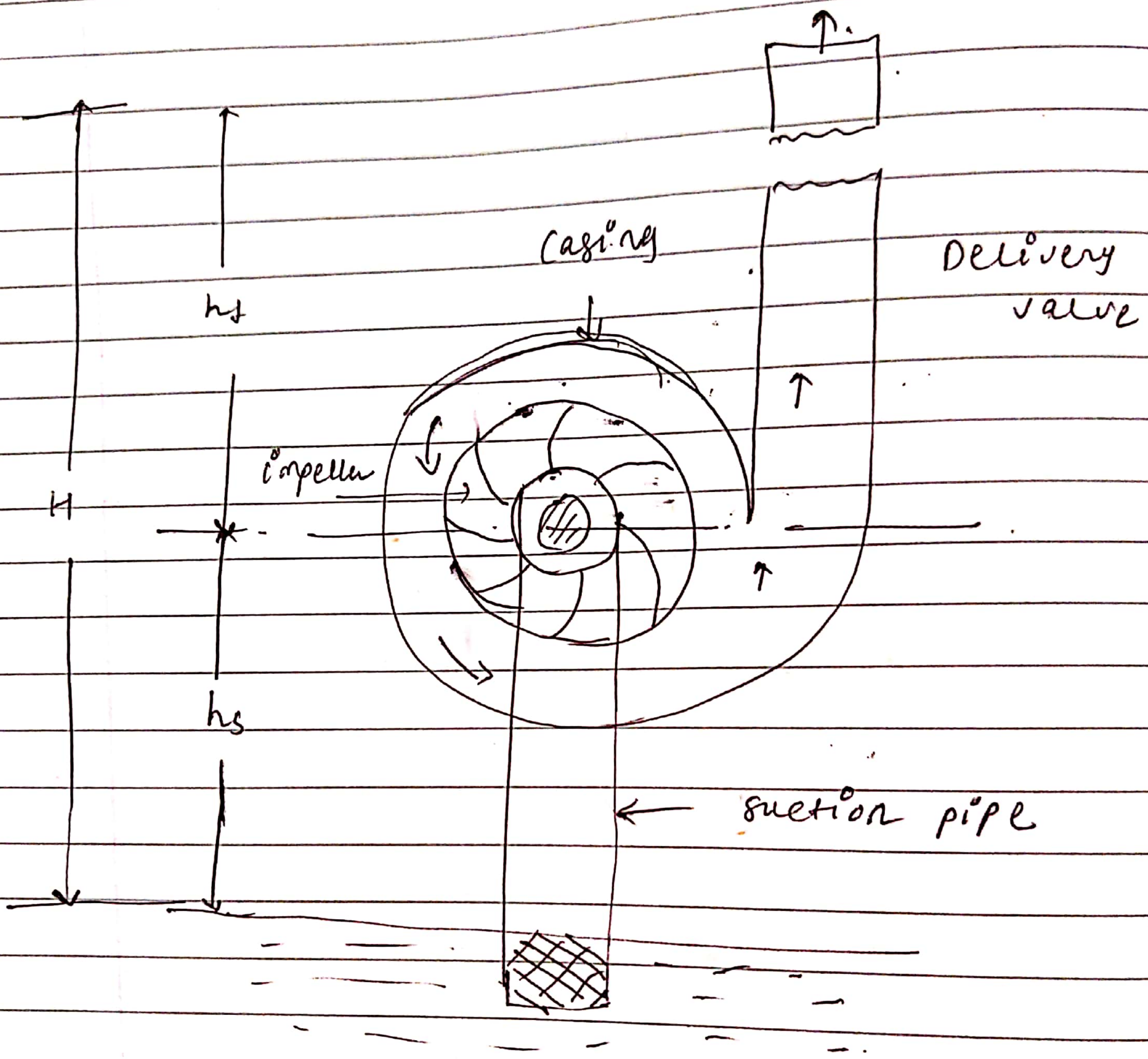
Centrifugal pump

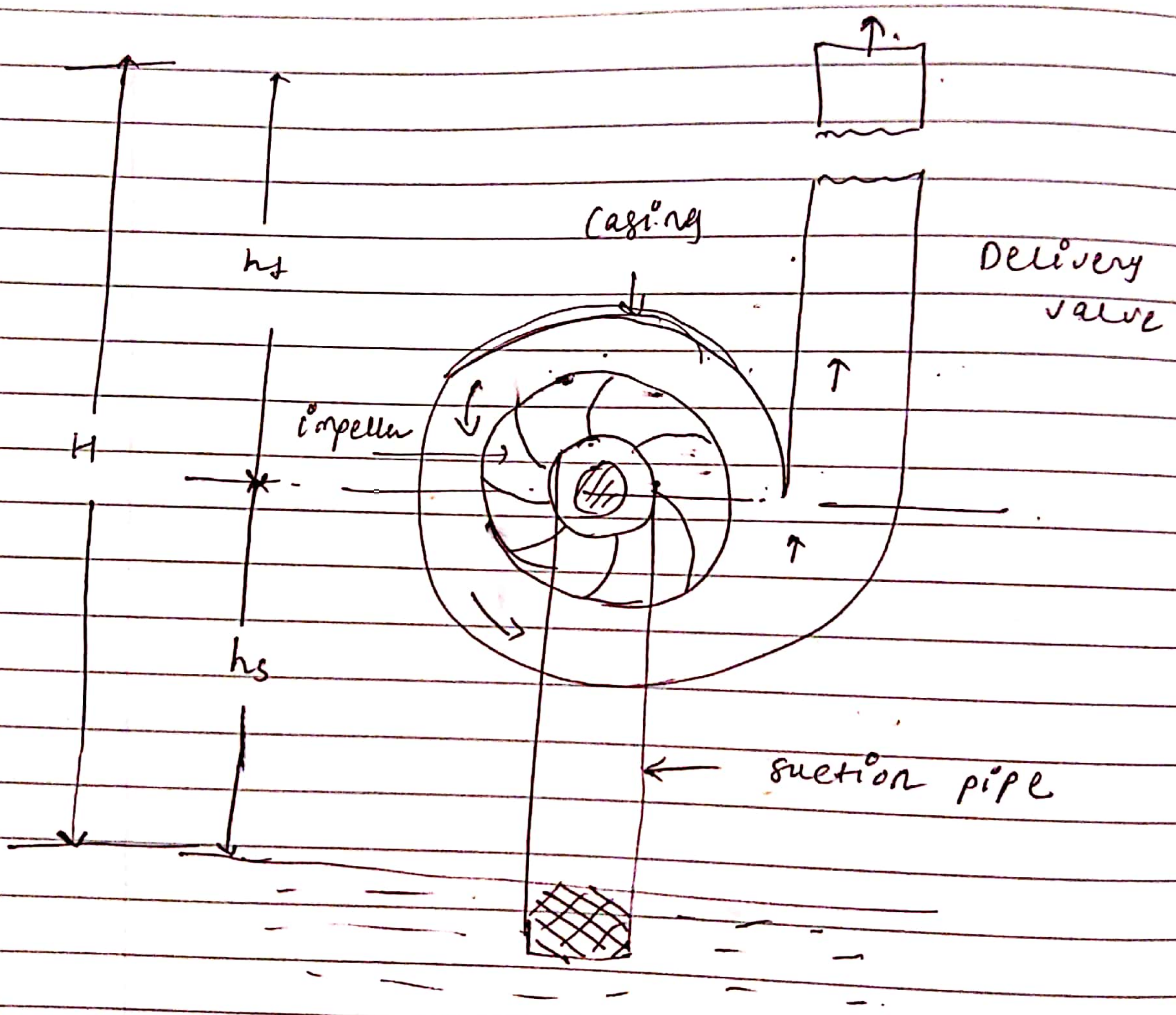


Main parts of pump

1 Impeller
2. Casing
3 suction pipe
4 delivery pipe

Scanned with CamScanner

Centrifugal pump

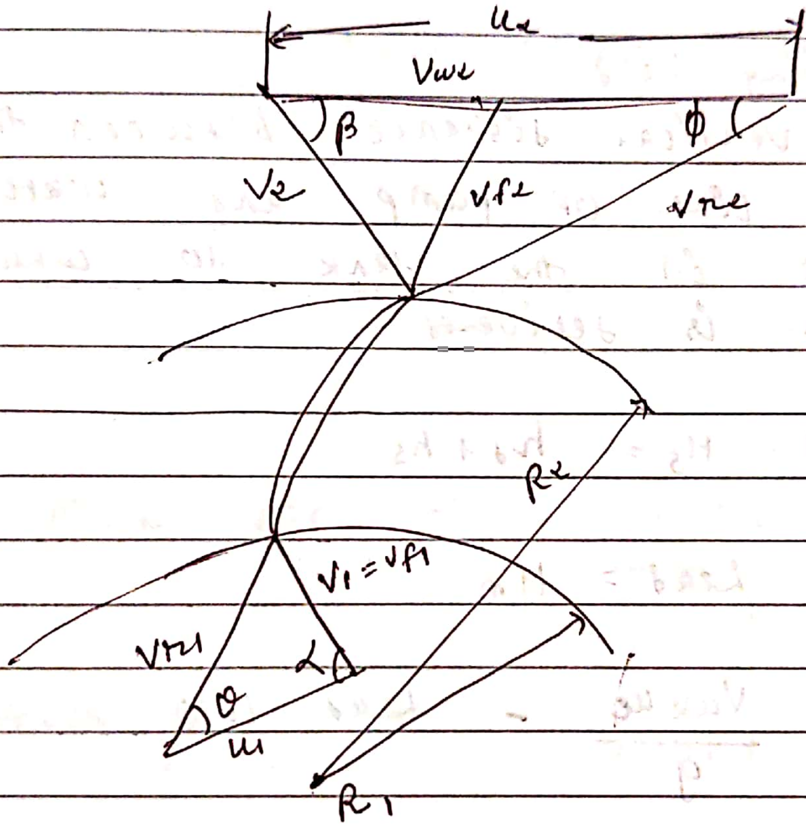


Main parts of pump

1 Impeller
2. Casing
3 suction pipe
4 Delivery pipe

)

W.D and velocity diagram.



$u_1 = \pi D_1 N / 60$, $u_2 = \pi D_2 N / 60$.

$W.D = -\frac{1}{g} [V_{w1} u_1 - V_{w2} u_2]$ (- work done on imp

$= + \frac{1}{g} [V_{w2} u_2]$.

$Q = \pi D_1 B_1 V_{f1} = \pi D_2 B_2 V_{f2}$.

- h_s = suction head
  = vertical dist of the centre line of pump above the water surface in tank or pump.

- h_d = Delivery head
  = The vertical distance between the centre line of pump and water surface in the tank to which water is delivered.

- suction head = H_s = $h_d + h_s$

