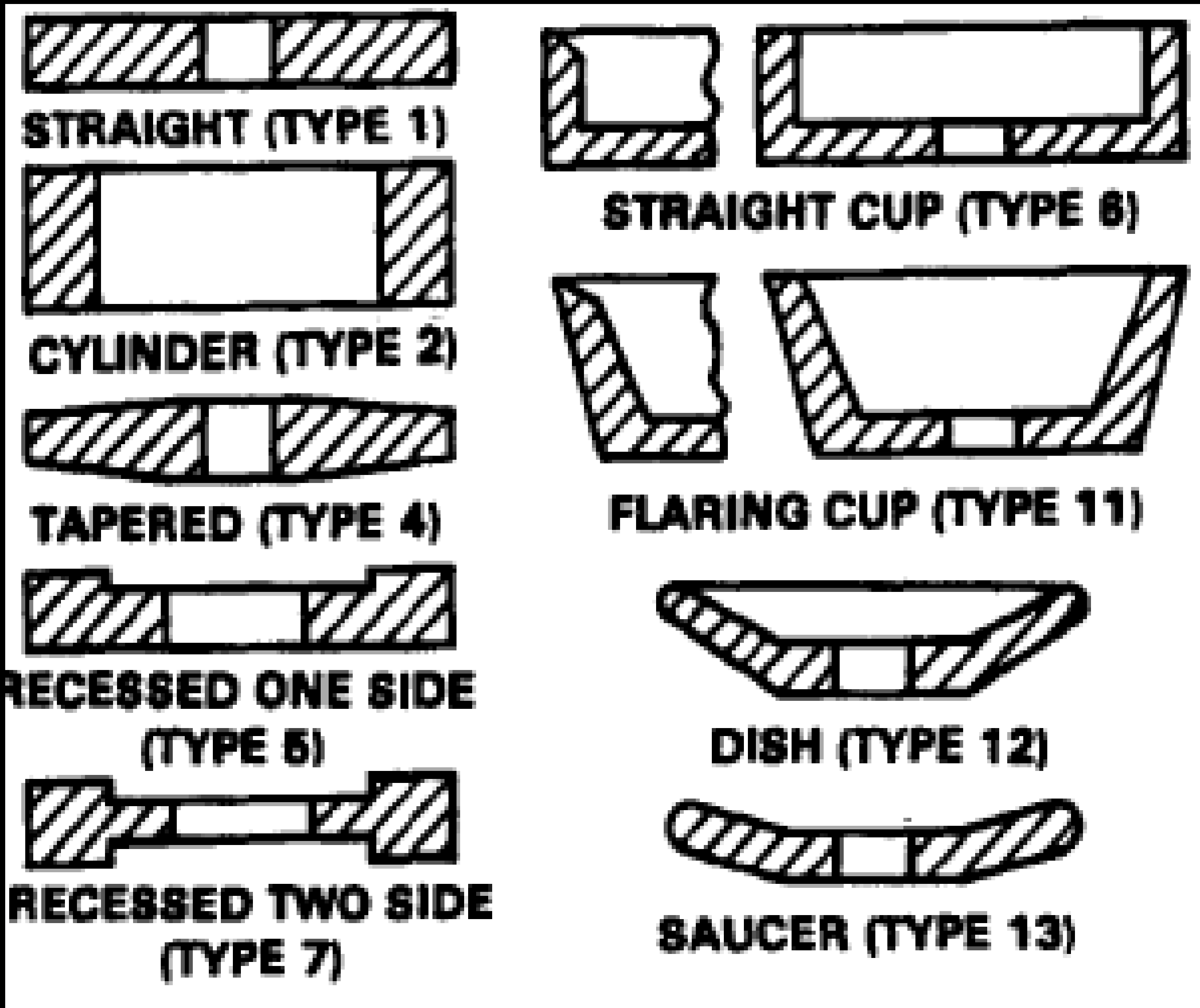
- The shape of grinding wheel should be such that it permits proper contact between the wheel and all of the permits proper contact between the wheel and all of the surface must be ground.
- They are classified in the following groups:

  i. Straight side grinding wheel

  ii. Cylindrical wheels

  iii. Cup wheels

  iv. Dish wheels


STRAIGHT (TYPE 1)
CYLINDER (TYPE 2)
TAPERED (TYPE 4)
RECESSED ONE SIDE (TYPE 5)
RECESSED TWO SIDE (TYPE 7)
STRAIGHT CUP (TYPE 6)
FLARING CUP (TYPE 11)
DISH (TYPE 12)
SAUCER (TYPE 13)

(WHEEL DESIGNING):

- It consists of 6 symbols representing following properties of grinding wheel:
  i. Manufacturer's symbol
  ii. Type of abrasive
  iii. Grain size
  iv. Grade
  v. Structure
  vi. Type of bond
  vii. Manufacture symbol (optional) for reference

Example of a wheel specification:

51 A 36 L 5 V 40

51 → Manufacturer's symbol indicating type of abrasive

A → Abrasive (aluminium oxide)

36 → Grain size(medium)

L → Grade(medium)

5 → Structure(dense)

V → Bond(vitrified)

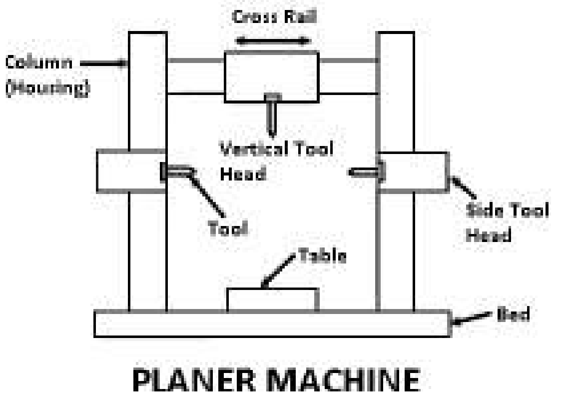
40 → Manufacture symbol (suffix) optional

WHEEL IDENTIFICATION:

Prefix	Abrasive	Grain size	Grade	Structure	Bond	Suffix
45	C	54	H	6	S	23
(Optional)	A → Al2O3	Coarse → 10,12,14,16, 20,24	Soft → H,I,J,K	Dense → 1,2,3,4	Vitrified(V)	(optional)
By	Aluminium oxide	Medium → 30,36,46,54,60	Medium → L,M,N,O	Medium → 5,6,7,8	Silicate(S)	By
Manufacturer	S → SiC	Fine → 80,100,120,150,1 80	Hard → P,Q,R,S	Open → 9,10,11,12,13 ,14	Shellac(E)	Manufacturer
	Silicon	Very fine → 220,240,280,320, 400,500,600	Very hard → T,U,V,W		Rubber(R)	
	Carbide				Resinoide(R)	
					Oxychloride (O)	

Planer Machine

The **planer machine** is similar to a shaper machine. It intended to produce plane and flat surfaces by a single-point cutting tool. **A planer machine is very large** and massive compared to a shaper machine. It is capable of a machining heavy workpiece, which cannot be fit on a shaper table.



The fundamental difference between a shaper and a planer is that

 In a planer, the work which is supported on the table reciprocates over the stationary cutting tool. And the feed is supplied by the lateral movement of the tool.
 In a shaper, the tool which is mounted upon the ram reciprocates. And the feed is given by the crosswise movement of the table.

Types of Planer Machine

Following are the different **types of planer machine**:
1. Standard or Double housing type planer machine
2. open side type planer machine
3. Pit planer machine
4. Edge or plate planer
5. Divided table planer

Different classes of work necessitate designing the different types of planer machine to suit various requirements of our present-day industry.
Read Also: Slotter Machine: Types, Parts and Operations [Complete Guide]

Parts of Planer Machine

Following are the important parts of the planer machine:
- Bed
- Table or Platen
- Housing or Column
- Cross rail
- Tool head
- Driving and Feed Mechanism

Bed

- The bed of a planer is a box-like casting having cross ribs. It is very large in size and heavy in weight and it supports the column and all other moving parts of the machine.
- The bed is made slightly longer than twice the length of the table so that the full length of the table may be moved on it.
- It is provided with precision ways over the entire length on its top surface and the table slides on it.
- In a standard machine, two V-type of guideways are provided.
- Three or more guideways may be provided on a very large wide machine for supporting the table.
- Some of these guideways may be the flat type to lend support to the table.
- The guideways should be horizontal, true and parallel to each other.
- The ways are properly lubricated and in modern machines oil under pressure is pumped into the different parts of the guideways to ensure a continuous and adequate supply of lubricants.
- The hollow space within the box-like the structure of the bed houses the driving mechanism for the table.

Table

- The table supports the work and reciprocates along with the ways of the bed.
- The planer table is a heavy rectangular casting and is made of good quality cast iron.
- The top face of the planer table is accurately finished in order to locate the work correctly.
- T-slots are provided on the entire length of the table so that the work and work holding devices may be bolted upon it.
- Accurate holes are drilled on the top surface of the planer table at regular intervals for supporting the poppets and stop pins.
- At each end of the table, a hollow space is left which acts as a trough for collecting chips. Long works can also rest upon the troughs.
- A groove is cut on the side of the table for clamping planer reversing dogs at different positions.
- In a standard planer, the table is made up of one single casting but in a divided table planer there are two separate tables mounted upon the bedways.

The tables may be reciprocated individually or together. All planets have some form of safety device to prevent the heavily loaded table from running away in case of electrical or mechanical failure which otherwise would have caused severe damage to the machine.
 Hydraulic bumpers are sometimes fitted at the end of the bed to stop the table from overrunning giving cushioning effect.
 In some machines, if the table overruns, a large cutting tool bolted to the underside of the table will take a deep cut on a replaceable block attached to the bed, absorbing the kinetic energy of the moving table.

Housing

 The housings also called columns or uprights are rigid box-like vertical structures placed on each side of the bed and are fastened to the sides of the bed.
 They are heavily ribbed to take up severe forces due to cutting.
 The front face of each housing is accurately machined to provide precision ways on which the cross rail may be made to slide up and down for accommodating different heights of work.
 Two side-toolheads also slide upon it. The housing encloses the Crossrail elevating screw, vertical and crossfeed screws for tool heads, counterbalancing weight for the Crossrail, etc. These screws operated either by hand or power.

Cross rail

 The Crossrail is a rigid box-like casting connecting the two housings. This construction ensures the rigidity of the machine.
 The Crossrail may be raised or lowered on the face of the housing and can be clamped at any desired position by manual, hydraulic or electrical clamping devices.
 The Crossrail when clamped should remain absolutely parallel to the top surface of the table, i.e. it must be horizontal irrespective of its position.
 This is necessary to generate a flat horizontal surface on a workpiece because the tool follows the pat on the Crossrail during crossfeed.
 The two elevating screws in the two housing are rotated by an equal amount to keep the Crossrail horizontal in any position.
 The front face of the cross rail is accurately machined to provide a guide surface for the tool head saddle.
 Usually, two toolheads, are mounted upon the Crossrail which are called railhead.
 The Crossrail has screws for vertical and crossfeed of the toolheads and a screw for elevating the rail. These screws rotated either by hand or by power.

Read Also: Horizontal Boring Machine [Types, Tools and Operations]

Tool-head

The tool head of a planer is similar to that of a shaper both in construction and operation. The important parts of a tool head are:

1. Saddle
2. Swivel base
3. Vertical Slide

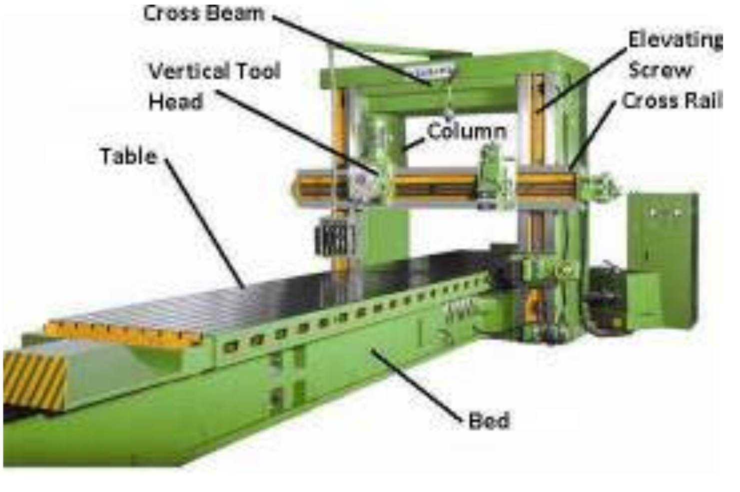
4. Apron
5. Clapper box
6. Clapper block
7. Toolpost
8. Down feed screw
9. Apron clamping bolt,
10. Apron swivelling pin
11. Mechanism for cross and down-feed of the tool.

Different Types of Planer Machine

1. Standard or Double housing type planer machine
2. open side type planer machine
3. Pit planer machine
4. Edge or plate planer
5. Divided table planer

1. Standard or Double Housing Planer Machine

The **standard or double housing planer** is the most widely used types of planer machine in workshops. **A double housing planer** has a long heavy base on which a table reciprocates on accurate guideways.



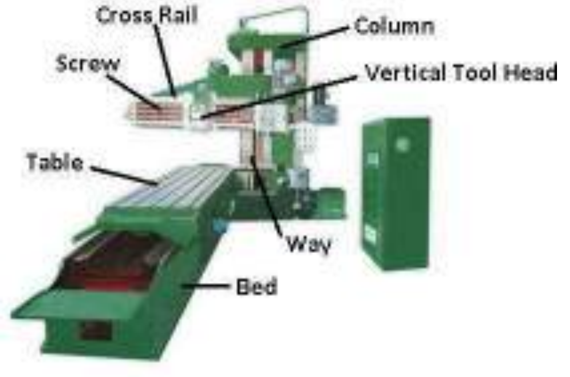
DOUBLE HOUSING PLANER

The length of the bed is little over twice the length of the table.
 Two massive vertical housings or uprights are mounted near the middle of the base, one on each side of the bed. To ensure the rigidity of the structure, these two housings are connected at the top by a cast-iron member.
 The vertical faces of the two housing are accurately machined so that horizontal Crossrail carrying two tool heads may slide upon it.
 The tool heads which hold the tools are mounted upon the Crossrail.
These tools may be feed either by the power in Crossrail or vertical direction. In addition to these tool heads, there are two other tool heads which are mounted upon the vertical face of the housing.

They can also be moved either in a vertical or horizontal direction to apply feed. The planer table may be **driven** either by **mechanical or hydraulic devices.**

Openside Planer Machine

An openside planer has a housing only on one side of the base. And the Crossrail is suspended from the housing as a cantilever. This feature of the machine allows the large and wide workpiece to be clamped on the table and reciprocated over the cutting tool.

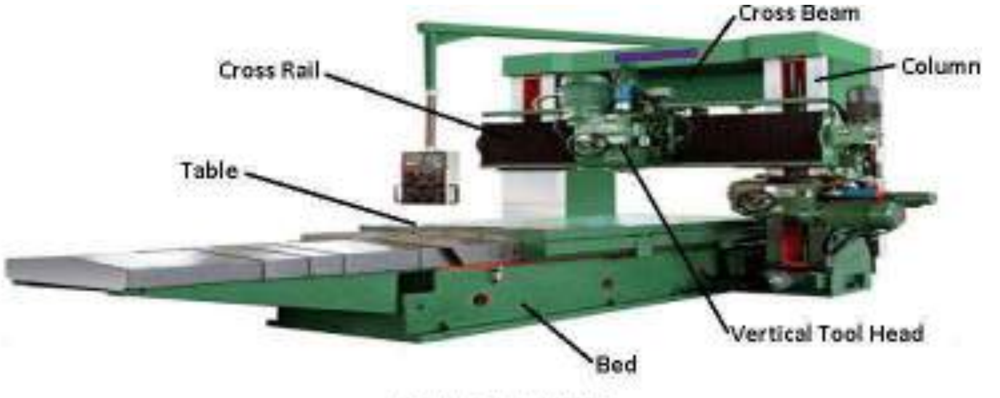


OPEN SIDE PLANER

One side of the planer being opened, large and wide jobs may project out of the table and reciprocate without being interfered by the housing.
In a double housing planer, the maximum width of the job which can be machined is limited by the distance between the two housing. As the single housing has to take up the entire load, it is made extra-massive to resist the forces.
Only three tool heads are mounted on this machine. The constructional and driving features of the machine are the same as that of a double housing planer.

3. Pit Planer Machine

A pit type planer is massive in construction. It differs from an ordinary planer. In this the table is stationary and the column carrying the Crossrail reciprocates on massive horizontal rails mounted on both sides of the table.



PIT PLANER

This types of planer machine are suitable for machining a very large work which cannot be supported on a standard planer. This machine design saves much of floor space.

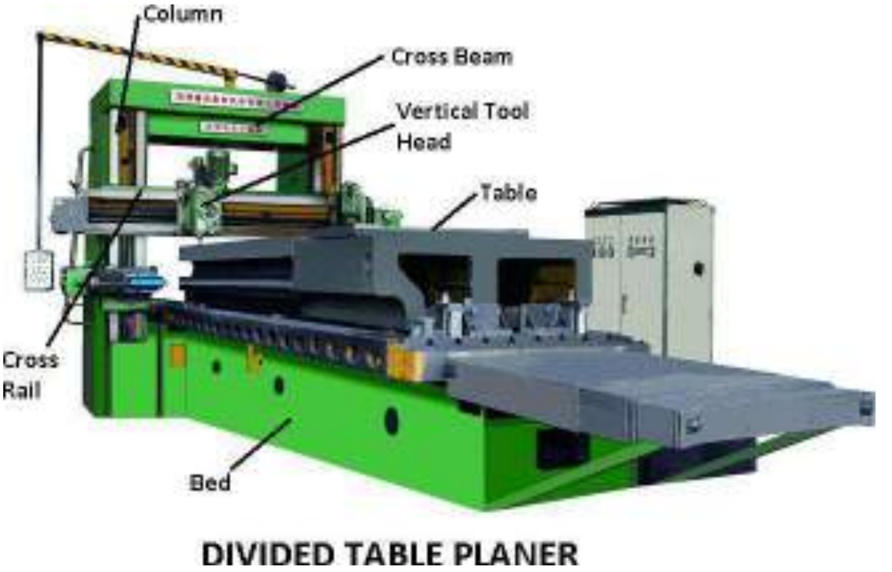
The length of the bed required in a pit type planer is little over the length of the table. Whereas in a standard planer the length of the bed is near twice the length of the table. The uprights and the Crossrail are made sufficiently rigid to take up the forces while cutting.

4. Edge or Plate Planer

The design of a plate or edge planer is totally unlike that of an ordinary planer. It is specially intended for squaring and bevelling the edges of steel plates. Also used for different pressure vessels and ship-building works.

One end of a long plate which remains stationary is clamped with the machine frame by a large number so air operated clamps. The cutting tool is attached to a carriage which is supported on two horizontal ways of the planer on its front end.
The operator can stand on a platform extending from the carriage. The carriage holding the tool reciprocates over the edge of the plate. The feed and depth of cut are adjusted by the tool holder which can be operated from the platform.

5. Divided Table Planer



DIVIDED TABLE PLANER

This type of planer has two tables on the bed which may be reciprocated separately or together.
This type of design saves much of idle time while setting the work. The setting up of a large number of identical workpieces on the planing machine table takes quite a long time. It may require as much time for setting up as may necessary for machining.
To have continuous production on the table is used for setting up the work. While the other reciprocates over the cutting tool finishing the work. When the work on the second table is finished, it is stopped and finished jobs are removed.

Fresh jobs are now set up on this table while the first table holding the jobs now reciprocates over the tool. When a heavy and large job has to be machined, both the table are clamped together and are given reciprocating movement under the tool.

Slotter Machine

The **slotter machine** falls under the category of the reciprocating type of machine tool similar to a shaper to a shaper or a planner. It operates almost on the same principle as that of a shaper.
The major difference between a slotter machine and a shaper machine is that in a slotter the ram holding the tool reciprocates in the vertical axis. whereas in a shaper the ram holding the tool reciprocates in a horizontal axis. A vertical shaper and slotter machines are almost similar to each other as regards their construction, operation, and use.

The only difference being, in the case of a **vertical shaper,** the ram holding the tool may also reciprocate at an angle to the horizontal table in addition to the vertical stroke. The ram can be swivelled not more than 5° to the vertical.

The slotter machine is used for

 Cutting grooves, keyways and slots of various shapes.
 Used for making regular and irregular surfaces both internal and external.
 For handling large and awkward workpiece.
 For cutting internal or external gears and many other operations which cannot be easily machined in any other machine tool described before.

The **slotter machine** was developed by **Brunel** in the year 1800 much earlier than a shaper was invented.

Types of Slotter Machine

There are mainly two **types of slotter machine.**
1. Puncher slotter.
2. Precision slotter.

1. Puncher Slotter

The puncher slotter machine is a heavy, rigid machine designed for removal of a large amount of metal from large forgings or castings. The length of stroke of a puncher slotter is sufficiently large. It may be as long as 1800 to 2000mm.

The puncher slotter ram is usually driven by a spiral pinion meshing with the rack teeth cut on the underside of the ram. The pinion is driven by a variable speed reversible electric motor similar to that of a planer. The feed is also controlled by electrical gears.

2. Precision Slotter

The precision slotter machine is a lighter machine and is operated at high speeds. The machine is designed to take light cuts giving the accurate finish.

Using special jigs, the machine can handle a number of works on a production basis. The precision slotter machines are also used for general purpose work and are usually fitted with Whitworth quick return mechanism.

Slotter Size

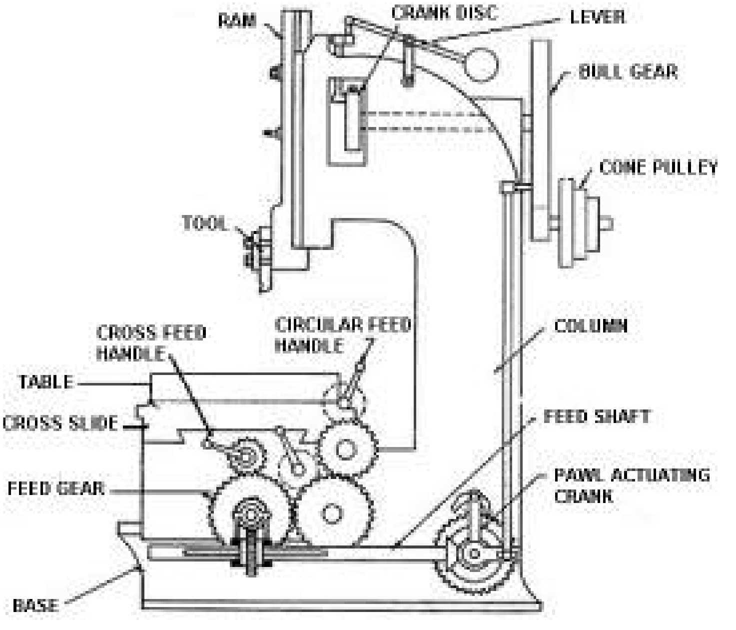
The size of a slotter machine like that of a shaper is specified by the maximum length of stroke of the ram, expressed in mm. The size of a general-purpose or precision slotter usually ranges from 80 to 900mm.

To specify a slotter correctly the diameter of the table in mm. Amount of cross and longitudinal travel of the table expressed in mm. The number of speeds and feeds available, h.p. of the motor, floor space required etc. should also be stated.

Parts of Slotter Machine

The different parts of a slotter machine are,

1. Base.
2. Column.
3. Saddle.
4. Crosslide.
5. Rotating table.
6. Ram and tool head assembly.
7. Ram drive mechanism.
8. Feed mechanism.



SLOTTER MACHINE

1. Base or Bed

 The base is rigidly built to take up all the cutting forces and the entire load of the machine.
 The top of the bed is accurately finished to provide guideways on which the saddle is mounted.
 The guideways are perpendicular to the column face.

2. Column

 The column is the vertical member which is cast integrally with the base and houses driving mechanism of the ram and feeding mechanism.
 The front vertical face of the column is accurately finished for providing ways in which the ram reciprocates.

3. Saddle

 The saddle is mounted upon the guideways and may be moved toward or away from the column either power or manual control to supply longitudinal feed to the work.
 The top face of the saddle is accurately finished to provide guideways for the cross-slide. These guideways are perpendicular to the guideways on the base.

4. Cross-slide

 The cross-slide is mounted upon the guideways of the saddle and maybe moved parallel to the face of the column.
 The movement of the slide may be controlled either by hand or power to supply crossfeed.

5. Rotary Table

 The rotary table is a circular table which is mounted on the top of the cross-slide.
 The table may be rotated by rotating a worm which meshes with a worm gear connected to the underside of the table.
 The rotation of the table may be effected either by hand or power. In some
 In some machines, the table is graduated in degrees that enable the table to be rotated for indexing or diving the periphery of a job in the equal number of parts.
 T-slots are cut on the top face of the table for holding the work by different clamping devices. The rotary table enables a circular or contoured surface to be generated on the workpiece.

6. Ram and Toolhead Assembly

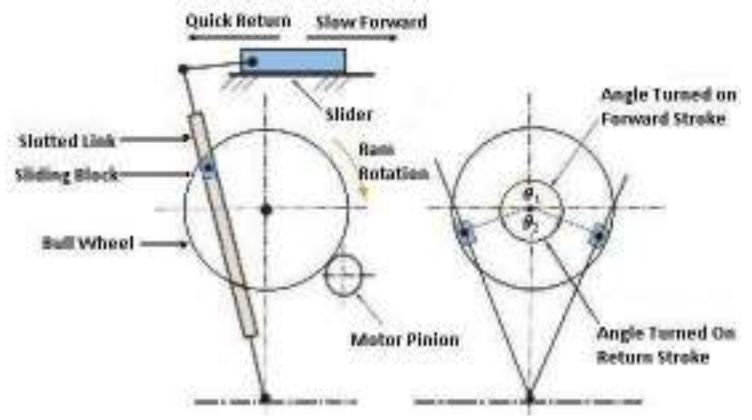
 The ram is the reciprocating member of the machine mounted on the guideways of the column. It supports the tool at its bottom end on a tool head.
 A slot is cut on the body of the ram for changing the position of the stroke.
 In some machines, special type for tool holders is provided to relieve the tool during its return stroke.

Ram Drive Mechanism

A slotter removes metal during downward cutting stroke only whereas during upward return stroke no metal is removed. The reduce the idle return time quick return mechanism is incorporated in the machine. The usual types of ram drive mechanism are,
1. Whitworth quick return mechanism.
2. Variable speed reversible motor drive mechanism.
3. Hydraulic drive mechanism.

Whitworth Quick Return Mechanism

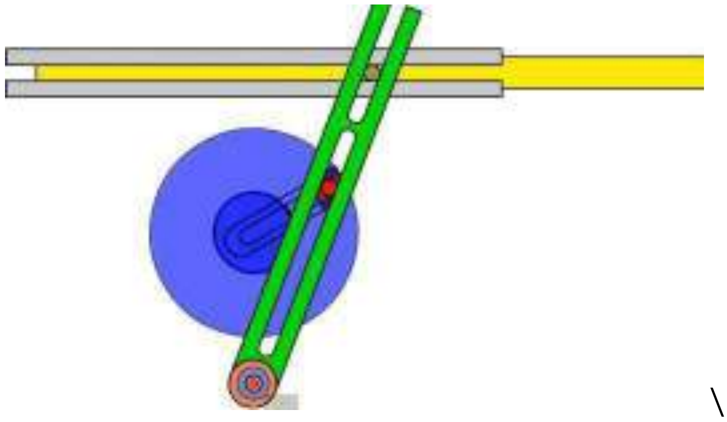
A simple Whitworth quick return mechanism as shown in fig.
The bull gear is mounted on a fixed hub at the rear end of the machine and it is rotated by a driving pinion from the motor. The driving plate is connected to the main shaft through the fixed hub. The main shaft is placed eccentrically with respect to the bull gear centre.



The bull gear holds the crankpin with sliding block and slides in a driving plate. So that when the bull gear rotates, imparts rotary motion to the driving plate and shaft causing the disc to rotate at the end of the main shaft.
The disc is connected to the lower end of the connecting rod eccentrically by means of a pin in a radial T-slots on the face of the disc, which converts the rotary motion of the disc into reciprocating motion of the ram connected to the top end of the connecting rod.

The Principle of a Quick Return Mechanism

The principle of quick return mechanism can be explained simply by a line diagram. A and B are the fixed centres of the bull gear and the driving plate. The crack pin and the slide block rotate in a circular path at a constant speed in a driving plate about B. This causes the disc to rotate through the main shaft.



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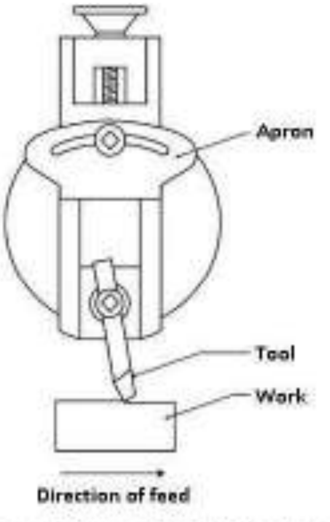
The pin 3 on the disc rotates in a circular path about the fixed point B. The length of the ram is equal to twice the narrow of eccentricity and it is equal to 2x3B (3B= throw of eccentricity). When the slide block is at C, the ram is at the maximum upward position of the stroke and when it is at D, the ram is at the maximum downward position.
If the bull gear rotates in an anticlockwise direction and the slide block rotates through an angle CAD, the ram performs downward cutting stroke, whereas when the block rotates through an angle DAC the ram perform return stroke.
As the block rotates at a constant speed the rotation of slide block through an angle CAD during cutting stroke takes longer time than the rotation through an angle DAC during the return stroke. Thus the quick return motion is obtained.

Slotter Machine Operations

1. Machining cylindrical surface.
2. Flat surface Machining.
3. Machining irregular surface and cam machining.
4. Machining slots, keyways and grooves.

1. Flat Surfaces Machining

The external and internal flat surfaces may be generated on a workpiece easily in a slotter machine. The work to be machined is supported on parallel strips so that the tool will have clearance with the table when it is at the extreme downward position of the stroke.

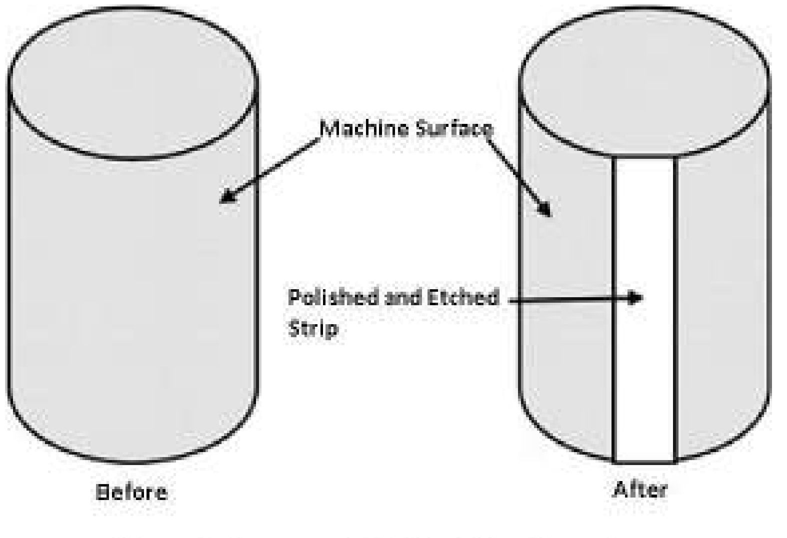


Machining of Flat Surface

The work is then clamped properly on the table and the position and the length of the stroke is adjusted. A clearance of 20 to 25mm is left before the beginning of cutting stroke, so that the feeding movement may take place during this idle part of the stroke.
The table is clamped to prevent any longitudinal or rotary travel and the cut is started from one end of the work. The crossfeed is supplied at the beginning of each cutting stroke and the work is completed by using a roughing and a finishing tool. While machining an internal surface, a hole is drilled into the workpiece through which the slotter tool may pass during the first cutting stroke.
A second surface parallel to the first machined surface can be completed without disturbing the setting by simply rotating the table through 180° and adjusting the position of the saddle. A surface perpendicular to the first machined surface may be completed by rotating the table by 90° and adjusting the position of the saddle and cross slide.

2. Machining Circular Surfaces

The external and internal surface of a cylinder can also be machined in a slotter machine. The work is placed centrally on the rotary table and packing pieces and clamps are used to hold the work securely on the table.



Machining of Cylindrical Surface

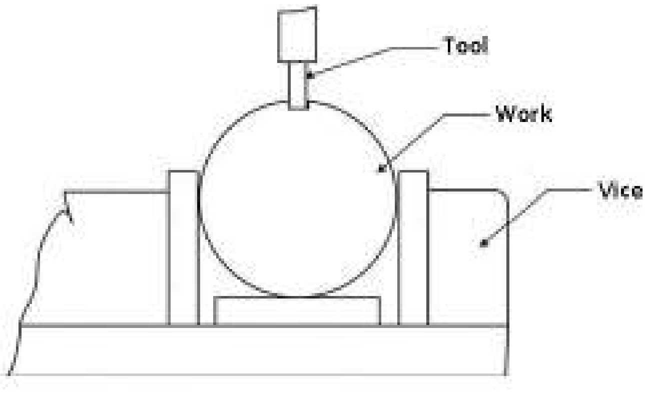
The tool is set radially on the work and necessary adjustments of the machine and the tool are made. The saddle is clamped in its position and the machine is started. While machining, the feeding is done by the rotary table feed screw which rotates the able through a small arc at the beginning of each cutting stroke.

3. Machining Irregular Surfaces or Cams

The work is set on the table and necessary adjustments of the tool and the machine are made as detailed in other operation. By combining cross, longitudinal and rotary feed movements of the table any contoured surface can be machined on a workpiece.

4. Machining Grooves or Keyways

Internal and external grooves are cut very conveniently machine. A slotter is specially intended for cutting internal grooves which are difficult to produce in other machines.



Machining of Keyways

External or internal gear teeth can also be machined in a slotter by cutting equally spaced grooves on the periphery of the work. The indexing or dividing the periphery of the work is done by the graduations on the rotary table.

Difference between shaper and slotter machine

1. In shaper machines, the direction of cutting stroke is horizontal with slower than the return stroke. But in slotter machines, the direction of cutting stroke is vertical with slower than the return stroke.
2. In shaper, Ram holding the tool reciprocates in a horizontal axis whereas, in slotter, the ram holding the tool reciprocates in a vertical axis.
3. Shaper machine is used to produce horizontal, vertical or inclined flat surfaces. Whereas in slotter machine is used for cutting keyways, grooves and slots of various shapes, for making regular and irregular surfaces both external and internal, for cutting internal gears, for handling large and for awkward jobs

Performance of I.C engine

Chapter - 1

Indicated Power (IP)

The energy available to the piston due to expansion of gas.

Brake Power (BP)

It is the energy available at the end of engine shaft. It can be determine by using the break mechanism

Frictional Power (FP)

The energy lost during the converting of indicated power into brake power

$$FP = IP - BP$$

Mechanical efficiency (η_{mech})

$$\eta_m = \frac{\text{Brake Power}}{\text{Indicated power}}$$

It is the ratio of Brake power to indicated power.

Thermal efficiency

It is are of two types.

1. Brake thermal efficiency η_{bth}
2. Indicated thermal efficiency η_{ith}

① Brake thermal efficiency (η_{bth}, $\eta_{overall}$, η_{engine})

$$\eta_{bth} = \frac{\text{Brake Power}}{\text{Heat input per sec}}$$

Indicated thermal efficiency.

$$\eta_{ith} = \frac{\text{Indicated power}}{\text{Heat input per sec.}}$$

Heat input per sec

$= \dot{M}_f \times C.V$

unit

$\frac{kg}{sec} \times \frac{kJ}{kg} = \frac{kJ}{sec} = kW$

where $\dot{M}_f$ = Mass flow rate

C.V = Calorific value of the fuel

Brake thermal efficiency is the over all efficiency or engine efficiency.

Relative efficiency

Relative efficiency of the IC engine can be defined as the ratio of indicated thermal efficiency to the air standard efficiency

Air standard efficiency means the efficiency of air standard cycle that is otto cycle, diesel cycle and duel cycle.

Volumatic efficiency

It is the ratio of actual volume of air that entered into the cylinder to the theoritical swept volume.

$$\eta_v = \frac{\text{actual volume}}{\text{swept volume}} = \frac{V_a}{V_s}$$

V_a can be calculated from ideal gas equation $P_1 V_a = M_a R T_1$

Theoritical swept volume

$$V_s = \frac{\pi}{4} \times d^2 \times L \times K \times \frac{N}{60} \times a$$

where V_s = theoritical swept volume
d = diameter of the cylinder
L = Length of the cylinder
N = speed in rpm
a = depend on the number of stroke.

For two stroke $a = 1$
4 " $a = \frac{1}{2}$
6 " $a = \frac{1}{3}$
8 " $a = \frac{1}{4}$

Air fuel ratio. (AFR)

It is defined as the ratio of mass of air to the mass of fuel enter into the cylinder $AFR = \frac{1}{FAR}$ $\boxed{AFR = \frac{m_a}{m_f}}$

Fuel air ratio (FAR)

The ratio of mass of fuel enter into the cylinder to the mass of air

Dt 20.1.2020

Mean effective pressure

It is an imaginary pressure which will remain constant to gives same workdone as by the actual cycle for the same change in volume.

Assignment - I

How to find molecular mass of air.

Equivalency Ratio (ϕ)

It is defined as the ratio of actual fuel air ratio to the theoritical fuel air ratio

* If $\phi > 1$ then it is rich AFM

$\phi = 1$ then it is perfect AFM

$\phi < 1$ then it is lean AFM

AFM = Air fuel mixture

Specific fuel consumption

Mathematically

x specific $y = \frac{y}{x}$

Brake specific fuel consuption

$= \frac{\dot{m}_F}{BP}$

Indicated specific fuel consuption

$= \frac{\dot{M}_f}{IP}$

→ Brake specific fuel consumption (B.S.F.C)

It is the ratio between mass of fuel consume to the brake power

→ Indicated specific fuel consuption (I.S.F.C)

It is the ratio between mass of fuel consume to the indicated power.

DL - 22.01.2020

During the test on single cylinder engine working on four stroke cycle, the following readings are taken

Effective diameter of break wheel - 630 mm

Dead load on break - 200 N

Spring balance reading - 30 N

Speed - 450 rpm

Area of indicator digram = 420 mm^2

length of indicator diagram = 60 mm

spring scale = 1.1 bar/mm

diameter of cylinder = 100 mm

Stroke = 150mm

quantity of oil used = 0.815 kg/h

calorific value of oil = 42000 kJ/kg

Calculate break power, indicated power, mechanical efficiency, brake thermal efficiency, break specific fuel consumption.

~~breadth~~ ~~with~~ width of indicator diameter

$$= \frac{Area}{length} = \frac{420}{60}$$

$$= 7 \text{ mm}$$

Mean effective pressure

= width × spring scale 7 × 1.1 = 7.7 bar

Brake Power

$= 2\pi NT = \frac{2\pi N \times wl}{60}$ watt $= \frac{2\pi N wl}{60000}$ kW

or $2\pi NT$ watt

N in rps

w = break load in newton

L = length of arm in meter

N = speed of rpm

T = Torque

2π = angle turn in radians through one revolution

Dynamometer is basically torque measuring device - It is used to absorb ~~and~~ power during the period in which engine is tested.

In case of rope brake

without considering the diameter of rope

$$B.P = \frac{(w-s)\,\pi DN}{60} \text{ watt}$$

Consider the diameter of rope

$$B.P = \frac{(w-s)\,\pi\,(D+d)\,N}{60} \text{ watt}$$

$$B.P = \frac{(200-30)\,\pi\, 0.630 \times 450}{60}$$

~~= 2523.4843~~ = 2523.4843 W

= 2.523 kW

Indicated power

$$I.P = \frac{P_m \times LAn \times 10^5 \times k}{60} \text{ watt} = \frac{P_m \times LAn \times 10^2 \times k}{60} \text{ kW}$$

P_m = mean effective pressure in bar

L = length of stroke in meter

A = Area of the piston cylinder

n = Number of working stroke per minute

K = number of cylinder

when P_m is in N/m^2 or Pa

$$I.P = \frac{P_m \times LAn \times k}{60} \text{ watt}$$

$$= \frac{7.7 \times 0.15 \times 7.85 \times 10^{-3} \times \frac{N}{2} \times 1}{60}$$

$$= \frac{7.7 \times 0.15 \times 7.85 \times 10^{-3} \times \frac{450}{2} \times 1}{60}$$

$$= 3401.75 \text{ watt}$$

mechanical efficiency

$$= \frac{B.P}{I.P}$$

$$= \frac{2523.48}{3401.75} = 0.7418 \times 100$$

$$= 74.18\%$$

Brake thermal efficiency

$$= \frac{B.P}{\text{Heat input per sec}} = \frac{B.P \times 3600}{m_f \times C_v}$$

$$= \frac{2.523248 \times 3600}{0.815 \times 42000}$$

~~= 0.2653~~

= 0.26539

= 26.539 %

Brake specific fuel consumption

$$= \frac{m_f}{B.P} = \frac{0.815}{2.52} = 0.323 \ kg/B.P$$

Dt 27.01.2020

Q1 If the engine diamention of a two cylinder two stroke from the following

Engine speed - 4000 rpm

volumatic effinency 0.77

mechanical efficiancy = 0.75

mass fuel consumption = 10 lit/h

Sp. gr. = 0.73

air fuel ratio = 18

Piston speed = 600 m/min

indicated mean effective = 5 bar

Take R for gas mixture = 281 J/kg K and

stp = 15°c NTP = 25°c

1 bar

Q2 A four stroke petrol engine with a compression ratio of 6.5 to 1 and total piston displacement 5.2×10^{-3} m^3 developes 100 kW break power and consumes 33 kg of petrol per hour of cal. value of 44300 kJ/kg at 3000 rpm.

Find

1. Break mean effective pressure
2. Break thermal efficiency η_{bth}
3. Air standard efficiency ($\gamma = 1.4$)
4. Air fuel ratio by mass

Assume a volumetric efficiency of 80%. 1 kg of petrol vapours occupy 0.26 m^3 at 1.013 bar and 15°c. take R for air 287 J/kg K

(1 Ans)

Given

N = 4000 rpm

$\eta_v = 0.77$

$\eta_m = 0.75$

$M_f = 10$ lts/hr $= 10 \times 0.73 = 7.3$ kg/hr

sp. gr. $= 0.73$

AFR $= 18:1$

piston speed

$= 2L \times N$

$600 = 2 \times L \times 4000$

$L = \frac{600}{2 \times 4000}$

$= 0.075$ m

$= 75$ mm

$\eta_v = \frac{V_a}{V_s}$

$V_a = \frac{M_a R_a T}{P} = \frac{2.19 \times 281 \times 288}{10^5}$

$= 1.77$ m³/min

$AFR = \frac{M_a}{M_f} = \frac{18}{1}$

$M_a = 18 \times M_f$

$= 18 \times 7.3$

$= 131.4$ kg/h $= \frac{131.4}{60}$ kg/min

$= 2.19$ kg/min

$V_s = \frac{\pi}{4} D^2 \times L \times k \times \frac{N}{60} \times a$

$$V_s = \frac{\pi}{4}(D)^2 \times 0.075 \times 2 \times \frac{4000}{60} \times 1$$

$$V_s = 7.85\,(D)^2 \ m^3/sec$$

$$= 7.85 \times 60$$

$$= 471 D^2 \ m^3/min$$

$$\eta_v = \frac{V_a}{V_s}$$

$$V_s = \frac{V_a}{\eta_v}$$

$$471 \cdot D^2 = \frac{1.77}{0.77}$$

$$D^2 = \frac{2.29}{471}$$

$$D = \sqrt{4.88 \times 10^{-3}}$$

$$= 0.069857 \ m$$

$$= 69.857 \ mm$$

$$I.P = \frac{P_m \times LA\pi \times 100 \times K}{60} \ kw$$

$$= \frac{2.5 \times 10^5 \times 0.075 \times 0.003739 \times 4000 \times 100 \times 2}{60}$$

$$= 18.69 \ kw$$

$$\eta_m = \frac{B.P}{I.P}$$

$$A = \frac{\pi}{4} \times D^2$$

$$= 0.0037391\ m^2$$

$$BP = 18.69 \times 0.75$$

$$= 14.0175$$

Chapter -2

Air Compressor

Air compressor

It is a machine which compress the air and raise it's pressure. Compressed air is used for

① pneumatic drills

② Paint spraying

③ In starting and supercharging of internal combustion engines.

④ Jet engines

Classification of air compressors

According to working

① Reseprocating ② Rotary

According to numbes of stages.

① single stage ② multi stage

According to action

① single acting ② Double acting

Termenology

Inlet Pressure

It is the pressure at which air enter into the compressor.

Outlet / discharge pressure

It is the pressure at which air exit from the compressor.

Compression Ratio or Pressure Ratio

* The ratio must be greater then one

Pressur ratio my be defined as the ratio of discharge pressure to inlet pressure.

Compresser Capacity

It can be defined as the volume of air delivered by the compresser.

unit m^3/min or m^3/sec

Free air delivery

It is the actual volume delivered by the compresser at NTP (Normal Temperature and pressure)

Swept volume

It is the volume of air sucked by the compresser.

