Module - 2

Centrifugal pump

Pump :

It is a hydraulic machine which converts mechanical energy into hydraulic energy.

There are 2 types of pumps :

i) **Positive displacement pump** :- The amount of water entering to the pump which discharges completely in this types of pump.

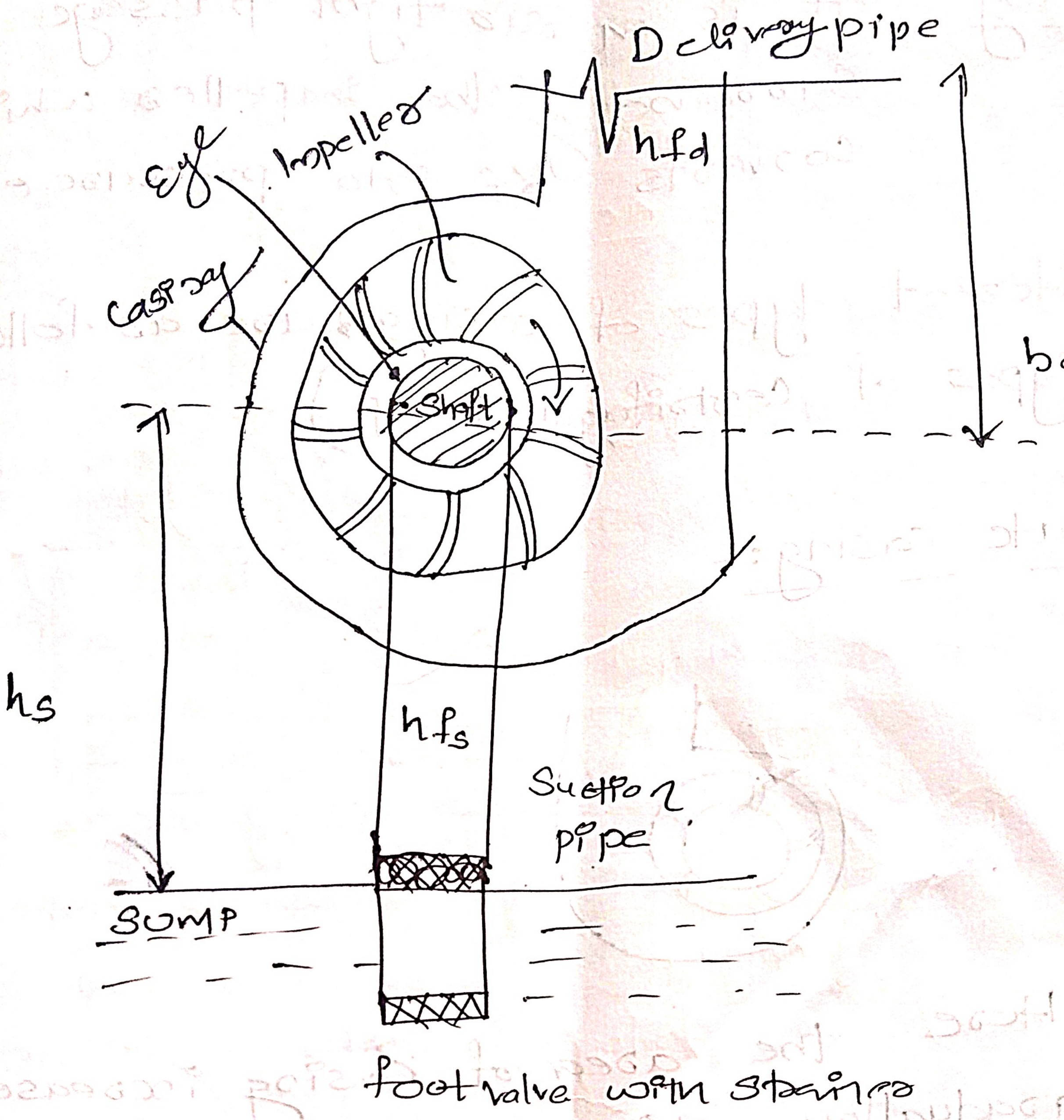
Eg : Reciprocating pump.

ii) **Roto dynamic pump** :- Here the working principle is, due to the rotation or centrifugal action of a machine component.