- manometric head = H_m

(a) $H_m = \frac{V_{w2} u_2}{g}$ − head loss

(b) h_m = ~~fo~~
= Total head at outlet of pump − Total head at inlet of pu

$$= \left(\frac{P_o}{\rho g} + \frac{V_o^2}{2g} + z_o\right) - \left(\frac{P_i}{\rho g} + \frac{V_i^2}{2g} + z_i\right)$$

(c) ~~H~~$h_m = h_s + h_d + h_{fs} + h_{fd} + V_d^2/2g.$

Page No.
Date :

⇒ Efficiency of centrifugal pump

(i) Manometric efficiency : η_{man}

$$\eta_{man} = \frac{\text{Manometric head}}{\text{Head imparted by impeller to water}}$$

$$= \frac{H_m}{\frac{V_{w2} u_2}{g}} = \frac{g H_m}{V_{w2} u_2}$$

(ii) Mech. eff. $\eta_m = \frac{\text{Power at the impeller}}{\text{Power at the shaft}}$

$$\text{power at impeller in kW} = \frac{\text{Workdone by impeller per sec.}}{1000}$$

=> Efficiency of centrifugal pump

(i) Manometric efficiency : η_{man}

$$\eta_{man} = \frac{\text{Manometric head}}{\text{Head imparted by impeller to water}}$$

$$= \frac{H_m}{\frac{V_{w2} u_2}{g}} = \frac{g H_m}{V_{w2} u_2}$$

(ii) Mech. eff. $\eta_m = \frac{\text{Power at the impeller}}{\text{Power at the shaft}}$

Power at impeller in kW $= \frac{\text{Workdone by impeller per sec.}}{1000}$

$$= \frac{W}{g} \times \frac{V_{w2} u_2}{1000}$$

$$\eta_m = \frac{W/g \, \frac{V_{w2} u_2}{1000}}{S.P}$$

(iii) $\eta_0 = \eta_{man} \times \eta_m$.

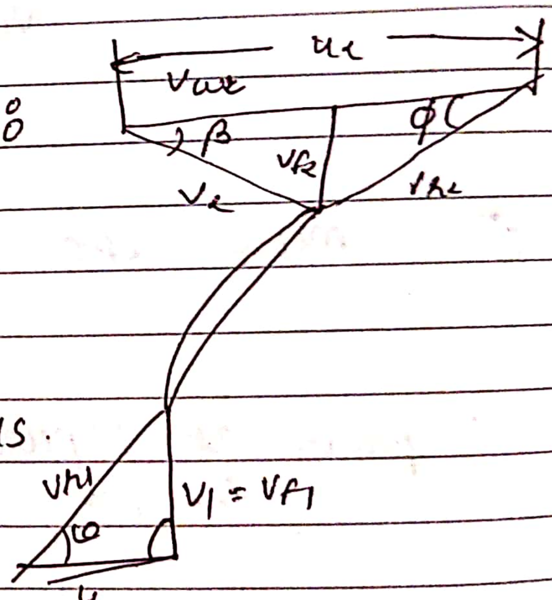
1.1

The internal and external diameters of the impeller of centrifugal pump are 200 mm and 400 mm respectively. The pump is running at 1200 rpm. The vane angles of the impeller at inlet and outlet are 20° and 30° resp. The water enters the impeller radially and velocity of flow is constant. Determine work done by impeller per unit weight of water.