$\frac{\pi}{4} d^2 \times l$ $a^2 \times l$ $ab \times l$

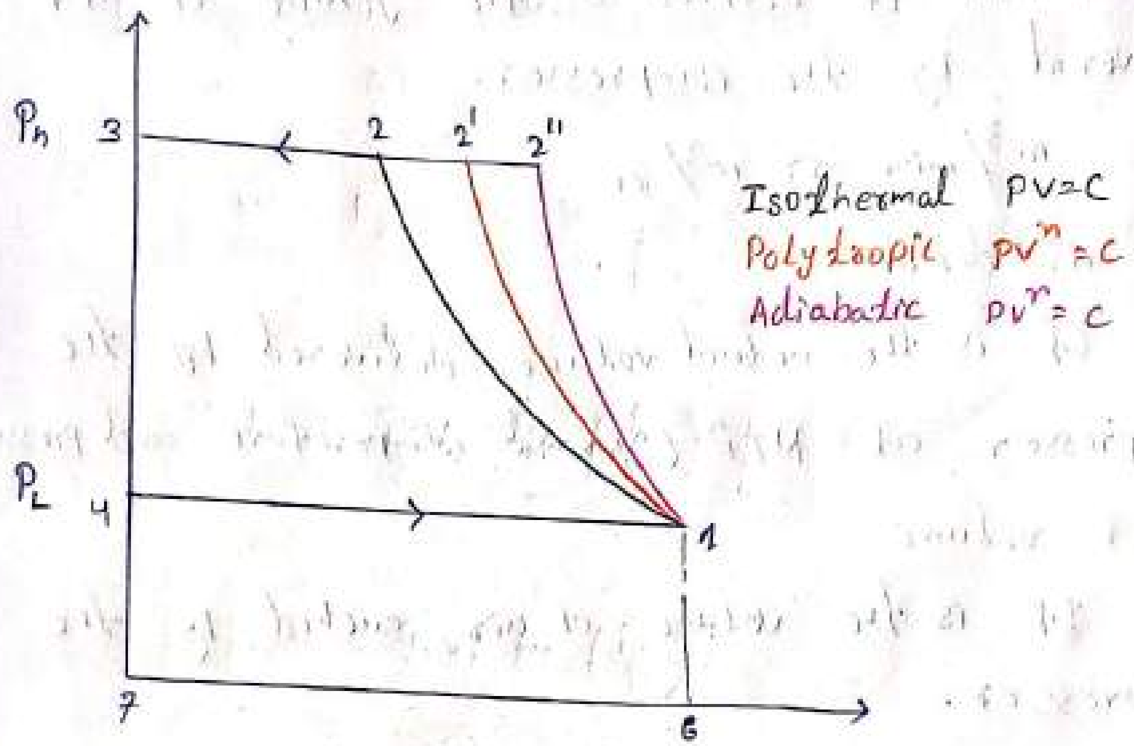
cylinderical   square   rectangular.

Mean effective pressure

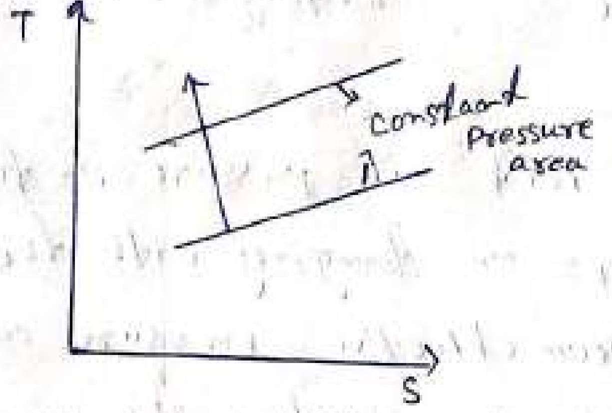
As a matter of fact air pressure on the compresser piston keeps on changing with the moment of piston. Mean effective pressure can be found mathematically by dividing the work done per cycle to the swept volume or stroke volume.

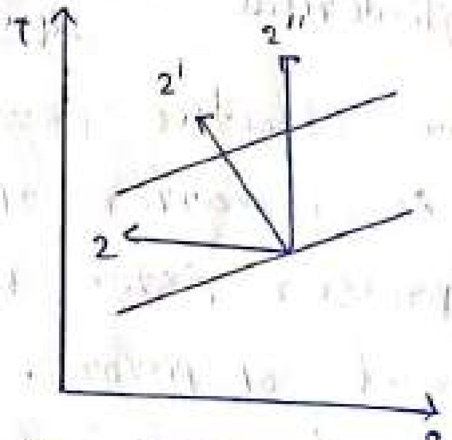
Work done of a single stage Reciprocating Compressor without clearance volume

03.02.2020



Area under the pv digram = work done

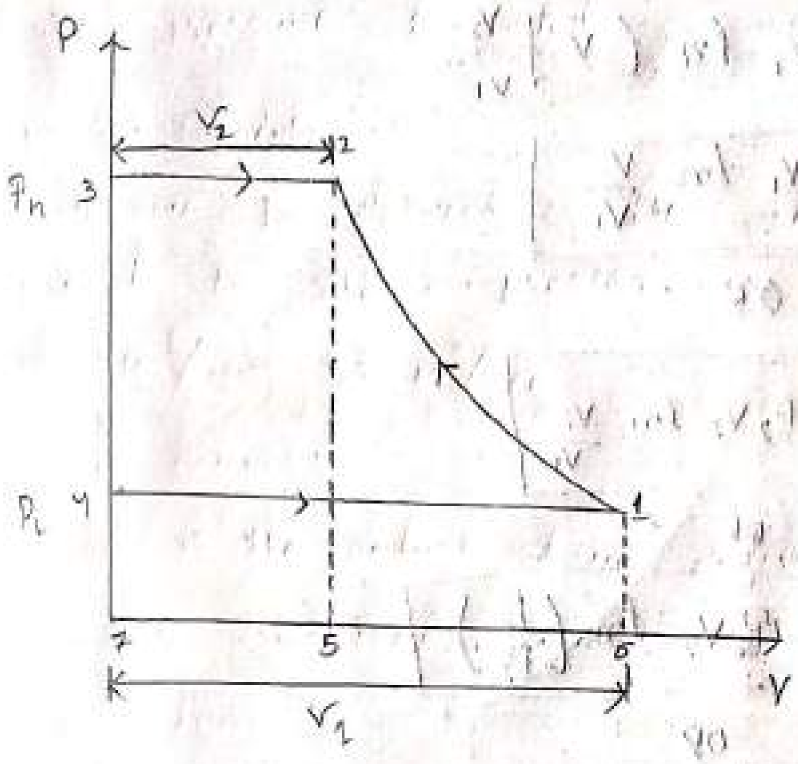




Work done in isothermal process

W = Area 12341

= Area 234752 + Area 25612 − Area 147561



$P_l = P_1 = P_4$

Pressure before compression

$P_h = P_2 = P_3$

Pressure after compression

$P_2 > P_1$

V_1 = volume before compression

V_2 = volume after compression

$$W = P_2 V_2 + P_2 V_2 \ln\left(\frac{V_2}{V_1}\right) - P_1 V_1$$

$$P_1 V_1 = P_2 V_2 = PV = C$$

$$\Rightarrow P_1 V_1 = PV$$

$$\Rightarrow P = P_1 \left(\frac{V_1}{V}\right) \qquad \left[\frac{V_2}{V_1} = \frac{P_1}{P_2}\right]$$

$$W = \int P \, dv$$

$$= P_1 \int \frac{V_1}{V} \, dv$$

$$= P_1 V_1 \int \frac{dv}{v}$$

$$W = P_1 V_1 \ln [V]_{V_1}^{V_2}$$

$$\boxed{W = P_1 V_1 \ln \frac{V_2}{V_1}}$$

OR

$$\boxed{W = P_2 V_2 \ln \frac{V_2}{V_1}}$$

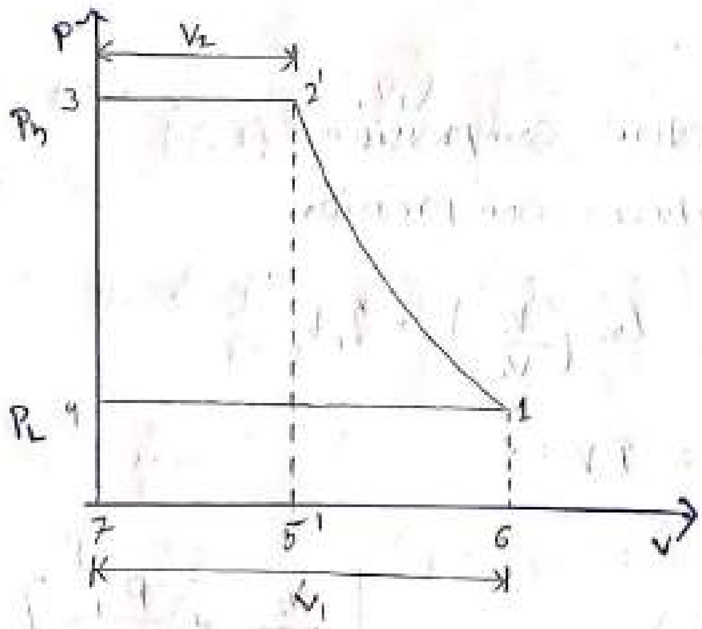
OR

$$\boxed{W = P_2 V_2 \ln \left(\frac{P_1}{P_2}\right)}$$

OR

$$\boxed{W = P_1 V_1 \ln \left(\frac{P_1}{P_2}\right)}$$

Polytropic Process



W = Area 12'341

= Area 2'3475'2' + Area 2'5'612'

− Area 1475'61

$$W = P_2V_2 + \frac{P_2V_2 - P_1V_1}{n-1} - P_1V_1$$

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

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

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

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

we know

$$P_1V_1^n = P_2V_2^n$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = \left(\frac{V_1}{V_2}\right)^{n-1}$$

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

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

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

$$W = \frac{n}{n-1}(mRT_1)\left[\frac{T_2}{T_1} - 1\right]$$

$$\boxed{W = \frac{n}{n-1}\, mR(T_2 - T_1)}$$

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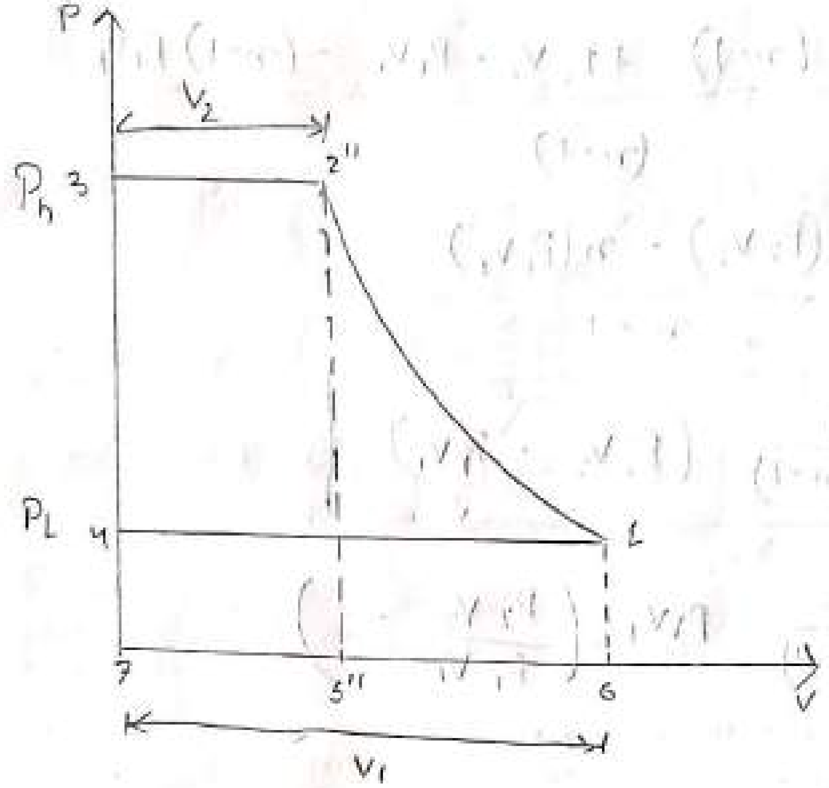
For Isoentropic Compression



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

$$w = \frac{\gamma}{(\gamma-1)}(P_1V_1)\left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

$$w = \frac{\gamma}{\gamma-1} mR(T_2 - T_1)$$

we know

$$\gamma = \frac{C_p}{C_v} \qquad C_p - C_v = R$$

$$C_p\left(1 - \frac{C_v}{C_p}\right) = R$$

$$C_p\left(1 - \frac{1}{\gamma}\right) = R$$

$$C_p\left(\frac{\gamma-1}{\gamma}\right) = R$$

$$w = \frac{\gamma}{\gamma-1} \, mC_p \left(\frac{\gamma-1}{\gamma}\right)(T_2 - T_1)$$

$$w = mC_p (T_2 - T_1)$$

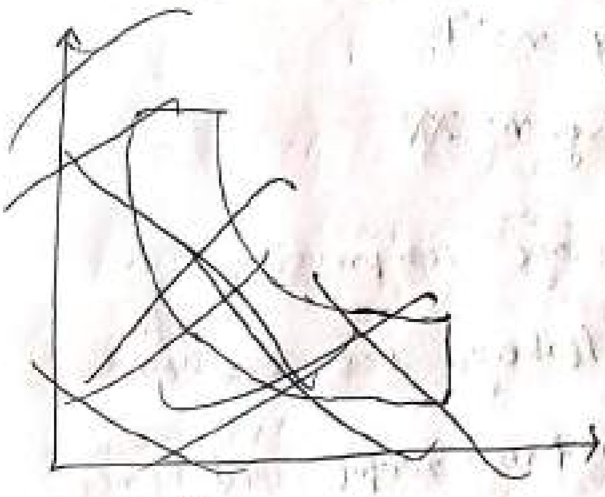
work done during isoentropic compression is equal to the heat required to raise the temperature from T_1 to T_2

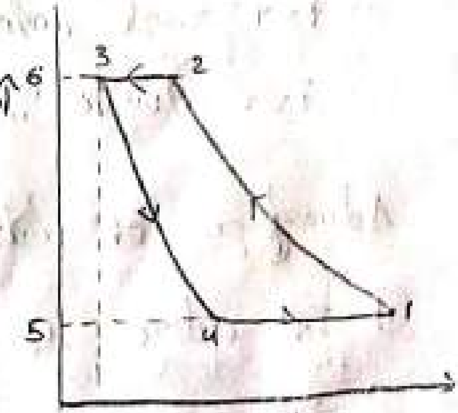
So the work done is minimum when compression process is isothermal

workdone is maximum when compression process is adiabatic or isoentropic.

Dt 10.02.2020

work done by reciprocating air compressor with clearance volume





$Pv^n = c$

$n = 1 \rightarrow$ Isothermal

$n = \gamma \rightarrow$ adiabatic

Effective swept volume $= V_1 - V_4$

clearance volume $= V_3$

work done = Area under the 1-2-3-4-1

= Area (1-2-3-6-5-4-1)

- Area (3-6-5-4-3)

$$= \frac{n}{n-1} P_1V_1 \left(\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right) - \frac{n}{n-1} P_4V_4 \left(\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right)$$

$$= \frac{n}{n-1} P_1 (V_1 - V_4) \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$= \frac{n}{n-1} \times m R T_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

Power required to drive single stage receprocating compressor

$$P = \frac{w \times n}{60} \quad \text{unit is watt}$$

where n = no. of working stroke per minute

w = ~~load~~ work done

For single acting $n = N$

For double acting $n = 2N$

Advantage of multistage compression

① It reduce the leakage loss considerably

② It gives more uniform torque and hence a small size flywheel is required

③ It reduces the cost of compressor.

Chapter - 3 Dt 17.02.2020

Properties of steam

A gas referes to a substance that has a single define thermodynamic state at room temperature.

Vapour

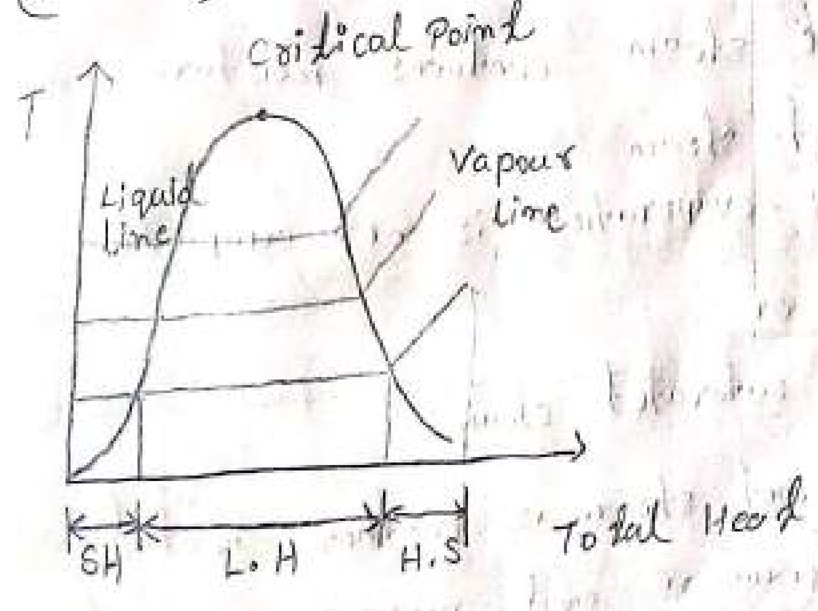
Vapour referes to a substance that is a mixture of two phase at room temperature

Boling temperature of water is 100°C at atmospheric pressure (Atmospheric pressure - 1.01325 bar)

Steam

The vapour into which water is converted when heated forming a white mist of minute water droplete or partices in the air.

steam does not obey the ideal gas equation (PV = MRT)



Dt 19.02.2020

Saturated liquid line

The line which forms boundary line between water and steam.

Saturated vapour line

The line which forms boundary line between wet and superheated steam.

Critical point

It is the that point of pressure and tempr were liquid flashes into vapour or vice-versa

Sensiable heat

Latent heat

heat of super heating

→ wet steam

when the steam contains moisture, it is known as wet steam

It mean evaporation is not complete

→ Dry steam or

Dry saturated steam

when the wet steam is further heated at constant temperature and pressure, it does not contain any moisture or water partical then it is known as dry steam

It mean evaporation is complete and the total latent heat is absorb.

super heated steam

when the dry steam is further heated at constant pressure, it is known as super heated steam. It increase the temperature.

Dryness fraction

$$x = \frac{mg}{mp + mg} = \frac{mg}{m}$$

where

M_p = mass of water in suspention / mass of water particle present in the steam.

x = dryness fraction

M_g = mass of actual dry steam

m = mass of wet steam

$= mg + M_p$

It is the ratio of the mass of the actual dry steam to the mass of same quantity of wet steam. It denoted by 'x'. It ranges from 0 to 1.

Dt - 26.07.2020

Sensible heat of water

It is the amount of heat absorb by one kg of water when heated at a constant pressure from the freezing ~~...~~ point to the temperature of formation of steam. It is also known as liquid heat.

sensible heat = mass x specific heat x Rise in temperature

$$= 1 \times 4.2 \,[(t+273) - (0+273)]$$

4.2 is specific heat of water

Latent heat of vaporization

It is the amount of heat absorb to evaporate one kg of water at it's boiling point or saturation temperature without change in temperature

It is denoted by $h_{fg} = (h_g - h_f)$ and it depends upon pressure. As pressure increases h_{fg} decreases and it vise versa

If the steam is wet with a dryness fraction 'x' then latent heat of vaporisation

$= x h_{fg}$

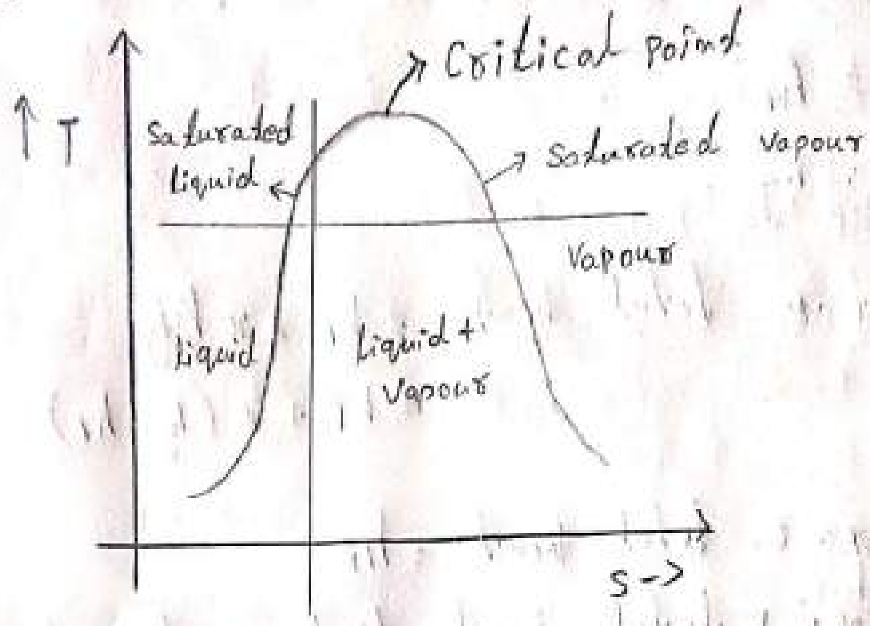
$= x(h_g - h_f)$

Enthalpy or total heat of steam

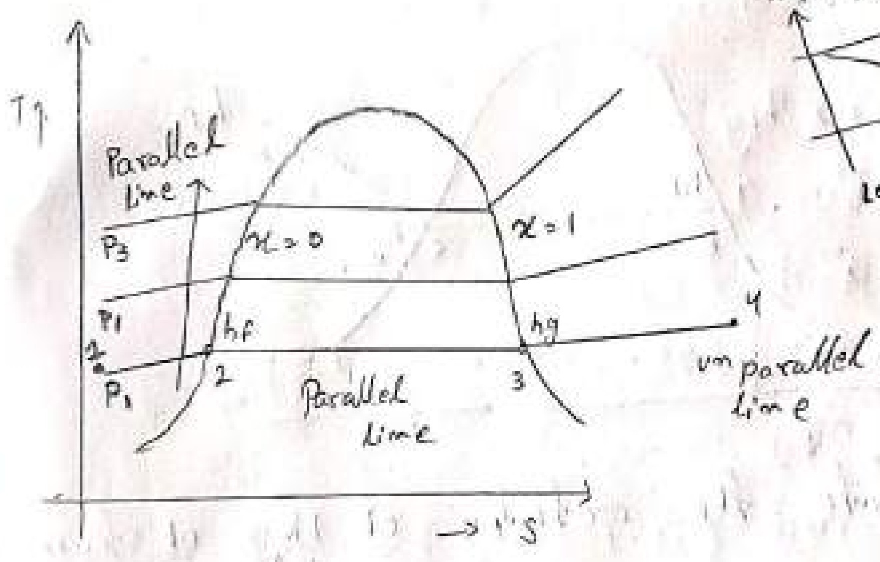
Amount of heat is absobe from freezing point to saturation temprature plus the heat absorve during to evaporation

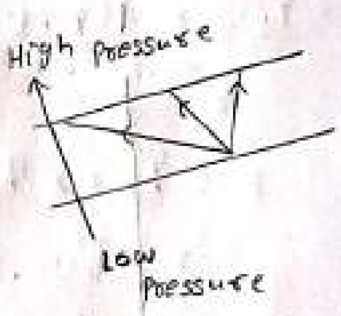
Total heat = sensible heat + Latent heat.

T-S digram



horizontal lines are isothermal lines
vertical lines are isotropic lines or adiabatic line





→ Constant pressure line are parallel in liquid and liquid + vapour region

→ In vapour region constant pressure line are diverging in nature

→ Liquid + vapour region is also known as vapour dome

→ At critical point $h_{fg} = 0$

$h_2 = h_f$

$h_3 = h_g$

wet steam total heat $= h_f + x h_{fg}$

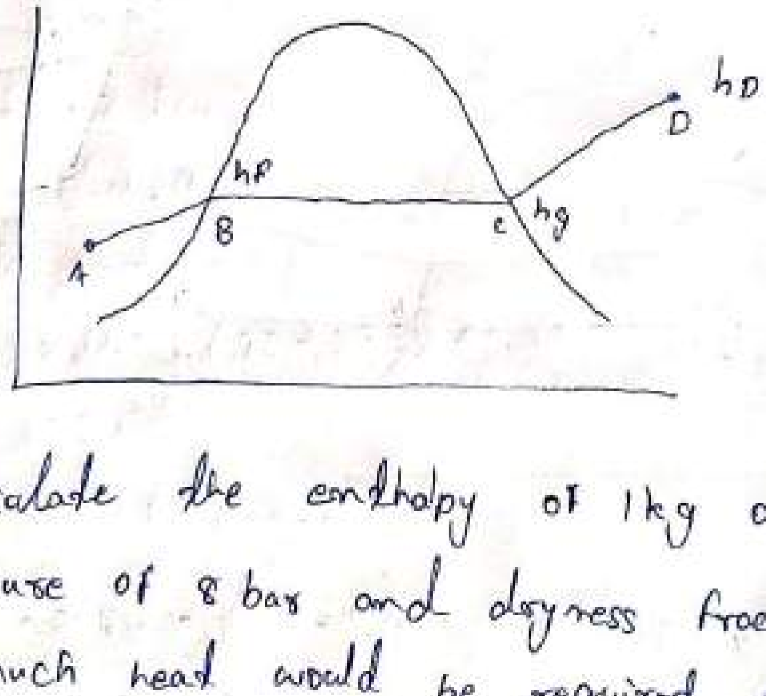
$= h_f + x (h_g - h_f)$

for $x = 0$ total heat $= h_f$

$x = 1$ total heat that is dry steam

$= h_f + h_{fg}$

Dt 2.03.2020



Q Calculate the enthalpy of 1kg of steam at a pressure of 8 bar and dryness fraction of 0.8 how much heat would be required to raise 2kg of steam from water at 20°c

Ans Given

At pressure 8 bar

$h_f = 720.9$ kJ/kg

$h_{fg} = 2046.5$ kJ/kg

$x = 0.8$

$h = h_f + x h_{fg}$

$= 720.9 + 0.8 \times 2046.5$

$= 2358.1$ kJ/kg

Sensible $= 1 \times 4.2 \left[(20+273)-(0+273)\right]$

$= 84$

sensible heat of water

0 - 100

For 1kg = 2358.1

sensible heat of water

0 - 20 = 84

For 2kg = 84 × 2
= 166

For
2kg = 2358.1 × 2
= 4716.2 kJ/kg

(0-100) - (0-20)

For 2kg = 4716.2 - 166
= 4550.2 kJ/kg

N.B. Change in temperature in K scale and Celsius scale is same

Q Determine the quantity of heat required to produce 1kg of steam at a pressure of 6 bar at a temperature of 25°C under the following condition.

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① when the steam is wet having a $x = 0.9$

② when the steam is dry saturated.

③ when it is super heated at a constant pressure at $250°c$ assuming the mean specific heat of super heated steam to be $2.3 kJ/kg\ K$

Given

At 6 bar

$h_f = 670.4\ kJ/kg$

$h_{fg} = 2085\ kJ/kg$

$T_{sat} = 158.8°$

$x = 0.9$

$h = h_f + x\,h_{fg}$

$= 2546.9$

Sensible heat

$= 1 \times 4.2 [(25 + 273) - (0 + 273)]$

$= 105\ kJ$

heat required $(25 - 100)$

$(0 - 100) - (0 - 25)$

$2546.9 - 105$

$= 2441.9\ kJ$

(ii) $h_{fg} = (h_g - h_f)$

$h_g = h_{fg} + h_g$

$= 2755.4\ kJ/kg$

heat required (25 - 158.8)

= 2755.4 - 105

= 2650.4 KJ

(iii) $h_p = h_g + C_{p\,vap} (T_{sup} - T_{sat})$

$= 2755.4 + 2.3 (250 - 158.8)$

$= 2965.16$ KJ

heat required (25 - 250)

= 2965.16 - 105

= 2860.16 Kg

Q steam enter an engine at a pressure of 12 bar with a 67°C super heat it is exhusted at a pressure of 0.15 bar and $x = 0.95$ find the drop in enthalpy of the steam.

Given

$h_f = 798.4$ KJ/kg

$h_{fg} = 1984.3$ KJ/kg

$(T_{sup} - T_{sat}) = 67°c$

$C_{p\,vap} = 2.3$

Entry

$h_D = h_f + h_{fg} + C_{p\,vap} (T_{sup} - T_{sat})$

= 2936.8 KJ/kg

Exhusted at (0.15)

$h_f = 226$ KJ/kg

$h_{fg} = 2373.2$ kJ/kg

$x = 0.95$

$h = h_f + x h_{fg}$

$= 2480.54$ kJ/kg

Drop in enthalpy

$= 2936.8 - 2480.54$

$= 456.26$ kJ/kg

Advantage of super heating the steam

→ as it contains more heat the capacity to do work is increased with out increasing the pressure

→ The high tempr of super heated steam help in increasing the thermal efficiancy

STEAM GENERATOR

1.0. Overview

A boiler is an enclosed vessel in which water is heated and circulated, either as hot water or steam, to produce a source for either heat or power. A central heating plants may have one or more boilers that use gas, oil, or coal as fuel. The steam generated is used to heat buildings, provide hot water, and provide steam for cleaning, sterilizing, cooking, and laundering operations. Small package boilers also provide steam and hot water for small buildings.

1.1. STEAM GENERATION THEORY

To acquaint you with some of the fundamentals underlying the process of steam operation, suppose that you set an open pan of water on the stove and turn on the heat. You find that the heat causes the temperature of the water to increase and, at the same time, to expand in volume. When the temperature reaches the boiling point (212°F or 100°C at sea level), a physical change occurs in the water; the water starts vaporizing. When you hold the temperature at the boiling point long enough, the water continues to vaporize until the pan is dry. A point to remember is that the temperature of water does not increase beyond the boiling point. Even if you add more heat after the water starts to boil, the water cannot get any hotter as long as it remains at the same pressure.

Now suppose you place a tightly fitting lid on the pan of boiling water. The lid prevents the steam from escaping from the pan and this results in a build-up of pressure inside the container. However, when you make an opening in the lid, the steam escapes at the same rate it is generated. As long as water remains in the pan and as long as the pressure remains constant, the temperature of the water and steam remains constant and equal.

The steam boiler operates on the same basic principle as a closed container of boiling water. By way of comparison, it is as true with the boiler as with the closed container that steam formed during boiling tends to push against the water and sides of the vessel. Because of this downward pressure on the surface of the water, a temperature in excess of 212°F is required for boiling. The higher temperature is obtained simply by increasing the supply of heat; therefore, the rules you should remember are as follows:

1. All of the water in a vessel, when held at the boiling point long enough, will change into steam. As long as the pressure is held constant, the temperature of the steam and boiling water remain the same.
2. An increase in pressure results in an increase in the boiling point temperature of water.

A handy formula with a couple of fixed factors will prove this theory. The square root of steam pressure multiplied by 14 plus 198 will give you the steam temperature. When you have 1 psig (pounds per square inch gauge) of steam

pressure, the square root is one times 14 plus 198 which equals 212°F which is the temperature that the water will boil at 1 psig.
The equation for figuring out the steam temperature is:
Let P = Steam Pressure, T = Steam Temperature

$$\sqrt{P} \times 14 + 198 = T$$

There are a number of technical terms used in connection with steam generation. Some
of these commonly used terms you should know are as follows:

- Degree is defined as a measure of heat intensity.
- Temperature is defined as a measure in degrees of sensible heat. The term sensible heat refers to heat that can be measured with a thermometer.
- Heat is a form of energy measured in ***British thermal units (BTU)**.* One Btu is the amount of heat required to raise 1 pound of water 1degree Fahrenheit at sea level.
- Steam means water in a vapor state. Dry ***saturated*** steam is steam at the saturation temperature corresponding to pressure, and it contains no water in suspension. Wet saturated steam is steam at the saturation temperature corresponding to pressure, and it contains water particles in suspension.
- The quality of steam is expressed in terms of percent. For instance, if a quantity of wet steam consists of 90 percent steam and 10 percent moisture, the quality of the mixture is 90 percent.
- Superheated steam is steam at a temperature higher than the saturation temperature corresponding to pressure. For example, a boiler may operate at 415 psig (pounds per square inch gauge). The corresponding saturation temperature for this pressure is 483°F, and this will be the temperature of the water in the boiler and the steam in the drum. This steam can be passed through a super-heater where the pressure remains about the same, but the temperature will be increased to some higher figure.

2.0.0 BOILER FITTINGS and ACCESSORIES

A sufficient number of essential boiler fittings (*Figure 9-1*) and accessories are discussed in this section to provide a background for further study. As a reminder, and in case you should run across some unit or device not covered here, check the manufacturer's manual for information on the details of its construction and method of operation.

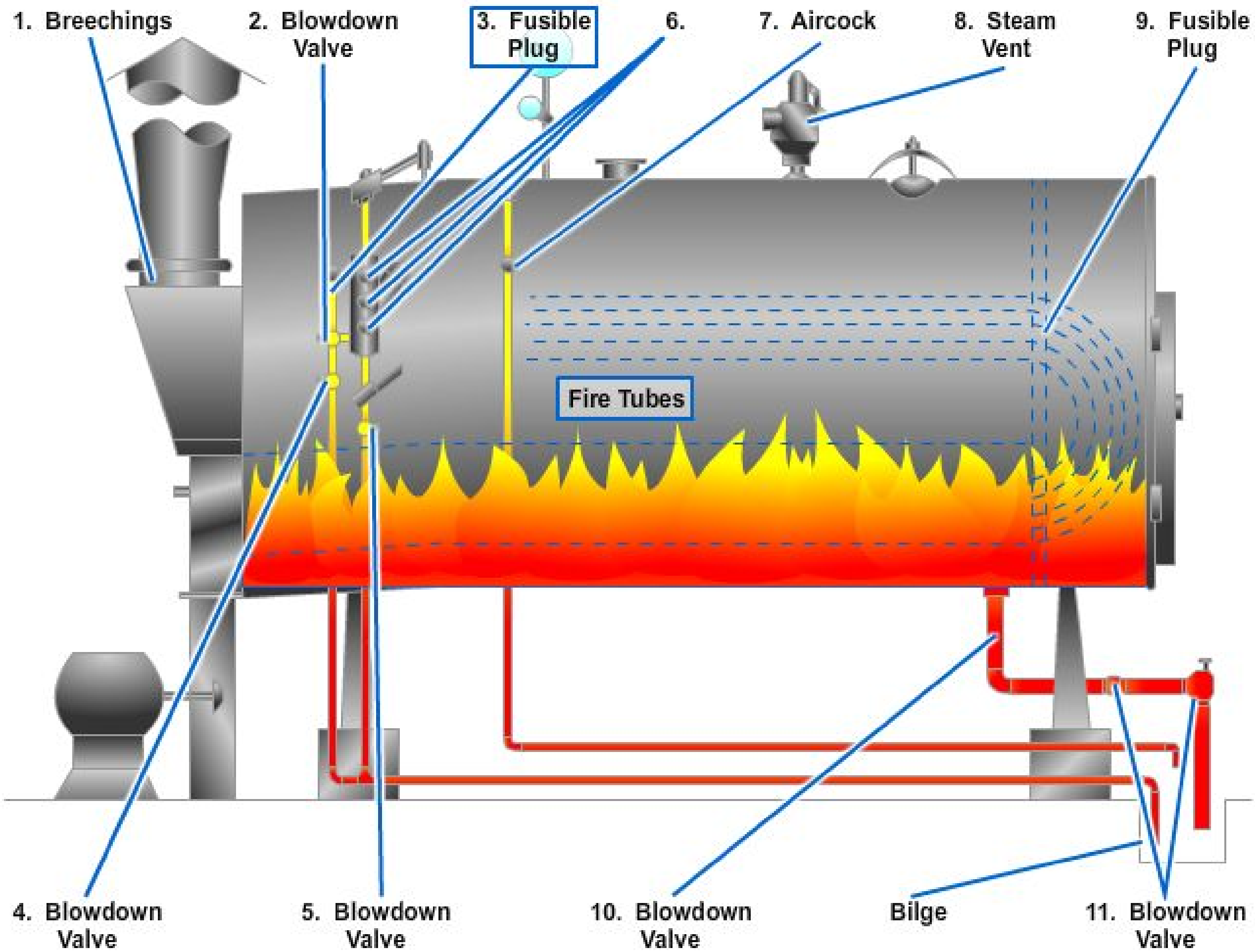


Figure 9-1—Boiler fittings.

The term "fittings" includes various control devices on the boiler. Fittings are vitally important to the economy of operation and safety of personnel and equipment. You must understand fittings if you are to acquire skill in the installation, operation, and servicing of steam boilers.

All boilers require boiler fittings to operate safely. The American Society of Mechanical Engineers (ASME) requires all boiler fittings to be made of materials that withstand the pressure and temperatures that boilers are subject to. All of the boiler fittings discussed are important and must be operated and maintained properly to operate a boiler safely.

2.1.0 Air Cock

An air cock is located in the uppermost steam space of a boiler, as shown in *Figure 9-2*. This design allows for air to enter and escape during filling and draining of the boiler. Before firing a cold boiler with no steam pressure, open the air cock to allow air to escape during the heating of the water. When steam begins to come out of the air cock piping, close the valve.

2.2.0 Chimneys, Draft Fans, and Breechings

Figure 9-2 — Aircock.

Chimneys are necessary for discharging the products of combustion at an elevation high enough to comply with health requirements and to prevent a nuisance because of low-flying smoke, soot, and ash. A boiler needs a draft to mix air correctly with the fuel supply and to conduct the flue gases through the complete setting. The air necessary for combustion of fuel cannot be supplied normally by a natural draft. Therefore, draft fans may be used to ensure that the air requirements are properly attained. Two types of draft fans used on boilers are forced-draft and induced-draft fans. They are damper controlled and usually are driven by an electric motor.

The forced draft fan forces air through the fuel bed, or fuel oil burner, and into the furnace to supply air for combustion. The induced draft fan draws gases through the setting, thus facilitating their removal through the stack. Breechings (see Item 1 in *Figure 9-1*) are used to connect the boiler to the stack. They are usually made of sheet steel with provision for expansion and contraction. The breeching may be carried over the boilers, in back of the setting, or even under the boiler room floor. Keep breechings as short as possible and free from sharp bends and abrupt changes in area. The cross-sectional area should be approximately 20 percent greater than that of the stack to keep draft loss to a minimum. A breeching with a circular cross section causes less draft loss than one with a rectangular or square cross section.

2.3.0 Blowdown Valves

Figure 9-3 — Blowdown valve.

Blowdown valves on boilers are located on the water column and on the lowest point of the water spaces of the boiler (*Figure 9-3*). The blowdown valves on a boiler installed at the bottom of each water drum and header are used to remove scale and other foreign matter that have settled in the lowest part of the water spaces. Boilers are also blown down to control concentration of dissolved and suspended solids in boiler water. The water column blowdown permits removal of scale and sediments from the water column. Additionally, some boilers have what is called a surface blowdown. The surface blowdown is located at the approximate water level so as to discharge partial steam and water. The surface blowdown removes foaming on the top of the water surface and any impurities that are on the surface of the water.

2.4.0 Fusible Plugs

Fusible plugs are used on some boilers to provide added protection against low water. They are constructed of bronze or brass with a tapered hole drilled lengthwise through the plug. They have an even taper from end to end. This tapered hole is filled with a low-melting alloy consisting mostly of tin. There are two types of fusible plugs—fire actuated and steam actuated.

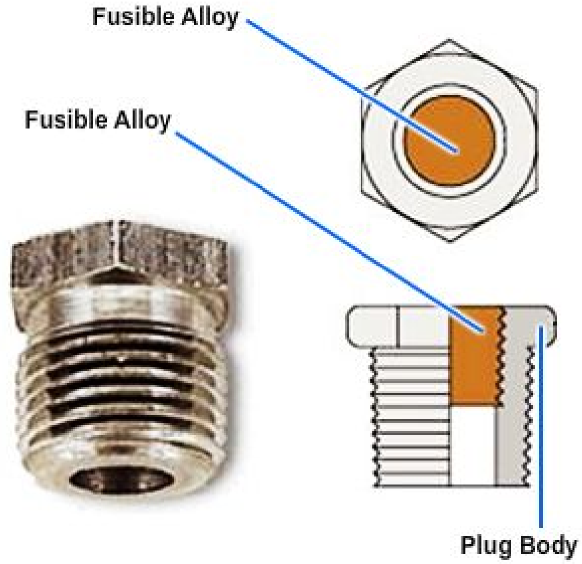


Figure 9-4 — Fusible plug.

The fire-actuated plug is filled with an alloy of tin, copper, and lead with a melting point of 445°F to 450°F. It is screwed into the shell at the lowest permissible water level. One side of the plug is in contact with the fire or hot gases, and the other side is in contact with the water (*Figure 9-4*). As long as the plug is covered with water, the tin does not melt. When the water level drops below the plug, the tin melts and blows out. Once the core is blown out, a whistling noise will warn the operator. The boiler then must be taken out of service to replace the plug.

The steam-actuated plug is installed on the end of a pipe outside the drum. The other end of the pipe, which is open, is at the lowest permissible water level in the steam drum. A valve is usually installed between the plug and the drum. The metal in the plug melts at a temperature below that of the steam in the boiler. The pipe is small enough to prevent water from circulating in it. The water around the plug is much cooler than the water in the boiler as long as the end of the pipe is below the water level. However, when the water level drops below the open end of the pipe, the cool water runs out of the pipe and steam heats the plug. The hot steam melts and blows the tin out, allowing steam to escape from the boiler warning the operator. This type of plug can be replaced by closing the valve in the piping. It is not necessary to take the boiler out of service to replace the plug.

Fusible plugs should be renewed regularly once a year. Do NOT refill old casings with new tin alloy and use again. ALWAYS USE A NEW PLUG.

2.5.0 Water Column

A water column is a hollow vessel having two connections to the boiler (*Figure 9-5*). Water columns come in many more designs than the two shown in *Figure 9-5*; however, they all operate to accomplish the same principle. The top connection enters the steam drum of the boiler through the top of the shell or drum. The water connection enters the shell or head at least 6 inches below the lowest permissible water level. The purpose of the water column is to steady the water level in the gauge glass through the reservoir capacity of the column. Also, the column may eliminate the obstruction on small diameter, gauge-glass connections by serving as a sediment chamber.

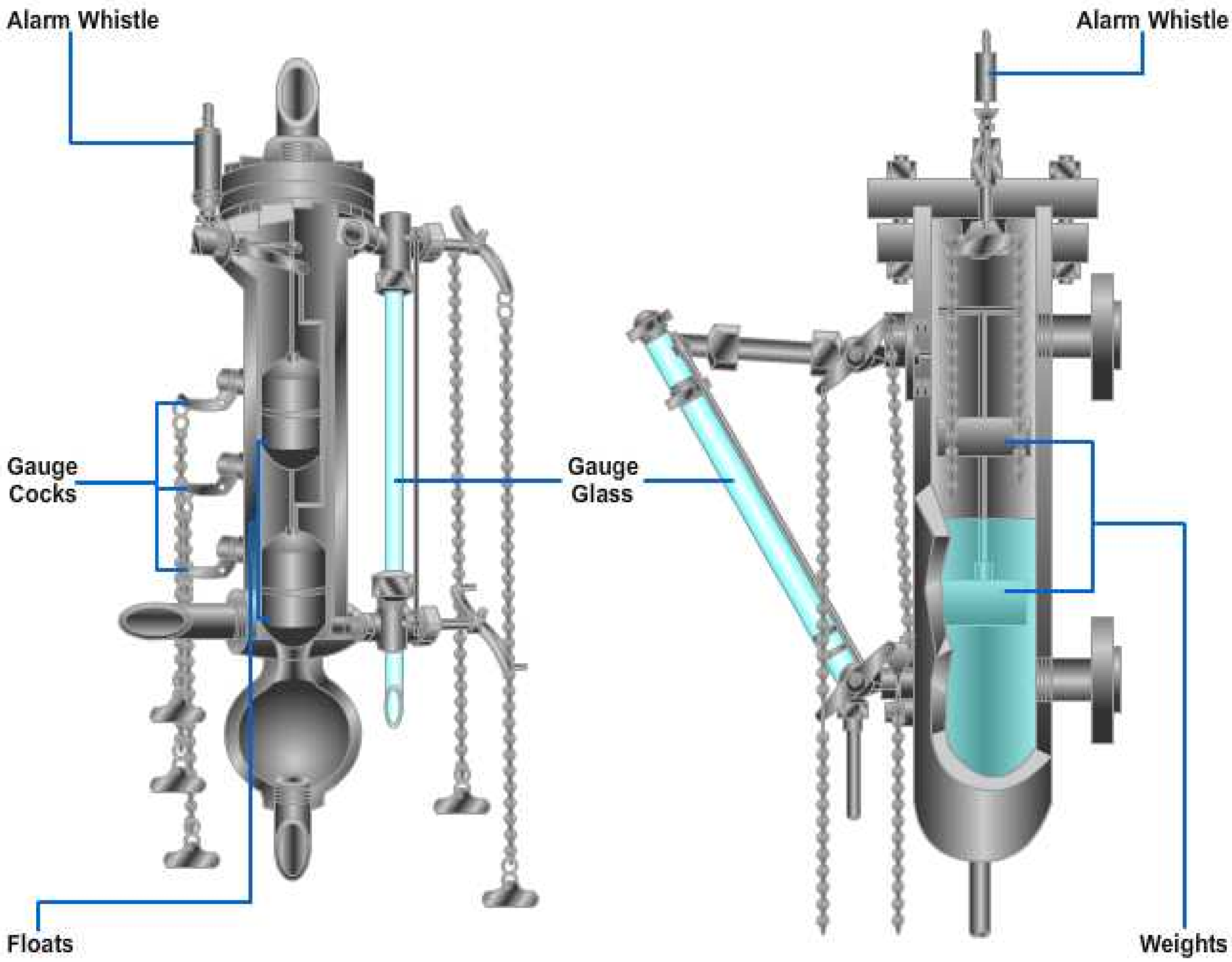


Figure 9-5—Typical water columns.

The water columns shown are equipped with high- and low-water alarms that sounds a whistle to warn the operator. The whistle is operated by either of the two floats or the solid weights shown in *Figure 9-5*.

2.5.1 Water Level Control

The water level control not only automatically operates the boiler feed pump but also safeguards the boiler against low water by stopping the burner. Various types of water level controls are used on boilers. At Seabee activities, boilers frequently are equipped with a float-operated type, a combination float and mercury switch type, or an electrode probe type of automatic water level control. Each of these types is described below.

The float-operated type of feedwater control, similar in design to the feedwater control shown in *Figure 9-6*, is attached to the water column. This control uses a float, an arm, and a set of electrical contacts. As a low-water cutoff, the float rises or lowers with the water level in an enclosed chamber. The chamber is connected to the boiler by two lines, a setup which allows the water and steam to have the same level in the float chamber as in the boiler. An arm and linkage connects the float to a set of electrical contacts that operate the feedwater pump when the water lowers the float. When the water supply fails or the pump becomes inoperative and allows the water level to continue to drop, another set of contacts operates an alarm bell, buzzer, or whistle, and secures the burners.