Eg : Centrifugal pump.

Centrifugal pump

Centrifugal pump



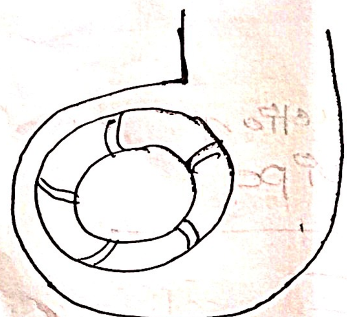
1) Impeller : The rotating part of a Centrifugal pump is called impeller which consist of series of backward curved vanes. The centre of impeller is called eye. The motor shaft is coupled to the

impeller

ii) **Casing:** It is an air-tight passage surrounding the impeller which converts KE into pressure energy.

⇒ Different types of casings are as follows:- (Types of centrifugal pump).

a) **Volute casing:-**

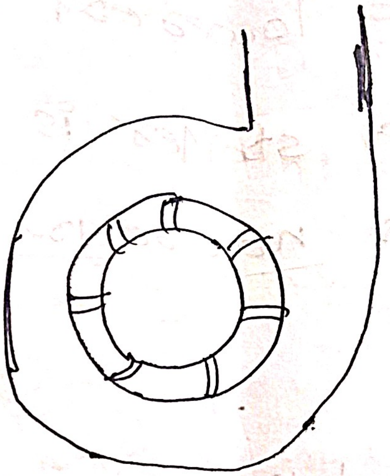


Here the area of casing increases gradually which decreases the velocity head and convert it into equivalent pressure head.

(2)

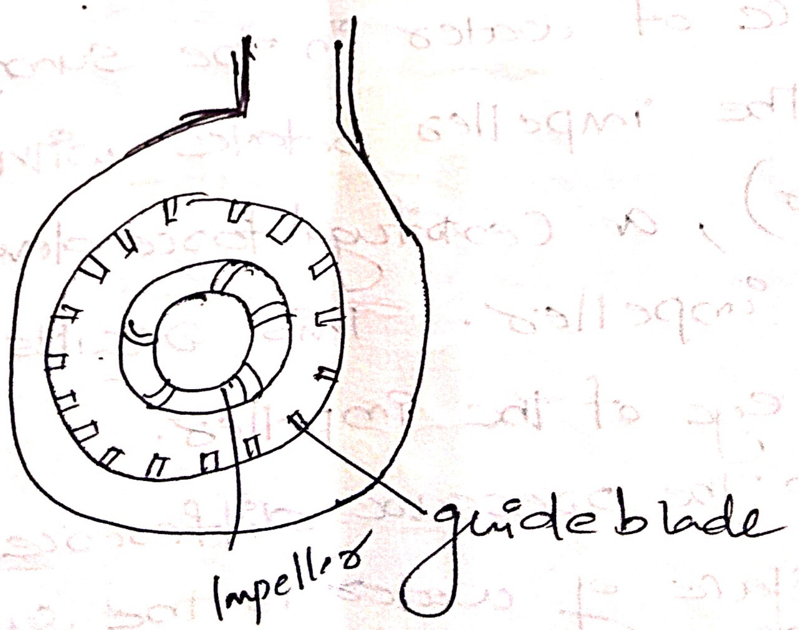
⇒ Formation of Eddie's which can cause a slight decrease in efficiency of pump in this type of casing

b) Vortex casing :



In this type of casing, the chance of formation of Eddies is less compared to volute casing. The area of casing is almost uniform throughout

c) Diffuser pump / Centrifugal pump with a diffuser



3) Suction pipe :

At the lower end of suction pipe, a foot valve with a strainer is ~~fitted~~. ~~for~~

- foot valve is a non return valve

4) Delivery pipe :

The delivery system or tank can be connected to the pump through delivery pipe.