⇒ $D_1 = 200\,mm$, $D_2 = 400\,mm$

$N = 1200\,rpm$, $\theta = 20°$, $\phi = 30°$

$\alpha = 90°$, $V_{w1} = 0$, $V_{f1} = V_{f2}$.



$u_1 = \dfrac{\pi D_1 N}{60}$, $u_2 = \dfrac{\pi D_2 N}{60}$

$= 12.56\,m/s$, $= 25.13\,m/s$.

$\tan\theta = \dfrac{V_{f1}}{u_1}$, $V_{f1} = 12.56 \times \tan 20°$

$= 4.57\,m/s$.

$V_{f1} = V_{f2} = 4.57\,m/s$.

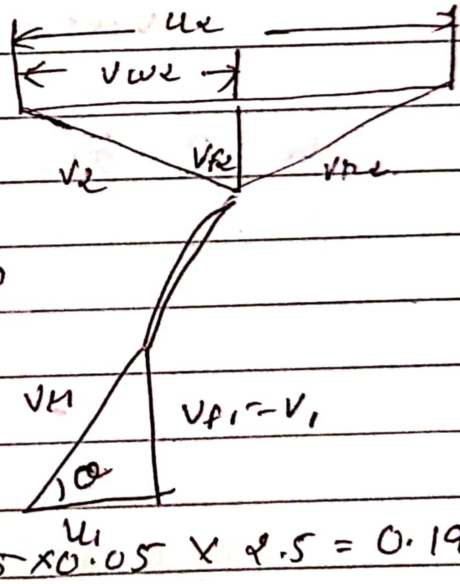
$\tan\phi = \dfrac{V_{f2}}{u_2 - V_{w2}} =$, $V_{w2} = 17.215$

$\dfrac{W.D\ per\ sec}{weight/sec} = \dfrac{1}{g} V_{w2} u_2$

$= \dfrac{17.215 \times 25.13}{9.81} = 44.1\ N\cdot m/N$

Page No.
Date :

A centrifugal pump having outer diameter equal to two times of inner diameter and running at 1000 rpm works against a total head of 40 m. The velocity of flow through the impeller is constant and equal to 2.5 m/s. The vanes are set back at an angle of 40° to the outlet. If the outer diameter of the impeller is 500 mm and width at outlet is 50 mm. Determine (i) vane angle at inlet (ii) workdone by impeller on water per second and (iii) manometric eff.



$N = 1000\,rpm$, $H_m = 40\,m$, $V_{f1} = V_{f2} = 2.5\,m/s$

$\phi = 40°$, $D_2 = 500\,mm = 0.5\,m$

$D_1 = D_2/2 = 0.25\,m$, $B_2 = 50\,mm = 0.05\,m$

$u_1 = \frac{\pi D_1 N}{60} = 13.09$, $u_2 = \frac{\pi D_2 N}{60} = 26.18$.

$Q = \pi D_2 B_2 V_{f2} = 3.14 \times 0.5 \times 0.05 \times 2.5 = 0.1963\,m^3/s$

(i) vane angle at inlet

$\tan\theta = \frac{V_{f1}}{u_1}$

$= 10° 48'$

(ii) W.D by impeller on water per second

$$= \frac{W}{g} \times V_{w2} u_2$$

$$= \frac{\rho \times Q \times g}{g} \times V_{w2} u_2$$

$$\tan\phi = \frac{V_{f2}}{u_2 - V_{w2}} = \frac{2.5}{26.18 - V_{w2}}$$

$$26.18 - V_{w2} = \frac{2.5}{\tan\phi} = 2.979.$$

$$V_{w2} = 23.2 \text{ m/s}.$$

W.D by impeller = ~~1000~~

$$= \frac{V_{w2} u_2}{g} \times W$$

$$= \frac{\rho \times Q \times g \times V_{w2} u_2}{g}$$

$$= 1000 \times 9.81 \times 23.2 \times 26.18$$

$$= 119227.9 \text{ N.m/s.}$$

$$\eta_m = \frac{g H_m}{V_{w2} u_2} = \frac{9.81 \times 40}{23.2 \times 26.18}$$

$$= 64.4\%$$

19.9 Find the power required to drive a centrifugal pump which delivers 0.04 m^3/s of water to a height of 20 m through a 15 cm diameter pipe and 100 m long. The overall eff of the pump is 70% and co. eff of f = 0.15 in for $h_f = 4fLV^2/2gD$