The combination float and mercury switch type of water level control shown in *Figure 9-6, Frame 1* reacts to changes made within a maintained water level by breaking or making a complete control circuit to the feedwater pump. It is a simple two-position type control, having no modulation or differential adjustment or setting. As all water level controllers should be, it is wired independently from the programmer. The control is mounted at steaming water level and consists of a pressurized float, a pivoted rocker arm, and a cradle-attached mercury switch. The combination float and mercury switch type of water-level control functions as follows: As the water level within the boiler tends to drop, the float lowers. As the float lowers, the position of the mercury switch changes. Once the float drops to a predetermined point, the mercury within the tube runs to its opposite end. This end contains two wire leads, and when the mercury covers both contacts, a circuit is completed to energize the feedwater pump. The pump, being energized, admits water to the boiler. As the water level within the boiler rises, the float rises. As the float rises, the position of the mercury switch changes. Once the float rises to a predetermined point, the mercury runs to the opposite end of its tube, breaking the circuit between the wire leads and securing the feedwater pump. The feedwater pump remains off until the water level again drops low enough to trip the mercury switch.

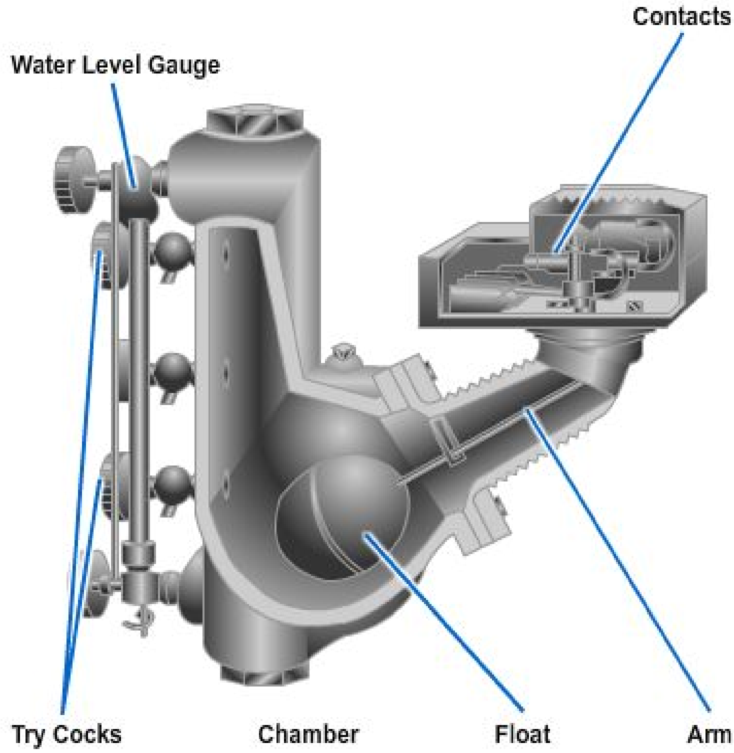


Figure 9-6 — Combination float and mercury switch type of feedwater control.

Because of the hazards associated with mercury, these switches are being phased out. The electrode probe type of feedwater control and low-water cutoff and the solid state (*Figure 9-6, Frame 2*) type of switches are replacing them. The solid state components are controlled by a ground wire connected to the side of the reservoir and a probe that extends into the water column. When the water is at the acceptable level, current is available and the switch remains closed. When the water level drops, the current is reduced and the switch is activated thus turning on the water pump. If the water level drops too far down the probe, the burner cutout switch is activated and the burner will not come on until the water reaches the appropriate level.

The electrode probe type of feedwater control and low-water cutoff consists of an electrode assembly and a water level relay (*Figure 9-7*). The electrode assembly contains three electrodes of different lengths corresponding to high, low, and burner cutout in the boiler drum.

To understand the operation of a boiler circuit, refer to *Figures 9-7*and *9-8* as you read the information in *Table 9-2*. Although this information is not complete, it is presented here to acquaint you with the operation of the electrode type of boiler water-level control.

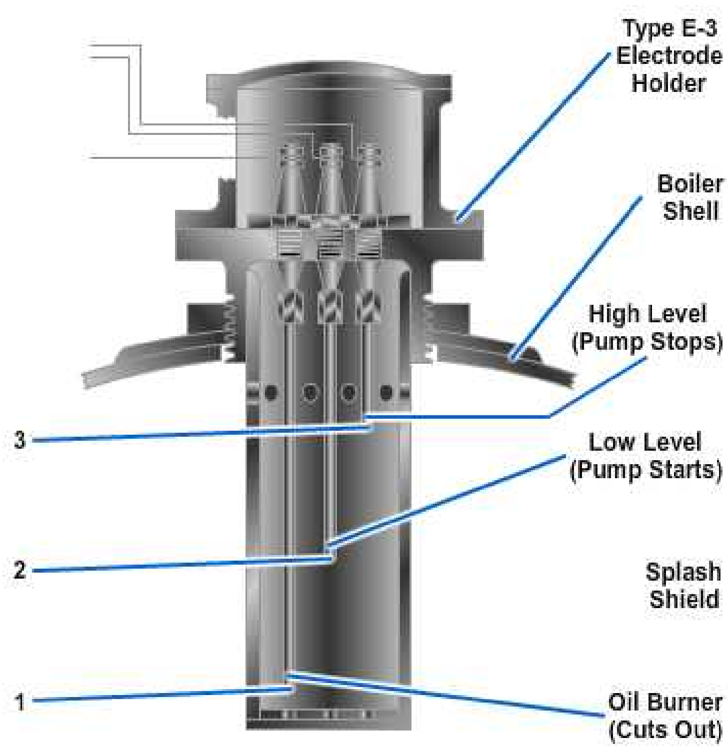


Figure 9-7 — Electrode type of water-level control.

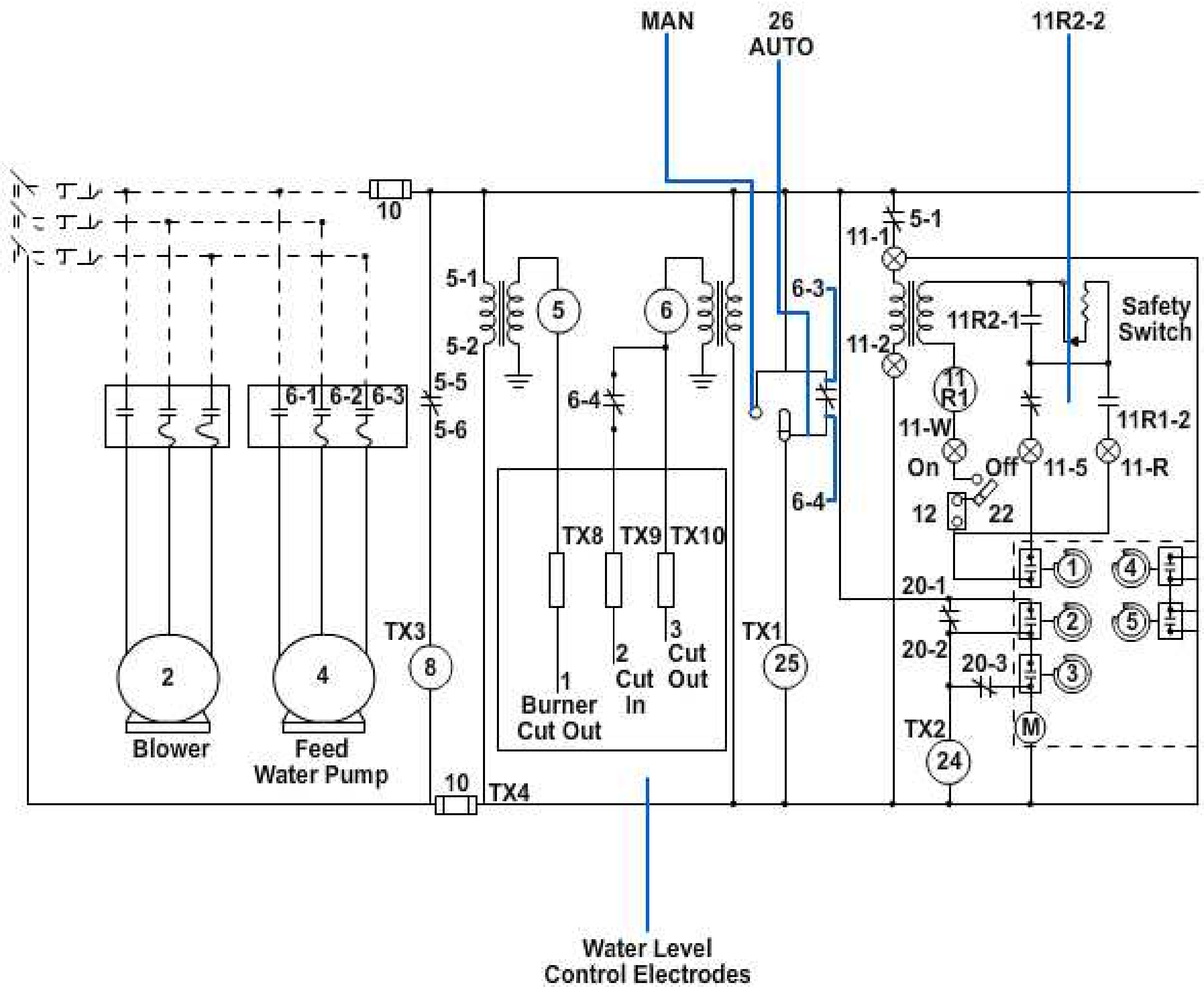


Figure 9-8—Typical boiler circuit.

Table 9-2 — Operation of a boiler circuit.

Operation	Action	Results
When the feed pump switch is in the auto position.	The feed pump motor is energized.	The feed pump will operate under control of the water-level relay.
When the water level in the boiler reaches the level of electrode #3.	The circuit through the electrode is grounded and this completes the circuit.	All of the contacts labeled #6 change positions. The three feed pump contacts that are normally closed, open, and contact 6-4 closes which maintains the grounded circuit through electrode #2.
When the water level falls below electrode #2.	The circuit through relay #6 will no longer be grounded because the water is not in contact with the electrode.	This de-energizes relay #6, so all of the contacts labeled #6 return to their normal positions. Contacts 6-1 through 6-3 close and 6-4 opens. The feedwater pump is energized and water is pumped into the boiler.
When the water level rises again to electrode #3.	Relay #6 will energize again.	The cycle continues and the water level in the boiler is maintained.
When the water level falls below electrode #1.	Relay #5 will be de-energized.	Contact 5-1 will open. This action de-energizes the entire control circuit. The boiler is now shut down and the low-water alarm is sounded.

2.5.2 Try Cocks

The purpose of the try cocks is to prove the water level in the boiler. You may see water in the gauge glass, but that does not mean that the water level is at that position in the boiler. If the gauge glass is clogged up, the water could stay in the glass, giving a false reading. The try cocks, on the other hand, will blow water, steam, or a mixture of steam and water out of them when they are manually opened. When steam is discharged from the lowest try cock, you have a low-water condition.

WARNING

When the water level is proved using the try cocks, personnel should stand off to the side of the try cocks away from the discharge. The discharged steam or scalding water can cause severe burns.

2.5.3 Gauge Glass

The gauge glass allows the boiler operator to see the water level in the boiler. Normally there are two valves associated with the gauge glass. One valve is located at the top and one is located at the bottom of the gauge glass. These two valves, named gauge cock valves, secure the boiler water and steam from the gauge glass. Another valve located in line with the gauge glass is used to blow the gauge glass down.

2.6.0 Safety Valve

The safety valve shown in *Figure 9-9* is the most important of boiler fittings. It is designed to open automatically to prevent pressure in the boiler from increasing beyond the safe operating limit. The safety valve is installed in a vertical position and attached directly to the steam space of the boiler. Each boiler has at least one safety valve; when the boiler has more than 500 square feet of heating surface, two or more valves are required.

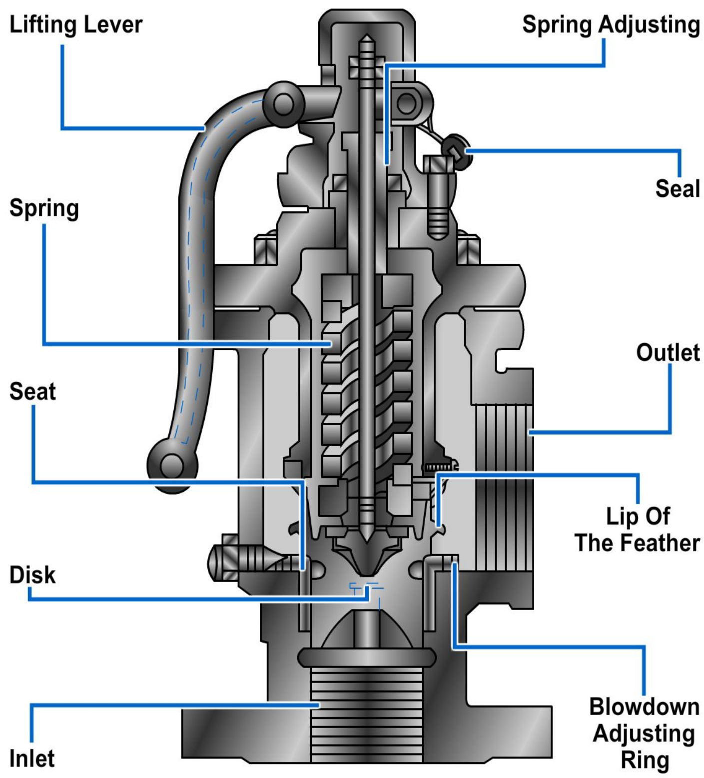


Figure 9-9 — Spring-loaded safety valve.

There are several different types of safety valves in use, but all are designed to open completely (POP) at a specific pressure and to remain open until a specified pressure drop (BLOWDOWN) has occurred. Safety valves must close tightly, without chattering, and must remain tightly closed after seating.

To understand the difference between boiler safety valves and ordinary relief valves is important. The amount of pressure required to lift a relief valve increases as the valve lifts, because the resistance of the spring increases in proportion to the amount of compression. When a relief valve is installed on a steam drum, it opens slightly when the specified pressure is exceeded, a small amount of steam is discharged, and then the valve closes again. Thus a relief valve on a steam drum is constantly opening and closing; this repeated action pounds the seat and disk and causes early failure of the valve. Safety valves are designed to open completely at a specified pressure to overcome this difficulty.

Several different types of safety valves are used on boilers; however, they all lift on the same general principle. In each case, the initial lift of the valve disk, or feather, is caused by static pressure of the steam acting upon the disk, or feather. As soon as the valve begins to open, however, a projecting lip, or ring, of the larger area is exposed for the steam pressure to act upon. The resulting increase in force overcomes the resistance of the spring, and the valve pops, that is, it opens quickly and completely. Because of the larger area now presented, the valve reseats at a lower pressure than that which caused it to lift originally.

Lifting levers are provided to lift the valve from its seat (when boiler pressure is at least 75 percent of that at which the valve is set to pop) to check the action and to blow away any dirt from the seat. When the lifting lever is used, raise the valve disk sufficiently to ensure that all foreign matter is blown from around the seat to prevent leakage after being closed.

The various types of safety valves differ chiefly as to the method of applying compression to the spring, the method of transmitting spring pressure to the feather, or disk, the shape of the feather, or disk, and the method of blowdown adjustment. Detailed information on the operation and maintenance of safety valves can be found in the instruction books furnished by the manufacturers of this equipment.

2.7.0 Steam Injector Feed System

The steam injector is a boiler feed pump that uses the velocity and condensation of a jet of steam from the boiler to lift and force a jet of water into the boiler (*Figure 9-10*). This injection of water is many times the weight of the original jet of steam.

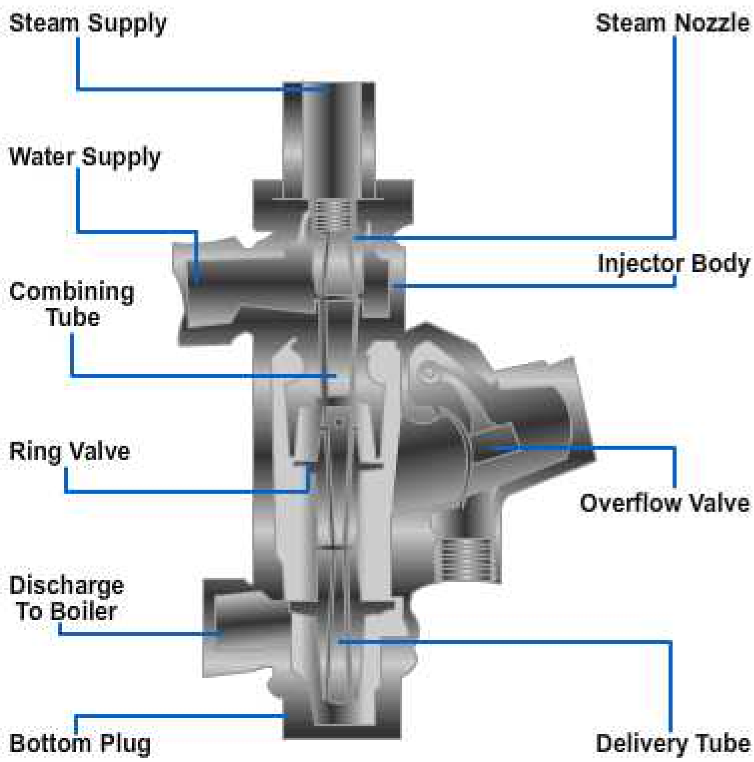


Figure 9-10 — Cross-sectional view of a steam injector.

The injector is used to some extent in boiler plants as an emergency or standby feed unit. It does not feed very hot water. Under the best conditions, it can lift a stream of water having a temperature of 120°F about 14 feet.

The installation of an injector is not a difficult operation because the unit is mounted on the side of the boiler. The four connections to the injector are as follows (*Figure 9-11*):

1. The discharge line to the boiler feedwater inlet
2. The steam supply line from the boiler
3. The water overflow line
4. The water supply line from the reservoir.

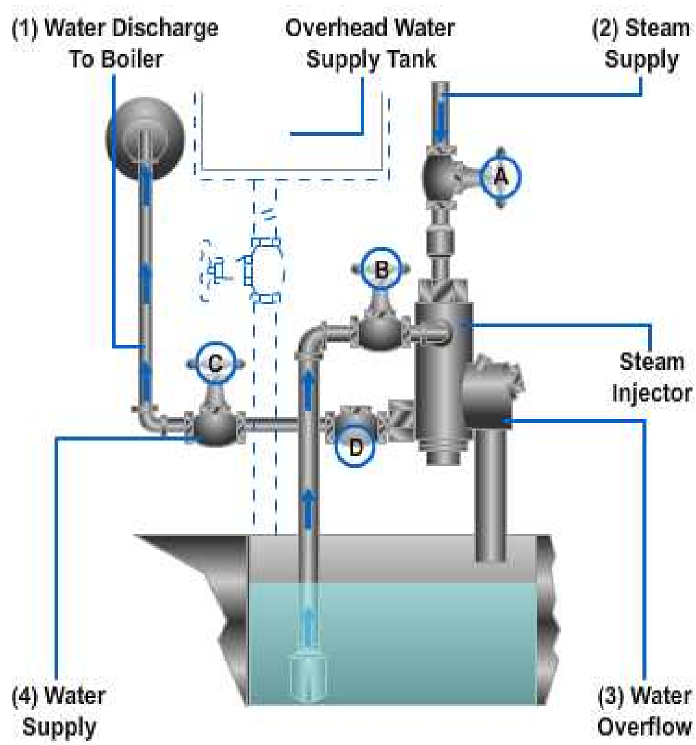


Figure 9-11 — Injector piping.

The controls for the injector include the following (*Figure 9-11*):

A. Steam supply valve

B. Water supply valve

C. Discharge valve to the boiler

D. Check valve in the discharge line

As you might expect, some degree of skill is needed to start the injector. After the injector begins to operate, however, it continues automatically until shutdown by the operator.

When starting the injector, first open the water supply valve (*Figure 9-11B*) about one full turn. Next quickly turn the steam supply valve (*Figure 9-11A*) all the way open. At this point, steam rushes into the combining tube of the injector. As the steam speeds past the water supply opening, it creates a suction that draws water through the opening into the combining tube. Water and steam are now mixed together inside the injector, and the pressure opens a valve that leads to the boiler. Meanwhile, there is an excess of water in the injector; this excess is discharged through the overflow valve. As the next step of the procedure, slowly turn the water supply valve (*Figure 9-11B*) toward the closed position until the overflow stops. The overflow valve has now closed, and all of the water being picked up from the supply line is going into the boiler. Remember, this feedwater system is used on boilers only as a standby method for feeding water.

For the injector to operate, the water supply should not be hotter than 120°F. When several unsuccessful attempts are made to operate the injector, it will become very hot and cannot be made to prime. When you encounter this problem, pour cold water over the injector until it is cool enough to draw water from the supply when the steam valve is opened.

2.8.0 Handholes and Manholes

Handholes and manholes provide maintenance personnel access into a boiler to inspect and clean it internally as needed. These handholes and manholes will be covered in depth when boiler maintenance is discussed later in this chapter.

2.9.0 Boiler Accessories

Figure 9-12 provides a graphic presentation of important boiler accessories. Refer to it as you study *Table 9-3*, which gives a brief description of each accessory, its location, and function.

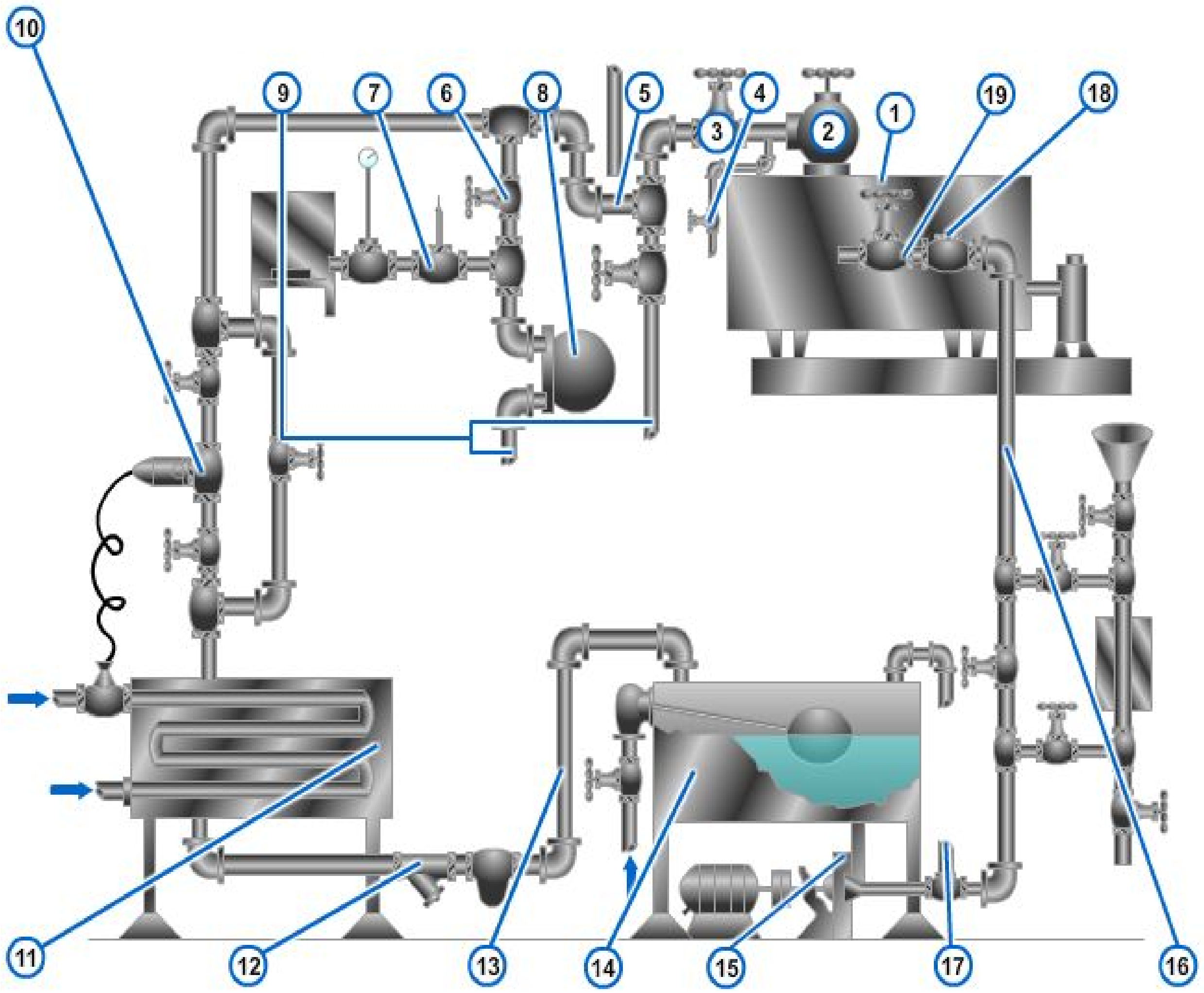


Figure 9-12 — Boiler accessory equipment.

Table 9-3 — Boiler accessories, location, and function.

Item	Accessory	Location	Function
1	Boiler	Boiler room	Generate steam or hot water in a closed vessel.
2	Main steam stop	On the steam outlet of a boiler	Place the boiler on line or off line.
3	Guard valve	On the steam outlet of a boiler directly following the main steam stop valve	Guard or backup to main steam stop valve.
4	Daylight (drain) valve	Between the main steam-stop valve and the guard valve	Open only when the main steam and guard valves are closed. Indicates if one of the valves is leaking through.
5	Main steam line	The line that conveys steam from a boiler to all branch or distribution lines. When a system is supplied by a bank of boilers connected into the same header, the line(s) conveying steam for the boiler(s) to the header	Carry steam from the boiler to the branches or distribution lines.
6	Root valve	Installed in branch or distribution lines just off of the main steam line	Isolate a branch or distribution line (serves as an emergency shutoff).
7	Pressure regulating valves (PRV)	Installed as close as practical (after a reducing station) to the equipment or area it serves	Equipment that requires lower pressure than main steam line pressure (coppers, dishwashers, steam chests, or turbines).
8	Steam trap	Installed on the discharge side of all steam heating or cooking equipment, dead ends, low points, or at regular intervals throughout a steam system (automatic drip legs)	Automatically drains condensate and prevents the passage of steam through equipment.
9	Drip legs	Provided throughout a system where condensation is most likely to occur, such as low spots, bottom of risers, and	Remove condensate from a system manually.

		dead ends	
10	Temperature regulating valve (TRV)	Install in the steam supply line close to equipment needing temperature regulation	Control steam flow through a vessel or heating equipment.
11	Heat exchanger	Locate as close as practical to the source for which it is going to supply heated water or oil	An unfired pressure vessel that contains a tube nest or electrical element. Used to heat oil or water.
12	Strainer	Install in steam and water lines just ahead of PRVs, TRVs, steam traps, and pumps	Prevent malfunction or costly repairs to equipment and components by trapping foreign matter such as rust, scale, and dirt.
13	Condensate line	Return line extends from the discharge side of steam traps to the condensate/makeup feedwater tank	Carry condensated steam back through piping for reuse in the boiler or heating vessel.
14	Condensate/makeup tank	Close to the boiler as practical and at a higher level than the boiler feed-pump suction line	Provide storage space for condensate and makeup/feedwater and vent noncondensable gases to the atmosphere.
15	Feed pump	Installed between the condensate/makeup/feedwater tank and the boiler shell or steam drum.	Supplies water to boiler as required.
16	Feedwater pipe	This line extends from the discharge side of the feedwater pump to the boiler shell or drum (installed below the steaming water level)	Provide feedwater to the boiler when required.
17	Relief valve	Between the feed pump and the nearest shutoff valve in the external feed line	Relieve excessive pressure should the external feed line be secured and the feed pump started accidently. A ruptured line or serious damage to the feed

			pump could occur if there were no relief valve.
18	Feed check valve	Between the feed pump and the stop valve in the feed water pipe	Prevent backflow from the boiler through the feedwater line into the condensate/feedwater tank during the off cycle of the pump.
19	Feed stop valve	In the feedwater line as close to the boiler as possible between the boiler and feed check valve	Permit or prevent the flow of water to the boiler.

Test your Knowledge (Select the Correct Response)

2. What is the melting point of a fire-actuated fusible plug filled with an alloy of tin, copper, and lead?

   A. 415°F
   B. 425°F
   C. 435°F
   D. 445°F

3.0.0 TYPES of BOILERS

The Utilitiesman (UT) is concerned primarily with the fire-tube type of boiler, since it is the type generally used in Seabee operations. However, the water-tube type of boiler may occasionally be used at some activities. The information in this chapter primarily concerns the different designs and construction feature of fire-tube boilers.

The basis for identifying the two types is as follows:

- Water-tube boilers are those in which the products of combustion surround the tubes through which the water flows.
- Fire-tube boilers are those in which the products of combustion pass through the tubes and the water surrounds them.

3.1.0 Water-Tube Boilers

Water-tube boilers may be classified in a number of ways. For our purpose, they are classified as either straight tube or bent tube. These classes are discussed separately in succeeding sections. To avoid confusion, make sure you study carefully each illustration referred to throughout the discussion.

3.1.1 Straight Tube

The straight-tube class of water-tube boilers includes three types:

1. Sectional-header cross drum
2. Box-header cross drum
3. Box-header longitudinal drum

In the sectional-header cross drum boiler with vertical headers, the headers are steel boxes into which the tubes are rolled. Feedwater enters and passes down through the down-comers (pipes) into the rear sectional headers from which the tubes are supplied. The water is heated and some of it changes into steam as it flows through the tubes to the front headers. The steam-water mixture returns to the steam drum through the circulating tubes and is discharged in front of the steam-drum baffle that helps to separate the water and steam.

Steam is removed from the top of the drum through the dry pipe. This pipe extends along the length of the drum and has holes or slots in the top half for steam to enter.

Headers, the distinguishing feature of this boiler, are usually made of forged steel and are connected to the drums with tubes. Headers may be vertical or at right angles to the tubes. The tubes are rolled and flared into the header. A handhole is located opposite the ends of each tube to facilitate inspection and cleaning. Its purpose is to collect sediment that is removed by blowing down the boiler.

Baffles are usually arranged so gases are directed across the tubes three times before being discharged from the boiler below the drum.

Box-header cross drum boilers are shallow boxes made of two plates—a tube-sheet plate that is bent to form the sides of the box, and a plate containing the handholes that is riveted to the tube-sheet plate. Some are designed so that the front plate can be removed for access to tubes. Tubes enter at right angles to the box header and are expanded and flared in the same manner as the sectional-header boiler. The boiler is usually built with the drum in front. It is supported by lugs fastened to the box headers. This boiler has either cross or longitudinal baffling arranged to divide the boiler into three passes. Water enters the bottom of the drum, flows through connecting tubes to the box header, through the tubes to the rear box header, and back to the drum.

Box-header longitudinal drum boilers have either a horizontal or inclined drum. Box headers are fastened directly to the drum when the drum is inclined. When the drum is horizontal, the front box header is connected to it at an angle greater than 90 degrees. The rear box header is connected to the drum by tubes. Longitudinal or cross baffles can be used with either type.

3.1.2 Bent Tube

Bent tube boilers usually have three drums. The drums are usually of the same diameter and positioned at different levels. The uppermost or highest positioned drum is referred to as the steam drum, while the middle drum is referred to as the water drum, and the lowest, the mud drum. Tube banks connect the drums. The tubes are bent at the ends to enter the drums radially.

Water enters the top rear drum, passes through the tubes to the bottom drum, and then moves up through the tubes to the top front drum. A mixture of steam and water is discharged into this drum. The steam returns to the top rear drum through the upper row of tubes, while the water travels through the tubes in the lower rear drum by tubes extending across the drum, and enters a small collecting header above the front drum.

Many types of baffle arrangements are used with bent-tube boilers. Usually, they are installed so that the inclined tubes between the lower drum and the top front drum absorb 70 to 80 percent of the heat. The water-tube boilers discussed above offer a number of worthwhile advantages. For one thing, they afford flexibility in starting up. They also have a high productive capacity ranging from 100,000 to 1,000,000 pounds of steam per hour. In case of tube failure, there is little danger of a disastrous explosion of the water-tube boiler. The furnace not only can carry a high overload, it can also be modified for firing by oil or coal. Still another advantage is that it is easy to get into sections inside the furnace to clean and repair them. There are also several disadvantages common to water-tube boilers. One of the main drawbacks is their high construction cost. The large assortment of tubes required for this boiler and the excessive weight per unit weight of steam generated are other unfavorable factors.

3.2.0 Fire-Tube Boilers

There are four types of fire-tube boilers—Scotch marine boiler, vertical-tube boiler, horizontal return tubular boiler, and firebox boiler. These four types of boilers are discussed in this section.

3.2.1 Scotch Marine Boiler

The Scotch marine tire-tube boiler is especially suited to Seabee needs. *Figure 9-13* shows a portable Scotch marine tire-tube boiler. The portable unit can be moved easily and requires only a minimal amount of foundation work. A completely self-contained unit, its design includes automatic controls, a steel boiler, and burner equipment. These features are a big advantage because no disassembly is required when you must move the boiler into the field for an emergency.

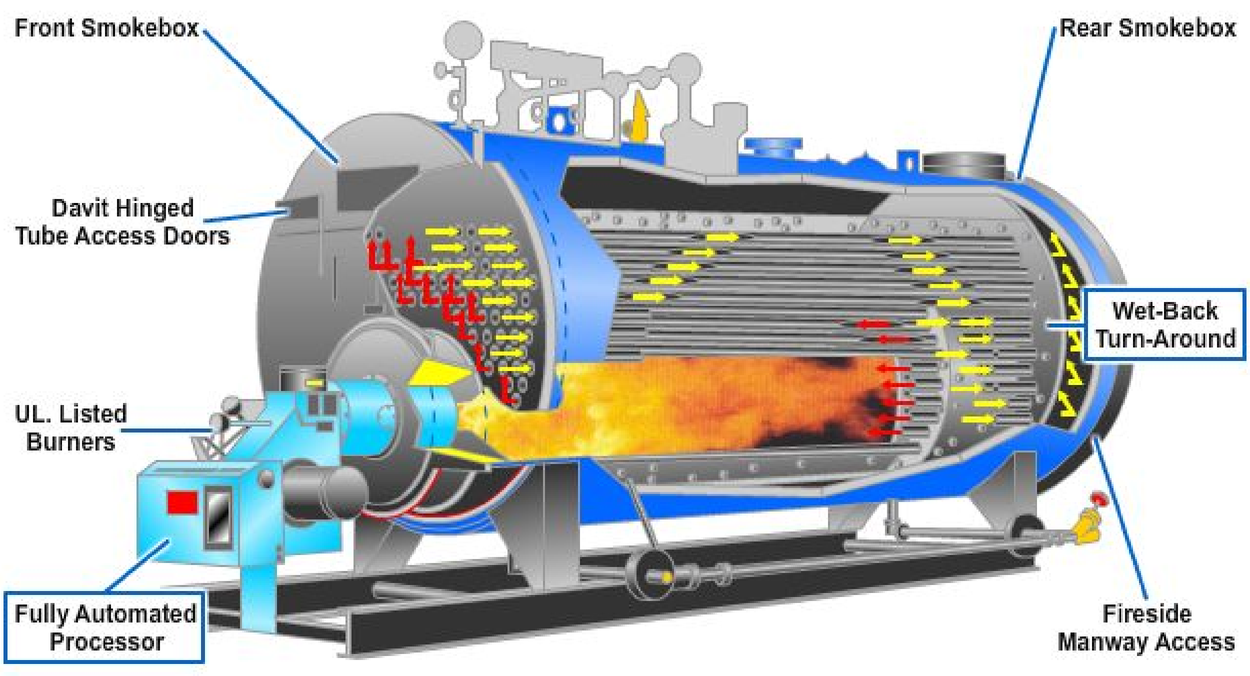


Figure 9-13 — Scotch marine type of fire-tube boiler.

The Scotch marine boiler has a two-pass (or more) arrangement of tubes that run horizontally to allow the heat inside the tubes to travel back and forth. It also has an internally fired furnace with a cylindrical combustion chamber. Oil is the primary fuel used to fire the boiler; however, it can also be fired with wood, coal, or gas. A major advantage of the Scotch marine boiler is that it requires less space than a water-tube boiler and can be placed in a room that has a low ceiling.

The Scotch marine boiler also has disadvantages. The shell of the boiler runs from 6 to 8 feet in diameter, a detail of construction that makes a large amount of reinforcing necessary. The fixed dimensions of the internal surface cause some difficulty in cleaning the sections below the combustion chamber. Another drawback is the limited capacity and pressure of the Scotch marine boiler.

An important safety device sometimes used is the fusible plug that provides added protection against low-water conditions. In case of a low-water condition, the fusible plug core melts, allowing steam to escape, and a loud noise is emitted which provides a warning to the operator. On the Scotch boiler the plug is located in the crown sheet, but sometimes it is placed in the upper back of the combustion chamber. Fusible plugs are discussed in more detail later in this chapter.

Access for cleaning, inspection, and repair of the boiler watersides is provided through a manhole in the top of the boiler shell and a handhole in the ***water leg***. The manhole opening is large enough for a person to enter the boiler shell for inspection, cleaning, and repairs. On such occasions, always ensure that all valves are secured, locked, and tagged, and that the person in charge knows you are going to enter the boiler. Additionally, always have a person located outside of the boiler standing by to aid you in case of an incident that would require assistance. The handholes are openings large enough to permit hand entry for cleaning, inspection, and repairs to tubes and headers.

Figure 9-14 shows a horizontal fire-tube boiler used in low-pressure applications. Personnel in the UT rating are assigned to operate and maintain this type of boiler more often than any other type of boiler. Refer to *Table 9-1* for equipment location.

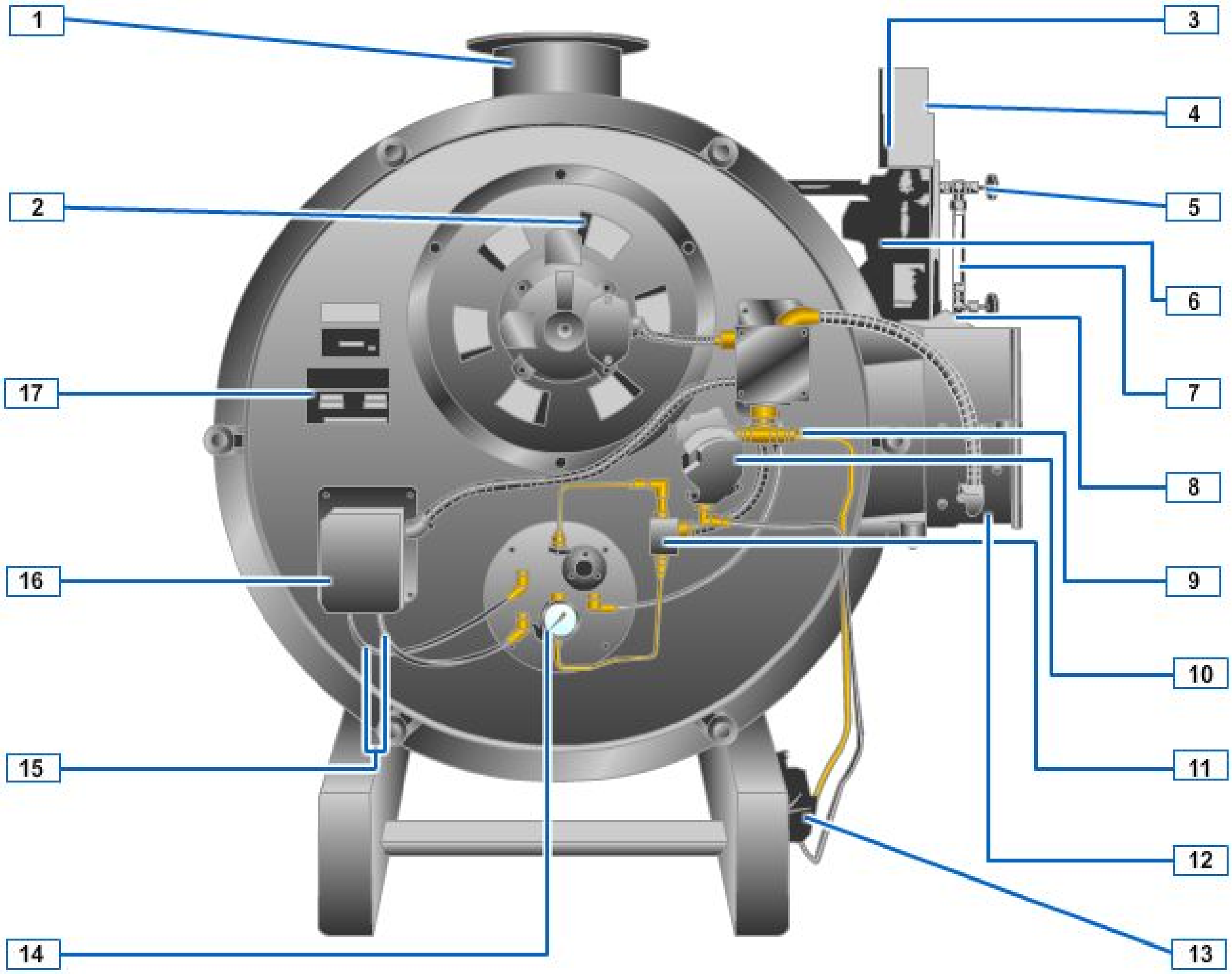


Figure 9-14—Horizontal fire-tube boiler used in low-pressure applications.

Table 9-1 — Horizontal fire-tube boiler parts location.

1. Vents	7. Water Level Gauge	13. Fuel Oil Supply Connection
2. Air Damper	8. Burner Switch	14. Fuel Oil Pressure Gauge
3. High Limit Pressure Control	9. Priming Tee	15. Ignition Cable
4. Steam Pressure Gauge	10. Oil Unit, Two Stage	16. Ignition Cable Box
5. Gauge Glass Shutoff Cock	11. Solenoid Oil Valve	17. Nameplate
6. Low Water Control	12. Service Connection Box	

3.2.2 Vertical-Tube Boiler

In some fire-tube boilers, the tubes run vertically, as opposed to the horizontal arrangement in the Scotch boiler. The vertical-tube boiler sits in an upright position *(Figure 9-15)*. Therefore, the products of combustion (gases) make a single pass, traveling straight up through the tubes and out the stack. The vertical fire-tube boiler is similar to the horizontal fire-tube boiler in that it is a portable, self-contained unit requiring a minimum of floor space. Handholes are also provided for cleaning and repairing. Though self-supporting in its setting (no brickwork or foundation being necessary), it MUST be level. The vertical fire-tube boiler has the same disadvantages as that of the horizontal-tube design—limited capacity and furnace volume.

Before selecting a vertical fire-tube boiler, you must know how much overhead space is in the building where it will be used. Since this boiler sits in an upright position, a room with a high ceiling is necessary for its installation.

The blowdown pipe of the vertical fire-tube boiler is attached to the lowest part of the water leg, and the feedwater inlet opens through the top of the shell. The boiler fusible plug is installed either (1) in the bottom tube sheet or crown sheet or (2) on the outside row of tubes, one third of the height of the tube from the bottom.

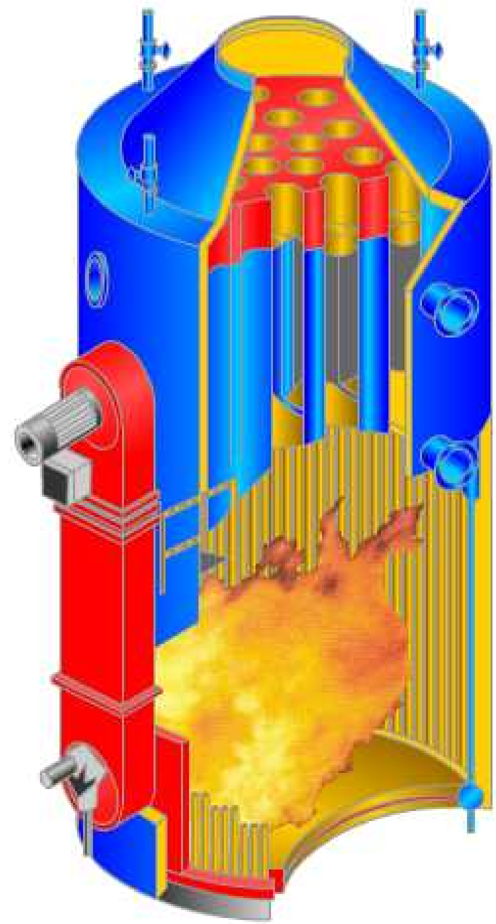


Figure 9-15—Cutaway view of a vertical fire-tube boiler.

3.2.3 Horizontal Return Tubular Boiler

In addition to operating portable boilers such as the Scotch marine and vertical fire-tube boilers, the UT must also be able to operate stationary boilers, both in the plant and in the field. A stationary boiler can be defined as one having a permanent foundation and not easily moved or relocated. A popular type of stationary fire-tube boiler is the horizontal return tubular (HRT) boiler shown in *Figure 9-16*.