Working Principle :

The pressure acting at the free surface of water in the sump is atmospheric

- when the impeller rotates with a prime mover (motor), a centrifugal force develops at the eye of the impeller. This results a -ve pressure at the eye of the impeller.

Due to the pressure difference b/w eye and free surface of water in the sump, the water enters from high pressure side to lower pressure side.

Priming in centrifugal pump : It is the operation in which the suction pipe, casing of the pump and a portion of delivery pipe upto delivery valve it is completely filled with water before starting the pump.

VR
KTU

When air is present in the pump, the pressure head developed at the eye is in terms of meters of air but the density of air is less than that of water. Therefore there is a lack of sufficient pressure head for the pumping action. To overcome this, fill the pump with water.

Cavitation in turbines and Pumps

VR

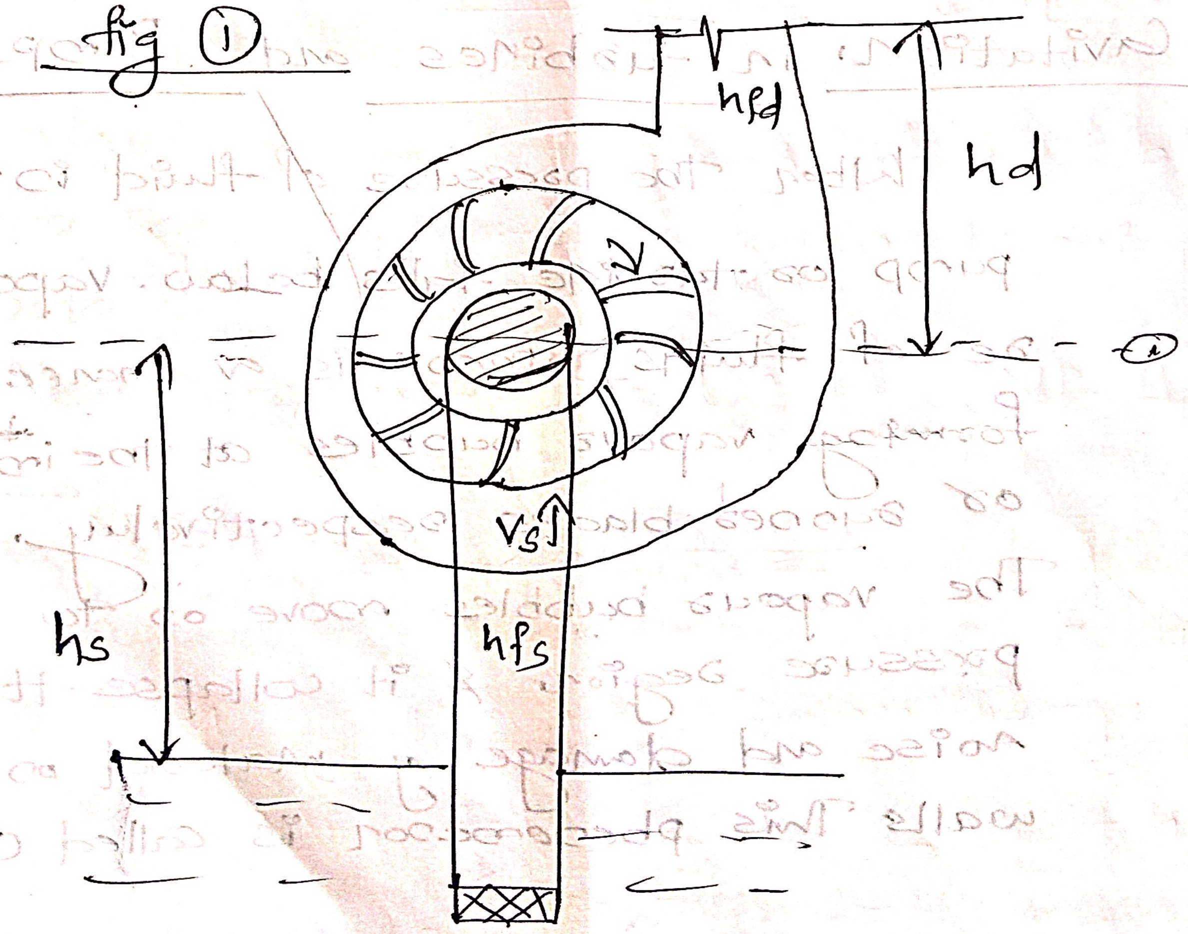
When the pressure of fluid in the pump or turbine falls below vapour pressure of fluids, there is a chance of forming vapour bubbles at the impeller or runner blades respectively. The vapour bubbles move on to high pressure region & it collapse. It makes noise and damage of material on pipe walls. This phenomenon is called cavitation.