$Q = 0.04\ m^3/s$. $L_s + L_D = 100m$

$H_s = h_s + h_d = 20m$ $\eta_o = 0.7$

$D_s = D_d = 15cm = 0.15cm$ $f = 0.15$

$V_s = V_d = V = Q/A = \frac{0.04}{\pi/4 D_s^2} = 2.26m.$

$h_{fs} + h_{fd} = h_f = \frac{4fLV^2}{2gD} = \frac{4 \times 0.15 \times 100 \times 2.26^2}{2 \times 9.81 \times 2}$

$= 10.41m$

$H_m = h_s + h_d + h_{fs} + h_{fd} + V_d^2/2g$

$= 20 + 10.4 + (2.26)^2/2 \times 9.81$

$= 30.67m.$

$\eta_o = \frac{W H_m}{1000 \times S.P} = \frac{\rho \times Q \times g \times H_m}{1000 \times S.P}$

$S.P = \frac{\rho Q g H_m}{1000 \times \eta_o}$

$= 17.19\ kW.$

19.8 The internal and external diameter of an impeller of a centrifugal pump which is running at 1000 rpm, are 200 mm and 400 mm respectively. The discharge through the pump is 0.04 m³/s and velocity of flow is constant and it is equal to 2. m/s. The diameters of the suction and delivery pipes are 150mm and 100mm resp, suction and delivery heads are 6m and 30m of water respectively. If the outlet vane angle is 45° and power required to drive the water pump is 16.186 kw find out

(i) vane angle of impeller at inlet
(ii) the overall eff. of pump
(iii) mano. eff. of pump.

→ $N = 1000$ rpm

$D_1 = 200mm = 0.2m$

$D_2 = 0.4m$

$Q = 0.04 m^3/s$

$V_{f1} = V_{f2} = 2 m/s. = V_1$

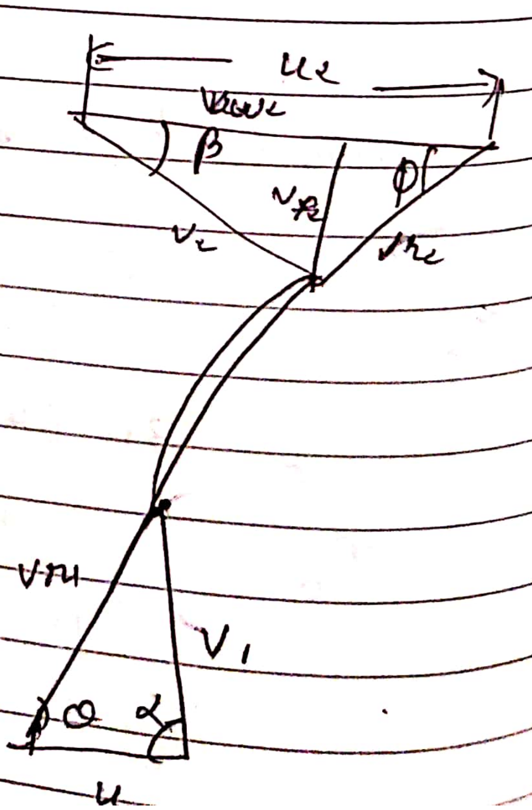
$D_s = 0.15m$, $D_d = 0.10m$

$h_s = 6m$

$h_d = 30m$

$\phi = 45°$

$P = 16.186$ kW



(i) Vane angle of impeller at inlet (θ)

$\tan\theta = \frac{V_1}{u_1} = \frac{2}{10.47}$ $u_1 = \frac{\pi D_1 N}{60} = 10.47 m/s$

$\theta = 10° 48'$

(ii)

$\eta_o = \frac{WHm}{1000 \times S.P} = \frac{\rho g\, Hm}{1000 \times P} = 0.02424\, Hm$

$Hm = \left(\frac{P_o}{\rho g} + \frac{V_o^2}{2g} + z_o\right) - \left(P_i/\rho g + V_i^2/2g + z_i\right)$

$P_o/\rho g = 30m$, $P_i/\rho g = 6$. $z_o = z_i$

$Hm = \left(30 + \frac{V_d^2}{2g}\right) - \left(6^2 + \frac{V_s^2}{2g}\right)$

$V_d = Q/\pi/4 (D_d)^2 = 5.9\ m/s$, $V_s = Q/\pi/4\ D_s^2$

$= 2.26 m/s$

$Hm = \left(30 + \frac{(5.9)^2}{2 \times 9.81}\right) - \left(6^2 + \frac{(2.26)^2}{2 \times 9.81}\right) = 25.06 m.$

$\eta_o = 0.02424\, Hm = 60.74$

$\Rightarrow \eta_{man} = \frac{gHm}{V_{w2} u_2}$ $u_2 = \frac{\pi D_2 N}{60} = 20.94.$