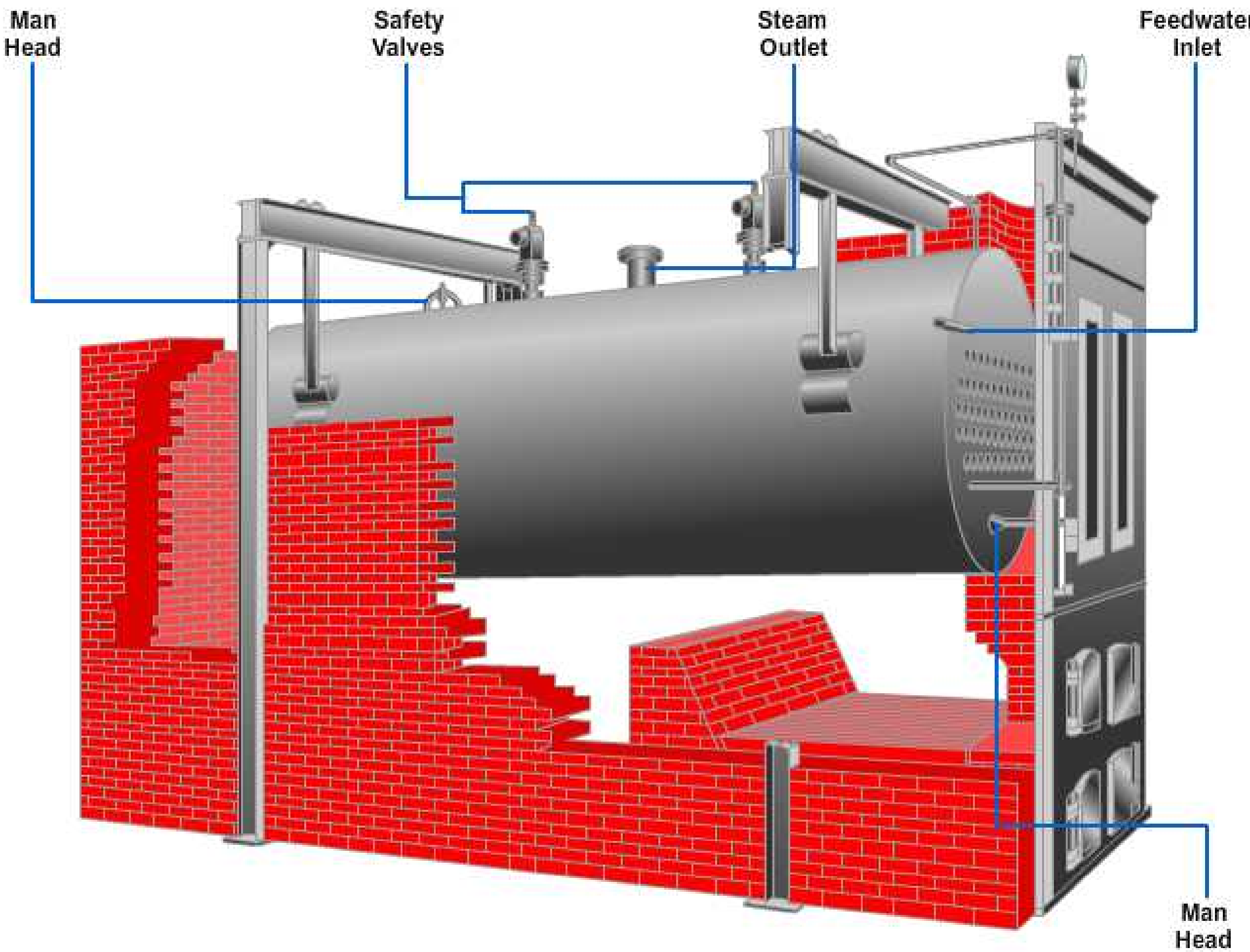


Figure 9-16—Horizontal return tubular (HRT) fire-tube boiler.

The initial cost of the HRT boiler is relatively low, and installing it is not too difficult. The boiler setting can be readily changed to meet different fuel requirements—coal, oil, wood, or gas. Tube replacement is also a comparatively easy task since all tubes in the HRT boiler are the same in size, length, and diameter.

The gas flows in the HRT boiler from the firebox to the rear of the boiler. It then returns through the tubes to the front where it is discharged to the breaching and out the stack.

The HRT boiler has a pitch of 1 to 2 inches to the rear to allow ***sediment*** to settle toward the rear near the bottom blowdown connection. The fusible plug is located 2 inches above the top row of tubes. Boilers over 40 inches in diameter require a manhole in the upper part of the shell. Those over 48 inches in diameter must have a manhole in the lower as well as in the upper part of the shell. Do not fail to familiarize yourself with the location of these and other essential parts of the HRT boiler. The knowledge you acquire will definitely help in the performance of your duties with boilers.

3.2.4 Firebox Boiler

Another type of fire-tube boiler is the firebox boiler that is usually used for stationary purposes. A split section of a small firebox boiler is shown in *Figure 9-17.*

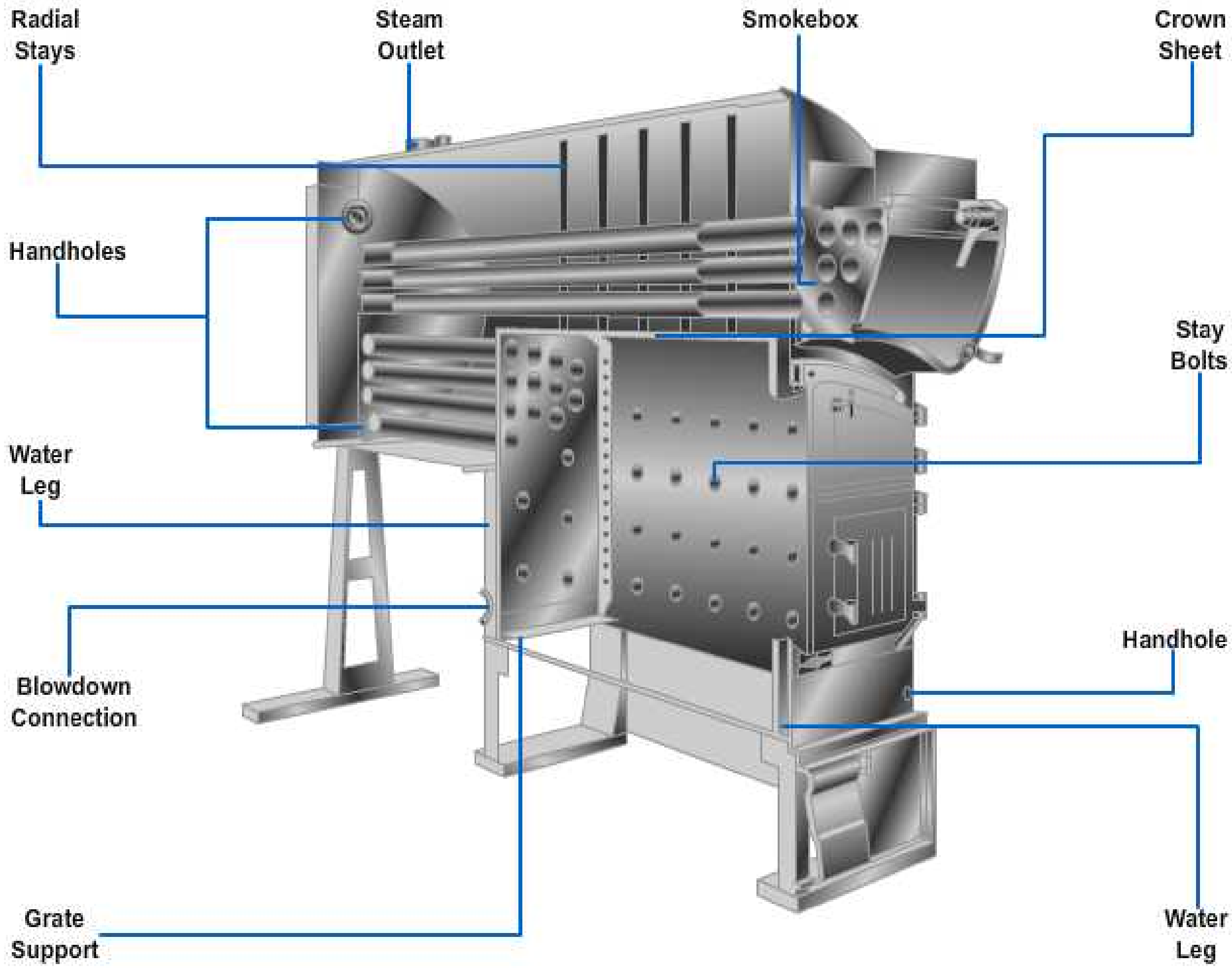


Figure 9-17—Split section of a small firebox boiler.

Gases in the firebox boiler make two passes through the tubes. Firebox boilers require no setting except possibly an ash pit for coal fuel. As a result, they can be quickly installed and placed in service. Gases travel from the firebox through a group of tubes to a reversing chamber. They return through a second set of tubes to the ***flue*** connection on the front of the boiler and are then discharged up the stack.

4.0.0 BOILER DESIGN REQUIREMENTS

A boiler must meet certain requirements before it is considered satisfactory for operation. Three important requirements for a boiler are as follows:

1. The boiler must be safe to operate.
2. The boiler must be able to generate steam at the desired rate and pressure.
3. The boiler must be economical to operate.

NOTE

Make it a point to familiarize yourself with the boiler code and other requirements applicable to the area in which you are located.

BOILER DRAUGHT: -

Draught is the pressure difference which is necessary to draw the required quantity of air for combustion and to remove the flue gases out of the system.

Thus, the object of producing draught in a boiler is:

(i) To provide sufficient quantity of air for combustion

(ii) To make the resulting hot gases, to flow through the system

(iii) To discharge these gases to the atmosphere through the chimney.

Usually this drought (pressure difference) in boiler is of small magnitude and is measured in mm of water column by means of draught gauge/manometer.

The amount of draught depends upon:

(i) Nature and depth of fuel on the grate.

(ii) Design of combustion chamber/firebox.

(iii) Rate of combustion required.

(iv) Resistance offered in the system due to baffles, tubes, superheater, economiser, air pre-heater, etc.

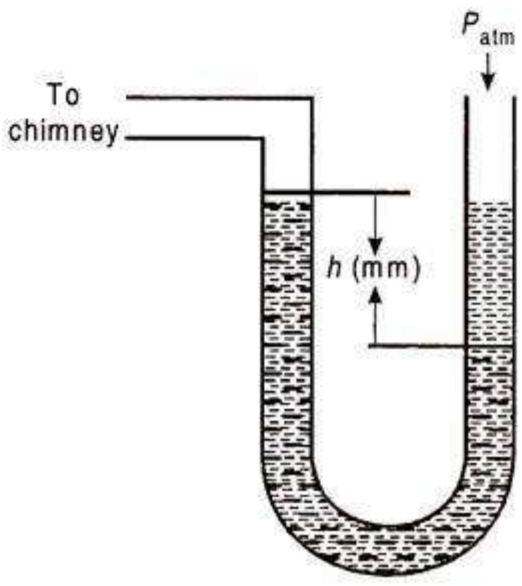


Fig. 11.22

Classification of Boiler Draught:

Draught is broadly classified into 2-types:

1. Natural or Chimney Draught:

In this case the amount of draught directly depends upon the height of chimney. It is produced due to the difference in densities between the column of hot gases in the chimney and a similar column of cold air outside the chimney.

Let us first consider the case when fires are not lighted.

Let, the atmospheric pressure at grate level be P_1 and P_2 be the atmospheric pressure at an altitude H. The pressure P_2 is lower than the pressure P_1 because with the altitude pressure goes on decreasing.

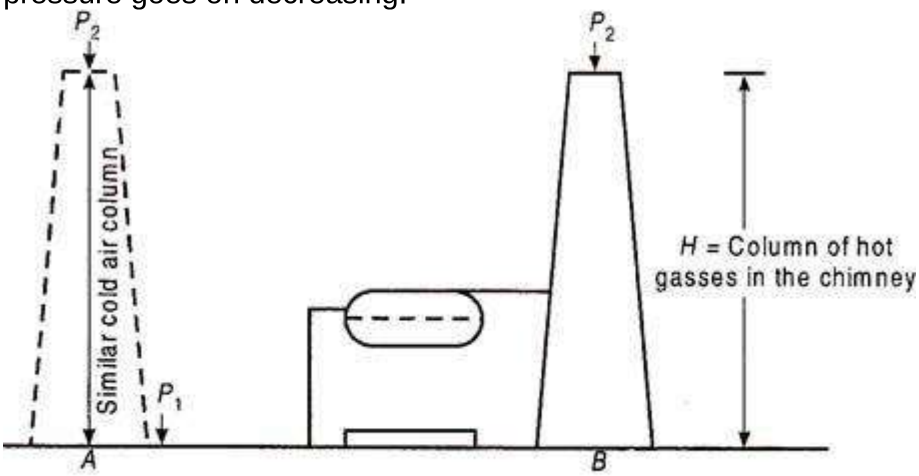


Fig. 11.23

Now let us consider the case when fires are lighted and the chimney is full of hot gases. Under these circumstances, the pressure at the base of the chimney is the sum of pressure P_2 at the top and the pressure due to hot gas column H. But pressure P_1 at grate is the sum of pressure P_2 and the pressure due to similar cold column of air H.

Since, ρ cold air > ρ hot gases

i.e., $P_A > P_B$

∴ P_2 + Pressure due to cold column H > P_2 + Pressure due to hot column H.

∴ Pressure at grate due to cold column > Pressure at the chimney base due to hot column H.

This difference is called static draught and because of the pressure difference, (draught) air will rush to the combustion chamber, where combustion of air and fuel takes place and hot gases are generated. Then these hot gases because of draught, flow through the system and finally they are exhausted to the atmosphere through the chimney.

Advantages of Natural Draught:

i. Easy to construct.

ii. No power is required for producing the draught.

iii. Long life of chimney.

iv. No maintenance is required.

Disadvantages:

i. Tall chimney is required.

ii. Poor efficiency.

iii. Decreases with increase in outside temperature.

iv. No flexibility it create more draught to take peak loads.

2. Artificial Draught:

In bigger power plants, the draught of the order of 25-350 mm of H_2O column is required. Far producing this much draught, the chimney height has to be increased considerably, which is neither convenient nor economical. Also, since the draught depends upon the climatic conditions, some mechanical equipments are used for producing the required draught and the draught so produced is called as the artificial draught.

i. Forced Draught:

In a Forced draught system, a Fan or Blower is provided is shown in figure which forces the air in the combustion chamber. In the combustion chamber combustion of air and fuel takes place and hot gases generated. These gases are forced to pass through the flues, economiser, air pre-heater and then they are exhausted after recovering heat of flue gases. This draught system is known positive draught system, since the pressure of gases throughout the system is above atmospheric pressure.

It is to be noted that, the function of chimney use is to discharge the gases high in the atmosphere to reduce air pollution and it is not much significant for producing draught.

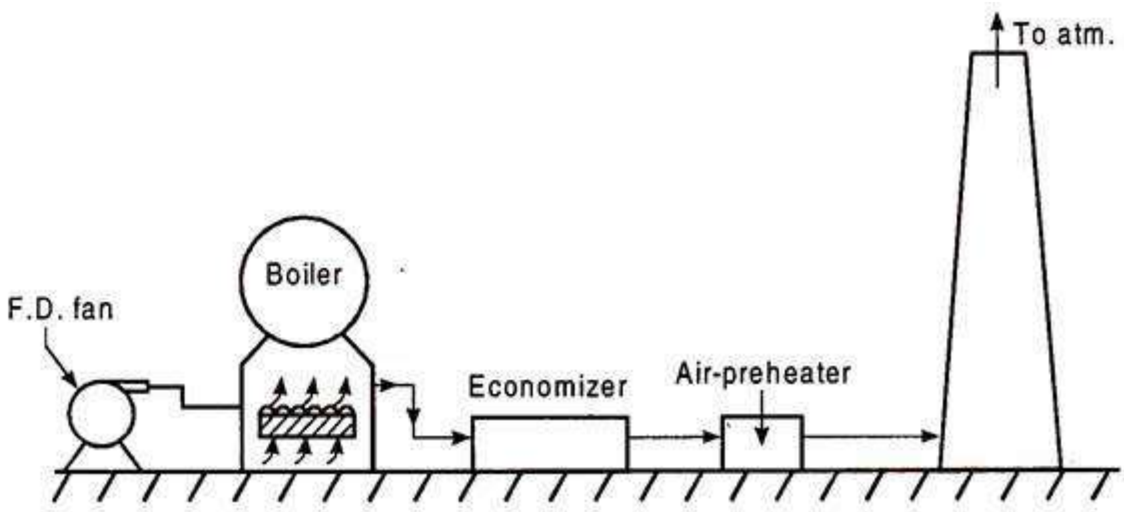


Fig. 11.24

ii. Induced Draught:

In this system, the Blower or Induced Draught fan is located near the base of chimney. The air is sucked in the system, by reducing the pressure through the system below atmosphere. The flue gases, generated after combustion are drawn through the system and after recovering heat in the economiser, air-preheater, they are exhausted through the chimney to the atmosphere.

Here it is to be noted that the draught produced is independent of the temperature of hot gases, so the gases may be discharged as cold as possible after recovering as much heat as possible.

Advantages of Forced Draught (F.D.) over Induced Draught (I.D.):

i. The size and power required by I.D. fan is more because this fan handles more gases.

ii. Since the I.D. fan handles hot gases, water cooled or air cooled bearings are to be used.

iii. F.D. fan consumes less power and normal bearing can be used.

iii. Balanced Draught:

It is always preferable to use combinations of I.D. and F.D. instead of Forced or Induced draught alone.

If Forced Draught alone is used then the furnace cannot be opened for firing or for inspection. Because the high pressure air/gases inside the furnace will try to blow out, and there is every chance of blowing out of the fire completely and the furnace may stop.

If Induced Draught fan alone is used, then also furnace cannot be opened either for firing or for inspection. Because the cold air will try to rush into the furnace, which reduces the effective draught.

To overcome both these difficulties Balanced Draught is used. In this case I.D. fan and F.D. fan are provided as shown.

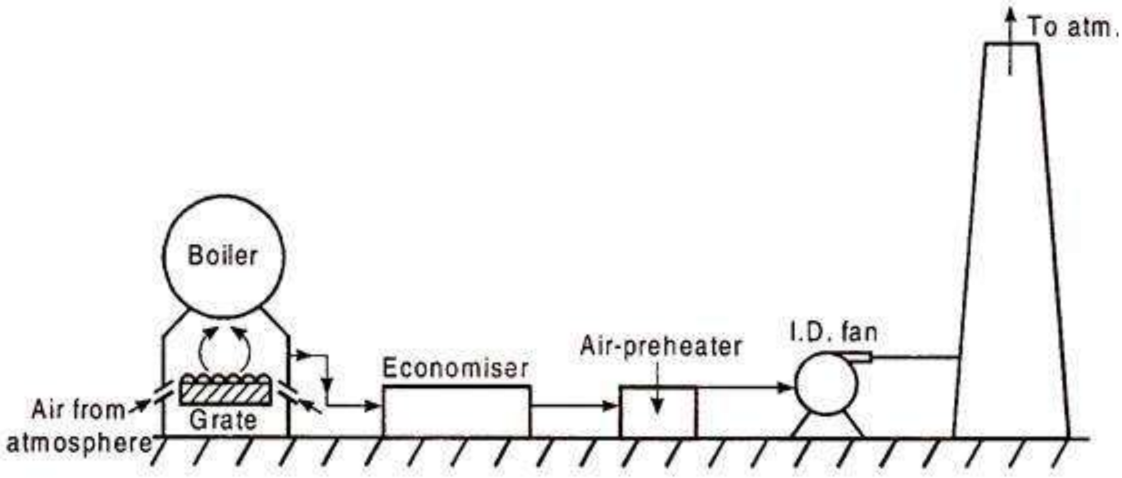
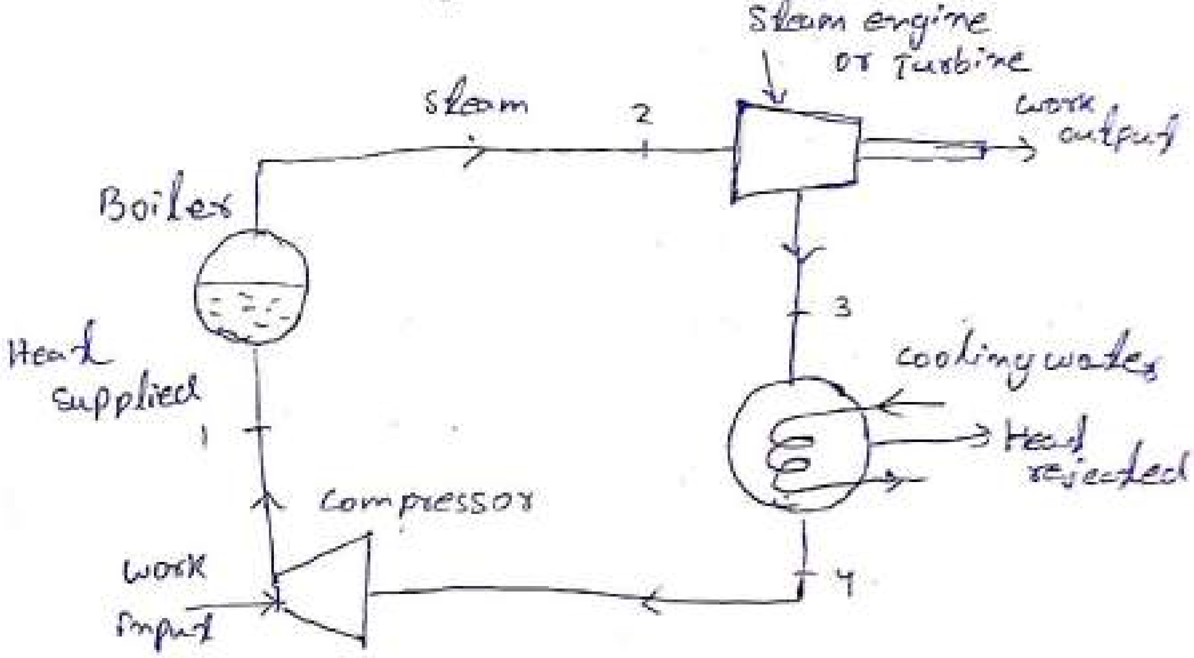


Fig. 11.25

Thermodynamic Vapour Cycle

Carnot cycle with steam as working substance

The schematic diagram of the carnot ~~cycle~~ engine is shown in figure and the carnot cycle using steam as the working substance is represented on p-v and T-S diagrams.



schematic diagram

Consider 1 kg of saturated water at pressure P_1 and absolute temperature T_1 as represented by point 1. The cycle is completed by the following four processes.

(1) Process 1-2 The saturated water at point 1 is isothermally converted into dry saturated steam, in a boiler, and the heat is absorbed

at a constant temp. T_1 and pressure P_1. The dry state of steam is respresented by point 2. It means that the temp. T_2 and pressure P_2 is equal to temperature T_1 and pressure P_1 respectively. This isothermal process is represented by curve 1-2 on P-V and T-S diagram.

we know that the heat absorbed by the saturated water during its conversion into dry steam is its latent heat of evaporation (i.e. $h_{fg_1} = h_{fg_2}$) corresponding to a pressure P_1 and P_2 ($\because P_1 = P_2$).

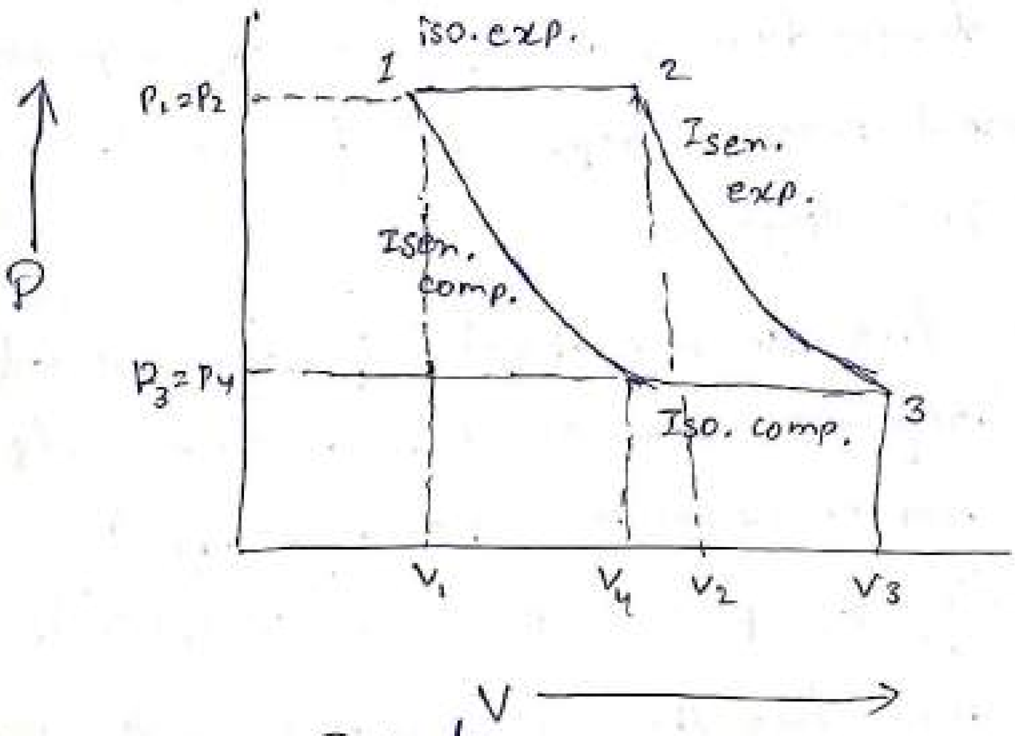
we also know that the area 1-2-b-a in the T-S diagram represents the heat absorbed to some scale, during the isothermal process.

$\therefore$ Heat absorbed during isothermal process (area 1-2-b-a),

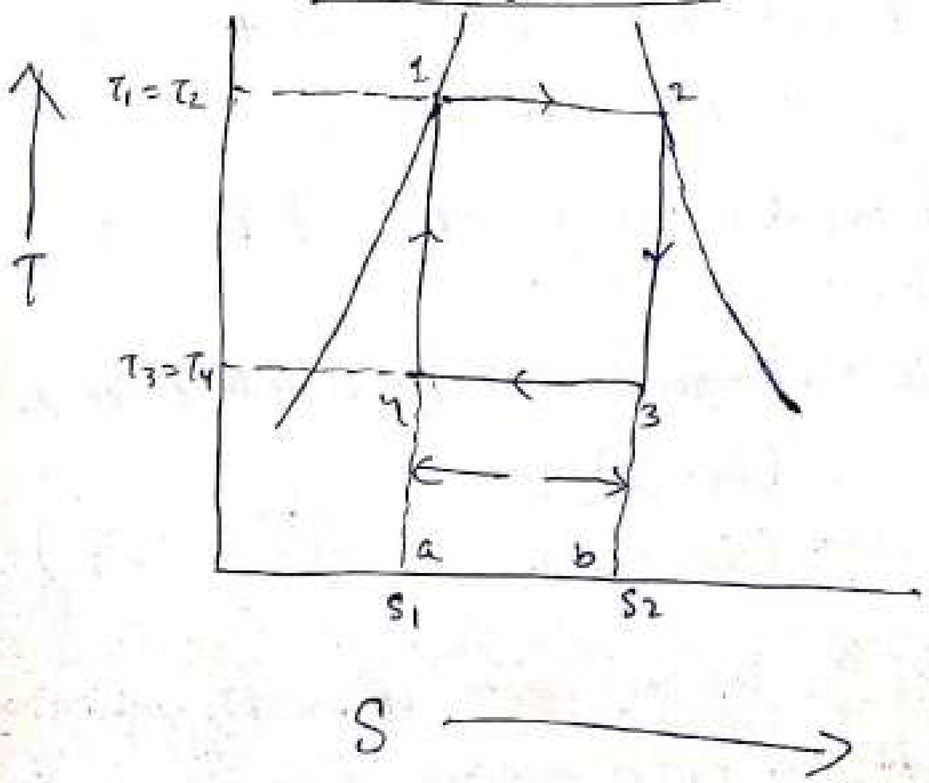
$$q_{1-2} = \text{change in entropy} \times \text{Absolute temp.}$$
$$= (S_2 - S_1)\, T_1$$
$$= (S_2 - S_1)\, T_2 \qquad (\because T_1 = T_2) \ldots (i)$$

(2) Process 2-3 The dry steam of point 2 now expands isentropically in a steam engine or turbine. The Pressure and temperature falls from P_2 to P_3 and T_2 to T_3 respectively. since no heat is supplied or rejected during this process, therefore

there is no change of entropy. The isentropic expansion is represented by the curve 2-3



P-V diagram



T - S diagram

(3) Process 3-4 The wet steam at point 3 is now isothermally condensed in a condenser and the heat is rejected at a constant temperature T_3 and pressure P_3. It means that the temp. T_4 and pressure P_4 is equal to the temp. T_3 and pressure P_3 respectively. This isothermal process is represented by the curve 3-4 on p-v and T-s diagrams.

we know that area 3-4-b-a in the T-S diagram represents the heat rejected to some scale during the isothermal process.

∴ Heat rejected during isothermal compression (area 3-4-a-b)

$$q_{3-4} = (S_2 - S_1)\, T_3 = (S_2 - S_1)\, T_4$$

$(\because T_3 = T_4)$ ... (ii)

(4) Process 4-1

The wet steam at point 4 is finally compressed till it returns back to its original state. The pressure and temperature rise from P_4 to P_1 and T_4 to T_1 respectively. The isentropic compression is represented by the curve 4-1 as shown in figure since no heat is absorbed or rejected during this process, therefore entropy remains constant.

This completes the cycle.

we know that work done during the cycle

= Heat absorbed − Heat rejected

$= (S_2 - S_1) T_1 - (S_2 - S_1) T_3$

$= (S_2 - S_1)(T_1 - T_3)$

Efficiency of the carnot cycle.

$$\eta = \frac{\text{work done}}{\text{Heat absorbed}}$$

$$= \frac{(S_2 - S_1)(T_1 - T_3)}{(S_2 - S_1) T_1}$$

$$= \frac{T_1 - T_3}{T} = 1 - \frac{T_3}{T_1}$$

T_1 = Highest temp. corresponding to the boiler pressure where $P_1 = P_2$

T_3 = lowest temp. corresponding to the condenser pressure where $P_3 = P_4$

Performance Criterial for Thermodynamic vapour cycle

Though, theoretically, the carnot cycle is the most efficient cycle. yet it is not considered as a standard of referance for the comparison of Performance of thermodynamic vapour cycle.

The following terms, in addition to the efficiency, are commonly used for the comparison of performance of thermodynamic vapour cycle.

① Efficiency ratio

It is also known as relative efficiency. It is defined as the ratio of thermal efficiency (or actual cycle efficiency) to Rankine efficiency (or ideal cycle efficiency) mathematically.

$$\text{Efficiency ratio} = \frac{\text{Thermal efficiency}}{\text{Rankine efficiency}}$$

Thermal efficiency :

$$= \frac{\text{Heat equivalent to one kilowatt hour (kWh)}}{\text{Total heat supplied to the steam per kWh}}$$

$$= \frac{3600 \times P}{m_s(h_2 - h_{f3})}$$

m_s = mass of steam supplied in kg/h and

P = power developed in kW

② work ratio

It is defined as the ratio of net work output to the gross (engine or turbine) output. mathematically

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work ratio = $\frac{\text{Net work output}}{\text{Gross output}}$

$= \frac{\text{Turbine work - Compressor work}}{\text{Turbine work}}$

③ **Specific steam consumption**

It is also known as steam rate or specific rate of flow of steam. It is defined as the mass of steam that must be supplied to a steam engine or turbine in order to develop a unit amount of work or power output. The amount of work or power output is usually expressed in killowatt hour (kWh), mathematically

specific steam consumption

$= \frac{1\,kWh}{w} = \frac{3600}{w} = \frac{3600}{h_2 - h_3}$ kg/kWh

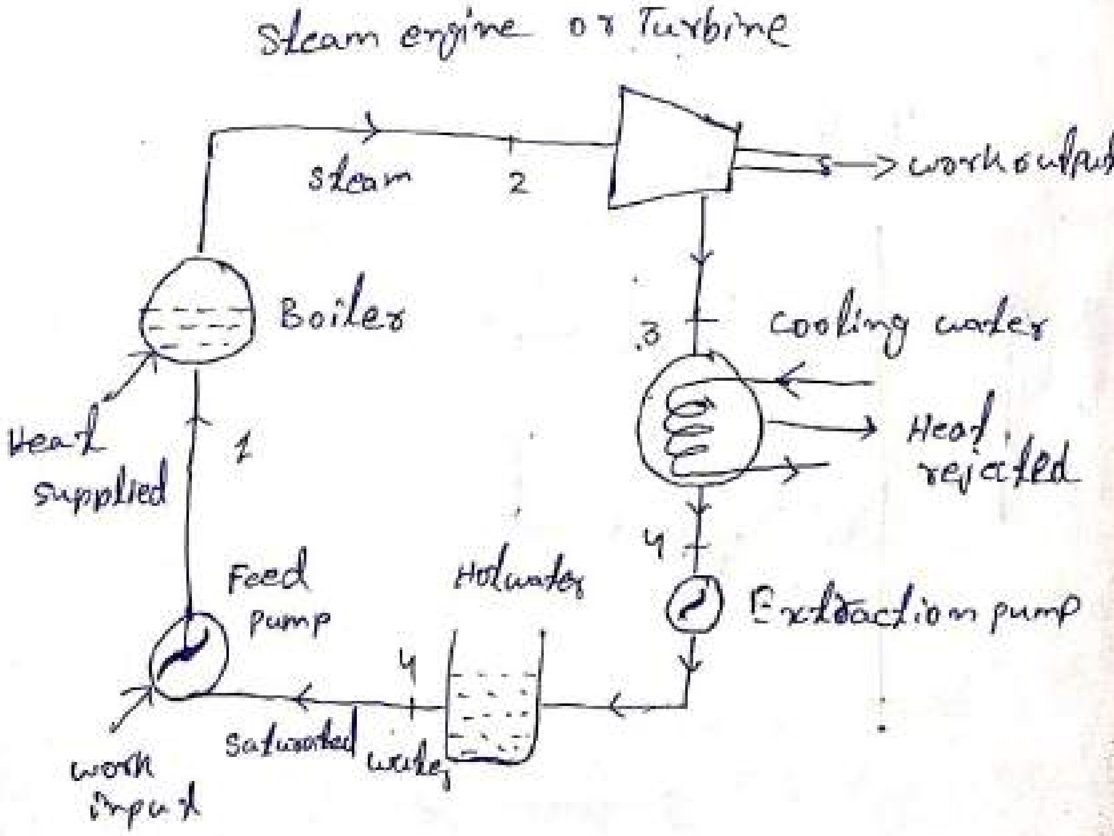
($\because$ 1 kWh = 3600 kJ)

w = Net workdone or power output

$= (h_2 - h_3)$ kJ/kg

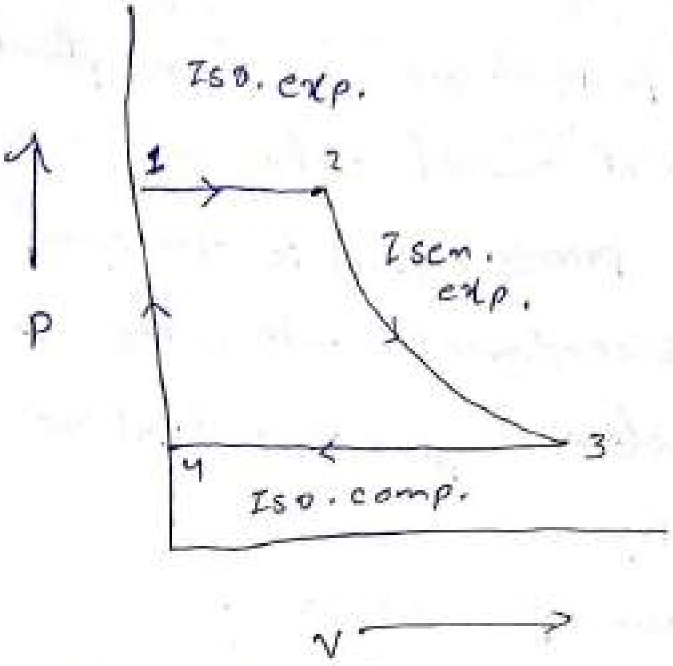
Rankine cycle

The Rankine cycle is an idea cycle for comparing the performance of steam plants. Its modified form of carnot cycle, in which the condensation process (3-4) is continued until the steam is condensed into water. The schematic diagram of a steam engine or a turbine plant is shown in figure.

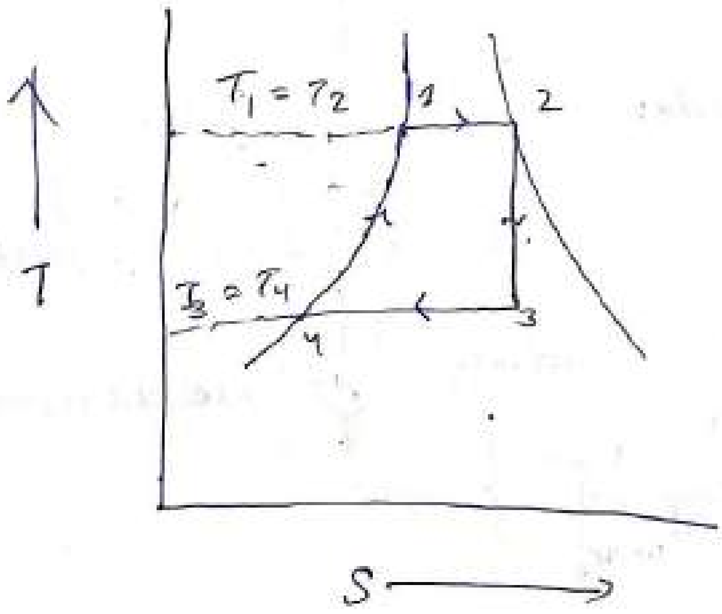


schematic diagram of steam engine or turbine plant

A Rankine cycle, using steam as a working substance is represent on p-V and T-s diagrams as shown in figure



P-V diagram



T - S diagram

consider 1 kg of saturated water at pressure P_1 and absolute temperature T_1 as represented by point 1. The cycle is completed by the following four processes.

① Process 1-2 The saturated water at point 1 is isothermally converted into dry saturated steam in a boiler, and the heat is absorbed at a constant temperature T_1 and pressure P_1. The dry state of steam is represented by point 2. It means that the temp. T_2 and pressure P_2 is equal to temp. T_1 and pressure P_1 respectively. This isothermal process is represented by curve 1-2 on p-v and T-s diagrams

we know that the heat absorbed during isothermal process by water during its conversion into dry steam is its latent heat of vaporisation (i.e. $h_{fg1} = h_{fg2}$), corresponding to a pressure p_1 or P_2 ($\because P_1 = P_2$).

② Process 2-3 → The dry saturated steam at point 2 now expand isentropically in an engine or turbine. The pressure and temperature fall from P_2 to P_3 and T_2 to T_3 respectively with a dryness fraction x_3. since no heat is supplied or rejected during this process, therefore there is no change of entropy. The isentropic expansion is represented by the curve 2-3

(3) Process 3-4 The wet steam at point 3 is now isothermally condensed in a condenser and the heat is rejected at constant temperature T_3 and pressure P_3 until the whole steam is condensed into water. It means that the temp. T_4 and pressure P_4 is equal to the temperature T_3 and pressure P_3 respectively. The isothermal compression is represent by curve 3-4 on P-V and T-S diagrams. The heat rejected by steam is its latent heat (equal to $x_3 h_{fg3}$).

(4) Process 4-1 The water at point 4 is now warmed in a boiler at constant volume from temp. T_4 to T_1. Its pressure also rises from P_4 to P_1. This warming operation is represented by the curve 4-1 on P-V and T-S diagram. The heat absorbed by water during this operation is equal to the sensible heat or liquid heat corresponding to the pressure P_1 ie. equal to sensible heat at point 1 minus sensible heat at point 4

Let $h_{f1} = h_{f2}$ = sensible heat or enthalpy of water at point 1 corresponding to a pressure of P_1 or P_2 ($\because P_1 = P_2$)

$h_{f4} = h_{f3}$ = sensible heat or enthalpy of water at point 4 corresponding to the pressure of P_4 or P_3 ($\because P_4 = P_3$)

∴ Heat absorbed during warming operation 4-1

$= h_{f1} - h_{f4}$

$= h_{f2} - h_{f3}$

and heat absorbed during the complete cycle

= Heat absorbed during isothermal operation 1-2 + Heat absorbed during warming operation 4-1

$= h_{fg2} + (h_{f2} - h_{f3}) = h_{f2} + h_{fg2} - h_{f3} = h_2 - h_{f3}$

(for dry steam, $h_2 = h_{f2} + h_{fg2}$) ......(i)

we know that heat rejected during the cycle

$= h_3 - h_{f4} = h_{f3} + x_3 h_{fg3} - h_{f4} = x_3 h_{fg3}$

($\because h_{f3} = h_{f4}$)

∴ work done during the cycle

= Heat absorbed – Heat rejected

$= (h_2 - h_{f3}) - x_3 h_{fg3}$

$= h_2 - (h_{f3} + x_3 h_{fg3})$

$= h_2 - h_3$ ($\because h_3 = h_{f3} + h_{fg3}$) ...(ii)

and efficiency (Rankine efficiency)

$$\eta_R = \frac{\text{work done}}{\text{Heat absorbed}}$$

$$= \frac{h_2 - h_3}{h_2 - h_{f3}}$$

Noted down

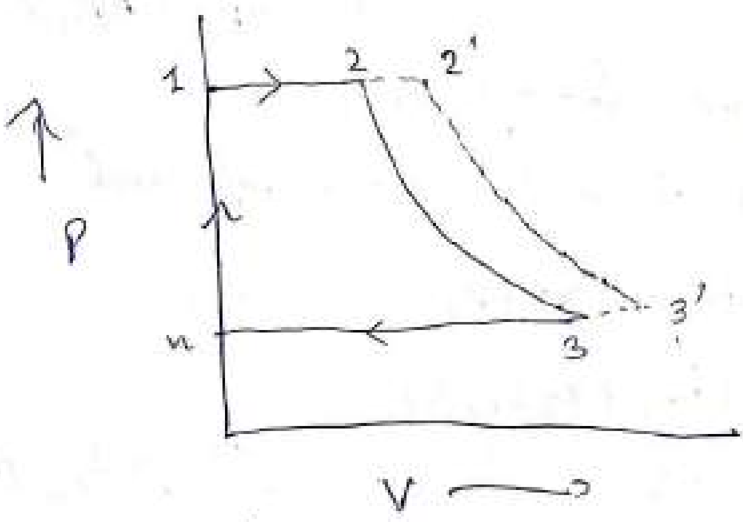
① The difference of enthalpies $(h_2 - h_3)$ is known as isentropic heat drop.

(3) If the expansion of steam (2-3') is not isentropic and follows the general Law pv^n = constant, then work done during the process will not be $(h_2 - h_3)$. The work done in this case will be given by the relatively

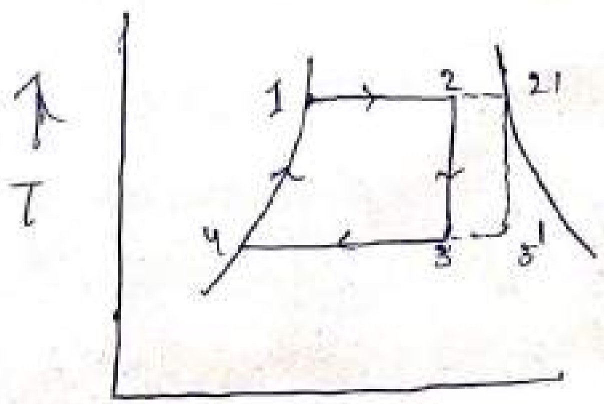
$$w = P_2 V_2 + \frac{P_2 V_2 - P_3 V_3}{(n-1)} - P_3 V_3$$

$$= \frac{n (P_2 V_2 - P_3 V_3)}{n-1}$$

Rankine cycle with Incomplete Evaporation



P-V diagram

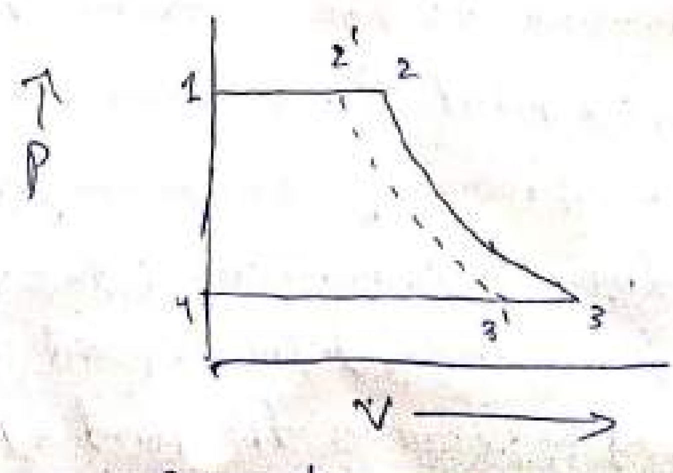


T-s diagram

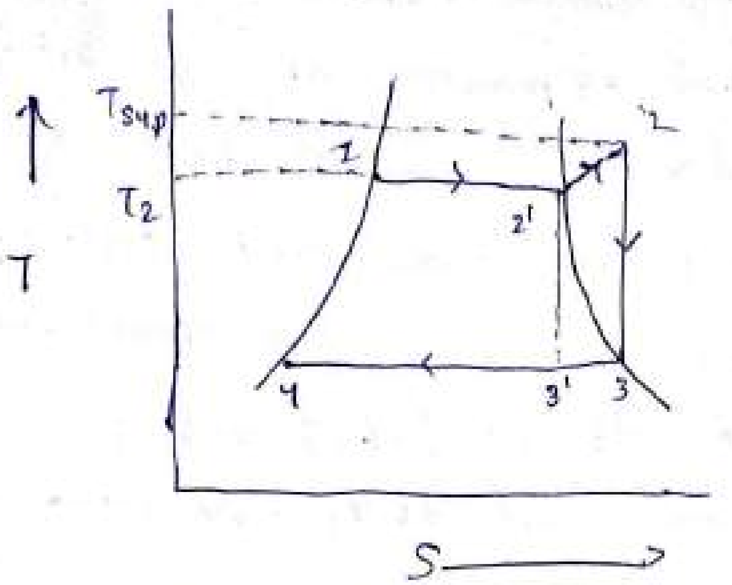
we have already discussed in the last article that in isothermal expansion of a Rankine cycle, the water is converted into dry saturated steam at a constant temp. T_1 and pressure P_1. Sometimes, the steam produced is not completely dry, but it is wet with dryness fraction equal to x_1. In such a case, the Rankine cycle may be represented on p-V and T-S diagram as shown in the figure

Rankine cycle with superheated steam

we have already discussed, in the last article, the case of a Rankine cycle where the steam produced is wet with dryness fraction x_2. But sometimes, the steam produced is superheated. In such a case, the Rankine cycle may be shown on p-V and T-S diagram as shown in figure.