Preventive methods :

- Always maintain the pressure of fluids greater than its vapour pressure. for eg: in case of water the water pressure in the pump or turbine donot falls below 2.5m of water.
- Provide a coating such as stainless steel or aluminium alloys at the affected areas.

Maximum suction lift

fig ①



Consider 2 sections at centre of the pump ~~&~~ at the free surface of water in the sump.
Apply Bernoulli's equ while taking free surface of liquid taken as datum.

$$\frac{P_a}{\rho g} + \frac{V_a^2}{2g} + Z_a = \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 + h_{fs} \quad \text{—(1)}$$

$\frac{V_a^2}{2g} = 0$, $Z_a = 0$, $Z_1 = h_s$, $V_1 = V_s$

Velocity at the free surface of liquid is $= 0$

$$\frac{V_a^2}{2g} = 0.$$

$Z_a = 0$

$Z_1 =$ Suction head (h_s)

$V_1 =$ Velocity at section 1 = Velocity in the suction pipe

$V_1 = V_s$

To reduce or eliminate cavitation, the pressure at section 1 is always greater than vapour pressure,

$$\frac{P_1}{\rho g} \geq \frac{P_v}{\rho g} \quad \text{or} \quad \frac{P_1}{\rho g} = \frac{P_v}{\rho g}$$

$$\therefore \frac{P_a}{\rho g} = \frac{P_v}{\rho g} + \frac{V_s^2}{2g} + h_s + h_{fs}$$

$$\frac{P_a}{\rho g} - \frac{P_v}{\rho g} + \frac{V_s^2}{2g} - h_{fs} = h_s$$

But $\frac{P_a}{\rho g} = H_a$, $\frac{P_v}{\rho g} = H_v$

$$\boxed{h_s = H_a - \left(H_v + \frac{V_s^2}{2g} + h_{fs}\right)}$$

Note: We have $P_a = 101325\ N/m^2$

$\therefore \frac{P_a}{\rho g} = \frac{101325}{9810} = 10.3$ m of water

$\therefore$ in centrifugal pump the possible suction lift always below 10.3m.

Net positive suction head: (NPSH)

$$NPSH = \frac{P_1}{\rho g} - \frac{P_v}{\rho g} + \frac{V_s^2}{2g}$$

$\Leftarrow$ from fig ①, Apply Bernoulli's equ, we have $\frac{P_a}{\rho g} = \frac{P_1}{\rho g} + \frac{V_s^2}{2g} + h_s + h_{fs}$

$$\frac{P_1}{\rho g} = \frac{P_a}{\rho g} - \frac{V_s^2}{2g} - h_s - h_{fs}$$

$$\therefore NPSH = \frac{P_a}{\rho g} - \cancel{\frac{V_s^2}{2g}} - h_s - h_{fs} - \frac{P_v}{\rho g} + \cancel{\frac{V_s^2}{2g}}$$