$\tan\phi = \frac{V_{f2}}{u_2 - V_{w2}}$ $\Rightarrow V_{w2} = 18.94 m/s$

$\eta_{man} = 61.98\%$

(i) Vane angle of impeller at inlet (θ)

$\tan\theta = \frac{V_1}{u_1} = \frac{2}{10.47}$ $\quad u_1 = \frac{\pi D_1 N}{60} = 10.47 \, m/s$

$\theta = 10°48'$

(ii) $\eta_o = \frac{WH_m}{1000 \times S.P} = \frac{\rho g H_m}{1000 \times P} = 0.02424 H_m$

$H_m = \left(\frac{P_o}{\rho g} + \frac{V_o^2}{2g} + Z_o\right) - \left(P_i/\rho g + V_i^2/2g + Z_i\right)$

$P_o/\rho g = 30m$, $P_i/\rho g = 6$. $Z_o = Z_i$

$H_m = \left(30 + \frac{V_d^2}{2g}\right) - \left(6^2 + \frac{V_s^2}{2g}\right)$

$V_d = Q/\frac{\pi}{4}(D_d)^2 = 5.9 \, m/s$, $V_s = Q/\frac{\pi}{4} D_s^2$

$= 2.26 \, m/s$

$H_m = \left(30 + \frac{(5.9)^2}{2 \times 9.81}\right) - \left(6^2 + \frac{(2.26)^2}{2 \times 9.81}\right) = 25.06 \, m.$

$\eta_o = 0.02424 H_m = 60.74$

$\Rightarrow \eta_{man} = \frac{g H_m}{V_{w2} u_2}$ $\quad u_2 = \frac{\pi D_2 N}{60} = 20.94.$

$\tan\phi = \frac{V_{f2}}{u_2 - V_{w2}} \Rightarrow V_{w2} = 18.94 \, m/s$

$\eta_{man} = 61.95\%$

n = no. of identical pumps arranged in parallel

$Q = n \times q$

A three stage centrifugal pump has impeller 40 cm in diameter and 2 cm wide at outlet. The vanes are curved back at an angle of 45° and reduce the circumferential area by 10%. The manometric efficiency is 90% and overall eff is 80%. Determine the head generated by the pump when running at 1000 rpm, delivering 50 LPS. What should be the shaft horse power?

$n = 3$, $D_2 = 40\text{ cm} = 0.4\text{ m}$, $B_2 = 0.02\text{ m}$, $\phi = 45°$

red: in area at outlet

Area of flow at outlet $= \pi D_2 B_2 \times 0.9$

$= 0.02262\text{ m}^2$

$\eta_{man} = 0.9$, $\eta_o = 0.8$, $N = 1000\text{ rpm}$.

$Q = 50\text{ LPS} = 0.05\text{ m}^3/\text{s}$.

$S.P = ?$, $H = ?$

$V_{f2} = Q/A_2 = 0.05/0.02262 = 2.21\text{ m/s}$.

Tangential velocity of impeller at outlet

$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.4 \times 1000}{60} = 20.94\text{ m/s}$$

$$\tan\phi = \frac{V_{f2}}{u_2 - V_{w2}} \quad \therefore u_2 - V_{w2} = \frac{V_{f2}}{\tan\phi}$$

$\eta_{man} = \frac{g H_m}{V_{w1} u_1}$ $\therefore 0.9 = \frac{9.81 \times H_m}{18.73 \times 20.94}$

$H_m = \frac{0.9 \times 18.73 \times 20.94}{9.81}$

$= 35.98\ m$

$\therefore$ Head $= n \times H_m = 3 \times 35.98$

$= 107.94\ m.$

Output $P = \frac{W \times H_m}{1000} = \frac{\rho \times Q \times g \times H_m}{1000}$

$= \frac{1000 \times 9.81 \times 0.05 \times 107.94}{1000}$

$= 52.94\ kW$

$\eta_o = \frac{\text{power output}}{\text{power input}} = \frac{52.94}{S.P}$

$S.P = \frac{52.94}{\eta_o} = \frac{52.94}{0.8}$

$= 66.175\ kW$

Page No.
Date :

⇒ minimum starting speed of centrifugal pump.