P-V diagram.



T-S diagram

In may be noted from the above figure, that 1-2-3-4 ~~respect~~ represents the Ranking cycle with superheated steam, where as 1-2'-3'-4 represents the cycle with complete evaporation. In such a case heat absorbed during isothermal expansion

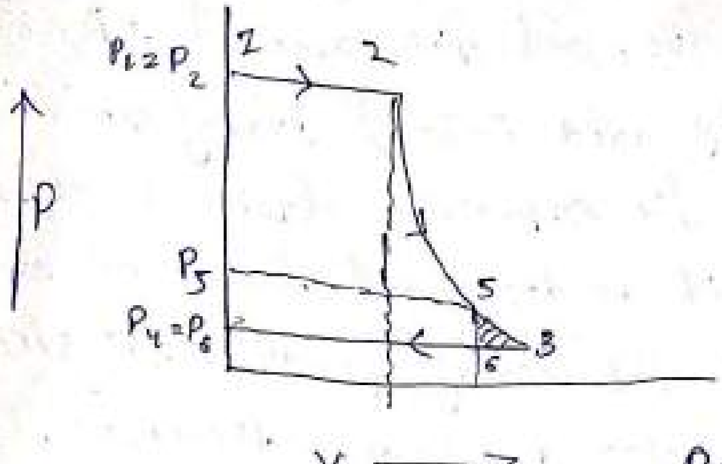
$$h_2 = h_{sup} = h_{g2} + C_p (T_{sup} - T_2)$$

Modified Rankine cycle

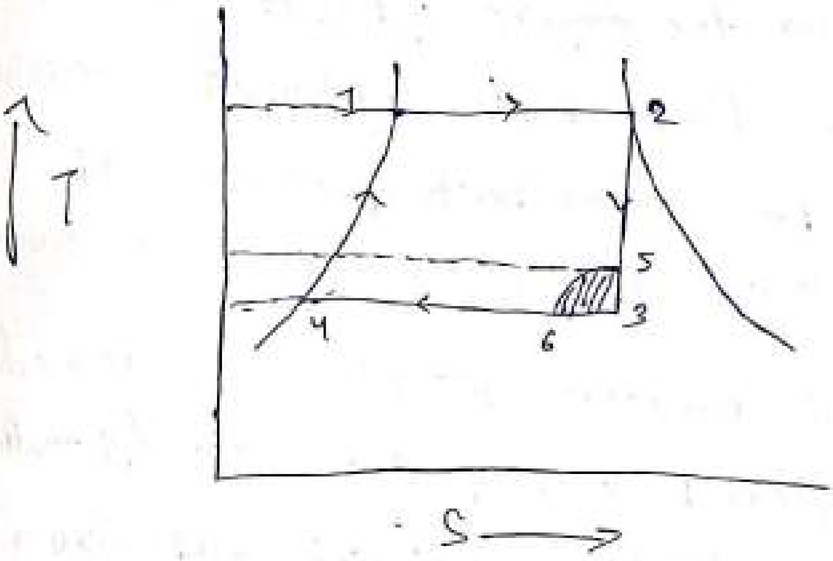
We have seen in the Rankine cycle, that the steam is expanded to the extreme toe of P-V diagram (at point 3) as shown in figure. But in actual reciprocating steam engines, it is found to be too uneconomical (due to large size of the cylinder) to expand steam to the full limit (i.e. upto the point 3)

It may be noted that the diagram is very narrow at the toe, and the amount of workdone (represented by area 5-3-6) during this final portion of the expansion stroke is extremely small. In fact, it is too small to overcome even the friction of the moving parts in the steam engine. The expansion of steam, therefore, is carries on in the engine cylinder, and a pressure higher than that of the condenser pressure or exhaust pressure or back pressure. This higher pressure is know as release pressure (P_5)

In order to overcome the above mentioned difficulty, the Rankine cycle is slightly modified. In a modified Rankine cycle, the expansion stroke of the piston is stopped at point 5 by cutting the toe of Rankine cycle, and the steam is exhausted from the cylinder at a constant volume. This causes a sudden drop of pressure from P_5 to P_6. The expansion of steam is, therefore, completed by a constant volume line 5-6 as shown in P-V diagram and T-S diagram as shown in figure. By doing so, the size of the cylinder and stroke length is considerable reduced.



P-V diagram



T-S diagram

Efficiency of Modified Rankine Cycle

Consider a modified Rankine cycle whose process are shown in figure

Let $P_1 = P_2$ = Pressure of steam at point 2

V_2 = volume of steam at point 2.

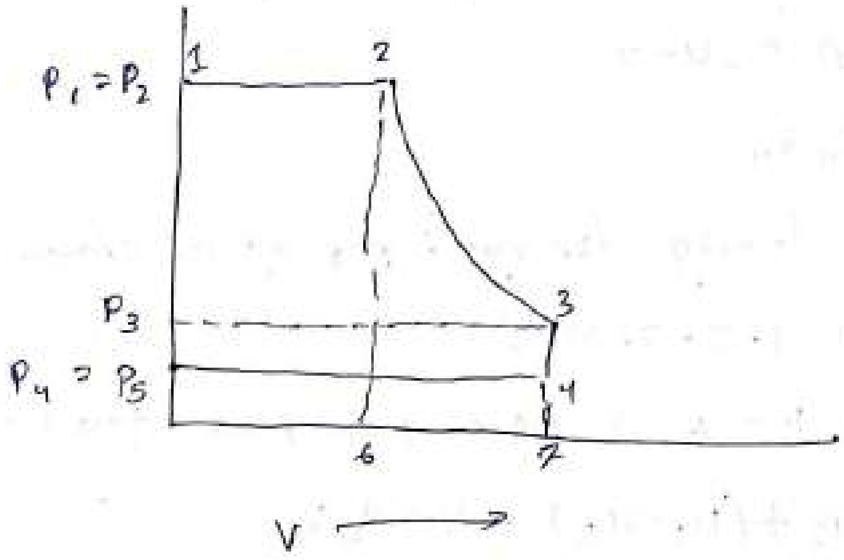
h_2 = Enthalpy or total heat of steam at point 2,

u_2 = Internal energy of steam at point 2

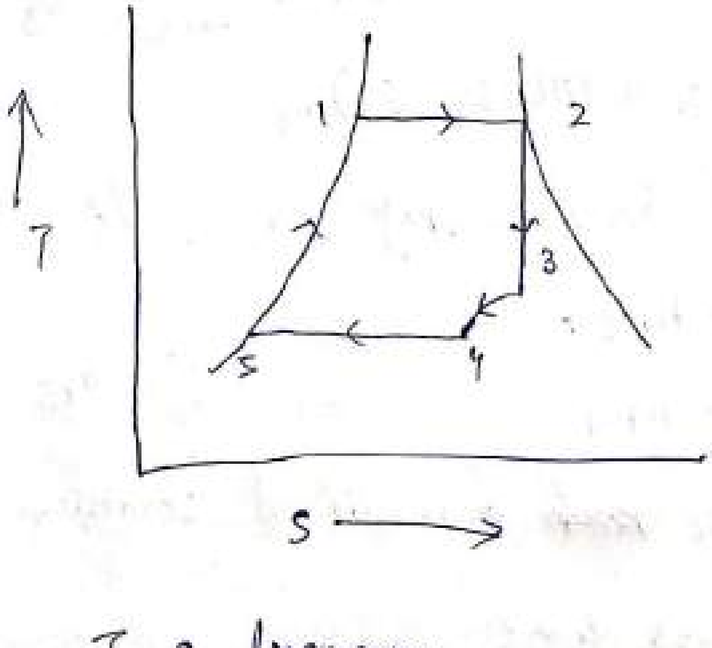
P_3, V_3, h_3, u_3 = corresponding value of steam at point 3

P_4 = Back pressure of steam at point 4

h_{f4} = sensible heat or enthalpy of water at point 4



P-V diagram



T-S diagram

we know that work done during constant pressure process = Area 1-2-6-0 = $100 P_2 V_2$

we know also that work done during isentropic expansion 2-3

$= \text{Area } 2-3-7-6$

$=$ change in internal energy

$= u_2 - u_3$

work done during constant pressure process 4-5

$= \text{Area } 0-5-4-7$

$= 100\, P_4 V_4$

$\therefore$ work done during the cycle per kg of steam

$W = \text{Area } 1-2-3-4-5$

$= \text{Area } 1-2-6-0 + \text{Area } 2-3-7-6 - \text{Area } 0-5-4-7$

$= 100 P_2 V_2 + (u_2 - u_3) - 100 P_4 V_4$

$= 100 P_2 V_2 + [(h_2 - 100 P_2 V_2) - (h_3 - 100 P_3 V_3)]$

$- 100 P_4 V_4 \quad \ldots (\because V_3 = V_4)$

$= h_2 - h_3 + 100 (P_3 - P_4) V_3$

We know that heat supply per cycle

$= h_2 - h_{f5}$

$= h_2 - h_{f4} \quad \text{---} (\because h_{f5} = h_{f4})$

Efficiency of the ~~[illegible]~~ modified Rankine cycle

$$\eta_{MR} = \frac{\text{work done}}{\text{Heat supplied}}$$

$$= \frac{(h_2 - h_3) + 100 (P_3 - P_4) V_3}{h_2 - h_{f4}}$$

Reheat cycle

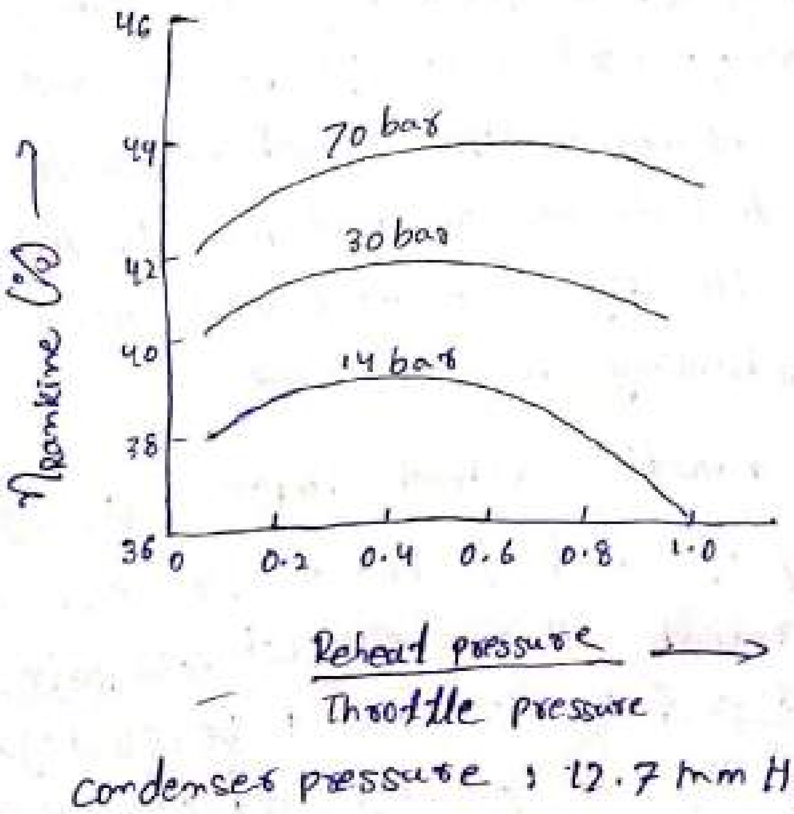
For attaining greater thermal efficiencies when the initial pressure of steam was raised beyond 42 bar it was found that resulting condition of steam after, expansion was increasingly wetter and exceeded the safe limit of 12 per cent condensation. It, therefore, become necessary to reheat the steam after part of expansion was over so that the resulting condition after complete expansion fell within the region of permissible wetness.

The reheating or resuperheating of steam is now universally used when high pressure and temperature steam conditions such as 100 to 250 bar and 500°c to 600°c are employed for throttle. For plants of still higher pressures and temperatures a double reheating may be used.

In actual practice reheat improve the cycle efficiency by about 5% for a 85/15 bar cycle. A second reheat will give a much less gain while the initial cost involved would be so high as to prohibit use of two stage reheat except in case of very high initial throttle conditions. The cost of reheat equipment consisting of boiler, piping and controls may be 5% to 10%

more than of the conventional boilers and this additional expenditure is justified only if gain in thermal efficiency is sufficient to promise a return of this investment. using a plant with a base load capacity of 5000 kW and initial steam pressure of 42 bar would economically justify the extra cost of reheating

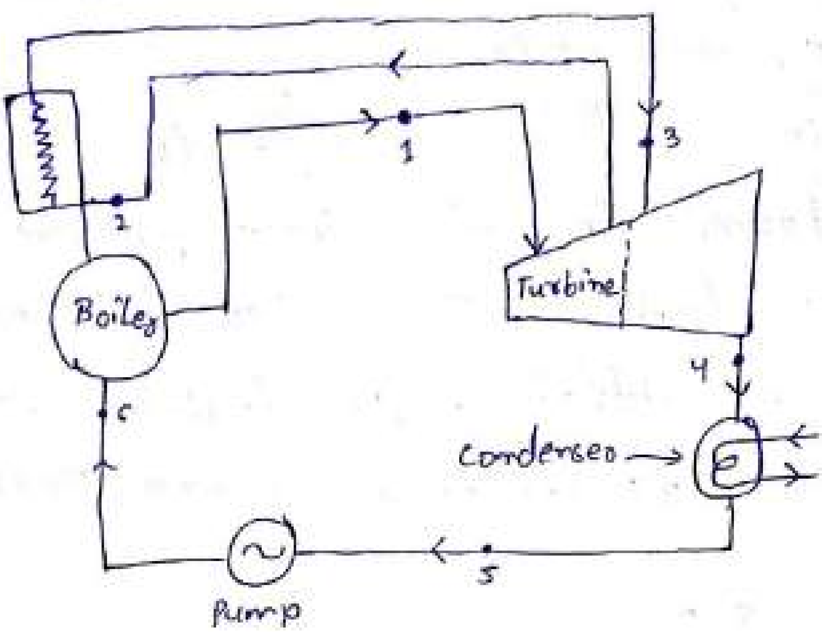
The improvement in thermal efficiency due to reheat is greatly dependent upon the reheat pressure with respect to the original pressure of steam.



Condenser pressure : 12.7 mm Hg

Temperature of throttle and heat 1427°C

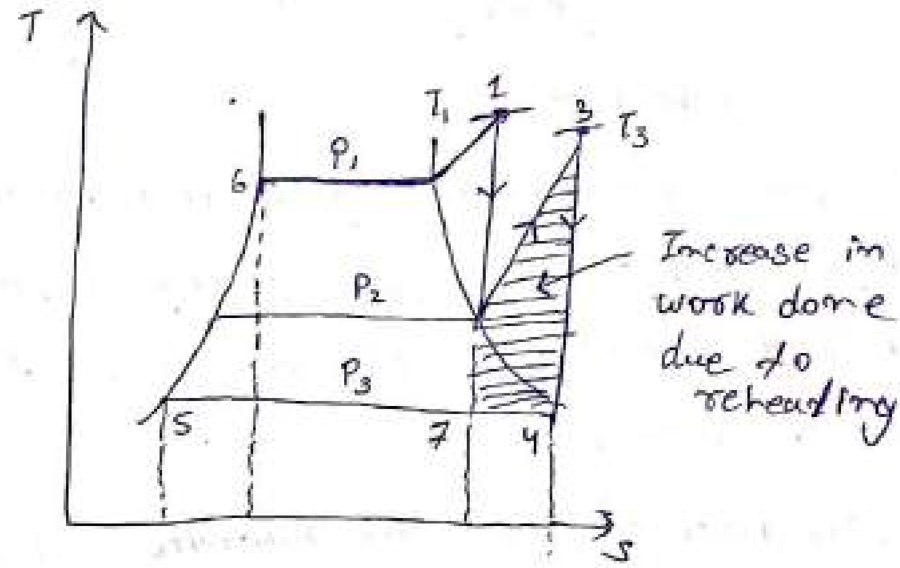
Effect of reheat pressure selection on cycle efficiency.



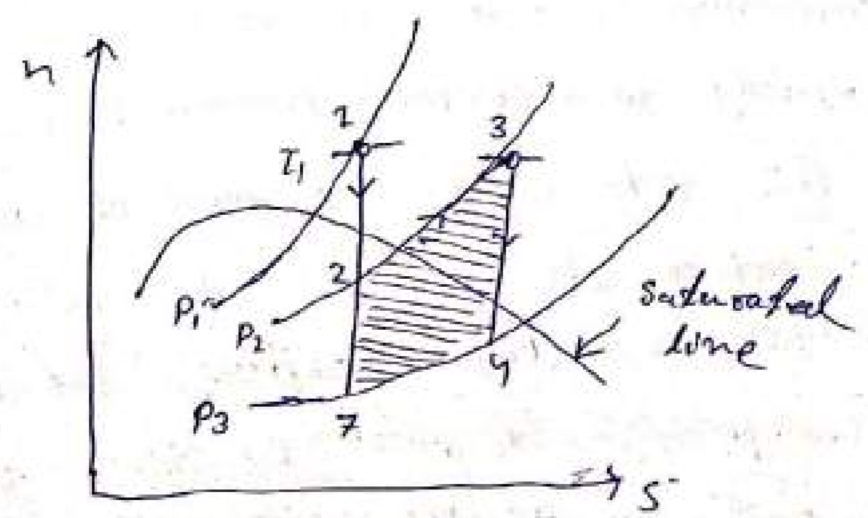
<u>Reheat cycle</u>

As shown a schematic diagram of a theoretical single stage reheat cycle. The corresponding representation of ideal reheating process on T-s and H-S chart are shown in figure

The following shows the formation of steam in the boiler. The steam as at state point 1 (i.e. pressure P_1 and temperature T_1) enters the turbine and expands isentropically to a certain pressure P_2 and temp. T_2. From this state point 2 the whole of steam is drawn out of the turbine and is reheated in a reheater to a temp T_3. (Although there is an optimum pressure at which the steam should be removed for reheating, if the highest return is to be obtained, yet, for simplicity, the whole steam is removed from the high pressure exhaust, where the pressure is about one-fifth of boiler pressure, and after underground a 10% pressure drop, in circulating through the heater, it is returned to intermediate pressure or low pressure turbine). This reheated steam is then readmitted to the turbine where it is expanded to condenser pressure isentropically.



T-S chart



h-s chart

Thermal efficiency with Reheating (neglecting Pump work):

Heat supplied $= (h_1 - h_{f4}) + (h_3 - h_2)$

Heat rejected $= h_4 - h_{f4}$

work done by the turbine = Heat supplied − Heat rejected

$$= (h_1 - h_{f4}) + (h_3 - h_2) - (h_4 - h_{f4})$$

$$= (h_1 - h_2) + (h_3 - h_4)$$

Thus, theoretical thermal efficiency of reheat cycle is

$$\eta_{thermal} = \frac{(h_1 - h_2) + (h_3 - h_4)}{(h_1 - h_{f4}) + (h_3 - h_2)}$$

If pump work

$$w_p = \frac{V_f (p_1 - p_b)}{1000} \text{ kJ/kg is considered,}$$

the thermal efficiency is given by:

$$\eta_{thermal} = \frac{[(h_1 - h_2) + (h_3 - h_4)] - W_p}{[(h_1 - h_{f4}) + (h_3 - h_2)] - W_p}$$

w_p is usually small and neglected

Thermal efficiency without reheating is

$$\eta_{thermal} = \frac{h_1 - h_7}{h_1 - h_{f4}} \quad (\because h_{f4} = h_{f7})$$

Advantages of Reheating

(1) There is an increased output of the turbine

(2) Erosion and corrosion problem in the steam turbine are eliminated.

(3) There is an improvement in the thermal efficiency of the turbines.

(4) Final dryness fraction of steam is improved.

(5) There is an increase in the nozzle and blade efficiencies.

Disadvantage

(1) Reheating required more maintenance.

(2) The increase in thermal efficiency is not appreciable in comparison to the expenditure incurred in reheating.

Supercheating of Steam:-

The primary object of supercheating steam and supplying it to the primemovers is to avoid too much wetness at the end of expansion. Use of inadequate degree of supercheat in steam engines would cause greater condensation in the engine cylinder; while in case of turbines the moisture content of steam would result in undue blade erosion. The maximum wetness in the final condition of steam that may be tolerated without any appreciable harm to the turbine blades is about 12%. Broadly each 1% of moisture in steam reduces the efficiency of that part of the turbine in which wet steam passes by 1% to 1.5% and in engines about 2 percent.

Regenerative cycle

In the Rankine cycle it is observed that the condensate which is fairly at low temperature has an irreversible mixing with hot boiler water and this result in decrease of cycle efficiency. Methods are, therefore, adopted to heat the feed water from the hot well of condenser irreversibly by interchange of heat within the system and thus improving the cycle efficiency. This heating method is called regenerative feed heat and the cycle is called regenerative cycle.

The principle of regeneration can be practically utilised by extracting steam from the turbine at several locations and supplying it to the regenerative heaters. The resulting cycle is known as regenerative or bleeding cycle. The heating arrangement comprises of: (i) for medium capacity turbines - not more than 3 heaters.

ii) for high pressure high capacity turbines - not more than 5 to 7 heaters; and

iii) for turbines of super critical parameters 8 to 9 heaters.

The most advantageous condensate heating temperature is selected depending on the turbine throttle conditions and this determines the number of heaters to be used. The final condensate heating temperature is kept 50 to 60°C below the boiler saturated steam temperature so as to prevent evaporation of water in the feed mains following a drop in the boiler drum pressure. The conditions of steam bled for each heater are selected so that the temperature of saturated steam will be 4 to 10°C higher than the final condensate temperature.

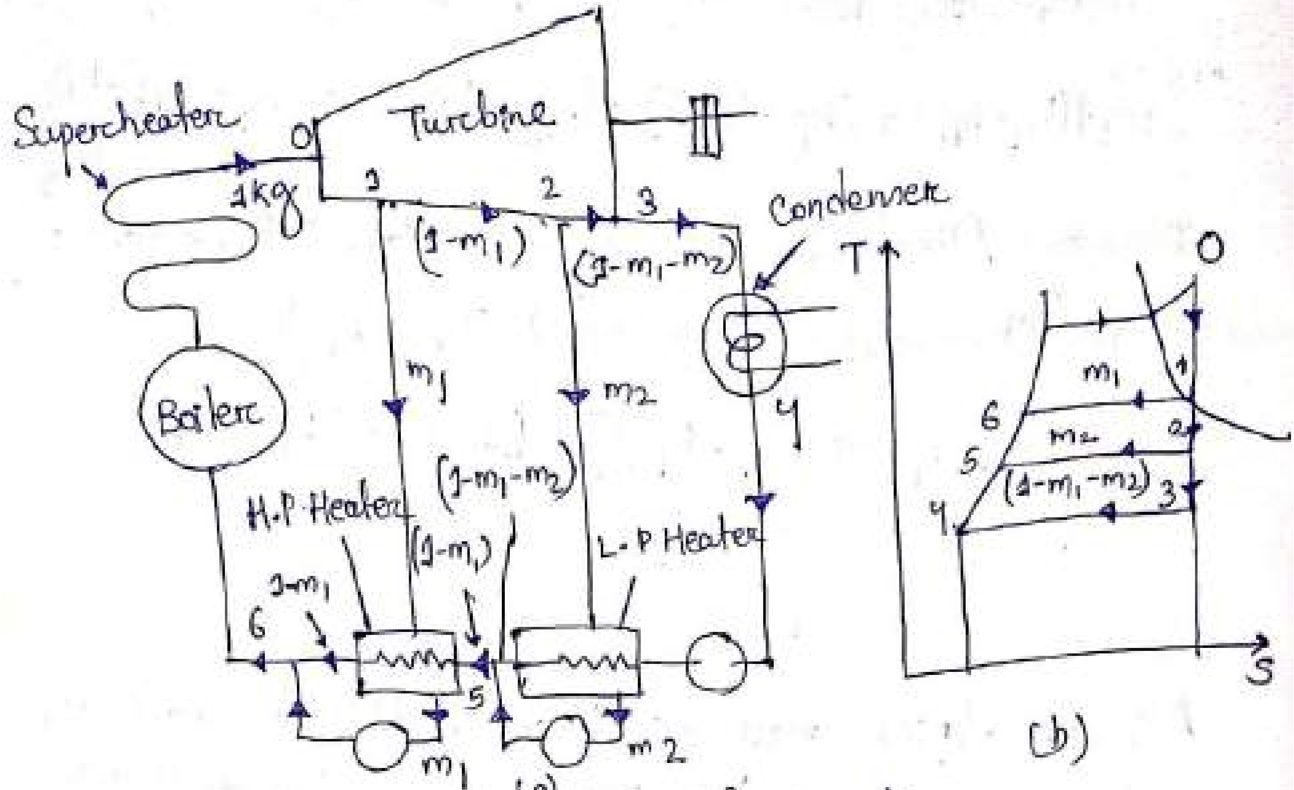


Fig. . Regenerative cycle.

fig. (a) shows a diagrammatic layout of a surface condensing steam power plant in which a surface condenser is used to condense all the steam that is not extracted for feed water heating. The turbines is double extracting and the boiler is equipped with a superheater. The cycle diagram (T-s) would appear as shown in fig (b). This arrangement constitutes a regenerative cycle.

Let m_1 = kg of high pressure (H.P) steam per kg of steam flow.

m_2 = kg of low pressure (L.P) steam extracted per kg of steam flow.

$1-m_1-m_2$ = kg of steam entering condenser per kg of steam flow.

$$m_1 (h_1 - h_{f_6}) = (1-m_1)(h_{f_6} - h_{f_5})$$

or $m_1[(h_1 - h_{f_6}) + (h_{f_6} - h_{f_5})] = (h_{f_6} - h_{f_5})$ or $m_1 = \dfrac{h_{f_6} - h_{f_5}}{h_1 - h_{f_5}}$

Energy / Heat balance equation for L.P heater:

$$m_2 (h_2 - h_{f_5}) = (1 - m_1 - m_2)(h_{f_5} - h_{f_3})$$

or $m_2[(h_2 - h_{f_6}) + (h_{f_5} - h_{f_3})] = (1-m_1)(h_{f_5} - h_{f_3})$

$$m_2 = \frac{(1-m_1)(h_{f_5} - h_{f_3})}{(h_2 - h_{f_3})}$$

All enthalpies may be determined; therefore m_1 and m_2 may be found. The maximum temperature to which the water can be heated is dictated by that of bled steam. The condensate from the bled steam is added to feed water.

Neglecting pump work:

The heat supplied externally in the cycle.

$$= (h_0 - h_{f_6})$$

Isentropic work done $= m_1(h_0 - h_1) + m_2(h_0 - h_2) + (1 - m_1 - m_2)(h_0 - h_3)$

The thermal efficiency of regenerative cycle is

$$\eta_{thermal} = \frac{\text{Work done}}{\text{Heat supplied}}$$

$$= \frac{m_1(h_0 - h_1) + m_2(h_0 - h_2) + (1 - m_1 - m_2)(h_0 - h_3)}{(h_0 - h_{f_6})}$$

Advantages of Regenerative cycle over Simple Rankine cycles:

1- The heating process in the boiler tends to become reversible.

2- The thermal stresses set up in the boiler are minimised. This is due to the fact that temperature ranges in the boiler are reduced.

3- The thermal efficiency is improved because the average temperature of heat addition to the cycle is increased.

4- Heat rate is reduced.

5- The blade height is less due to the reduced amount of steam passed through the low pressure stages.

6- The blade height is less due to the

6- Due to may extraction there is an improvement in the turbine drainage and it reduces erosion due to moisture,

7- A small size condenser is required.

Disadvantage

1- The plant becomes more complicated.

2- Because of addition of heaters greater maintaince maintanance is required.

3- For given power a large capacity boiler is required.

4- The heaters are costly and the gain in thermal efficiency is not much in comparision to the heavier costs.

BASICS OF HEAT TRANSFER

The science of thermodynamics deals with the amount of heat transfer as a system undergoes a process from one equilibrium state to another, and makes no reference to how long the process will take. But in engineering, we are often interested in the rate of heat transfer, which is the topic of the science of heat transfer.

We all know from experience that a cold canned drink left in a room warms up and a warm canned drink left in a refrigerator cool down. This is accomplished by the transfer of energy from the warm medium to the cold one. The energy transfer is always from the higher temperature medium to the lower temperature one, and the energy transfer stops when the two mediums reach the same temperature.

In thermodynamics, energy exists in various forms. Here we are primarily interested in heat, which is the form of energy that can be transferred from one system to another as a result of temperature difference. The science that deals with the determination of the rates of such energy transfers is heat transfer.

Thermodynamics deals with equilibrium states and changes from one equilibrium state to another. Heat transfer, on the other hand, deals with systems that lack thermal equilibrium, and thus it is a nonequilibrium phenomenon.

The basic requirement for heat transfer is the presence of a temperature difference. There can be no net heat transfer between two mediums that are at the same temperature. The temperature difference is the driving force for heat transfer, just as the voltage difference is the driving force for electric current flow and pressure difference is the driving force for fluid flow***. The rate of heat transfer in a certain direction depends on the magnitude of the temperature gradient (the temperature difference per unit length or the rate of change of temperature) in that direction.*** The larger the temperature gradient, the higher the rate of heat transfer.

Application Areas of Heat Transfer: -

1. The human body is constantly rejecting heat to its surroundings, and human comfort is closely tied to the rate of this heat rejection. We try to control this heat transfer rate by adjusting our clothing to the environmental conditions.
2. Many household appliances are designed, in whole or in part, by using the principles of heat transfer on the basis of minimizing heat loss in winter and heat gain in summer.
   Examples: -the electric or gas range, the heating and air-conditioning system, the refrigerator and freezer, the water heater, the iron, and even the computer, the TV, and the VCR etc.
3. Heat transfer plays a major role in the design of many other devices, such as car radiators, solar collectors, various components of power plants, and even spacecraft.
4. The optimal insulation thickness in the walls and roofs of the houses, on hot water or steam pipes, or on water heaters is again determined on the basis of a heat transfer analysis with economic consideration.

Some Terms Related to Heat Transfer: -

Thermal Conductivity :– (k)

It can be defined as the rate of heat transfer through a unit thickness of the material per unit area per unit temperature difference.

→ It is the measure of the ability of the material to conduct heat.

High value — Good heat conductor
Low value — Poor heat conductor / Insulator

- Pure crystals and metals have highest thermal conductivity and gases and insulating materials the lowest.

Unit :- W/m·K (Watt per meter kelvin)

Thermal Diffusivity (α) :—

- It is the thermal conductivity divided by density and specific heat capacity at constant pressure.
- It measures the rate of heat transfer of heat of a material from the hot end to the cold end.

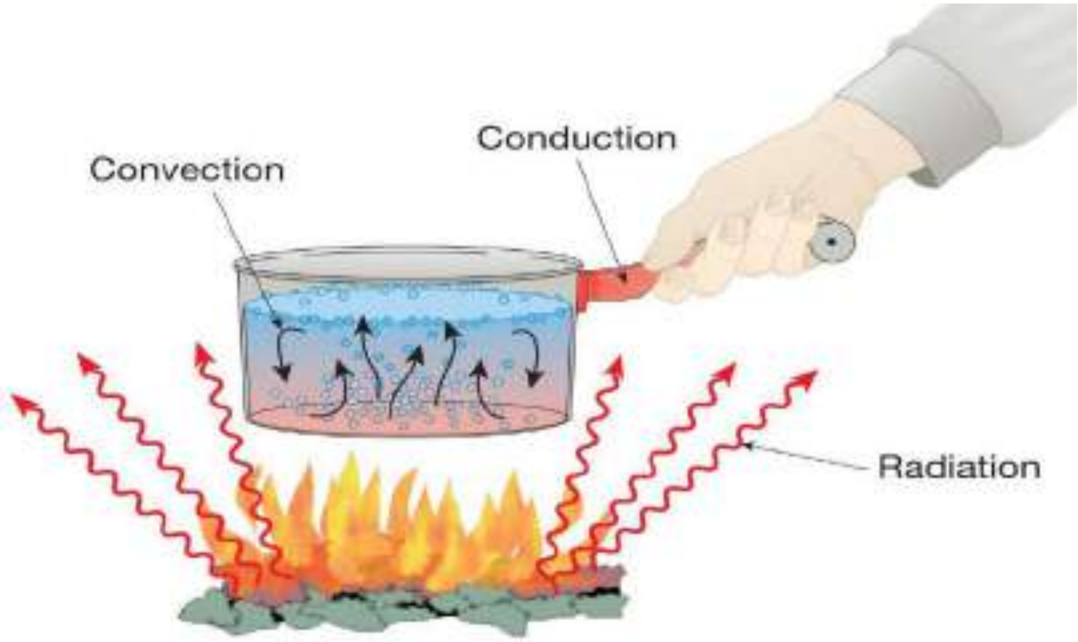
Unit :→ m^2/s

$$\alpha = \frac{\text{Heat conducted}}{\text{Heat stored}} = \frac{k}{\rho C_p}$$

where, C_p = Specific heat capacity (J/kg·K)
ρ = density (kg/m^3)
ρC_p – Volumetric heat capacity ($J/m^3.K$)

Larger the value of 'α', the faster the propagation of heat into the medium.

Modes of Heat Transfer: -



Heat can be transferred in three different modes:

- ❖ Conduction
- ❖ Convection
- ❖ Radiation

CONDUCTION: -

Conduction is heat transfer by means of molecular agitation within a material without any motion of the material as a whole.

Conduction can take place in solids, liquids, or gases. In gases and liquids, conduction is due to the collisions and diffusion of the molecules during their random motion. In solids, it is due to the combination of vibrations of the molecules in a lattice and the energy transport by free electrons.

The rate of heat conduction through a medium depends on the geometry of the medium, its thickness, and the material of the medium, as well as the temperature difference across the medium. We know that wrapping a hot water tank with glass wool (an insulating material) reduces the rate of heat loss from the tank. The thicker the insulation, the smaller the heat loss. We also know that a hot water tank will lose heat at a higher rate when the temperature of the room housing the tank is lowered. Further, the larger the tank, the larger the surface area and thus the rate of heat loss.

Fourier's Law

Consider steady heat conduction through a large plane wall of thickness $\Delta x = L$ and area A

Temperature difference across the wall $\Delta T = T_2 - T_1$

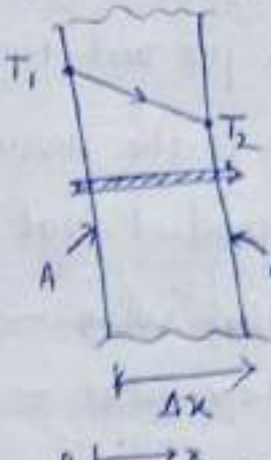


Fig:- Heat conduction through a large plane wall of thickness Δx and area A

According to experiment

$$\text{Rate of heat conduction} \propto \frac{(\text{Area}) \times (\text{Temp. difference})}{\text{Thickness}}$$

$$\Rightarrow \dot{Q}_{cond} = kA \frac{T_1 - T_2}{\Delta x} = -kA \frac{\Delta T}{\Delta x} \qquad (\text{As } \Delta T = T_2 - T_1)$$

where, k = Thermal conductivity of the material (Proportionality constant)

In differential form $\boxed{\dot{Q}_{cond} = -kA \frac{dT}{dx}}$

It is called Fourier's law of heat conduction.

Definition :- It states that the rate of heat conduction through a plane layer is proportional to the temperature difference across the layer and the heat transfer area, but is inversely proportional to the thickness of the layer.

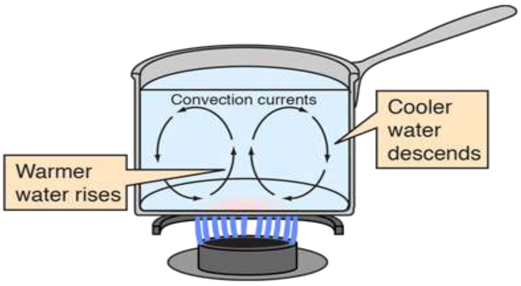
* Temperature Gradient :—
It can be defined as change in temp in a particular direction. Change may be rise or fall.

$$\frac{T_1 - T_2}{\Delta x} = \frac{\Delta T}{\Delta x} = \frac{dT}{dx}$$

CONVECTION: -

Convection is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion.

The faster the fluid motion, the greater the convection heat transfer. In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction. The presence of bulk motion of the fluid enhances the heat transfer between the solid surface and the fluid, but it also complicates the determination of heat transfer rates



Convection can also lead to circulation in a liquid, as in the heating of a pot of water over a flame. Heated water expands and becomes more buoyant. Cooler, more dense water near the surface descends and patterns of circulation can be formed.

Newton's Law of Cooling :-

The rate of convection heat transfer is observed to be proportional to the temperature difference.

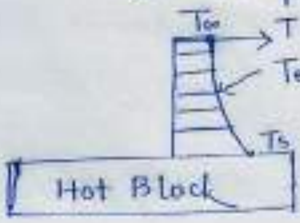
$$\dot{Q}_{conv} = hA_s(T_s - T_\infty)$$

where h - convection heat transfer coefficient $(W/m^2.K)$

A_s = Surface area through which convection heat transfer takes place

T_s = Surface temperature

T_∞ = Temp. of fluid sufficiently far from the surface



Temp variation of air → As distance increases temp decreases

RADIATION: -

Radiation is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules. Unlike conduction and convection, the transfer of energy by radiation does not require the presence of an intervening medium. In fact, energy transfer by radiation is fastest (at the speed of light) and it suffers no attenuation in a vacuum. This is how the energy of the sun reaches the earth.

Here we are interested in thermal radiation, which is the form of radiation emitted by bodies because of their temperature. It differs from other forms of electromagnetic radiation such as x-rays, gamma rays, microwaves, radio waves, and television waves that are not related to temperature.

All bodies at a temperature above absolute zero emit thermal radiation. Radiation is a volumetric phenomenon, and all solids, liquids, and gases emit, absorb, or transmit radiation to varying degrees. However, radiation is usually considered to be a surface phenomenon for solids that are opaque to thermal radiation such as metals, wood, and rocks since the radiation emitted by the interior regions of such material can never reach the surface, and the radiation incident on such bodies is usually absorbed within a few microns from the surface.

Stefan- Boltzmann Law: -

It states that the rate of radiation that can be emitted from a surface is directly proportional to the 4th power of absolute temp. T_s.

$$\dot{Q}_{emit,max} \propto A_s T_s^4 \Rightarrow \dot{Q}_{emit,max} = \sigma A_s T^4$$

In terms of energy it states that the total energy radiated per unit time(second) per unit area of a surface is directly proportional to the 4th power of absolute temp. T_s.

$$E \ \alpha \ T^4 \ => E = \sigma T^4$$

Where σ= Stefan- Boltzmann Constant

Value of σ= 5.67×$10^{-8} \frac{W}{m^2K^4}$

The law applies only to blackbodies, theoretical surfaces that absorb all incident heat radiation.

Black body radiation :-

A black body in thermal equilibrium (i.e. at constant temperature) emits electromagnetic radiation called black-body radiation.

Black body is an idealized physical body that absorbs all incident electromagnetic radiation, regardless of frequency or angle of incidence (It is idealized opaque and non-reflective body). It emits radiation at the maximum rate.

The radiation emitted by all ~~black~~ real surfaces is less than the radiation emitted by a black body at the same temperature. It can be expressed as

$$\dot{Q}_{emit} = \varepsilon \sigma A_s T_s^4$$

where ε = Emissivity of the surface

value of ε is in the range $0 \leq \varepsilon \leq 1$.

For black body $\varepsilon = 1$

The emissivity of the surface of a material is its effectiveness in emitting energy as thermal radiation. It is the ratio of the energy radiated from a material's surface to that radiated from a perfect emitter (i.e black body) at the same temp and wavelength and under same viewing condition.

Absorptivity (α) :-

It is a measure of how much of the radiation is absorbed by the body.

Value ranges in $0 \leq \alpha \leq 1$. $\alpha = \frac{\text{Absorbed radiation}}{\text{Incident radiation}}$

- Black body is a perfect absorber ($\alpha = 1$) as it is a perfect emitter

Transmissivity (τ) :-

It is a measure of how much of the radiation is transmitted by the body.

$$\tau = \frac{\text{Transmitted radiation}}{\text{Incident radiation}}, 0 \leq \tau \leq 1$$

Both ε and α of a surface depends on the temperature and wavelength of the radiation.

Kirchhoff's law of radiation states that the emissivity and absorptivity of a surface at a given temperature and wavelength are equal.

Dt 12.12.19

Q What is a machine

Ans machine is a contrivance does some use full work by availing some energy from other source

OR

A machine is a device and it we give some input to it, it give some out put It can not run by it self.

$$Power = \frac{2\pi NT}{60}$$ (τ)

Dt 13.12.19

SIMPLE MECHANISM

Branch of TOM

- Kinematics (with out considering force)
- Dynamics
  - Statics
  - Kinetics (considering forces)

Scope of subject theory of machine.

A desine of a machine is carried out in in the following six steps:-

① To know the purpose for which the machine is required to be used.

② To study the motion required to make the machine to the purpose started on the one

③ To select the contrivance to produce the required motion under ~~to~~. 2

④ To calculate the forces (static and dynamic acting in the members constituting the contrivance under ~~three~~ 3

⑤ To select suitable material for manufacture of the members under ~~no~~ 4

⑥ To proportion of member of the machine after knowing forces under 4 and materials on manufacturing and under 5

All the above six steps inter related.

The steps 2, 3, and 4 include the theory of machine.

Include 5 and 6 include the desine of machine of elements.

steps muber 2 include kinematics.

Resistance body :-

The body which does not suffer appreciable change in physical form by the force acting on it. ~~They~~ It did not be ~~rigid~~ a rigid and as such its includes elastic body, such as spring, belts, as well as fluids in hydraulic press.

Link or Element

A Link is a resistance body or assembly of resistance body which constitud part or parts of the machine connecting other parts which have motion relative to it.

OR

A link consist of number of parts, connected in such a way that they form one unit and have no motion relative to each other.

Example → piston, piston rod and cross-head.
→ crank pin, crank shaft and
→ cross-head, connecting rod, crank and frame

Classification of links

1. Rigid links Ex connecting rod, crank
2. Flexible links Ex spring, belt
3. fluid links Ex hydraulic press.

Kinematic pair

Two link or elements make a pair, which have relative motion between them.

Types of kinematic pair

① According to motion.

(i) sliding pair
(ii) Turning pair
(iii) Rolling pair
(iv) Screw pair
(v) Spherical pair

Assignment - I

Give the examples of the above five types of pair.

② According to contact surface

(i) Lower pair
(ii) Higher pair

(i) Lower pair

When two element have surface contact while in motion, the pair so form is known as lower pair. In this case the relative motion is purely turning or sliding. Ex shaft revolving in a bearing, straight line motion mechanism stearing gear, universal joint

(ii) Higher pair

When two elements have point or line contact while in motion, the pair so form is known as higher pair. In this case the motion is both sliding and turning. ex belt, chain rop,

(3) According to forces applied.

(i) closed pair

(ii) Un closed pair

(i) closed pair

when two elements of a pair are held together machanically it forms a closed pair. All lower pair are closed pair.

(ii) Un closed pair

when two elements of a pair are not held together by machanically it forms a un closed pair

Kinematic chain

when kinematic pairs are so coupled that the last link is joint to the first link to transmit a define completly constant motion its forms a kinematic chain

$$L = 2P - 4$$

$$L = \frac{2}{3}(J + 2)$$

L = Link
P = pair
J = joints.

Types of motion

① completly constrained motion
② partially constrained motion
③ In completely constrained motion

① completely constrained motion

The motion take place in a definite direction

② Partially constrained motion

when the constrained motion is not completed by it self but by some other means. Ex foot step bearing, rotor in a vertical turbine

③ Incompletely constrained motion.

when the motion take place in more then one direction

Mechanism

when number of pair are so connected that one of it's link and other move relative to each other. It is called a machanism.

There are as many mechanism as number of there are n link

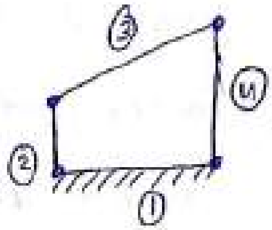
Types of machanism

① simple Ex 4 bar chain

② compound Ex more then 4 bar

Dt 16.12.19

Inversion



If in a kainamatic chain one link is fixed and other move relative to each other that is called a mechanism.

Let us take this mechanism is the original mechanism and if another linked is fixed of the kinematic chain and other move relative to each other, that is called another mechanism and this mechanism is called the inversion of the original mechanism

Types of ~~mechanism~~ kinematic chain

- Four bar chain (4-turning pair)
  - Beam engine (crank and lever)
  - coupled wheel of Locomotive (Double crank)
  - watts Indicator mechanism (Double lever)
- slider crank chain (3 pair turning + 1 sliding pair)
- Double slider cram k (2-turning 2- sliding)

slider crank chain

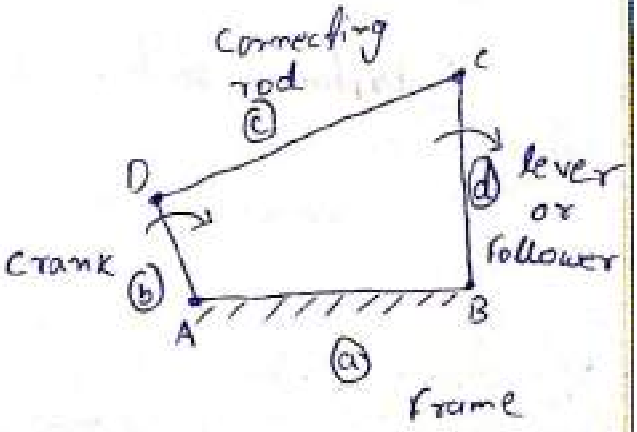
- Pendulum pump
- oscillating engine
- Quick Return motion
  - crank and slotted lever
  - whitworth type
- Gnome Engine

Double slider crank

- oldham coupling
- Donkey pump
- Elliptical trammels.