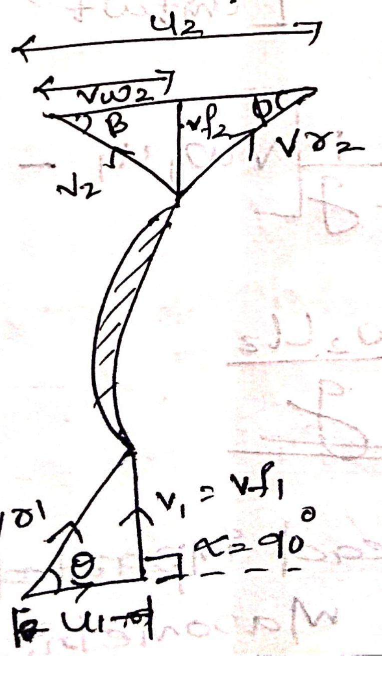
$$NPSH = \frac{P_a}{\rho g} - \frac{P_v}{\rho g} - h_s - h_{fs}$$

$$\frac{P_a}{\rho g} \quad \boxed{NPSH = H_a - H_v - h_s - h_{fs}}$$

Workdone by the impeller in a centrifugal pump.

To get maximum efficiency the water enters radially in a centrifugal pump. ie, radial at inlet $[V_{w_1}=0]$

ie, $V_{w_1} = 0$ & $\alpha = 90°$.



Centrifugal pump is a reverse inward flow reaction turbine.

for an inward flow reaction turbine,

$$\frac{WD/s}{\text{unit wt}/s} \text{ or } \frac{WD}{\text{unit wt}} = \frac{\rho a V_1 [V_{w_1}u_1 \pm V_{w_2}u_2]}{\rho g Q}$$

$$= \frac{\rho \cancel{a V_1} [V_{w_1}u_1 \pm V_{w_2}u_2]}{\rho g \cancel{a V_1}}$$

$$= \left[\frac{V_{w_1}u_1 \pm V_{w_2}u_2}{g}\right]$$

$$= \frac{1}{g}\left[V_{w_1}u_1 \pm V_{w_2}u_2\right]$$

WD/unit wt of a turbine

$$= -\left[\frac{WD}{\text{unit wt}} \text{ of centrifugal pump}\right]$$

$$= -\left(\frac{1}{g}\left[V_{w_1}u_1 - V_{w_2}u_2\right]\right)$$

$$= \frac{V_{w_2}u_2}{g}$$

It is the head imparted by the impeller on water. = Manometric head.

$V_{w_2} C_2$

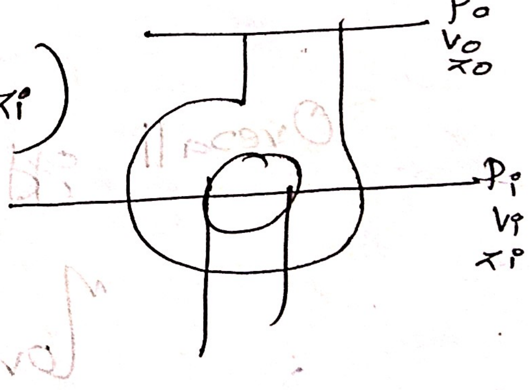
(Hm) <u>Manometric head</u>: H is the head of pump by the impeller on water or H is the working head of a centrifugal pump. H is also defined as the difference b/w head imparted by the water and loss of head in the pump.

$$H_m = \frac{V_{w_2} u_2}{g} - \text{Head loss}$$

⇒ Another methods to find manometric head areas:

Hm = Total head at outlet of the pump − Total head at inlet of the pump

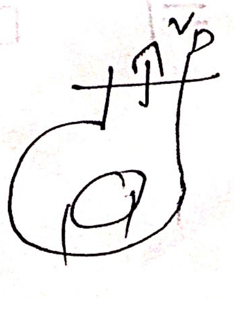
$$\frac{P_o}{\rho g} + \frac{V_o^2}{2g} + z_o - \left(\frac{P_i}{\rho g} + \frac{V_i^2}{2g} + z_i\right)$$