Head due to pressure rise in impeller $= \frac{\omega^2 r_2^2}{2g} - \frac{\omega^2 r_1^2}{2g}$

$\omega r_2 = u_2, \quad \omega r_1 = u_1$

→ Head due to pressure rise in impeller $= u_2^2/2g - u_1^2/2g$

The flow of water will commence only if head due to pressure rise in impeller $\geq H_m$

$$\frac{u_2^2}{2g} - \frac{u_1^2}{2g} \geq H_m$$

for minimum speed $\frac{u_2^2}{2g} - \frac{u_1^2}{2g} = H_m.$

$\eta_{man} = gH_m / V_{w2} u_2.$ $\quad H_m = \eta_{man} \times \frac{V_{w2} u_2}{g}.$

$$\frac{u_2^2}{2g} - \frac{u_1^2}{2g} = \eta_{man} \times \frac{V_{w2} u_2}{g}$$

$u_2 = \pi D_2 N / 60$ and $u_1 = \pi D_1 N / 60.$

$$\frac{1}{2g}\left[\left(\frac{\pi D_2 N}{60}\right)^2 - \left(\frac{\pi D_1 N}{60}\right)^2\right] = \eta_{man} \frac{\times V_{w2} \times \pi D_2 N}{60 \times g}.$$

dividing by $\frac{\pi N}{g \times 60}$

we get, $\frac{\pi N D_2^2}{120} - \frac{\pi N D_1^2}{120} = \eta_{man} \times V_{w2} D_2$

$\frac{\pi N}{120} [D_2^2 - D_1^2] = \eta_{man} \times V_{w2} D_2$

$N = \frac{120 \times \eta_{man} \times V_{w2} \times D_2}{\pi [D_2^2 - D_1^2]}$

$$Q = A \times V = \pi D B V_f$$

$$Q \propto D B V_f$$

$$\therefore \quad B \propto D$$

$$Q \propto B^2 V_f$$

$$u \propto \frac{\pi D N}{60} \quad \therefore \quad u \propto D N$$

$$u = K_v \sqrt{2 g H_m} \quad , \quad V_f = C_v \sqrt{2 g H}$$

$$u \propto V_f \propto \sqrt{H_m}.$$

$$\sqrt{H_m} \propto D N$$

$$Q \propto D^2 V_f$$

$$Q \propto \frac{H_m}{N^2} \times V_f$$

$$\propto \frac{H_m}{N^2} \times \sqrt{H_m}$$

Scanned with CamScanner

→ Specific speed of centrifugal pump (N_s).

A specific speed of a centrifugal pump is defined as the speed of geometrically similar pump which would deliver one cubic metre liquid per second against a head of one m[illegible]. It is denoted by N_s.

$Q = A \times V = \pi D B V_f$

$Q \propto D B V_f$

$\therefore \; B \propto D$

$Q \propto B^2 V_f$

$u \propto \frac{\pi D N}{60} \quad \therefore \; u \propto D N$

$u = K_u \sqrt{2 g H_m}, \; V_f = C_v \sqrt{2 g H}$

$u \propto V_f \propto \sqrt{H_m}.$

$\sqrt{H_m} \propto D N$

$Q \propto D^2 V_f$

$Q \propto \frac{H_m}{N^2} \times V_f$

$\propto \frac{H_m}{N^2} \times \sqrt{H_m}$

$Q \propto \frac{H_m^{3/2}}{N^2}$

$Q = K \frac{H_m^{3/[illegible]}}{N^2}$

for $H_m = 1\,m$[illegible]

$Q = 1\,m^3/s, \; N =$ [illegible]

$1 = K \frac{(1)^{3/2}}{(N_s)^2}$

$N_s^2 = K$

$Q = N_s^2 \frac{H_m^{[illegible]}}{N^{[illegible]}}$

$N_s =$ [illegible]

Specific speed of centrifugal pump (N_s).

A specific speed of a centrifugal pump is defined as the speed of geometrically similar pump which would deliver one cubic metre of liquid per second against a head of one metre. It is denoted by N_s.

$$Q = A \times V = \pi D B V_f$$

$$Q \propto D B V_f$$

$$\therefore B \propto D$$

$$Q \propto B^2 V_f$$

$$u \propto \frac{\pi D N}{60} \quad \therefore u \propto D N$$

$$u = K_v \sqrt{2gH_m}, \quad V_f = C_v \sqrt{2gH}$$

$$u \propto V_f \propto \sqrt{H_m}.$$

$$\sqrt{H_m} \propto D N$$

$$Q \propto D^2 V_f$$

$$Q \propto \frac{H_m}{N^2} \times V_f$$

$$\propto \frac{H_m}{N^2} \times \sqrt{H_m}$$

$$Q \propto \frac{H_m^{3/2}}{N^2}$$

$$Q = K \frac{H_m^{3/2}}{N^2}$$

For $H_m = 1\,m$, $Q = 1\,m^3/s$, $N = N_s$

$$1 = K \frac{(1)^{3/2}}{(N_s)^2}$$

$$N_s^2 = K$$

$$Q = N_s^2 \frac{H_m^{3/2}}{N^2}$$

$$N_s = N \sqrt{Q}$$

Scanned with CamScanner

(7) Model testing of centrifugal pumps.