Four bar chain

Q write short notes on four bar chain mechanism or Quadric cycle chain

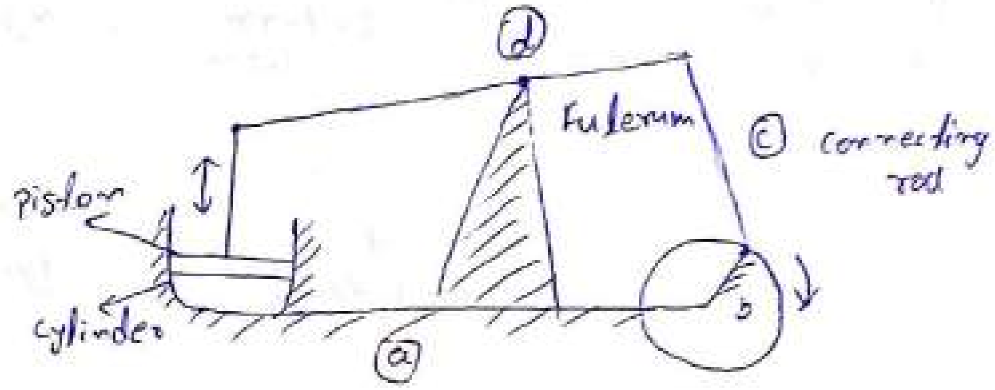


Grashoof's rule

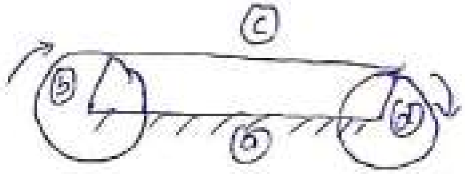
The sum of the length of the small and larger link should not be greater then the sum of the length of the other two linkes.

$$AD + CD \not> AB + BC$$

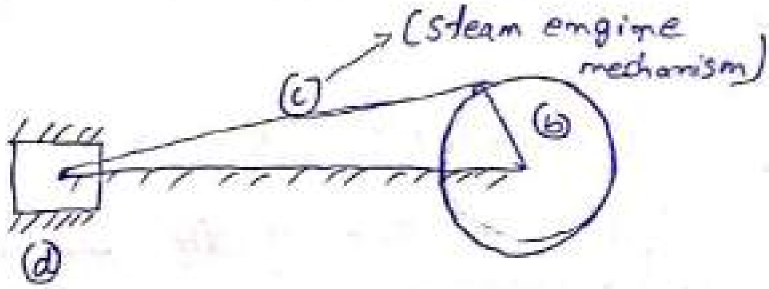
Beam Engine



Coupled wheel of locomotive



Q Explain slider crank chain mechanism



Differance between machine and mechanism

machine	mechanism
→ It is a assamble of number of linkes having relative motion and capable of transforming available energy into certain usefull work	→ It is also assamble of number of linkes and motion through one of them producing definite motion to other but not transmitting any force.
→ It is ~~consist~~ contituted of mechanism meant for transmitting energy to do usefull work	→ A mechanism is not ~~necess~~ necessarly a machine. It is a skeleton of machine which is not meant to transmit energy but to provide definite motion.
→ It is a practical development of any mechanism	→ The working model of mechine

Dt - 17. 12. 19.

Cam and follower

A cam is defind as a rotating or reciprocating element of a mechanism which impacts rotating, reciprocating or oscillating motion to another elements known as follower.

In most of cases cam connected with a frame forming a turning and follower is connected with a frame to formed a sliding pair

The cam and follower form a three link mechanism of higher pair type.

link - 1 Driver, cam has a curved or straight contact surface

link - 2 Driven, follower and gets motion with contact with cam

link - 3 frame which is used to support the cam and gide the follower.

Types of cam

① Radial or Disc type

② cylindrical

(i) Radial or Disc type.
(ii) Reciprocating
(iii) Tangent
(iv) circular

Types of follower

1. Knife edged
2. Roller type
3. Flat faced — offset / coinciding
4. Sferical faced

} According to surface contact

5. Reciprocating
6. Oscillating

} According to motion

7. Radial
8. offset

} According to path of motion of follower.

Assignment - 2

1. Draw the fig of all the types of cam and followers
2. Explain 4 bar chain mechanism
3. Number of degree of freedom for plain mechanism

It is define as the number of input parameters (pair variable) which must be independently control in order to bring the mechanism into a useful engineering perpose

$$n = 3(l-1) - 2j - h$$

where

n = number of degree of freedom

l = number of linkes

j = number of joint

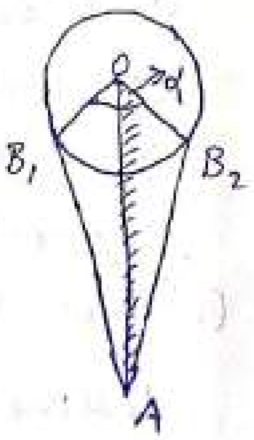
h = number of higher pair

Dt 18.12.19

Inversion of single slider crank chain

Crank and slotted lever mechanism

This type of mechanism is used in shaper machine



$$\frac{\text{Time of cutting stroke}}{\text{Time of return stroke}} = \frac{360 - \alpha}{\alpha}$$

Q A crank and slotted lever mechanism has a center distance of 300 mm between the center of oscillation of the slotted lever and the centre of rotation of crank. The radius of the crank is 120 mm. Find the ratio of the time of cutting to the time of return stroke

Given

AO = 300 mm

OB_1 = 120 mm

$$\sin\left(90 - \frac{\alpha}{2}\right) = \frac{OB_1}{OA}$$

$$\sin\left(90 - \frac{\alpha}{2}\right) = \frac{120}{300}$$

$$\sin\left(90 - \frac{\alpha}{2}\right) = 0.4$$

$$\cos\frac{\alpha}{2} = 0.4$$

$$\frac{\alpha}{2} = \cos^{-1}(0.4)$$

$$\frac{\alpha}{2} = 66.4218$$

$$\alpha = 66.4218 \times 2$$

$$= 132.8436$$

$$\text{The ratio} = \frac{\text{Time of cutting stroke}}{\text{Time of return stroke}}$$

$$= \frac{360 - \alpha}{\alpha}$$

$$= \frac{227.1564}{132.8436}$$

$$= 1.71$$

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Chapter 2

Friction

18.12.19

It is an opposing force which opposes the motion of the body in which a body moves or tends to move.

Different terms **Assignment - 3**

1. Friction (f)
2. Normal reaction (R_N)
3. co-efficient of friction $\left(\frac{f_L}{R_N}\right)$
4. limiting friction (f_L)
5. Angle of friction (ϕ)
6. Angle of repose (α)

Dt 19.12.19

Friction between nut and screw

Ex **Screw jack**

Mean Diameter $D_m = \frac{D_o + D_i}{2}$

$D_m = D_o - \frac{P}{2}$

$D_i = D_o - P$

D_o = outer diameter

D_i = Internal diameter

Terms related to screw thread

① helix angle (θ)

② Pitch

The axial distance between two thread

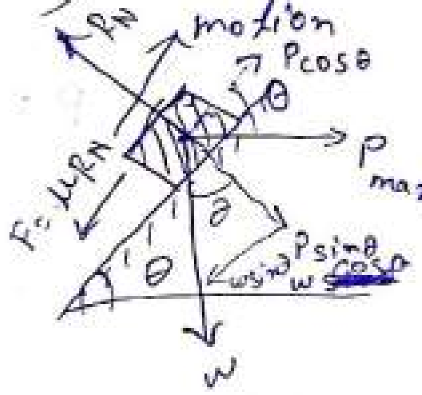
③ Lead

The distance moved by the screw in one rotation.

single start (pitch = Lead)

Double start (2pitch = Lead)

multipul start (n Pitch = Lead)



$\mu R_N = F$, R_N

$P\cos\theta$, $P\sin\theta$

$w\cos\theta$, $w\sin\theta$

$\Sigma H = 0$

$R = \sqrt{(\Sigma H)^2 + (\Sigma V)^2}$

$\Rightarrow \mu R_N + w\sin\theta = P\cos\theta$ —①

$\Sigma V = 0$

$\Rightarrow R_N = P\sin\theta + w\cos\theta$ —②

Putting the value of R_N in eqⁿ ①

$\mu(P\sin\theta + w\cos\theta) + w\sin\theta = P\cos\theta$

$\frac{\sin\phi}{\cos\phi}(P\sin\theta + w\cos\theta) + w\sin\theta = P\cos\theta$

$$\sin\phi(P\sin\theta + w\cos\theta) + w\sin\theta \times \cos\phi = P\cos\theta.\cos\phi$$

$$\Rightarrow P\sin\theta.\sin\phi + w\cos\theta.\sin\phi + w\sin\theta.\cos\phi = P\cos\theta.\cos\phi$$

$$\Rightarrow P(\sin\theta.\sin\phi - \cos\theta.\cos\phi) + w(\cos\theta.\sin\phi + \sin\theta.\cos\phi) = 0$$

$$\Rightarrow -P\cos(\theta+\phi) + w\sin(\theta+\phi) = 0$$

$$\Rightarrow w\sin(\theta+\phi) = P\cos(\theta+\phi)$$

$$\Rightarrow P = \frac{w\sin(\theta+\phi)}{\cos(\theta+\phi)}$$

$$= w\tan(\theta+\phi)$$

force required to raised the load

$$P = w\tan(\theta+\phi)$$

where

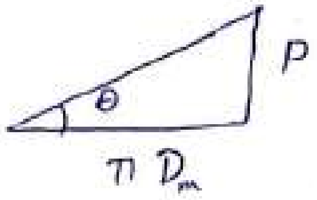
w = load to be lifted

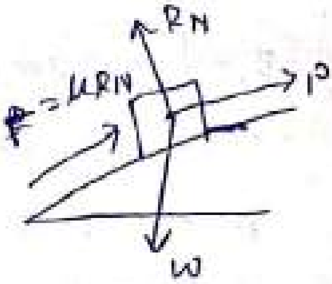
θ = helix angle

$\phi = \tan^{-1}(\mu)$

effort requird to lower the load

$$P = w\tan(\theta-\phi)$$





$$\tan\theta = \frac{P}{\pi D_m}$$

$$P_1 \times L = P \times \frac{d}{2}$$

$$P_1 = \frac{P \times d}{2L}$$

The mean diameter of a square threaded screw jack is 54 mm the pitch of the thread is 12 mm the coefficient of friction is 0.2 what force must be applied at the end of a handle of length 0.8 m long which is ⊥er to the longitudinal axis of the screw to raised a load of 21 kN and to lower it.

Efficiency of a screw jack

$$\eta = \frac{\tan\theta}{\tan(\theta+\phi)} = \frac{\text{Ideal effort}}{\text{actual effort}}$$

Prove

$$\eta_{max} = \frac{1-\sin\phi}{1+\sin\phi} \qquad \frac{d\eta}{d\phi} = 0$$

Dt - 20.12.19

$D = d = 54mm$

$P = 12\ mm$

$\mu = 0.2$

$l = 0.8m = 800mm$

$$P_1 \times l = \frac{P \times D}{2}$$

$$P_1 \times l = w[\tan(\theta \pm \phi)] \times \frac{D}{2}$$

$$\eta_{max} = \frac{1 - \sin\phi}{1 + \sin\phi} \quad (\alpha = \theta)$$

$$\eta = \frac{\tan\alpha}{\tan(\alpha+\phi)}$$

$$= \frac{\frac{\sin\alpha}{\cos\alpha}}{\frac{\sin \alpha+\phi}{\cos \alpha+\phi}}$$

$$= \frac{2\sin\alpha \cdot \cos(\alpha+\phi)}{2\cos\alpha \cdot \sin(\alpha+\phi)}$$

$$= \frac{\sin(\alpha+\phi) + \sin(\alpha-\phi)}{\sin(\alpha+\phi) - \sin(\alpha\pm\phi)}$$

~~[illegible]~~

A load of 10 kN is to be lifted by means of a screw jack of 12 mm pitch and 50 mm outer diameter if a force of 100 N is applied at the end of a lever to raise the load. what should be the length of the lever is used coefficient of friction is 0.15. what is the mechanical advantage. state whether the screw is self locking.

Given

$W = 10 kN = 10 \times 10^3 N$

$P = 12 mm$

$D_0 = 50 mm$

$P_1 = 100 N$

$\mu = 0.15$

$D_m = D_0 - \frac{P}{2}$

$= 50 - \frac{12}{2}$

$= 50 - 6$

$= 44 mm$

$P = w \tan(\alpha + \phi)$

$= w(\tan\alpha + \tan\phi)$

$$\tan \alpha = \frac{p}{\pi D_m}$$

$$= \frac{12}{\pi \times 44}$$

$$= 0.0868$$

$$P = 10^4 \times (0.0868 + 0.15)$$

$$= 2368 \text{ mm}$$

$$P_1 \times l = P \times \frac{D_m}{2}$$

$$l = \frac{P \times D_m}{2 \times P_1}$$

$$= \frac{2368 \times 44}{2 \times 100}$$

$$= 520.96 \text{ mm}$$

$$M.A = \frac{\text{Load Lifted}}{\text{Effort applied}} = \frac{W}{P_1}$$

$$= \frac{10^4}{100}$$

$$= 100 \text{ N/mm}$$

$\phi < \alpha$ = over hauling condition

$\phi > \alpha$ = self locking

condition of self locking

$\eta < 50\%$

$$\eta = \frac{\tan\alpha}{\tan\alpha + \tan\phi}$$

$$= \frac{0.0868}{0.0868 + 0.15}$$

$$= 0.3665$$

$$= 0.3665 \times 100$$

$$= 36.65\%$$

Let w = load lifted

p = effort

x = distance moved by load

y = distance moved by effort

Input	output
$P \times y$	$w.x$

$$\text{Loss} = Py - wx$$

~~reversible~~
~~irreversible~~

self locking | reversible

50

point of reversible or point of self locking

$w.x > Py - wx$ (reversible)

$w.x < Py - wx$ (irreversible)

$2w.x < Py$

$\frac{wx}{Py} < \frac{1}{2} \Rightarrow \eta < \frac{1}{2}$ or $\eta < 50\%$

Example 10.6 , 10.8

Dt 21.12.19

$D_m = 54 mm$

$p = 12 mm$

$\mu = 0.2$

$l = 0.8 m = 8 \times 100 = 800mm$

$W = 21 kN = 21 \times 10^3 N$

$\theta = \tan^{-1}\left(\frac{p}{\pi D_m}\right)$

$= \tan^{-1}\left(\frac{12}{\pi \times 54}\right)$

$= \tan^{-1}(0.0707)$

$= 4.044$

$\phi = \tan^{-1}(\mu)$

$= \tan^{-1}(0.2)$

$= (11.3099)$

$= 11.31$

$P_{raised} = W \tan(\theta + \phi)$

$= 21 \times 10^3 \times \tan(4.044 + 11.31)$

$= 5766.228 N$

$= 5.766 kN$

$P_{lower} = W \tan(\theta - \phi)$

$= 21 \times 10^3 \times \tan(\theta - \phi)$

$= 21 \times 10^3 \times \tan(\phi - \theta)$

$= 21 \times 10^3 \times \tan(11.31 - 4.044)$

$= 2677.49 N$

$= 2.677 kN$

Force required to raise the load at the end of the lever.

$$P_1 \times l = P \times d/2$$

$$P_1 = \frac{P \times d}{2l}$$

$$= \frac{5766.228 \times 54}{2 \times 800}$$

$$= 194.61 \, N$$

Force required to lower the load at the end of the lever

$$P_1 \times l = P \times d/2$$

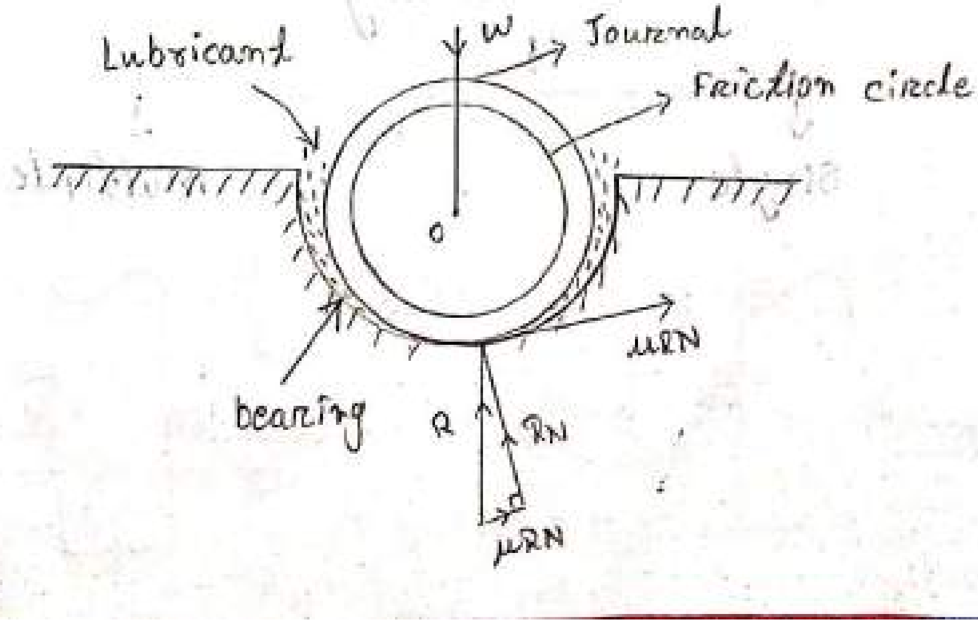
$$P_1 = \frac{P \times d}{2l}$$

$$= \frac{2677.49 \times 54}{2 \times 800}$$

$$= 90.36 \, N$$

Dl

Friction on Bearing



The fixed outer element of turning pair is called bearing.

The rotating element (position of the inner element) which fits in the outer bearing is called journal.

Types of bearing

① Roller bearing

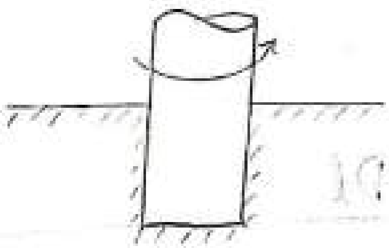
② Needle Roller bearing

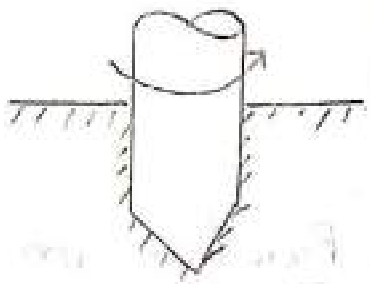
③ Ball bearing

Classification On the basis of shape and size

① Pivot bearing

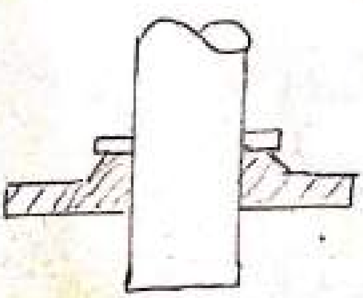
- Flat pivot bearing
- Conical pivot bearing

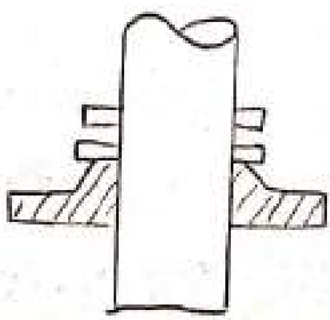




② Flat collar bearing

- Single
- Multiple



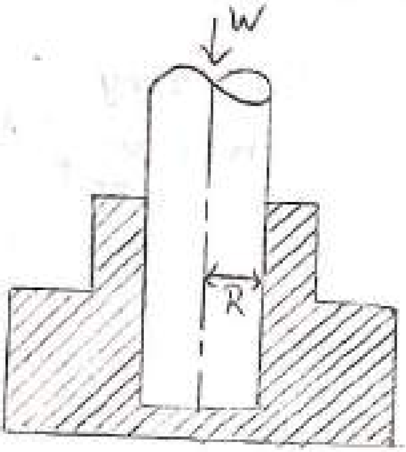


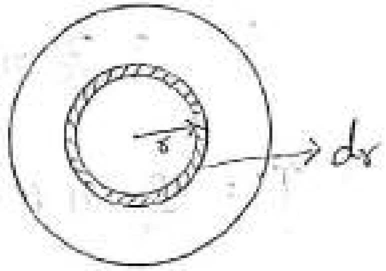
Torque transmitted in flat pivot for bearing

(a) Uniform pressure condition

(b) Uniform wear condition.

For Uniform Pressure





Let W = load transmitted over bearing surface

R = Radius of bearing surface

p = Intensity of pressure for Unit area.

μ = Coefficent of friction.

Consider a small ring of radius 'r' and thickness dr.

Area of ring $= (2\pi r)dr$

Load transmitted to the ring

$$\delta W = p \times \text{Area}$$
$$= p \times 2\pi r \cdot dr$$

Frictional resistance

$$F = \mu \cdot \delta W$$
$$= \mu \cdot p \times 2\pi r \cdot dr$$

Total torque

$$T = \int_0^R 2\pi \mu p r^2 dr$$

$$T = 2\pi \mu p \int_0^R r^2 dr$$

$$= 2\pi \mu p \left[\frac{r^3}{3}\right]_0^R$$

$$= 2\pi \mu p \frac{R^3}{3}$$

$$= \frac{2}{3}\pi \mu p . R^3$$

(Putting $p = \frac{W}{\pi R^2}$)

$$T = \frac{2}{3}\pi \mu \frac{W}{\pi R^2} \cdot R^3$$

$$\boxed{T = \frac{2}{3} \mu W R}$$

For Uniform wear Condition

$$p.r = c$$

$$p = \frac{c}{r}$$

we know

$$\delta W = p \times d_A$$

$$= p \times 2\pi r . dr$$

$$= \frac{c}{r} \cdot 2\pi r \, dr$$

$$= 2\pi c \, dr$$

$$W = \int_0^R \delta W$$

$$= \int_0^R 2\pi c . dr$$

$$= 2\pi c \left[r\right]_0^R$$

$$W = 2\pi C R$$

$$C = \frac{W}{2\pi R}$$

Frictional resistance

$$F = \mu . \delta W$$

$$= 2\pi\mu C . dr$$

Frictional ~~resistance~~ torque

$$T_r = F . r$$

$$= 2\pi\mu C r . dr$$

Total torque

$$T = \int_0^R T_r$$

$$= \int_0^R 2\pi\mu C r . dr$$

$$= 2\pi\mu C \int_0^R r\, dr$$

$$= 2\pi\mu C \left[\frac{r^2}{2}\right]_0^R$$

$$= 2\pi\mu \frac{W}{2\pi R} . \frac{R^2}{2}$$

$$\boxed{T = \frac{1}{2}\mu W R}$$

Assignment

A vertical shaft 200 mm in diameter rotating at 130 RPM rest on a flat end foot step bearing shaft carries a

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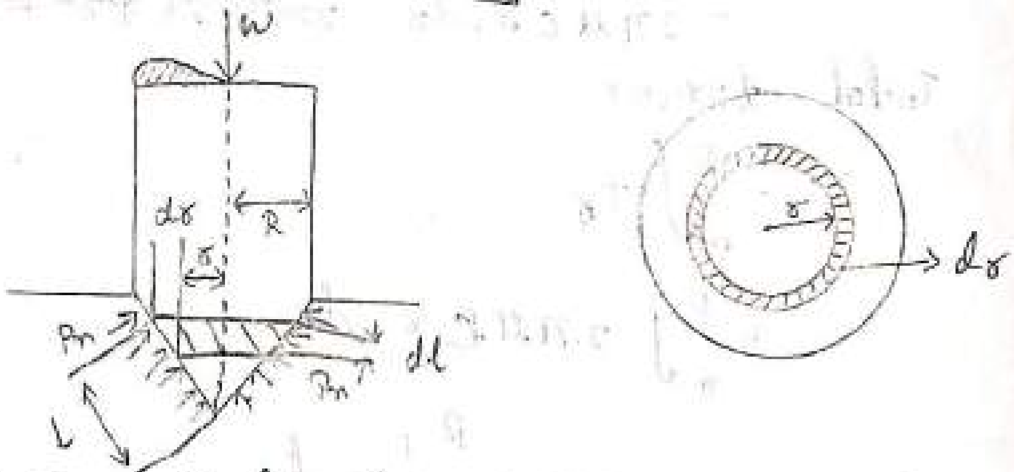
load of 28 kN. Assuming uniform pressure and coefficient of friction 0.04. Estimate power loss in friction.

Dt 13.01.2020

Torque Transmitted on Conical Pivote Bearing

(i) For Uniform Pressure



Let P_n = Intensity of pressure normal to the cone

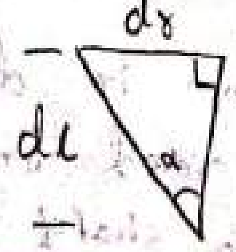
α = semi angle of cone

μ = coeff. of friction

R = Radius

dr = thickness of ring

dl = Small length



$\sin\alpha = \frac{dr}{dl}$

$dl = \frac{dr}{}$

$dl = dr \operatorname{cosec} \alpha$

Area of ring $= 2\pi r \cdot dl$

$= 2\pi r \cdot dr \operatorname{cosec} \alpha$

Normal load acting on the ring

δW_n = Normal Pressure × area

$= P_n \times 2\pi r \cdot dr \operatorname{cosec} \alpha$

Vertical load acting on the ring

δW = Vertical component of δW_n

$= \delta W_n \times \sin \alpha$

$= P_n \times 2\pi r dr \times \sin \alpha \times \frac{1}{\sin \alpha}$

$= P_n 2\pi r dr$

Total vertical load

$$W = \int_0^R \delta W$$

$$= \int_0^R P_n \cdot 2\pi r \cdot dr$$

$$= P_n 2\pi \int_0^R r \, dr$$

$$= P_n 2\pi \left[\frac{r^2}{2}\right]_0^R$$

$$= P_n 2\pi \frac{R^2}{2}$$

$$W = P_n \pi R^2$$

$$P_n = \frac{W}{\pi R^2}$$

Frictional force on ring

$F_r = \mu \, \delta W_n$

$= \mu . P_n \, 2\pi r . dr . \operatorname{cosec} \alpha$

Frictional Torque

$T_r = F_r . r$

$= \mu P_n \, 2\pi r^2 dr . \operatorname{cosec} \alpha$

Total Torque

$T = \int_0^R T_r$

$= \mu P_n 2\pi \left[\frac{r^3}{3}\right]_0^R \operatorname{cosec} \alpha$

$= \mu P_n 2\pi \frac{R^3}{3} \operatorname{cosec} \alpha$

$= \mu \frac{W}{\pi R^2} 2\pi \frac{R^3}{3} \operatorname{cosec} \alpha$

$= \mu W . \frac{2}{3} R \operatorname{cosec} \alpha$

$$T = \frac{2}{3} \mu W R . \operatorname{cosec} \alpha$$

(ii) Uniform wear condition

$P_r . r = C$

$P_r = \frac{C}{r}$

$$\delta w = P_r \cdot 2\pi r \cdot dr$$

$$= \frac{c}{r} \cdot 2\pi r \cdot dr$$

$$= 2\pi c \cdot dr$$

$$w = \int_0^R \delta w$$

$$= \int_0^R 2\pi c \cdot dr$$

$$= 2\pi c \left[r \right]_0^R$$

$$= 2\pi c R$$

$$c = \frac{w}{2\pi R}$$

$$T_r = 2\pi \mu P_r \cdot r^2 \cdot \operatorname{cosec} \alpha \cdot dr$$

$$T = \int_0^R T_r$$

$$= \int_0^R 2\pi \mu P_r \cdot r^2 \cdot \operatorname{cosec} \alpha \cdot dr$$

$$= \int_0^R 2\pi \mu \frac{c}{r} \cdot r^2 \cdot \operatorname{cosec} \alpha \cdot dr$$

$$= 2\pi \mu c \operatorname{cosec} \alpha \left[\frac{r^2}{2} \right]_0^R$$

$$= 2\pi \mu c \operatorname{cosec} \alpha \frac{R^2}{2}$$

$$= \pi R^2 \mu c \operatorname{cosec} \alpha$$

$$= \pi R^2 \mu \frac{w}{2\pi R} \operatorname{cosec} \alpha$$

$$T = \frac{1}{2} W \mu R \operatorname{cosec} \alpha$$

Formula derived

$T = \frac{2}{3} \mu W R \operatorname{cosec} \alpha$ (uniform Pressure)

$T = \frac{1}{2} \mu W R \operatorname{cosec} \alpha$ (unifor wear)

Q A conical Pivot bearing support a vertical shaft of 200 mm diameter it is subjected to a load of 35 kN. The angle of conic 120°. And the $\mu = 0.025$. find the power lost in friction when the speed is 150 rpm

Given

$D = 200$ mm $R = 100$ mm $= 0.1$ m

$W = 35$ kN $= 35 \times 10^3$ N

$2\alpha = 120^\circ \Rightarrow \alpha = \frac{120^\circ}{2} = 60^\circ$

$\mu = 0.025$

$N = 150$

(1) Uniform Pressure

$T = \frac{2}{3} \mu W R \operatorname{cosec} \alpha$

$= \frac{2}{3} \times 0.025 \times 35 \times 10^3 \times 0.1 \times \operatorname{cosec} 60^\circ$

$= \frac{2}{3} \times 0.025 \times 35 \times 10^3 \times 0.1 \times \frac{1}{\sin 60^\circ}$

$= 67.357$ Nm

$P = T . \omega$

$= 67.357 \times 35 \times 10^3$

$= 2357495$ J

$= 2357.495$ Kg

Assignment

Derive the formula for torque transmitted for flat pivot bearing under both condition

$$\int_0^R = \int_{r_2}^{r_1}$$

$$T = \frac{2}{3} \mu w \left(\frac{r_1^3 - r_2^3}{r_1^2 - r_2^2} \right)$$ uniform pressure

$$T = \frac{1}{2} \mu w (r_1 + r_2)$$ uniform wear.

Dt 20.01.2020

Clutch

Clutch

- Jaw clutch
  - Non expanding
  - Expanding
- Frictional clutch
  - Plate (disc)
    - single plate
    - multiple plate
  - Conical
- Hydraulic operated clutch

Clutch is a device to connect driving and driven shaft where driven shaft can be disconnect almost instantaneously from the driving shaft is disired by the operate or driver

<u>Working Principle of single clutch</u>

It consist of a clutch plate whose both sides are face with friction material. It is mounted on the hub which is free to move ~~axially~~ axialy along the splines of the driving shaft. The pressure plate is mounted inside the clutch body which is bolted to fly wheel. Both the pressure plate and fly wheel rotate with the engine crank shaft or driving shaft. The pressure plate pushes the clutch plate towards the fly wheel by means of a set of springs which are arranged radially inside the body.

When the clutch padal is pressed down it's linkcage forces the thrust bearing to move inward fly wheel and pressing the

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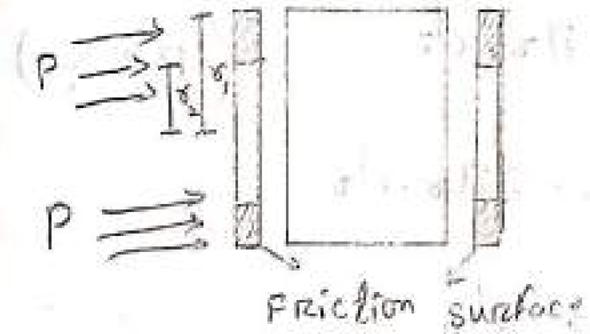
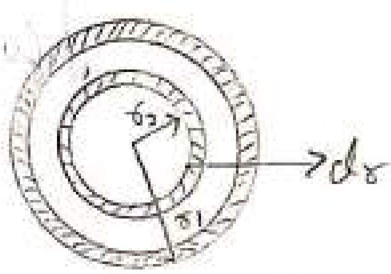
longer ends of the lever inwards. On the other hand when the foot in take up from the clutch padal the thrust bearing moves back by the lever. These allow the springs to extand and thus pressure plate push the clutch plate back towards the flywheel. The axial pressure exarted by the spring provide a frictional force and a torque is produced.

Torque transmitted by single clutch plate





Uniform Pressure Condition

We know $T_r = 2\pi\mu p r^2 dr$

Total torque

$$T = \int_{r_2}^{r_1} T_r$$

$$= \int_{r_2}^{r_1} 2\pi\mu p r^2 dr$$

$$= 2\pi\mu p \int_{r_2}^{r_1} r^2 dr$$

$$T_r = 2\pi \mu p \left[\frac{r^3}{3}\right]_{r_2}^{r_1}$$

$$= 2\pi \mu p \frac{(r_1^3 - r_2^3)}{3}$$

$$= \frac{2}{3} \cdot \pi \mu \frac{w}{\pi (r_1^2 - r_2^2)} (r_1^3 - r_2^3) \qquad \left(p = \frac{w}{\pi (r_1^2 - r_2^2)}\right)$$

$$= \frac{2}{3} \mu w \left(\frac{r_1^3 - r_2^3}{r_1^2 - r_2^2}\right)$$

Uniform wear condition

$$\int w = p \cdot 2\pi r \cdot dr \qquad \left(p = \frac{c}{r}\right)$$

$$= \frac{c}{r} \cdot 2\pi r \cdot dr$$

$$= 2\pi c \, dr$$

Total work done

$$w = \int_{r_2}^{r} 2\pi c \, dr$$

$$= 2\pi c \left[r\right]_{r_2}^{r_1}$$

$$= 2\pi c (r_1 - r_2)$$

$$c = \frac{w}{2\pi (r_1 - r_2)}$$

we know $T_r = 2\pi \mu c \cdot r \, dr$

Total torque

$$T = \int_{r_2}^{r_1} 2\pi \mu C r \, dr$$

$$= 2\pi \mu C \left[\frac{r^2}{2}\right]_{r_2}^{r_1}$$

$$= 2\pi \mu C \left(\frac{r_1^2 - r_2^2}{2}\right)$$

$$= \frac{2\pi \mu \omega}{2\pi (r_1 - r_2)} \times \left(\frac{r_1^2 - r_2^2}{2}\right)$$

$$= \frac{1}{2} \mu \omega \left(\frac{r_1^2 - r_2^2}{r_1 - r_2}\right)$$

$$= \frac{1}{2} \mu \omega \frac{(r_1 + r_2)(r_1 - r_2)}{(r_1 - r_2)}$$

$$= \frac{1}{2} \mu \omega (r_1 + r_2)$$

IMP

In case of problem on single plate clutch torque transmitted

$$T = n \cdot \frac{\mu \omega (r_1 + r_2)}{2} \quad \text{or} \quad \text{(uniform wear)}$$

$$T = \frac{2n}{3} \mu \omega \frac{(r_1^3 - r_2^3)}{(r_1^2 - r_2^2)} \quad \text{(uniform pressure)}$$

If both sides of the plate is effective and $n = 2$

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For multiple disc plate clutch

$n = n_1 + n_2 - 1$

where n_1 = numbers of disc plate on driving shaft

n_2 = number of disc plate into driven shaft

Assignment

Q1 A single plate disc clutch with both sides effective has outer and inner diameter are 300mm and 200mm respectively. The maximum intensity of pressure at any contact surface is not to exceed 0.1 N/mm². If $\mu = 0.3$ determine the power transmitted by the clutch at a speed of 2500 RPM

Q2 A multiple disc plate clutch has 3 disc on driving shaft and 2 on the driving shaft the out side diameter of the concaved surface is 250 mm. and inside diameter is 120 mm. assuming uniform wear and $\mu = 0.3$. Find the maximum intensity of pressure between the disc for transmitting 5 kW at 1575 RPM

Frictional break

A break is a appliance by mean of which artifical frictional resistance is applied to a moving body to to it's motion or stop it's motion. The break absorbe either kinatic energy of the moving member or potential energy given up by objects. The energy absorbe by the breaks is dissipated in the form of heat. The capacity of the break is depend upon the following facters.

1. Unit pressure between breaking surface
2. high coefficent of friction between breaking surface
3. deri velocity of the break drum
4. Projected area of the friction surface.

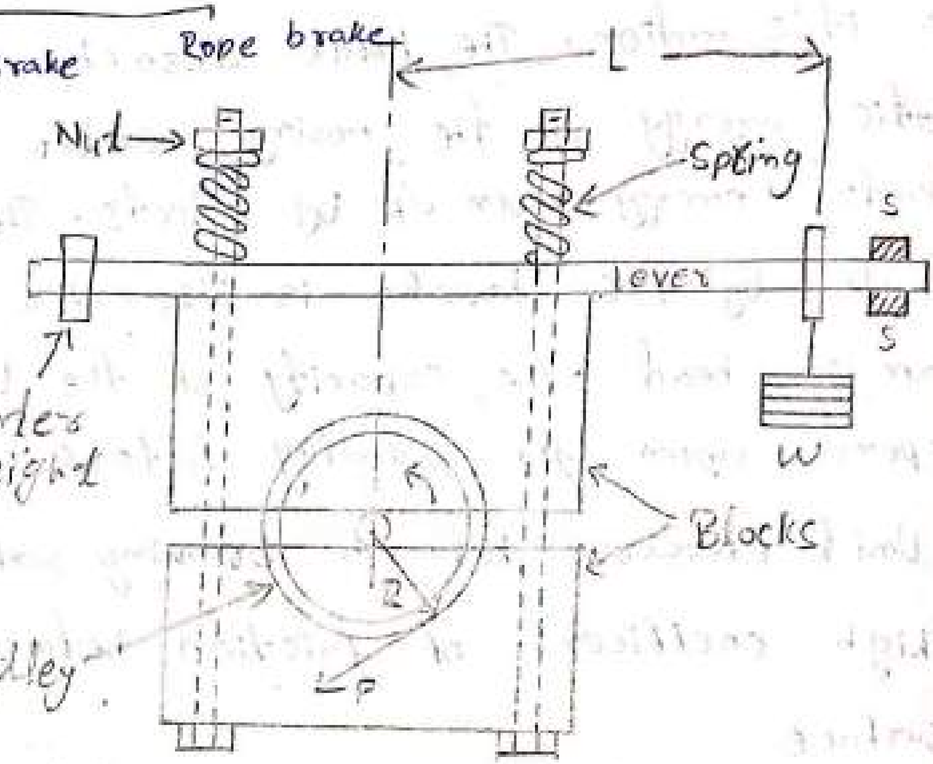
Material for breaking surface

1. high coeffient of friction
2. high wear rate
3. high heat decipation capacity
4. Adiquate mechanical strength
5. Should not be effected by oil, acid and mositure.

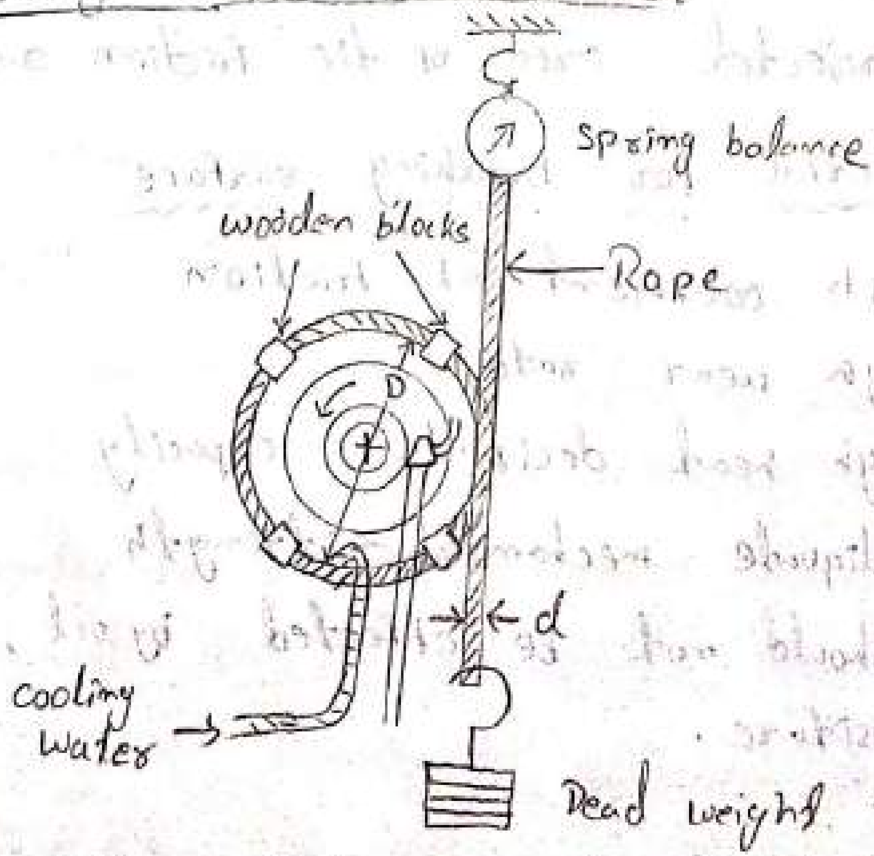
Dt 21.01.2020

Dynamometer

- absorption dynamometer
  - Prony Brake
  - Rope brake
- transmission dynamometers



Prony brake dynamometer



Rope brake dynamometer

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Prony brake dynamometer

w = weight at the outer end of the lever in newtons

L = Length between w and center of the pulley

$T = w.L = F.R$ N-m

Break power

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

Rope brake dynamometer

$B.P = \frac{(w-S)\pi D N}{60}$ watt

or

$B.P = \frac{(w-S)\pi (D+d) N}{60}$ watt

Dt 22.01.2020

Q In an experiment the following observations are obtained.

Dead weight = 600 N

spring load = 180 N

r.p.m = 200

Dia. of pulley = 1.2 m

dia. of rope = 12.5 mm

Find the breake power obtained

$B.P = \frac{(w-S)\pi (D+d) N}{60}$

$= \frac{(600-180)\pi (1.2 + 0.0125) 200}{60} = 5332.85$ W

Chapter - 3

Power transmission

Flat Belt Drive power transmission

① Belt drive — Flat belt drive / V-belt drive
② chain drive
③ Rope drive
④ Gear drive

Types of belt drive as per speed of belt

$V \leq 10 m/s$ ① Low velocity drive

$V > 10 m/s$, $< 22 m/s$ ② medium velocity drive

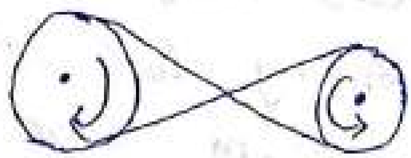
$V > 22 m/s$ ③ High velocity drive

Types of flat belt drive according to connection of belt

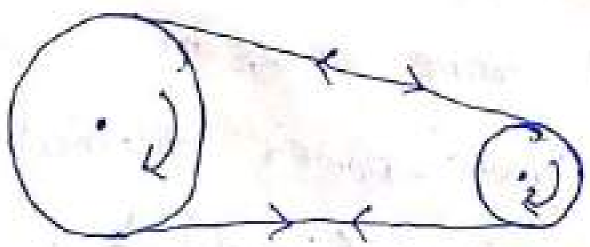
① open belt drive

② Crossed belt drive

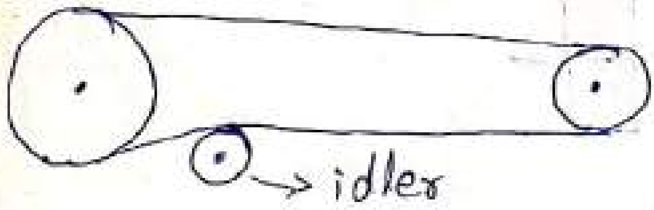
③ Quarter turn belt drive



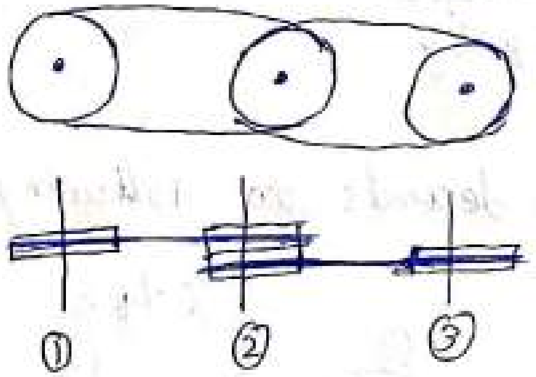
Cross belt drive



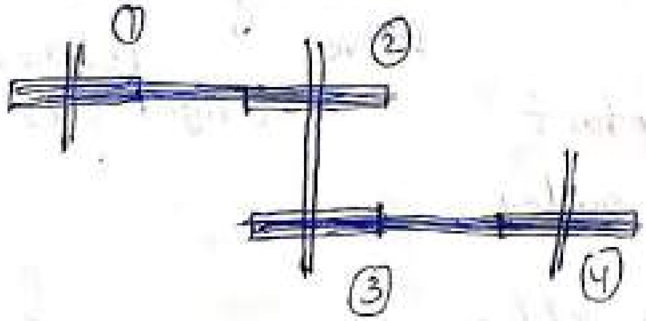
④ Belt drive with idler pulley



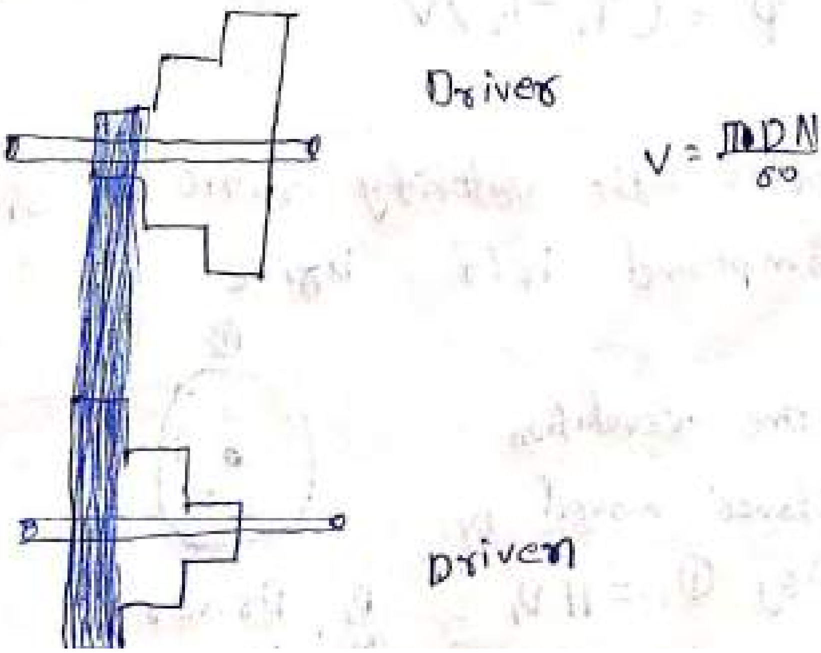
⑤ simple belt drive



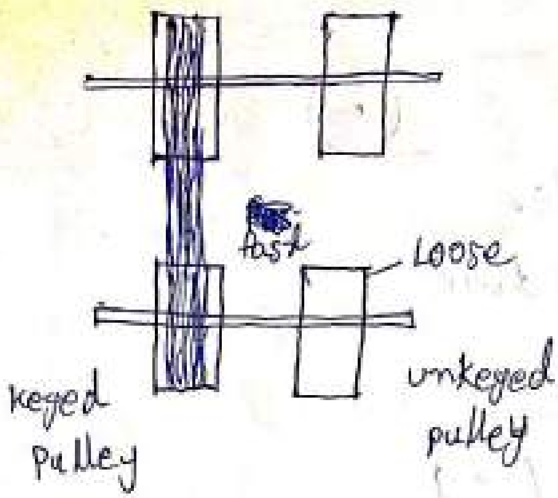
⑥ Compound belt drive



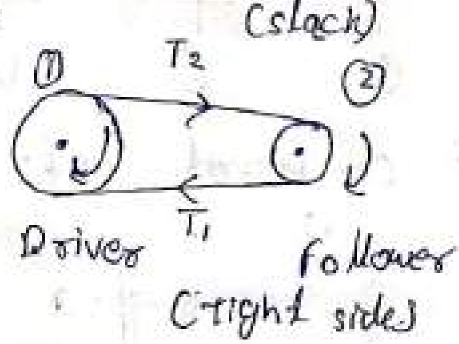
⑦ Stepped or cone pulley drive



⑧ Fast and loose pulley drive



Power transmission depends on following factor



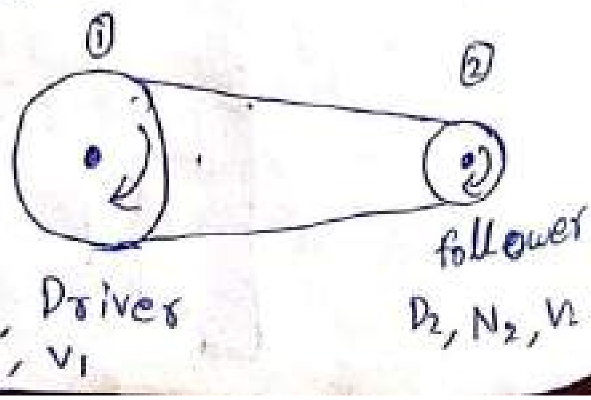
① velocity of belt (v).