$\frac{P_o}{\rho g} + V_o^2$ .. $H_m = \frac{V_{w_2} u_2 - 11}{g}$ V_{w_2}

⇒ Another Method : Adding all heads above the free surface of water in the sump

$$H_m = h_s + h_d + h_{fs} + h_{fd} + \frac{V_D^2}{2g}$$



⇒ Efficiencies of Centrifugal pump

Manometric efficiency, η_{mano} = $\dfrac{\text{Manometric head}}{\text{Head imparted by the impeller}}$

$$\boxed{\eta_{mano} = g \cdot \frac{H_m}{V_{w_2} u_2}}$$

$\eta = \dfrac{H_m}{V_w}$

Mechanical efficiency:

$$\eta_{mech} = \frac{WD/s}{\text{Shaft power}}$$

$\eta \; WD/s$

Overall efficiency:

$$\eta_{overall} = \frac{\text{Manometric head}}{\text{Head imparted by impeller}}$$

⇒ Discharge through the pump

$Q = \pi D_1 B_1 V_{f_1}$

$Q = \pi B D_1$

$$Q = \pi D_1 B_1 V_{f_1}$$
$$= \pi D_2 B_2 V_{f_2}$$

where D_1 - Inner diam of the impeller

D_2 - Outer diam " " "

find diam of impo? D_2

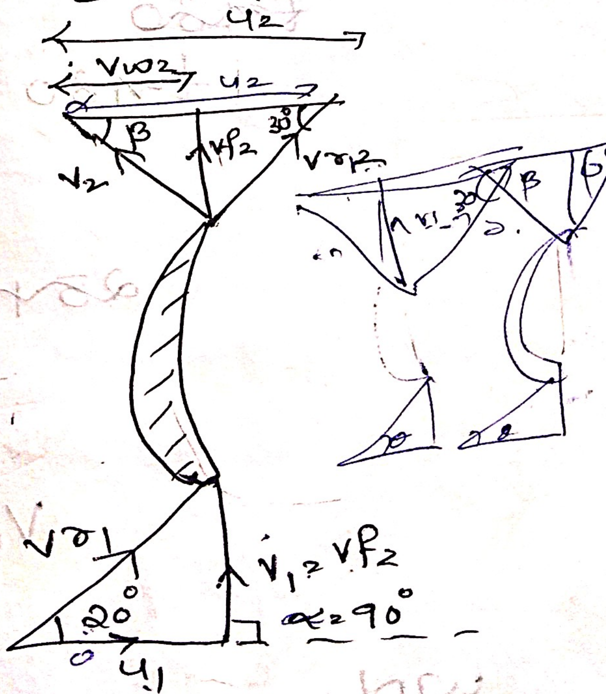
2) The internal & external diam of impeller of centrifugal pump 200mm and 400mm respectively. The pump is running at 1200rpm. Vain angle of at inlet & outlet are 20° & 30° respectively. The water enters the impeller radially & velocity of flow is constant throughout. find the workdone per unit of water.

$D_1 = 200\,mm = 200\times10^{-3}\,m$

$D_2 = 400\,mm = 400\times10^{-3}\,m$

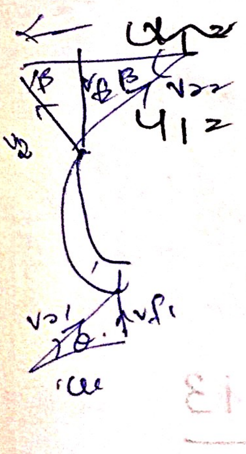
$N = 1200\,rpm$

$\theta = 20^\circ, \quad \phi = 30^\circ$



$Vf_1 = Vf_2$

$$\frac{WD/s}{wt/s} = \frac{Vw_2 u_2}{g}$$



$$u_1 = \frac{\pi D_1 N}{60}$$

$$= \frac{\pi \times 200\times10^{-3}\times1200}{60}$$

$$= 12.56$$

$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 400 \times 10^{-3} \times 1200}{60}$$