(i) $(N_s)_m = (N_s)_p$

$$\left(\frac{N\sqrt{Q}}{(H_m)^{3/4}}\right)_m = \left(\frac{N\sqrt{Q}}{(H_m)^{3/4}}\right)_p$$

(2) $u = \frac{\pi D N}{60}$ $\quad \because u \propto \sqrt{H_m}$

$\sqrt{H_m} \propto DN$

$\frac{\sqrt{H_m}}{DN} = \text{const.}$

$$\left(\frac{\sqrt{H_m}}{DN}\right)_m = \left(\frac{\sqrt{H_m}}{DN}\right)_p$$

(3) $Q \propto D^2 V_f$

$\propto D^2 \times DN$ $\quad u \propto V_f \propto DN$

$\propto D^3 N$

$\frac{Q}{D^3 N} = \text{const}$ $\quad \therefore \left(\frac{Q}{D^3 N}\right)_m = \left(\frac{Q}{D^3 N}\right)_p$

n power = $\frac{\rho Q g H_m}{75}$

$P \propto Q H_m$

$Q \propto D^3 N$, $H_m \propto D^2 N^2$

$P \propto D^3 N \times DN$

$P \propto D^4 N^2$ $\therefore \frac{P}{D^5 N^3} = C.$

$$\left(\frac{P}{D^5 N^3}\right)_m = \left(\frac{P}{D^5 N^3}\right)_p$$

Scanned with CamScanner

19.18 A single stage cent. pump with impeller diameter of 30 cm rotates at 2000 rpm and lifts 3 m^3 of water per second to a height of 30 m with an efficiency of 75%. Find the no. of stages and diameter of each impeller of a similar multistage pump to lift 5 m^3 of water per second to a height of 200 m when rotating at 1500 rpm

Total height

$D_1 = 30cm = 0.3 m$, $N_1 = 2000$ rpm

$Q_1 = 3 m^3/s$ $H_{m_1} = 30 m$, $\eta_{man} = 0.75$

$Q_2 = 5 m^3/s$, $H = 200 m$, $N_2 = 1500$

D_2

(i) $$\left(\frac{N\sqrt{Q}}{(H_m)^{3/4}}\right)_m = \left(\frac{N\sqrt{Q}}{(H_m)^{3/4}}\right)_p$$

$$\left(\frac{2000 \times \sqrt{3}}{(30)^{3/4}}\right)_m = \left(\frac{1500 \times \sqrt{5}}{(H_m)^{3/4}}\right)_2$$

$h_{m_2} = 28.71 m.$

No. of stage $= \frac{\text{Total head}}{\text{Head / stage}}$

$= 200 / 28.71$

= 7 ...

Page No.
Date :

$$\frac{\sqrt{H m_1}}{D_1 N_1} = \frac{\sqrt{H m_2}}{D_2 N_2}$$

$$\frac{\sqrt{30}}{0.30 \times 2000} = \frac{\sqrt{28.71}}{D_2 \times 1500}$$

$$D_2 = 391.3 \text{ mm}$$

(7) CAVITATION

It is phenomenon of formation of vapour bubbles of a flowing liquid in a region where the pressure of liquid falls below its vapour pressure and sudden collapsing of these vapour bubbles in a region of higher pressure.

When vapour bubbles collapse, a very high pressure is created. The metallic surfaces, above which these vapour bubble collapse, is subjected to these high pressure, which is causing pitting action on the surface. Thus cavities are formed on metalic surface, also considerable noise and vibrations are produced.

Cavitation includes formation of vapour bubbles of the flowing liquid and collapsing of these vapour bubbles. Formation of vapour bubbles of the flowing liquid take place only whenever the pressure in any region falls below vapour pressure. When the pr of liquid falls below the vapour pressure, liquid starts boiling and vapour bubbles are formed. These vapour bubbles are carried along with the flowing liquid to higher pressure zones where these vapour condense and bubbles collapse. Due to sudden collapsing of these bubbles on metalic surface, high pr is produced and metalic surfaces are subjected to high local stresses. Thus the surfaces are damaged.

Thoma's cavitation factor for centrifugal pump.

$$\sigma = \frac{(H_b) - H_s - h_{Ls}}{H}$$

$$= \frac{(H_{atm} - H_v) - H_s - h_{Ls}}{H}$$

Effects of cavitation

- The metalic surfaces are damaged and cavities are formed on the surface.
- Due to sudden collapse of vapour bubble, considerable noise and vibration are produced.
- The efficiency of turbine blades decrease due to cavitation. Due to pitting action on the surface of liquid, turbine blade becomes rough and force on the turbine blades decreases. which reduces corrosion and it reduces eff.