② Arc of contact of smaller pulley.

③ Tension in belt.

$$P = (T_1 - T_2)v$$

Derive the velocity ratio of simple and compound belt Drive



In one revolution distance moved by pulley ① $= \pi D_1$

In N_1 revolution distance = $\pi D_1 N_1$ m/min

$$V_1 = \frac{\pi D_1 N_1}{60} \text{ m/s}$$

$$V_2 = \frac{\pi D_2 N_2}{60} \text{ m/s}$$

$v_1 = v_2$

$$\frac{\pi D_1 N_1}{60} = \frac{\pi D_2 N_2}{60}$$

$$\frac{N_2}{N_1} = \frac{D_1}{D_2}$$

If thickness of belt is considere (t)

$$\frac{N_2}{N_1} = \frac{D_1 + t}{D_2 + t}$$

If there is slip

$$\frac{N_2}{N_1} = \frac{D_1}{D_2}\left(1 - \frac{S}{100}\right)$$

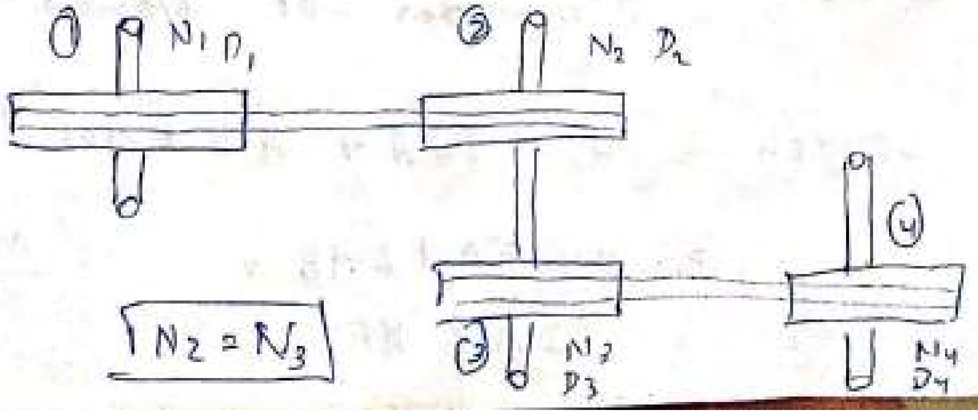
$S = S_1 + S_2$

S_1 = slip % is Driver

S_2 = slip % in follower

Dt 27-1-2020

Velocity radio of compound belt drive



$N_2 = N_3$

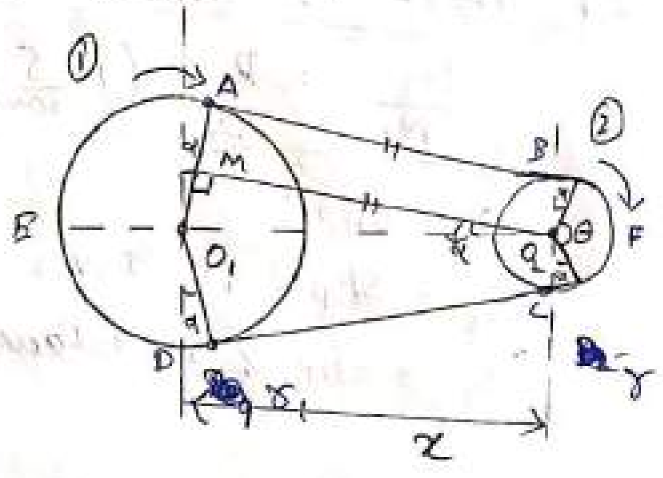
$$\frac{N_2}{N_1} = \frac{D_1}{D_2}, \quad \frac{N_4}{N_3} = \frac{D_3}{D_4}$$

$$\frac{N_2}{N_1} \times \frac{N_4}{N_3} = \frac{D_1 D_3}{D_2 D_4}$$

$$\frac{N_4}{N_1} = \frac{D_1 D_3}{D_2 D_4}$$

$$\frac{\text{r.p.m of last follower}}{\text{r.pm of 1st driver}} = \frac{\text{product of diameter of drivers}}{\text{Product of diameter of followers.}}$$

Derive the formula for length of belt for open belt drive LS.



Let D_1 = Diameter of Driver

D_2 = Diameter of follower

Length = Arc DEA + AB + Arc BFC + CD

= 2 Arc EA + 2 AB + 2 Arc BF

$$\frac{\text{Arc}}{\text{radius}} = \text{angle}$$

$= 2\,(\text{arc } BA + AB + \text{arc } BP)$

$$= 2\left[\left(\frac{\pi}{2}+\alpha\right)r_1 + \sqrt{x^2-(r_1-r_2)^2} + \left(\frac{\pi}{2}-\alpha\right)r_2\right]$$

construct a line mO_2 parallel to the line AB. Angle between $\angle O_1 O_2 m = \alpha$

$O_1 O_2 = x$

$O_1 m = r_1 - r_2$

$O_2 m = AB = \sqrt{x^2-(r_1-r_2)^2}$

$$\text{Length } (L) = 2\left[r_1\cdot\frac{\pi}{2} + r_1\alpha + x\sqrt{1-\left(\frac{r_1-r_2}{x}\right)^2} + r_2\cdot\frac{\pi}{2} - r_2\cdot\alpha\right]$$

we know $\sin\alpha = \dfrac{r_1-r_2}{x}$ or

$\alpha = \dfrac{r_1-r_2}{x}$ if α is small

$$L = 2\left[r_1\cdot\frac{\pi}{2} + r_1\frac{(r_1-r_2)}{x} + x\sqrt{1-\left(\frac{r_1-r_2}{x}\right)^2} + r_2\cdot\frac{\pi}{2} - r_2\frac{(r_1-r_2)}{x}\right]$$

$$L = 2\left[r_1\cdot\frac{\pi}{2} + r_1\frac{(r_1-r_2)}{x} + x\left(1-\frac{1}{2}\cdot\left(\frac{r_1-r_2}{x}\right)^2\right) + r_2\cdot\frac{\pi}{2} - r_2\frac{(r_1-r_2)}{x}\right]$$

$$L = 2\left[\frac{\pi}{2}(r_1 + r_2) + \frac{(r_1 - r_2)}{x}(r_1 - r_2) + x - \frac{(r_1 - r_2)^2}{2x^2}\right]$$

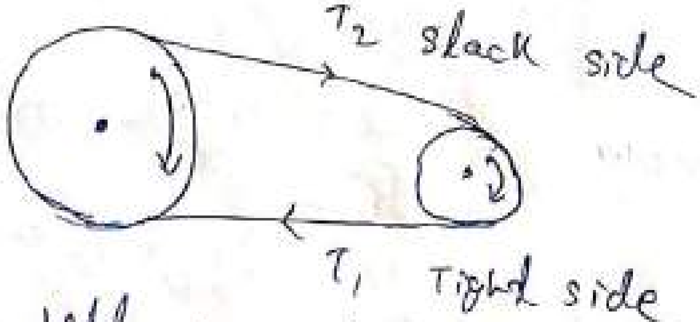
$$= \pi(r_1 + r_2) + \frac{2}{x}(r_1 - r_2)^2 + 2x - \frac{(r_1 - r_2)^2}{2x}$$

$$\boxed{L = \pi(r_1 + r_2) + \frac{(r_1 - r_2)^2}{x} + 2x}$$

Assignment

Derive the formula for length of belt for cross belt drive.

Creep of Belt



As the belt is continuous by moving from slack side to Tight side the belt is expand and when the belt is come to Tight side to slack side then it contrastion

If creep occurs

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \times \frac{E + \sqrt{\sigma_2}}{E + \sqrt{\sigma_1}}$$

E = young'es modulus

σ_1 = stress of belt in tight side

σ_2 = stress of belt in slack side

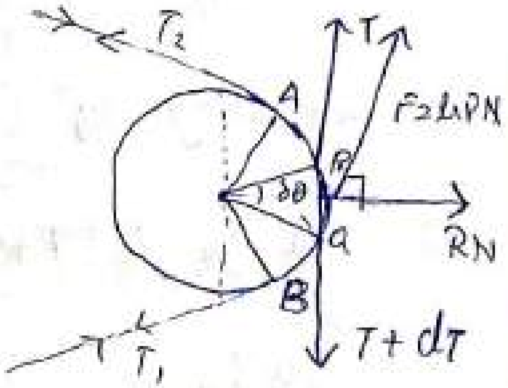
Q Derive the ratio of driving tension for flat belt drive or prove that

$$\frac{T_1}{T_2} = e^{\mu\theta}$$

θ = Angle of contact

μ = coefficient of friction between belt and the pulley

$$\log_e \frac{T_1}{T_2} = \mu\theta$$



Considering equillibrium resolving the forces

$\Sigma H = 0$

$$\Rightarrow T \sin\frac{\delta\theta}{2} + (T + dT)\sin\frac{\delta\theta}{2} = R_N \quad \text{--- (i)}$$

$\Sigma V = 0$

$$\Rightarrow T\cos\frac{\delta\theta}{2} + \mu R_N = (T + \delta T)\cos\frac{\delta\theta}{2} \quad \text{--- (2)}$$

Putting $\sin\frac{\delta\theta}{2} = \frac{\delta\theta}{2}$

$\cos\frac{\delta\theta}{2} = 1$

solving eq^n (1) and (2)

we get $\log_e \frac{T_1}{T_2} = \mu\theta$

$$\Rightarrow \frac{T_1}{T_2} = e^{\mu\theta}$$

Simplifing eq^n (1)

$$R_N = (T + dT)\frac{\delta\theta}{2} + T \times \frac{\delta\theta}{2} \quad \left\{ \sin\frac{\delta\theta}{2} = \frac{\delta\theta}{2} \right\}$$

$$= \frac{T\delta\theta}{2} + \frac{dT\,\delta\theta}{2} + \frac{T\delta\theta}{2}$$

$$= \frac{2T\delta\theta}{2} \quad \left[\frac{dT\,\delta\theta}{2} \text{ is very small} \right]$$

$$R_N = T.\delta\theta \quad \sim (3)$$

Simplifing eq^n (2)

$$\mu R_N = (T + dT)\cos\frac{\delta\theta}{2} - T\cos\frac{\delta\theta}{2}$$

$$\mu R_N = T + dT - T \quad \left[\cos\frac{\delta\theta}{2} = 1 \right]$$

$$\mu R_N = dT$$

$$R_N = \frac{dT}{\mu} \quad \text{—— (4)}$$

putting the value of R_N in eq^n (4)

$$T\,\delta\theta = \frac{dT}{\mu}$$

$$\frac{dT}{T} = \delta\theta \times \mu$$

Integrating both sides by T_2 and T_1 and from 0 to θ

$$\int_{T_2}^{T_1} \frac{dT}{T} = \mu \int_0^{\theta} \delta\theta$$

$$\log_e\left[\frac{T_1}{T_2}\right] = \mu\theta$$

$$\boxed{\frac{T_1}{T_2} = e^{\mu\theta}}$$

Dt 28.01.2020

Power transmitted by flat belt drive

$$\boxed{P = (T_1 - T_2)\,V}$$

Condition for maximum power

Q what is the condition for maximum power transmitted by a flat belt drive

$$\boxed{T = 3T_C} \qquad \boxed{T = T_1 + T_C}$$

T = maximum tension

T_C = centrifugal tension

$$\boxed{T = mv^2}$$

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$P = (T_1 - T_2) v$

$= \left(T_1 - \frac{T_1}{e^{\mu\theta}}\right) v$

$= T_1 \left(1 - \frac{1}{e^{\mu\theta}}\right) v$

$= T_1 . V . C$

$= (T - T_c) v . C$

$= T.v.C - mv^2 . v . C$

$= T.V.C - mv^3 . c$

For maximum power

$\frac{dp}{dv} = 0$

$\frac{dp}{dv} = T.C - m3v^2 C$

$0 = T - m3v^2$

$T = m3v^2$

$$\boxed{T = 3T_C}$$

$$\boxed{V = \sqrt{\frac{T}{3m}}}$$

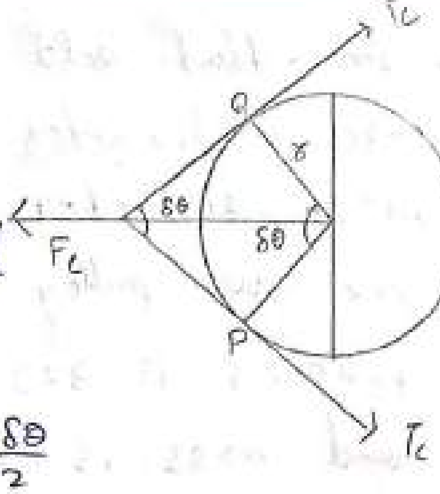
$$\boxed{P_{max} = (T_1 - T_2) \sqrt{\frac{T}{3m}}}$$

Prove that $T_C = mv^2$

Let m = mass of belt per unit length.

Then length of PQ

$= m r . \delta\theta$



Resolving the force horizontal and vertical force

$$F_c = T_c \cos\frac{\delta\theta}{2} + T_c \cos\frac{\delta\theta}{2}$$

$$F_c = 2 T_c \cos\frac{\delta\theta}{2}$$

$$\frac{mv^2}{r} = 2 T_c$$

$$T_c = \frac{mv^2}{2r}$$

$$= \frac{mr . d\theta}{2r}$$

Initial tension

$$T_0 = \frac{T_1 + T_2 + 2T_c}{2}$$

$$= \frac{T_1 + T_2}{2}$$

* If $V > 10\ m/s$ T_c is considered

1Q] In a belt drive the belt is 1kg/m length and velocity is 12 m/sec and it transmit power of 9.6 kw if coefficient of friction is 0.3 and angle of contact is 205° determine initial tension and strength of the belt.

2Q. In a flat belt drive the driver pulley have a diameter of 1.52 m and driven pulley has a diameter of 0.8 m and distance between the two pulley is 4 m. RPM of the follower is 320. Initial tension is 2.8 kN and mass is 1.8 kg/m if coefficent of friction is 0.25 find the power.

3Q. Two parallel shafts 8 m apparts are provided with 300 mm and 400 mm diameter pulley and are connected by means of cross belt. The direction of rotation of the follower is to be reveresed by changing over to an open belt drive. How much length of the belt has to be reduced.

Dt 29.01.2020

① $L_o = \pi(r_1+r_2) + \frac{(r_1-r_2)^2}{x} + 2x$

② $L_c = \pi(r_1+r_2) + \frac{(r_1+r_2)^2}{x} + 2x$

③ $P = (T_1 - T_2)v$

④ $\frac{T_1}{T_2} = e^{\mu\theta}$

⑤ $\sin\alpha = \frac{r_1-r_2}{x}$ or $\frac{r_1+r_2}{x}$

⑥ $\theta = (180^\circ - 2\alpha)\frac{\pi}{180}$ or $(180^\circ + 2\alpha)\frac{\pi}{180}$

⑦ $T = 3T_c$ - (for max^m power)

⑧ $V = \sqrt{\frac{T}{3m}}$ (For max^m power)

⑨ $T_c = mV^2$

⑩ T = max^m tension $= T_1 + T_c$

⑪ T = max^m tension $= \sigma \cdot b \cdot t$

where σ = stress of belt

b = width of belt

t = thickness of belt

⑫ $m = \rho \cdot l \cdot b \cdot t$

l = length of belt

ρ = density of belt

⑬ $T_0 = \frac{T_1 + T_2 + 2T_c}{2}$ or $\frac{T_1 + T_2}{2}$

⑭ $\frac{N_2}{N_1} = \frac{d_1}{d_2}$

⑮ $\frac{N_2}{N_1} = \left(\frac{E + \sqrt{\sigma_2}}{E + \sqrt{\sigma_1}}\right)$

⑯ $\frac{N_2}{N_1} = \frac{d_1}{d_2}\left(1 - \frac{S}{100}\right)$

⑰ $\frac{N_2}{N_1} = \frac{d_1 + t}{d_2 + t}$

Q4 A lather belt 125 mm width and 6mm thick and transmit power from pulley of 750 mm diameter running at 450 rpm if angle of contact is 140° and $\mu = 0.3$ and mass of $1 m^3$ of lather belt is 1Mg and stress of the belt 2.75 mpa, find maximum power

⑤ Find the power required for a belt drive running at velocity of 600m/min where coefficient of friction is 0.3 angle of contact 160° and maximum tension 700 N

⑥ Find the width of the belt necessary for a flat belt drive transmitting power of 7.5 KW from a pulley of diameter 300mm at a rpm of 600, coefficient of friction 0.22, angle of contact 200° and maximum tension is 8 N/m width of the belt. Assum $t = 10$ mm.

⑦ write the advantage and disadvantage of v belt drive over flat belt drive.

Gear / Gear train

Dt 3.02.2020

Addendum circle
Dedendum circle
pitch circle

Addendum → The distance or hight from the pitch circle to addendum circle

Dedendum → The distance or hight from the pitch circle to dedendum circle

module (m) :- $\left(\frac{D}{T}\right)$

It is the ratio between pitch circle diameter to the number of teeth

Diametral pitch $P_d = \frac{T}{D} = \frac{1}{m}$

reciprocal of module (m)

clearance

~~teeth~~ The distance between the bottom of one teeth to the top of the other teeth is called clearance.

Differance types of gear

→ (A) according to position of the shaft or the gear

1. parallel shaft gears.
   Ex spur gear
2. Non parallel intersecting
   Ex Bevel gear
3. Non parallel non intersecting (Non coplaner)
   Ex spiral gear

(b) according to speed of the gear

1. Low velocity gear $v > 3.5$ ~~per sec~~ m/s
2. medium velocity gear $3.5 \gg 10$ ~~per sec~~ m/s
3. high velocity gear < 10 ~~per sec~~ m/s

(c) According to arrangement

1. External
2. Internal

(d) According to position of the teeth of the gear

1. straight tooth gear
2. Inclined tooth gear
3. Rack and pinion

10.02.2020

In a flat belt drive the driver pulley have a diameter of 1.5 m and driven pully is 4m rpm of the following is 320. ~~Internal~~ Initial tension is 2.8 KN and mass is 1.8 kg/m coefficent of friction is 0.25 find the power

$d_1 = 1.5m$

$d_2 = 0.8 m$

$x = 4m$

$N_1 = 320$ rpm

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$T_0 = 2.8$ kN

$m = 1.8$ kg/m

$\mu = 0.25$

Formular used

$P = (T_1 - T_2) v$

$v = \frac{\pi D_2 N}{60}$

$\frac{T_1}{T_2} = e^{\mu \theta}$

$T_0 = \frac{T_1 + T_2 + 2T_c}{2}$

$T_c = m v^2$

$\theta = (180 - 2\alpha) \frac{\pi}{180}$

$\sin \alpha = \frac{r_1 - r_2}{x}$

$V = \frac{\pi D_2 N}{60}$

$= \frac{\pi \times 0.8 \times 320}{60}$

$= 13.4041$ m/s

$\sin \alpha = \frac{0.75 - 0.4}{4}$

$= 0.0875$

$\alpha = \sin^{-1} 0.0875$

$= 5.0198$

$\theta = (180 - 2 \times 5.0198) \frac{\pi}{180}$

$= 2.9663$

$T_c = mv^2$

$= 1.8 \times (13.4041)^2$

$= 323.4058 \ N$

$\frac{T_1}{T_2} = e^{0.25 \times 2.9663}$

$\frac{T_1}{T_2} = 2.099$

$T_1 = 2.099 T_2$

$T_0 = \frac{T_1 + T_2 + 2T_c}{2}$

$2.8 \times 10^3 = \frac{2.099T_2 + T_2 + 2 \times 323.4058}{2}$

$5.6 \times 10^3 = 3.099T_2 + 646.8116$

$3.099 T_2 = 5.6 \times 10^3 - 646.8116$

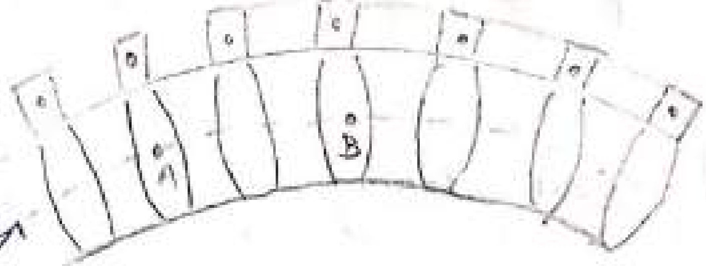
$T_2 = \frac{4953.1884}{3.099}$

$= 1598.31 \ N$

$T_1 = 2.099 \times 1598.31$

$= 3354.85 \ N$

circular pitch (P_c) $= \frac{\pi D}{T}$



pitch circle

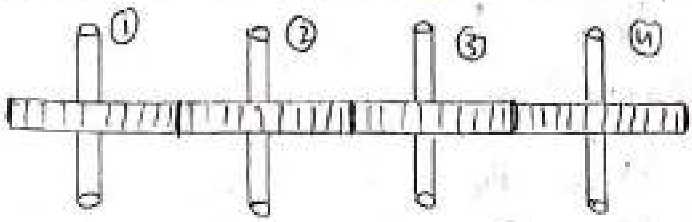
It is the distance measured along pitch circle circumference from a point of 1 tooth to the corresponding point of next adjacent tooth

Gear train

Types of Gear train

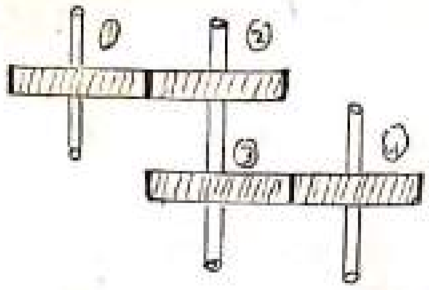
1. Simple Gear train
2. Compound Gear train
3. Reversed Gear train
4. Epicyclic Gear train

Simple Gear train

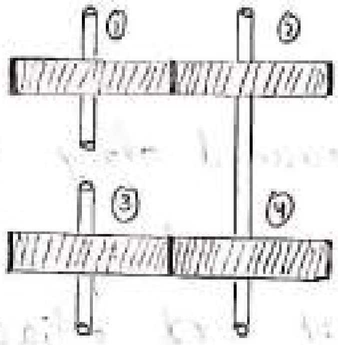


One shaft one gear

Compound Gear train

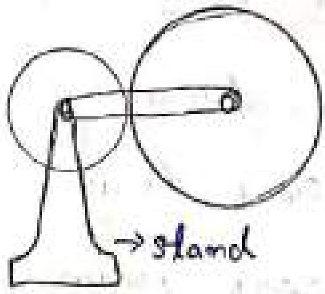


Reversed Gear train

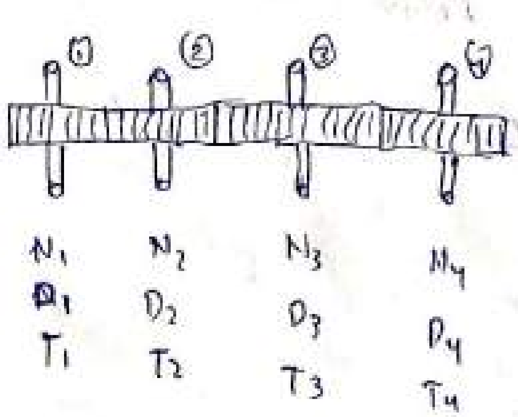


It is the axis of the shaft driven and axis of the shaft of the last follower remain in one line.

Epicyclic Gear train



1)



Consider gear ① and ②

$$\frac{N_2}{N_1} = \frac{T_1}{T_2} = \frac{D_1}{D_2} \quad \text{——— ①}$$

consider ③ and ④

$$\frac{N_4}{N_3} = \frac{T_3}{T_4} \quad \text{——— ②}$$

consider ② and ③

$$\frac{N_3}{N_2} = \frac{T_2}{T_3} \quad \text{——— ③}$$

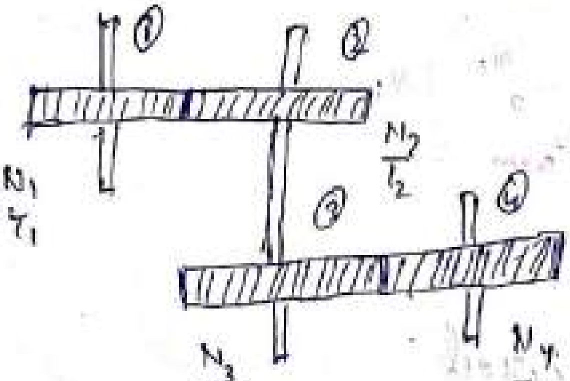
multiplying equation ① ② and ③

$$\frac{N_2}{N_1} \times \frac{N_4}{N_3} \times \frac{N_3}{N_2} = \frac{T_1}{T_2} \times \frac{T_3}{T_4} \times \frac{T_2}{T_3}$$

$$\boxed{\frac{N_4}{N_1} = \frac{T_1}{T_2}}$$

$$\frac{\text{r.p.m of last follower}}{\text{r.p.m of first driver}}$$

2)



Considering gear ① and ②

$$\frac{N_2}{N_1} = \frac{T_1}{T_2} \quad \text{——— ①}$$

Considering ③ and ④

$$\frac{N_4}{N_3} = \frac{T_3}{T_4} \quad \text{——— ②}$$

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multiplying equation ① and ②

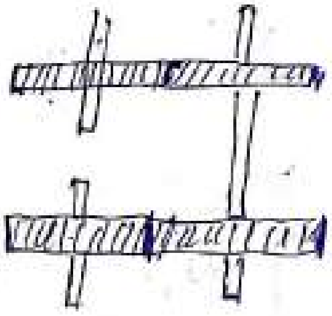
$$\frac{N_2}{N_1} \times \frac{N_4}{N_3} = \frac{T_1 T_3}{T_2 T_4}$$

$$\frac{N_4}{N_1} = \frac{T_1 T_3}{T_2 T_4}$$

$$\frac{\text{Product of no of teeth of drivers}}{\text{Product of no of teeth of followers}}$$

③ Reversed

$$\frac{N_4}{N_1} = \frac{T_1 T_3}{T_2 T_4}$$

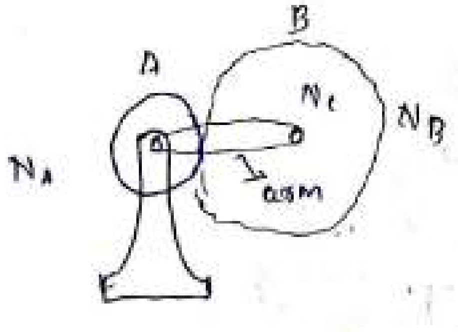


condition

$$r_1 + r_2 = r_3 + r_4$$

$$T_1 + T_2 = T_3 + T_4$$

11.02.2020



If N_c is fixed

$$\frac{N_B}{N_A} = \frac{T_A}{T_B}$$

$$\boxed{\frac{N_B - N_c}{N_A - N_c} = -\frac{T_A}{T_B}}$$

In alybaric method of calculation velocity ratio formula

$$\frac{N_B - N_C}{N_A - N_C} = -\frac{T_A}{T_B}$$

Tabular method

Step No.	Condition of motion	Revolution of Element		
		Arm C	Gear A	Gear B
1	Gear A rotates +1 revolution clockwise	0	+1	$\frac{-T_A}{T_B}$
2	Gear A rotates 'x' revolution C.W [multiply by (x)]	0	+ x	$x \times \frac{T_A}{T_B}$
3	Gear A rotates 'x' revolution and add 'y' revolution	0+y =y	x+y	$y - x\frac{T_A}{T_B}$
4	Total motion	y	x+y	$y - x\frac{T_A}{T_B}$

Q. In a epicyclic gear train an arm carries two gear A and B having 36 and 45 teeth respectively. If the arm rotates at 150 rpm in anticlockwise direction about center of gear 'A' which is fixed. Determine the speed of gear 'B' - if the gear 'A' instead of being fixed makes 300 rpm in the clockwise direction what will be the speed of the gear 'B'.

$y = -150$

$x + y = 0$

$x = 150$

$N_B = y - x \frac{T_A}{T_B}$

$N_B = -150 - 150 \frac{36}{40}$

$= -270$

$y = -150$

$x + y = 300$

$x - 150 = 300$

$x = 450$

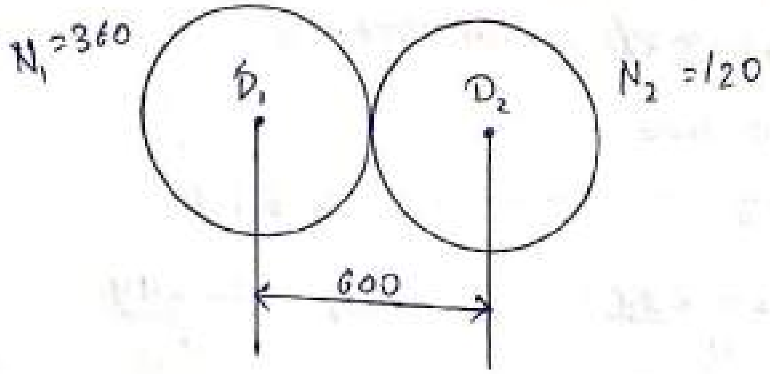
$N_B = y - x \frac{T_A}{T_B}$

$= -150 - 450 \times \frac{36}{40}$

$= -510$

module $(m) = \frac{D}{T}$

circular pitch $P_c = \frac{\pi D}{T}$



$\frac{D_1}{2} + \frac{D_2}{2} = 600$

$R_1 + R_2 = 600$

$D_1 + D_2 = 1200$

$\frac{N_2}{N_1} = \frac{T_1}{T_2}$

$\frac{120}{360} = \frac{T_1}{T_2}$ — (2)

$\frac{\pi D_1}{T_1} = \frac{\pi D_2}{T_2} = P_c$

$\frac{D_1}{D_2} = \frac{T_1}{T_2} = \frac{1}{3}$

$D_1 = 1200\ D_2$

$D_1 + 3D_1 = 1200$

$D_1 = \frac{1200}{4} = 300mm$

$D_2 = 900$

$\frac{\pi D_1}{T_1} = 25 \Rightarrow T_1 = \frac{\pi D_1}{25}$

$= \frac{\pi \times 300}{25}$

$= 37.69$ "

$$\frac{\pi D_2}{T_2} = 25$$

$$T_2 = \frac{\pi D_2}{25}$$

$$= \frac{\pi \times 900}{25} = 113.09$$

From the problem the number of teeth on gear 1 is not a integer.

Let us take

$T_1 = 38$ $\quad$ $T_2 = 114$

$$D_1 = \frac{25 \times 38}{\pi} = 302.39 \text{ mm} \qquad D_2 = \frac{25 \times 114}{\pi} = 907.18 \text{ mm}$$

$$r_1 = \frac{302.34}{2} = 151.17 \qquad r_2 = \frac{907.18}{2} = 453.59$$

$$r_1 + r_2 = 604.76 \text{ mm.}$$

GOVERNOR

Function – 1) It regulates the mean speed of an engine when there are variations of loads.

2) When load on the engine increases speed decreases so it becomes necessary to increase supply of working fluid.

3) When load on the engine decreases speed increases so less working fluid is reqd.

4) The governor automatically controls the supply of working fluid under variations of load and keeps the mean speed within certain limits.

Working:– when load increases, the configuration of governor changes and a valve is moved to increase the supply of the working fluid. Conversely when the load decreases, the speed in engine increases and governor decreases the supply of working fluid.

CLASSIFICATION. Governor

- ① CENTRIFUGAL
  - Pendulum type (Watt Governor)
  - Loaded type
    - Dead weight type
      - Porter
      - Proell
    - Loaded type
      - Hartnell
      - Wilson Hartnell
      - Gardner with gravity & Spring Control
      - Hartung
      - Pickering
- ② INERTIA

Centrifugal Governor – These governors are based on the balancing of centrifugal force on the rotating balls by an equal and opposite radial force known as controlling force (acting gravity or spring).

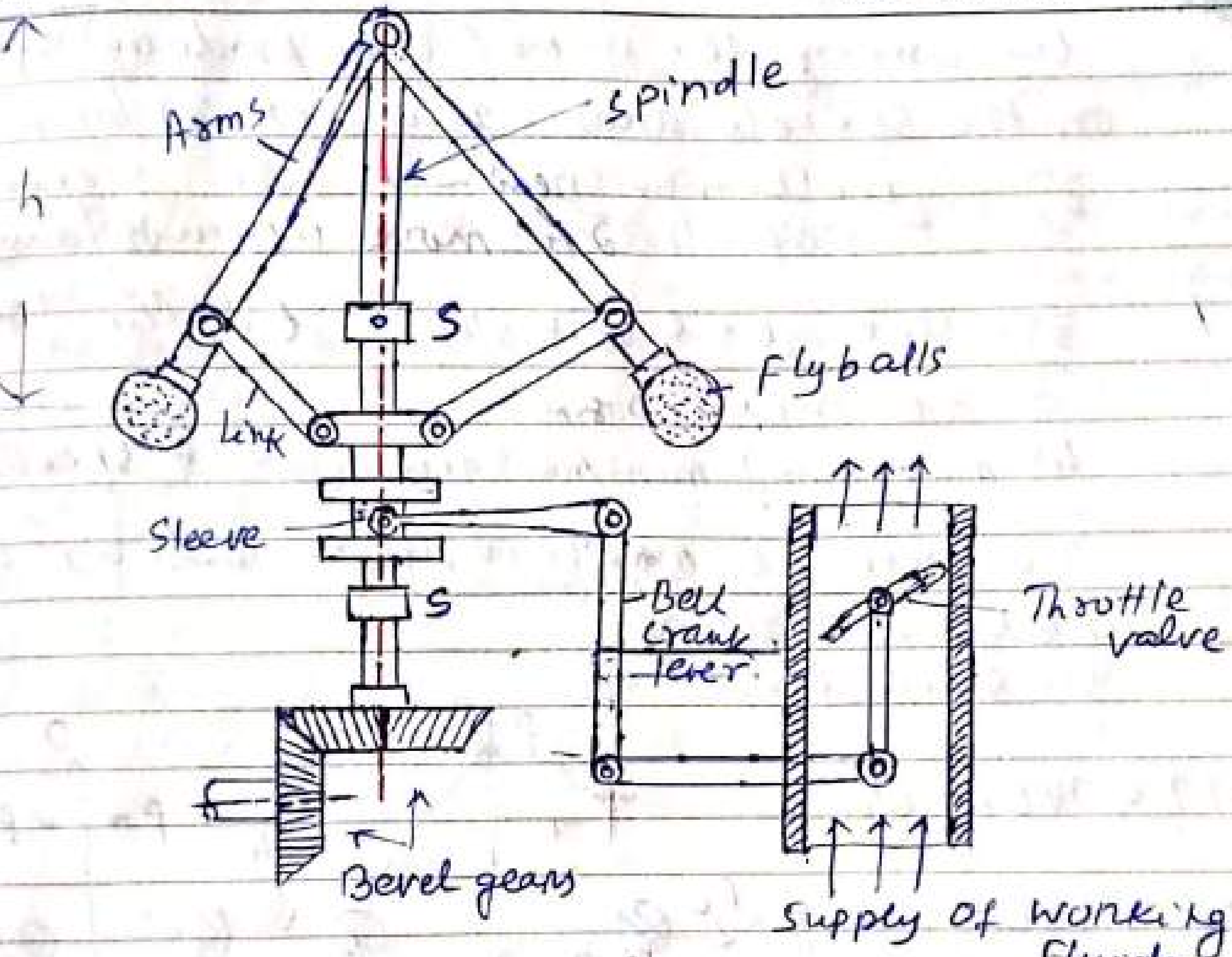
The shaft of a primemover is connected to the governor shaft by means of gear or belt drive. modern Governors get their connection from the primemover shaft through some servomechanism or electronic device. In a centrifugal governor two balls are fixed with the arms to the shaft of governor. The ball thus revolve with the shaft giving rise to centrifugal force acting radially outwards. The centrifugal force is balanced by controlling force acting radially inwards which is provided by a dead weight of spring or both. The governor balls or fly balls revolve with a spindle which is driven by the engine through bevel gears. The upper ends of arms are pivoted to the spindle so that the balls may rise up or fall down as they revolve about the vertical axis. The arms are connected by the links to a sleeve which is keyed to the spindle. This sleeve revolve with spindle but can slide up and down. The ball and the sleeve rises when spindle speed increases and falls when speed decreases

In order to limit the travel of sleeve in upward and downward directions, two stops S.S are provided on spindle. The sleeve is connected by a bell crank lever to a throttle valve. The supply of working fluid decreases when sleeve rises and increases when it falls.

When the load on the engine increases the engine and the governor speed decreases. This reduces centrifugal force on balls. So balls move inwards and sleeve moves downwards. The downward movement of sleeve operates a throttle valve at the other end of the bell crank lever to increase the supply of working fluid and thus engine speed is increased. In this case the extra power output is provided to balance the increased load. When the load on the engine decreases, the engine and the governor speed increases, which results in the increase of centrifugal force on the balls. Thus the balls move outwards and the sleeve rises upwards. This upward movement of the sleeve reduces the supply of the working fluid and hence the speed is decreased. In this case the power output is reduced.

Note. When the balls rotate at uniform speed, controlling force = centrifugal force. So they balance each other.

Centrifugal Governor.



Inertia Governor. In this case the positions of the balls are effected by the rate of change of speed i.e. angular acceleration or retardation of Governor shaft.

Since the action of governor is due to rate of change of speed and not a finite change of speed, a more rapid response to change of load is obtained. However due to practical difficulty of balancing the inertia force caused by balls of the governor to the controlling force, this type of governor is not preferred to centrifugal type.

TERMS USED IN GOVERNORS.

1) Height of a governor – (h) – vertical distance from centre of ball to a point where the axes of the arms (arms produced) intersect on the spindle axes. It is denoted by h.

2) Equilibrium speed → when sleeve does not tend to move upwards / downwards.

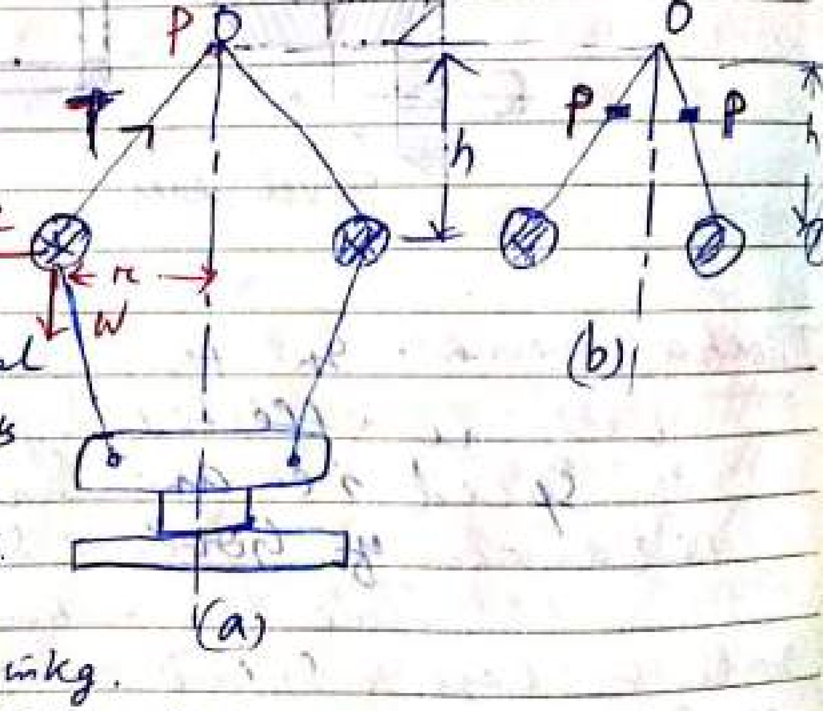
3) Mean Equilibrium speed. It is the speed at mean position.

4) maximum & minimum Equilibrium of speeds – the speeds at maxm and minm radius of rotation of balls.

5) Sleeve lift

WATT GOVERNOR

Simplest form of a centrifugal governor. It is basically a conical pendulum with links attached to a sleeve of negligible mass.



Let m = mass of ball in kg.
W = Wt. of ball in N = mg
T = Tension in the arm in N
ω = angular vel. of arm & ball about spindle axis
r = radius
F_c = centrifugal force = $m\omega^2 r$

Considering equilibrium of ball

$F_c \cdot h = (W \cdot r) = mgr$; $F_c = m\omega^2 r$.

$\Rightarrow h = g/\omega^2$

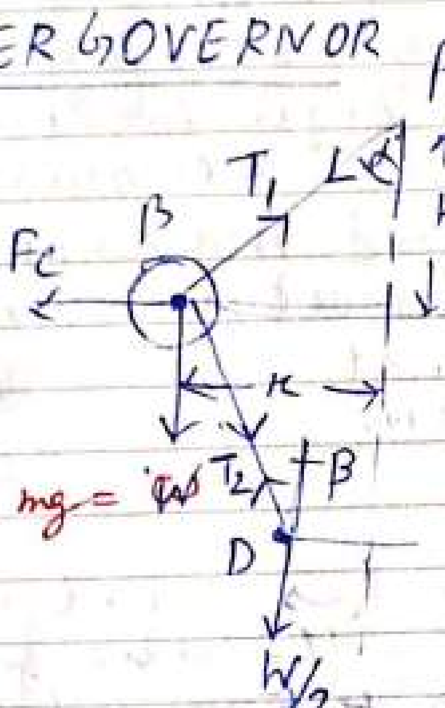
$\omega = 2\pi N/60$

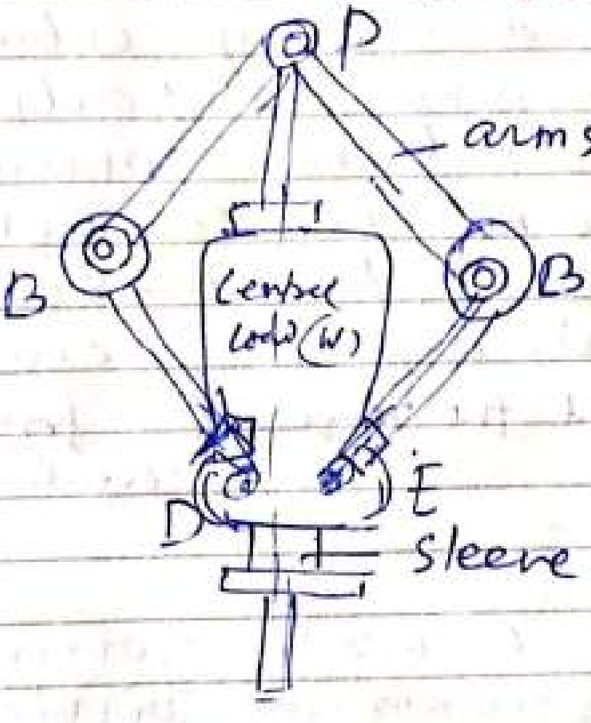
$$h = \frac{9.81}{(2\pi N/60)^2} = \frac{895}{N^2} \text{ m} \quad (60 \text{ to } 80 \text{ rpm})$$

Prob Calculate the vertical ht. of a watt governor when it rotates at 60 r.p.m. Also find the change in vertical height when its speed increases to 61 rpm.

$h = h_1 - h_2 = 0.008 m$

PORTER GOVERNOR





m = mass of each ball r = radius of rotation

w = wt. of each ball = mg.

M = mass of central load.

W = wt. " " = Mg.

F_c = centrifugal force acting on ball = $m\omega^2 r$

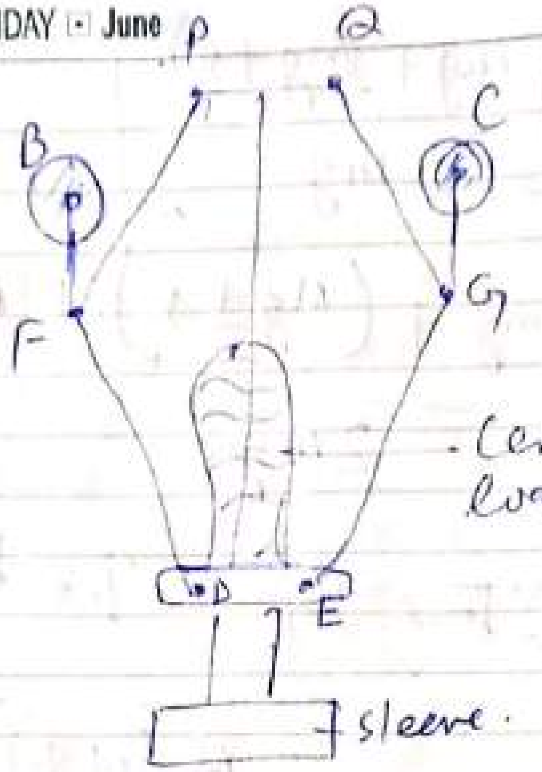
T_1 = Force in arms

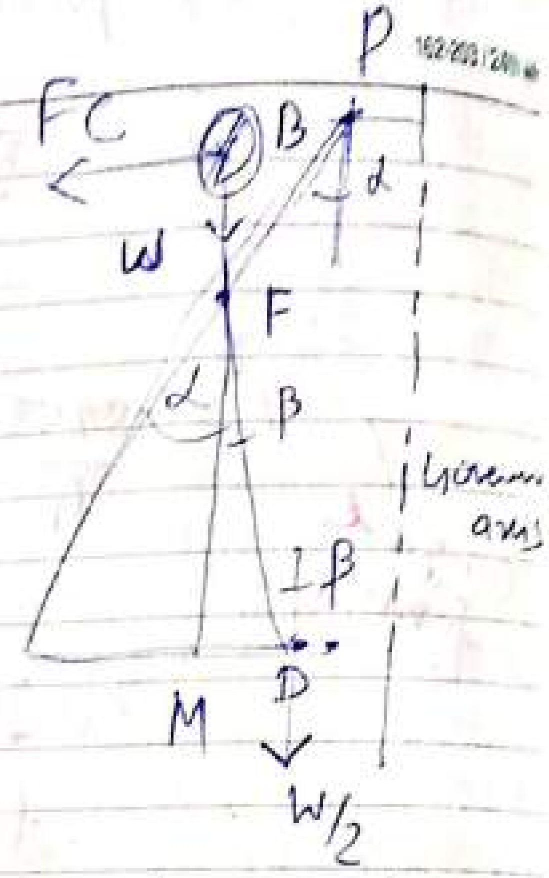
T_2 = Force in link

α = angle of inclination of arms to vertical

β = link to vertical

PRDELL GOVERNOR





The Proell Governor has the ball fixed at B and C to the extensiny link DF & EG. The arms FP & GQ are pivoted at P & Q respectively.

considering equillibrium of forces on one half of the governors. The Instantaneous centre (I) lies on the intersection of line PF produced and line from D drawn ⊥r to spindle axis. The perpendicular BM is drawn on ID.

Taking moment about I, using the same notations

$$F_C \times BM = w \times IM + \frac{W}{2} ID$$

$$= mg\, IM + \frac{Mg}{2} \times ID$$

simplifying we get

$$F_c = mg \times \frac{IM}{BM} + M.g\left(\frac{IM + ...}{BM}\right)$$

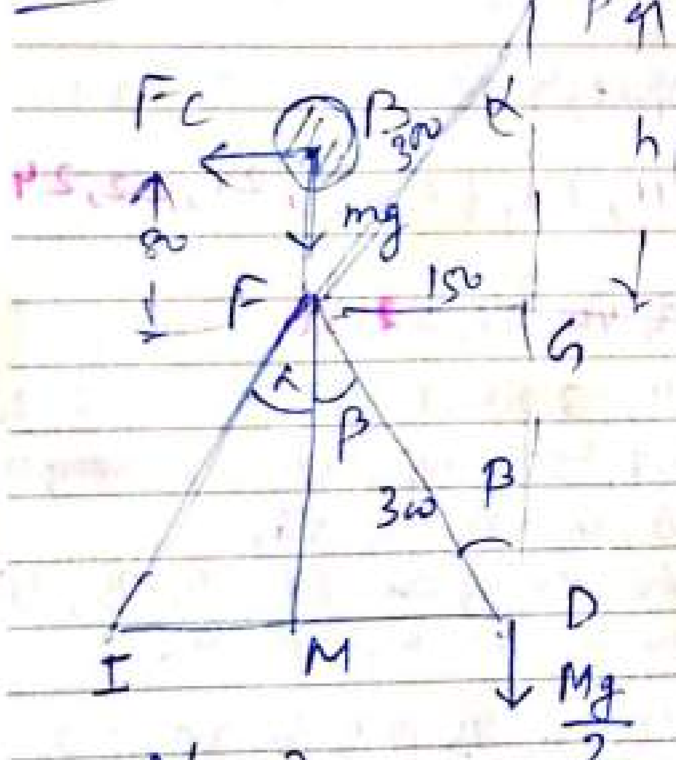
Dividing by FM
and putting $F_c = m\omega^2 r$, $\tan\alpha = \frac{r}{h}$, $q = \frac{\tan\beta}{\tan\alpha}$

$$N^2 = \frac{FM}{BM}\left[\frac{m + \frac{M}{2}(1+q)}{m}\right] \frac{895}{h}$$

Prob. Assign

A proell governor has equal arms of length 300mm. The upper and lower end of arms are pivoted on the axis of governor. The extension arms of lower links are each 80 mm long and parallel to the axis when the radii of rotation of the balls are 150 mm and 200 mm. The mass of each ball is 10kg and the mass of central load is 100kg. Determine the range of speed of governor.

Sol



$N_1 = ?$

1170 rpm

next figure

150 → 200.

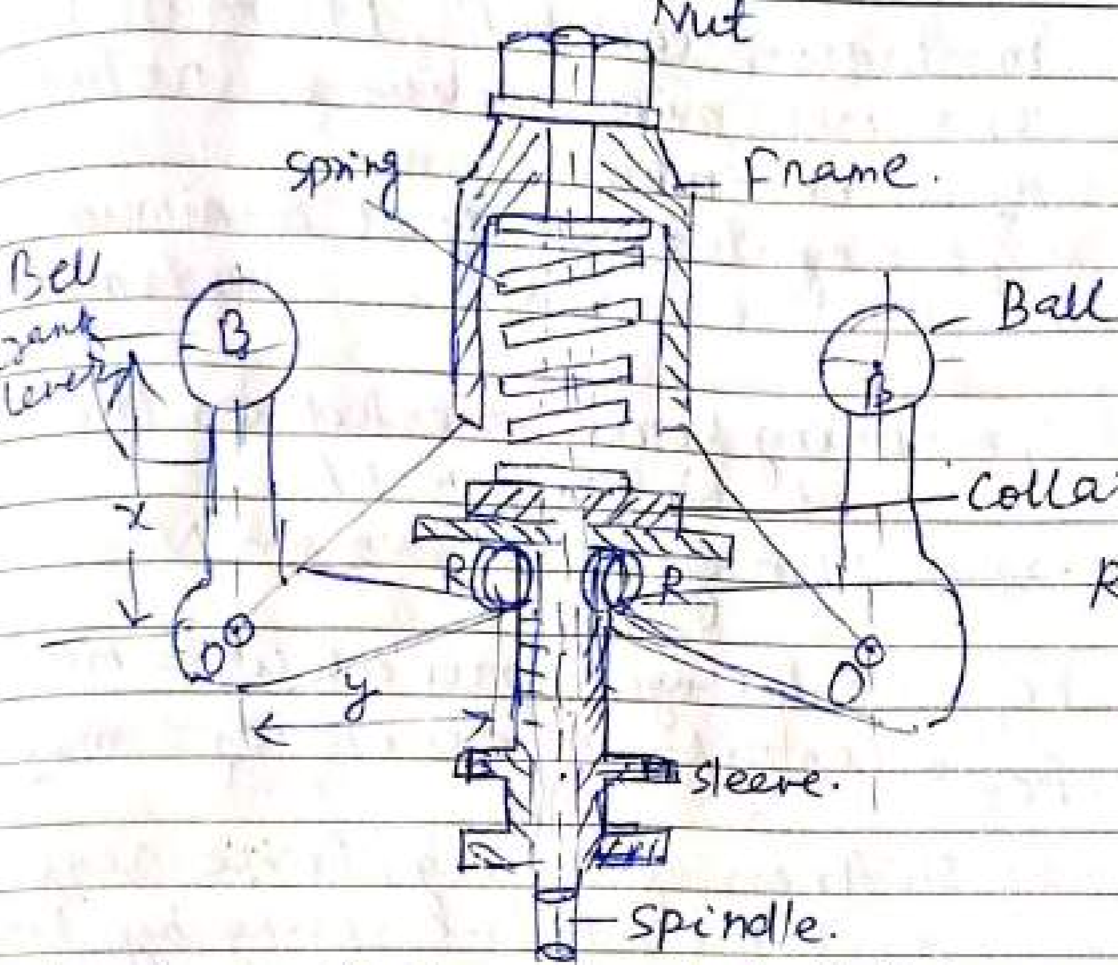
height h_2

$N_2 = ?$

1180 rpm

$N_2 - N_1 = 10$ rpm Ans

HARTNELL GOVERNOR



It is a spring loaded Governor. It consists of 2 bell crank lever pivoted at the points O, O to the frame. The frame is attached to the governor spindle and therefore rotates with it. Each lever carries a ball at the end of the vertical arm OB and roller at the end of horizontal arm OR. A helical spring in compression provides equal downward forces on the two rollers through a collar on sleeve. The spring force may be adjusted by screwing a nut up or down on the sleeve.

m = mass of each ball, M = mass of sleeve

r_1 = minimum radius of rotation

r_2 = maximum " "

ω_1 = angular velocity at minimum speed

ω_2 = " " " maximum "

S_1 = Spring force exerted on the sleeve at ω_1 in N.

S_2 = Spring force at ω_2 in N.

F_{C_1} = Centrifugal force at $\omega_1 = m\omega_1^2 r_1$

F_{C_2} = Centrifugal force at $\omega_2 = m\omega_2^2 r_2$

S = Stiffness of spring / Force required to compress the spring by 1mm

x = length of vertical or ball arm of lever in m

y = length of horizontal or sleeve arm of lever in m

r = distance of Fulcrum O from Governor axis or radius of rotation when the Governor is in mean position in mts.

$r = r_1 = 0.12$ m.

$h = (r_2 - r_1)\frac{y}{x}$

S =

F_{C2} = ?

S_1 ?

S_2 = ?

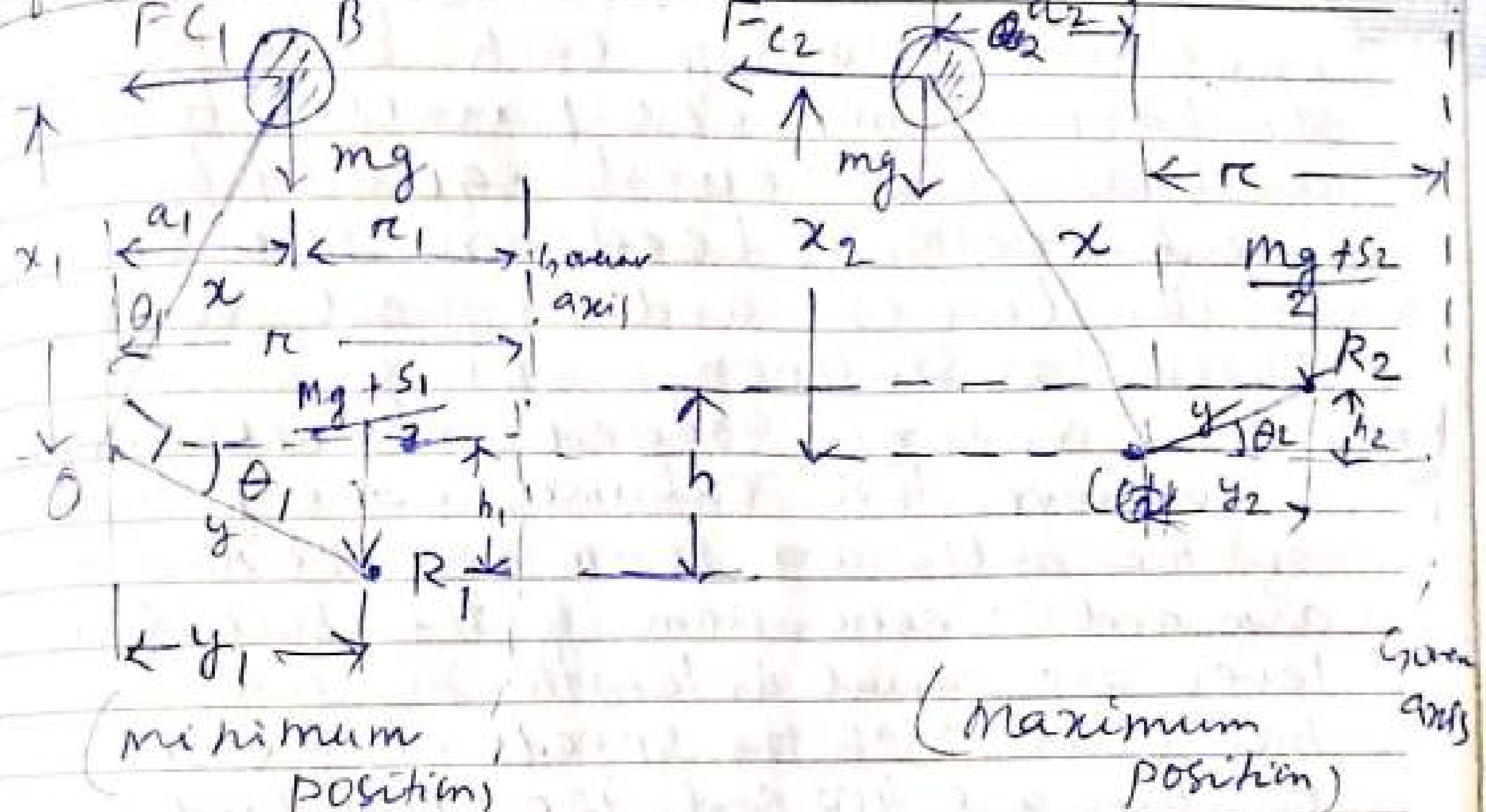
$= 0.145$

r_2 = ?

$Mg + S_1 = 2 F_{c1} \times \frac{x}{y}$ — (1) S_1 = Spring force exerted

$Mg + S_2 = 2 F_{c2} \times \frac{x}{y}$ — (2) S_2 = Spring on sleeve at ω_1 [illegible]

(If [illegible] not given)



(minimum position) (Maximum position)

$$s = \frac{S_2 - S_1}{h} = 2\left[\frac{F_{c2} - F_{c1}}{r_2 - r_1}\right]\left(\frac{x}{y}\right)^2, \quad x_1 = x_2 = x, \quad y_1 = y_2 = y$$

$$h = (r_2 - r_1)\frac{y}{x}$$

Prob. — A hartnell governor having a central sleeve spring and two right angled bell crank levers moves between 290 r.p.m and 310 r.p.m for a sleeve lift of 15 mm. The sleeve arm and the ball arms are 80 mm and 120 mm respectively. The levers are pivoted at 120 mm from the governor axis and mass of each ball is 2.5 kg. The ball arms are parallel to Governor axis at the lowest equilibrium speed. Detm. (1) Loads on the spring at the lowest and highest equilibrium speeds (2) Stiffness of spring.

Prob. 2. In a spring loaded Hartnell type governor the extreme radii of rotation of the balls are 80 mm and 120 mm. The ball arm and sleeve arm of the bell crank lever are equal in length. The mass of each ball is 2 kg. If the speeds at the two extreme positions are 400 and 420 rpm. Find (1) the initial compression of the central spring (2) spring constant.

Sol. Given $r_1 = 80\,mm = 0.08\,m$, $r_2 = 0.12\,m$, $x = y$, $m = 2\,kg$
$N_1 = 400$, $\omega_1 = 41.9\,rad/s$, $N_2 = 420\,rpm$,
$\omega_2 = 2\pi N/60 = 44\,rad/s$

$$F_{c_1} = m\omega_1^2 r_1 = 281\,N$$

$$F_{c_2} = m\omega_2^2 r_2 = 465\,N.$$

$$Mg + S_1 = 2F_{c_1} \times x/y \qquad (M = 0,\ x = y.)$$

$$\Rightarrow S_1 = 562\,N$$

$$Mg + S_2 = 2F_{c_2} \times \frac{x}{y} \Rightarrow S_2 = 930\,N.$$

$$h = (r_2 - r_1)\,y/x$$

$$s = \frac{(S_2 - S_1)}{h} = 9.2\,N/m. \quad \text{Ans}$$

Initial compression of Central Spring
$= \frac{S_1}{S} = \frac{562}{9.2} = 61\ mm$ Ans

SENSITIVITY — If there are two Governors A & B running at same speed. When this speed increases or decreases by a certain amount, the lift of sleeve of Gov. A is greater than the lift of sleeve of Govr. B. It is then said that the Governor A is more sensitive than Governor B. So sensitiveness is defined as the ratio of difference between maximum and minimum equillibrium speeds to the mean equillibrium speed.

so Sensitiveness $= \frac{N_2 - N_1}{N} = \frac{2(\omega_2 - \omega_1)}{\omega_1 + \omega_2}$

STABILITY — A Governor is said to be stable when for every speed within the working range there is a definite configuration i.e. there is only one radius of rotating governor balls at which the governor is in equillibrium. For a stable governor, if the equillibrium speed increases, the radius of governor balls must also increase.

ISOCHRONISM — A Governor is said to be isochronous when the equillibrium speed is constant – (Range of speed is zero) for all radii of rotating balls within the working range neglecting friction. The Isochronism is the stage of infinite sensitivity.

For Isochronism $N_2 - N_1 = 0$ or $N_2 = N_1$

So $h_1 = h_2$ which is impossible for Porter Governor. Hence porter Governor cannot be isochronous.

FLYWHEEL A flywheel used in machine serves as a reservoir which stores energy during the period when the supply of energy is more than the requirement and release it during the period when the requirement of energy is more than supply.

A flywheel does not maintain a constant speed, it simply reduces the fluctuation of speed.

OR

Flywheel controls the speed variation caused by fluctuating engine turning moment during each cycle of operation.

COEFFICIENT OF FLUCTUATION OF SPEED — The difference between maximum and minimum speeds during a cycle is called the maximum fluctuation of speed. The ratio of maximum fluctuation of speed to mean speed is called the coeff. of fluctuation of speed

$$C_s = \frac{N_1 - N_2}{N} = \frac{2(\omega_1 - \omega_2)}{\omega_1 + \omega_2} = \frac{V_1 - V_2}{V}$$

m = coefficient of steadiness

$$= \frac{1}{C_s}$$

$I = mk^2$

Kinetic Energy of Flywheel

$$E = \frac{1}{2} mk^2 . \omega^2$$

maximum Fluctuation of Energy

$$\Delta E = \frac{\pi^2}{900} \times mk^2 . N^2 . C_s$$

Assignment

Prob. The mass of flywheel of an engine is 6.5 tonnes and radius of gyration is 1.8 m. It is found from turning moment diagram that the fluctuation of energy is 56 kN-m. If mean speed of engine is 120 rpm, find maximum and minimum speeds.

N_1 114 rpm

Prob. The flywheel of steam engine has a radius of gyration of 1m and mass 2.0 kg. The starting torque of steam engine is 150 N-m and may be assumed constant. Detm 1) angular acceleration of flywheel 2) The K.E. of flywheel after 10 s from start.

45 kN-m

Prob. A horizontal cross compound steam engine develops 300 kW at 90 rpm. The coeff. of fluctuation of energy as found from turning moment diagram is to be 0.1 and fluctuating of speed is to be kept within $\pm$ 0.5 % of mean speed. Find weight of flywheel required if radius of gyration = 2 m. ($C_E = 0.1$, $k = 2$, $N = 90$, $P = 300 \times 10^3$ W

Ans $m = 5630$ kg

$W = mg$.

Fluctuation of speed ± 0.5 %.

so $\omega_1 - \omega_2 = 1\%$ of ω

$= 0.01 \omega$.

W.D/cycle $= P \times 60 / N$

$\Delta E = W.D \times C_E$

$C_S = \frac{\omega_1 - \omega_2}{\omega}$; $\Delta E = mk^2 \omega^2 . C_s$.

DISTINCTION BETN. FLYWHEEL & GOVERNOR

FLYWHEEL	GOVERNOR
1) The function of flywheel is to decrease the variation of speed due to difference in input and output, as one or both of them vary due to cyclic fluctuation	1) The function is to keep the speed of prime mover constant by adjusting the output of the engine to be equal to the external load in a given direction
2) A flywheel is useful in regulating the speed during one cycle.	2) A governor regulates the speed from cycle to cycle i.e over a no. of cycles of a prime mover.
3) Mathematically flywheel controls $\frac{\delta N}{\delta t}$	3) Mathematically it controls δN.
4) A flywheel stores up energy and gives up whenever required during a cycle.	4) It regulates the speed by regulating the quantity of working agent of prime mover.
5) A flywheel has no control over the quality of the working agent	5) It takes care of the change of quality of working agent.
6) A flywheel is not an essential element of every prime mover. It is used only in case there is undesirable cycle fluctuation of energy output or input	6) A governor, being an adjustor of supply with demand, is an essential element of every prime mover.

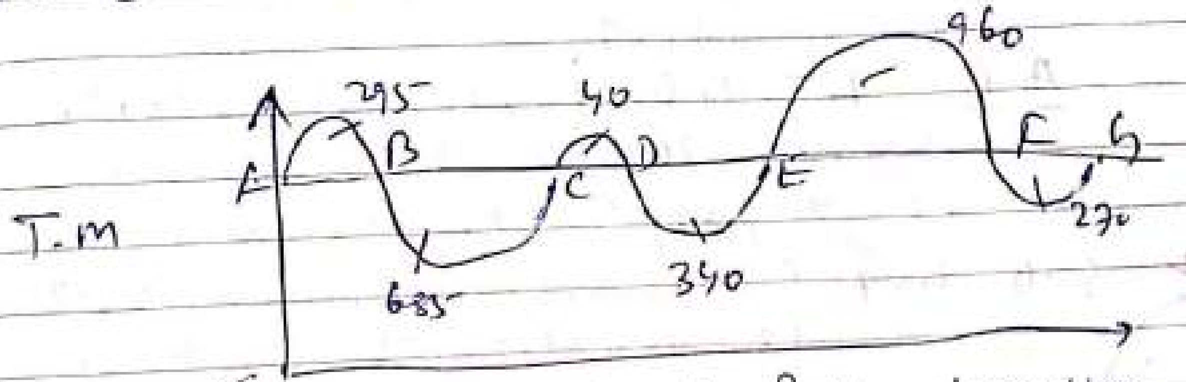
$E = K.E = \frac{1}{2} I \omega^2$

Torque = $I.\alpha$

Arb – The Turning moment diagram for a petrol engine is drawn to foll. scale,

Turning Moment → 1mm = 5 N-m, Crank angle → 1mm = 1°

The Turning moment diagram repeats itself at every half revolution of engine and the areas ~~below~~ above and ~~above~~ below the mean turning moment line taken in order are 295, 685, 40, 340, 960, 270 mm². The rotating parts are equivalent to a mass of 36 kg at a radius of gyration of 150 mm. Detm. C_s when engine runs at 1800 rpm.



[The area will be in mm² so 1mm × 1mm = crank angle]

Sol. – (i) Let E = energy at A

At B = E + 295 , D = E + 295 − 685 + 40

C = E + 295 − 685 E = E + 295 − 685 + 40 − 34[0]

F = E + 960

G = at F − 270

ΔE = max − min

$= -m^2 + \frac{\pi}{36}$,

Partial ...

classmate
Date
Page

Quality of Governor

1) Sensitiveness - The defination of the term has not been standardised and hence varies from auther to author. It is generally used to compare performance of 2 governors.

Defⁿ - 1) change in level of balls for 1% change in speed.

2) sensitiveness = $\frac{\text{range of speed}}{\text{mean speed}}$

2) Stability. A governor is said to be stable it has one equillibrium speed, neglecting friction for a given configuration. In other words an external force is applied on a sleeve of a governor running at a constant speed, it would change its configuration, but would immediately return to original one, as soon as the disturbing force is removed.

For spring controlled governors in which springs are compressed or extended within elastic limit, the centrifugal force curve would be a st...

$F = ar + b$

F = centrifugal force

a & b = constant

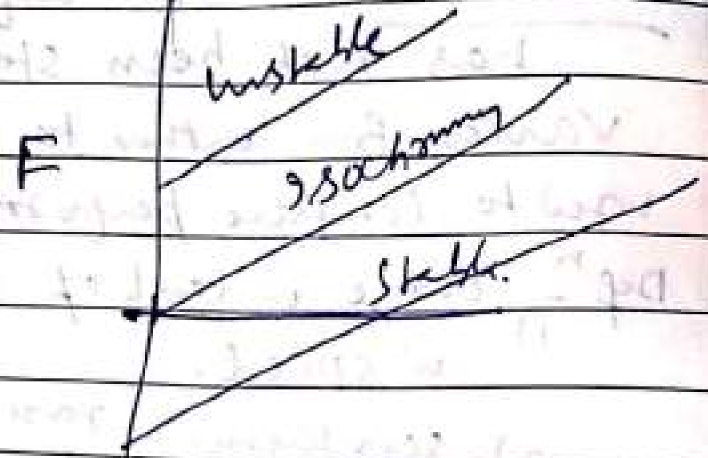
r = radius of rotation

$\tan\phi = \frac{F}{r} = a + \frac{b}{r}$

(2) If b is +ve, b > 0 — unstable

b < 0 — Stable

b = 0 — isochronous



An isochronous Governor runs at the same speed for different configuration.

Prob. In a spring Controlled Governor in which Controlling force curve is a St. line, the balls are 0.35 m apart when the controlling force is 1200 N and 0.2 m apart when controlling force is 600 N. At what speed the Governor will run when the balls are 0.25 m apart if each of them weighs 60 N? By how much the initial tension must be increased to make the Governor isochronous and what would then be speed of rotation?

Sol/ $F = ar + b$, $r = \frac{35}{2}$, $r = \frac{20}{2}$

$1200\,N = 17.5\,a + b$ — (1)

$600\,N = 10\,a + b$ — (2) $F = m\omega^2 r$

$a = \frac{600}{...}$, $b = ?$, $r = 0.25$

(ii) if $b = 0$

$F = 8r$

$= 8 \times r$

$m\omega^2 r = 8r$

$\Rightarrow \omega = ?$

$N = ?$

Effort of Governor.

~~Porter $= w\left(\frac{x^2-1}{2}\right).h$~~

~~$x, \frac{x+1}{w(x-1)} =$~~

When a governor is running at constant speed, the System is in equilibrium and hence the force acting on the Sleeve is zero. However the load changes, the speed changes and hence sleeve changes its position. This can only take place if a certain force acts on it and it would occupy a newly steady position when the resultant force acting on it again become zero. (The Average force that acts on the sleeve for a given % change of speed is known as the effort of the governor)

$\text{effort} = (x^2-1)\frac{W}{2}$

effort of porter > simple watt.

(PTO)

(P-4)

Power. The power of a governor is defined as the W.D on sleeve for a given % of speed. Power = effort × displacement

$$\text{Power} = w\left(\frac{x^2-1}{x}\right)^2 \cdot h \quad \text{— watt}$$

$$= (W+w)\left(\frac{x^2-1}{x}\right)^2 \cdot h \quad \text{— other}$$

Balancing of different masses rotating in same plane has already been taught in the class and a problem relating to it had also been assigned.

Now let us discuss the balancing of different masses rotating in different planes with illustrating with a problem. Look carefully how the problem has been solved by graphically. Because analytically it will be harder and cumbasome.

Problem

Four masses A, B, C and D are given in table below are to be completely balanced. The planes containing masses B and C are 30cm apart. The angles between B and C [containing masses] is 90°. B and C makes angle of 210° and 120° respectively with D in the same sense.

Find (i) the mass and angular position of A.

(ii) Position of planes A and D.

Table mass	mass (kg)	Radius (cm)
A	w	18
B	30	24
C	50	12
D	40	15

solution

Now prepare a table as follows

Name of mass	mass in kg	Radius in cm	Force = m.r	Distance from B	couple = m.r.L
A	w	18	18w	$-x$	$-18wx$
B	30	24	720	0	0
C	50	12	600	30	18,000
D	40	15	600	y	600y

Original Diagram according to Question

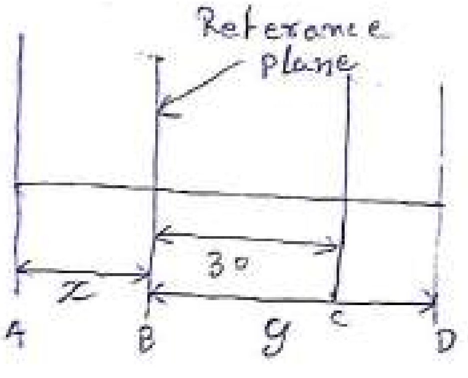


Fig-1

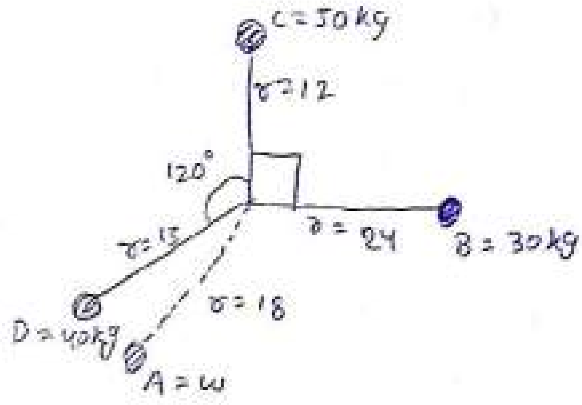
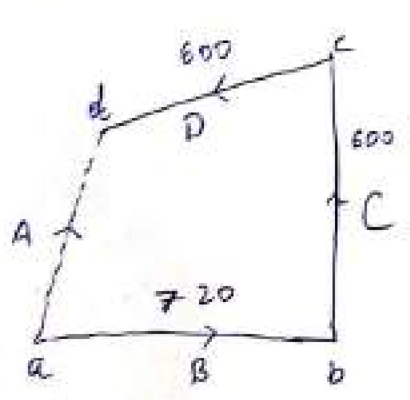


Fig-2

By taking a suitable scale draw forces diagram as below.



ab = 720

bc = 600

cd = 600

measure ad = ?

ad = 18w

w = ?

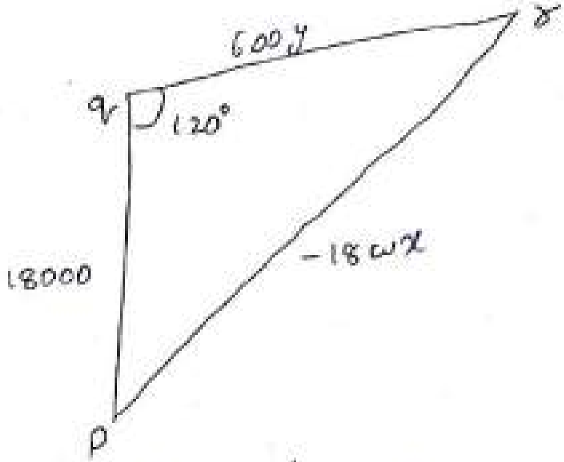
[force diagram]

To find angluar position a line parallel to 1810 is drawn in fig (2)

The mass A make ——— degree with mass D in anticlockwise direction.

Then draw the couple polygon to find x and y

Draw a line parallel to mass C and equal to 18000 kg cm^2 to a suitable scale.



From two end of this draw two line parallel to masses A and D both meeting and closing the couple polygon By measuring

$600y = qr$ (measure)

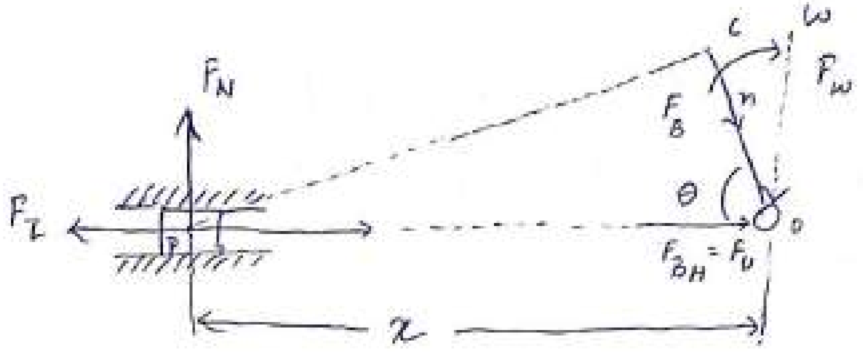
$y = ?$

$-18.\omega.x = pr$ (measure)

$x = ?$

Same ~~proced~~ Procedure will be adopted in balancing in practical (Tom lab)

Balancing of Reciprocating masses



Various forces acting on reciprocating parts of an engine ① Accelerating forces
② Inertial force

Resultant of all the forces acting on the body of the engine due to inertia forces only is known as <u>unbalanced</u> or <u>shaking forces</u>. If resultant of all the forces due to inertia effects in zero, then there will be no unbalanced force; But even then an unbalanced couple or shaking couple will be present.

Let F_R = force required to accelerate the reciprocating parts.

F_I = Inertia force due to reciprocating parts

F_N = Normal force

F_B = Force acting on crank shaft bearing

F_I is balanced by F_R

F_{BV} is balanced by F_N

Now $F_{BH} = F_U$ = Unbalanced force

$F_N \times x = F_{BV} \times x$ shaking couple

Effect of reciprocating parts is to produce a shaking force and shaking couple. since the shaking force and shaking couple vary in magnitude and direction during the engine cycle, therefore they cause very objectionable vibrations.

Thus the main aim of balancing the reciprocating masses is to eliminate the shaking force. It is not usually practical to eliminate completely but reciprocating masses are partially balanced.

$$F_I = F_R = m\omega^2 r \cos\theta + m\omega^2 r \frac{\cos 2\theta}{n}$$

$$n = \frac{\text{length of connecting rod}}{\text{crank radius}}$$

F_P = Primary unbalanced force

$= m\omega^2 r \cos\theta$

F_S = secondary unbalanced force

$= m\omega^2 r \cdot \frac{\cos 2\theta}{n}$

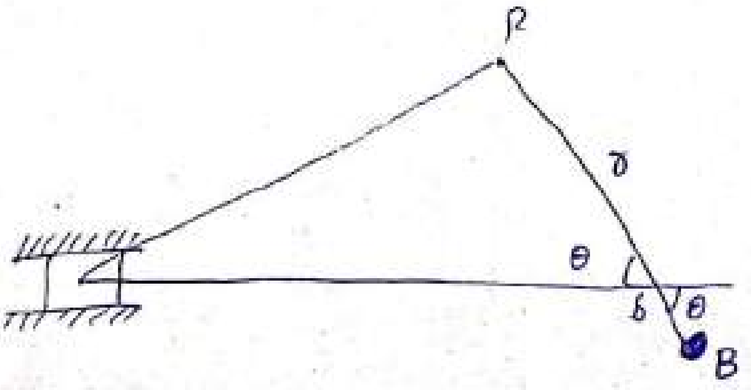
where m = mass of reciprocating parts

r = radius of crank

ω = angular speed

θ = crank angle.

Partial Balancing of Primary forces.



(Balancing of Reciprocating parts by a rotating mass fixed opposite to crank)

Here $B.b = R.r$ - (1) for complete balancing

But reciprocating parts are not completely balanced. a fraction (c) is balanced. It may be $\frac{2}{3}$, $\frac{1}{2}$ etc. etc.

$$\text{so } C.R.r = B.b \quad \text{———— (1)}$$

so unbalanced forces alon the line of stroke

$$= R\omega^2 r\cos\theta - B.\omega^2.b\cos\theta$$

$$= (1-C)\frac{R}{g}\omega^2 r\cos\theta \quad \text{———— (2)}$$

Unbalanced force perpendicular to line of stroke

$$= B.\omega^2 b\sin\theta$$

$$= \frac{C.R.r\,\omega^2\sin\theta}{g} \quad \text{———— (3)}$$

Resultant unbalanced force at any instant

$$= \frac{R\omega^2 r\sqrt{(1-c)^2\cos^2\theta + c^2\sin^2\theta}}{g} \quad \text{— (4)}$$

———— 0 ————

Chapter - 6

VIBRATION IN M/C PARTS

Vibration

when elastic bodies such as spring, beam and shaft are displaced from mean poistion (equillibrium position) by the application of external forces and then released, a vibratory motion or vibration is produced.

Related terms used in vibration

Amplitude - Max^m. displacement from mean position

Time period - Time taken to complete one vibration (cycle)

Frequency - No. of vibrations per second.
$\frac{1}{T}$ (unit Hertz - Hz)

Cycle - One complete vibration or oscillation (motion completed during a period)

Types of vibration

They may be classified according to

(a) the actuating force on the body

(b) the stresses in the supporting medium

[(a). Acc. to actuating force]

- Free or Natural
  - undamped
  - damped
- Forced
  - undamped
  - damped

[(b) Acc. to the stress in the supporting medium]

- Longitudinal
- Transverse
- Torsional

Free vibration

vibration which are not actuated by any outside force are said to be free vibration. As no external force. subsequent to the application of disturbing force acts, these vibrations should continue for ever as energy cannot be destroyed This type of vibration is also know as natural vibration.

Forced Vibration

vibration which are caused on maintained by a periodic disturbing force are know as forced vibrations. As the energy supplied by the disturbing force gets supplemented ~~by the disturbing force gets~~ from time to time, this type of vibrations becomes a permanent source of trouble.

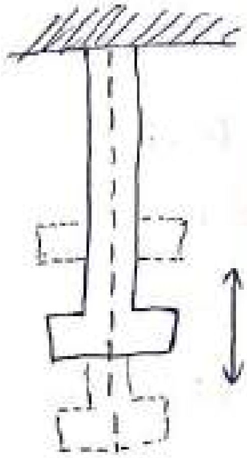
Damped vibration

when there is reduction in amplitude over every cycle of vibration, the motion is said to be damped vibration. This is due to the fact that certain amount of energy possessed by vibration system is always dissipated in overcoming frictional resistance to motion. As it is difficult to create perfect vacuum and also to have friction less motion. natural frequency dont occur in reality

Each of the above 3 types (free forced and damped) can be further sub divided into 3 types.

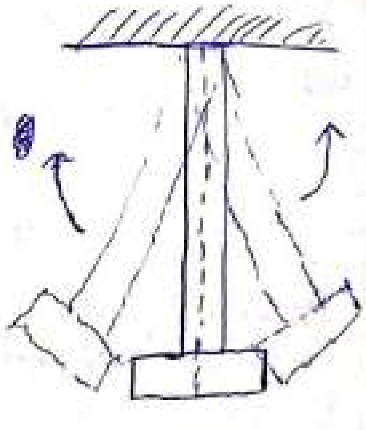
① Longitudinal
② Transverse
③ Torsional

Longitudinal vibration



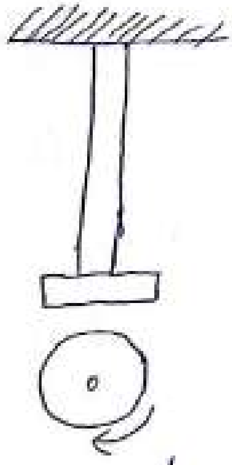
when particles of shaft moves parallel to axis of shaft. In this case different particles constituting the body move in parallel plane. In this case tensile and compressive stresses are produced.

Transverse vibration



If the body instead of moving vertically up and down as in longitudinal vibration, in the exaggerated manner as shown due to bending of supporting due to bending of supporting medium it is transverse. The ~~spring~~ spindle is subjected to tension and compression as a result of bending

<u>Torsional vibration</u>



If the particles of shaft move in a circle about the shaft (twisted and untwisted) the vibration is said to be torsional vibration. In this case torsional shear stress is produced.

<u>Question</u>

1. What is vibration? classify it
2. Write short notes on free, forced and damped vibration
3. Explain longitudinal, transversed and torsional vibration with diagram.

Formula for free longitudinal vibration

1. $F_n = \frac{1}{2\pi}\sqrt{\frac{g}{\sigma}}$ Hz

   where σ = deflection

   $= \frac{W \cdot l}{A \cdot E}$

2. $F_n = \frac{1}{2\pi}\sqrt{\frac{s}{m}}$, where s = stiffness

   $= \frac{\text{force}}{\text{deflection}}$

   m = mass of body suspended from constraints

Formula for free Torsional vibration

$$f_n = \frac{1}{2\pi}\sqrt{\frac{q}{I}}$$

where q = torsional stiffness

$= \frac{CJ}{l} \rightarrow \left(\frac{T}{\theta} = \frac{CJ}{l}\right)$

C = shear modulus

J = polar M.I

L = length

Problems

① A shaft of 100 mm ϕ and 1m length has one end fixed and other carries a mass of 500 kg at a radius of gyration 450 mm, find natural frequency if C = 80 GPa

② A cantilever shaft 50 mm ϕ and 400 mm long has a disc of mass 100 kg at its free end. E = 200 GN/m^2. Determine the longitudinal frequency

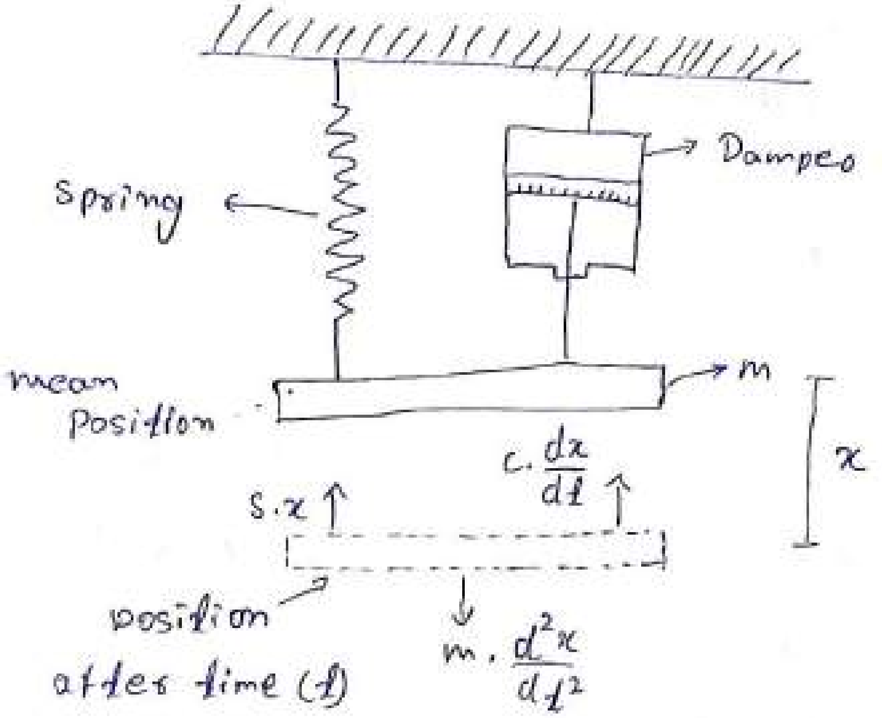
critical or whirling speed of a shaft

The speed at which the shaft runs so that the additional deflection of the shaft from the axis of rotation becomes infinite, is known as critical or whirling speed.

$$N_c = \frac{1}{2\pi}\sqrt{\frac{g}{\sigma}} = \frac{0.4985}{\sqrt{\sigma}} \text{ r.p.s}$$

same as Natural frequency but unit is r.p.m

Frequency of Free Damped vibration (Viscous Damping)



In vibrating system the effect of friction is referred as damping. The damping provided by fluid resistance is called viscous damping.

m = mass suspended from spring

s = stiffness

x = displacement from mean position

δ = static deflection of spring

$$= \frac{m.g}{s}$$

c = Damping coefficient

$$= \frac{\text{Damping force}}{\text{velocity}} \quad N/m/s$$

$\frac{dx}{dt}$ = velocity , $\frac{d^2x}{dt^2}$ = acceleration

Damping factor / Damping Ratio

$= \frac{C}{C_c} = \frac{\text{damping coefficient}}{\text{critical damping coefficient}}$

$C_c = 2m\omega_n = 2m\sqrt{S/m}$

$a = \left(\frac{C}{2m}\right)$ [a constant]

Over damping (large damping)

$\left(\frac{C}{2m}\right)^2 > \frac{S}{m}$

under damping (small damping)

$\frac{S}{m} > \left(\frac{C}{2m}\right)^2$

Logarithmic decrement

$$\delta = \frac{2\pi C}{\sqrt{C_c^2 - C^2}}$$

ω_n = Circular frequency of undamped vibration

$= \sqrt{\frac{S}{m}}$

ω_d = circular frequency of damped vibration

$= \sqrt{\omega_n^2 - a^2}$

frequency of vibration of system

$f_d = \frac{\omega_d}{2\pi}$ Hz

Assignment

① A vibrating system consists of mass of 200kg, a spring of stiffness 80 N/mm and a damper with damping coefficient of 800 N/m/s. Determine

(i) frequency of vibration of system
(ii) critical damping coefficient
(iii) Damping factor
(iv) Logarithmic decrement

Causes and Remedies of vibration in a mechanical system.

Causes

Vibration can occure due to one or more factors at any given time. The most common is imbalance, misaligonment, wear and looseness. ~~where~~ when the unbalanced weight rotates around the machine axis, centrifugal force is created. Due to occurence of Resonance also vibrations occure. (When a rotation frequency coincides with the resonance frequency of the machine, resonance occurs). It has a major impact. Bearing Damage also makes vibration. Damage of wear out gears also make vibration.

Remedies

Vibration cannot be completly remedied but can be controlled. The following precautions help to reduce whole body vibration exposure

(a) Limit the time spent by workers on a vibrating surface

(b) Isolation of vibrating source mechanically

(c) Equipments are well maintained to reduce vibration.

(d) Installation of vibration damping seats or springs to controll vibration.