$$= \underline{25.13 \, m/s}$$

$$\tan 20^\circ = \frac{V_{f_1}}{u_1} = \frac{V_{f_1}}{12.56}$$

$$\underline{V_{f_1} = 4.571 \, m/s}$$

$$V_{f_1} = V_{f_2} = 4.571 \, m/s$$

$$\tan 30 = \frac{V_{f_2}}{u_2 - V_{w_2}}$$

$\cancel{\tan 30}$

$$\tan 30 = \frac{4.571}{25.13 - V_{w_2}}$$

$$\cancel{25.13 - V_{w_2} = \frac{4.571}{\tan 30}}$$

$$\underline{V_{w_2} = 17.212 \, m/s}$$

$$\frac{WD/s}{Wt/s} = \frac{V_{w_2} u_2}{g} = \frac{17.212 \times 25.13}{9.81}$$

$$= \underline{44.1 \, J/N}$$

8) A centrifugal pump is to discharge $0.118\ m^3/s$ at a speed of 1450 rpm. Against a head of 25m. The impeller diam is 250 mm. & and its width is 50 mm. η_{mano} is 75%. Determine the vane angle at outlet of the impeller.

VQ

$Q = 0.118\ m^3/s$

$N = 1450\ rpm$

$H_m = 25\ m$

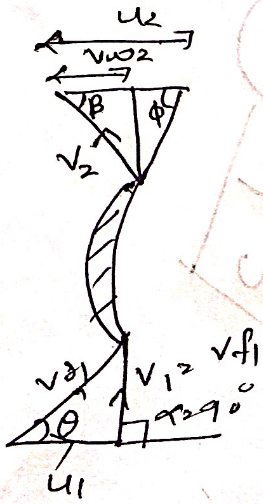
$D_2 = 250\ mm = 250 \times 10^{-3}\ m$, $B_2 = 50\ mm$

$\eta_{man} = 0.75$

$Q = \pi D_2 B_2 V_{f_2}$

$$\frac{0.118}{\pi \times 250 \times 10^{-3} \times 50 \times 10^{-3}} = V_{f_2}$$

$V_{f_2} = 3\ m/s$



$$\tan\phi = \frac{V_{f_2}}{u_2 - V_{w_2}}$$

$$u_2 = \frac{\pi D_2 N}{60} = 18.98\ m/s$$

$$\tan\phi = \frac{3}{18.98}$$

$$\eta_{mano} = \frac{gH_m}{V_{w_2} u_2}$$

$$V_{w_2} = \frac{9.81 \times 25}{0.75 \times 18.98}$$

$$V_{w_2} = 17.22 \text{ m/s}$$

$$\tan\phi = \frac{3}{18.98 - 17.22}$$

$$\phi = 59.6^\circ$$

2) UQ KTU

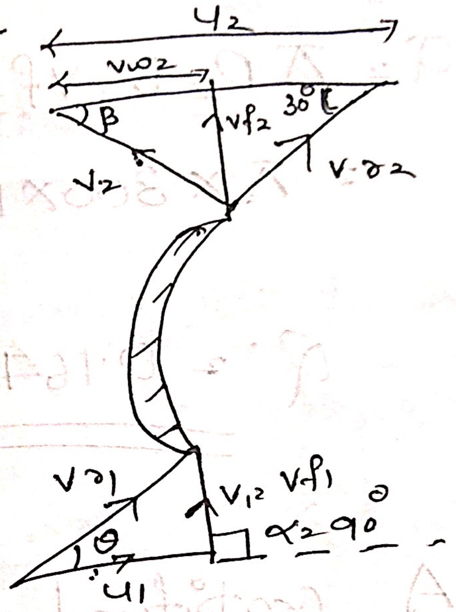
A centrifugal pump delivers water against a net head of 14.5m & a design speed of 1000 rpm. The vanes are curved back to an angle of 30° with the periphery. The impeller diam is 300mm & the width is 50mm. Determine discharge of pump if the manometric efficiency is 95%. ?

$H_m = 14.5\,m$, $N = 1000$ rpm

$D_2 = 300\,mm$ $\quad B_2 = 50\,mm$

$= 300\times10^{-3}\,m$ $\quad = 50\times10^{-3}\,m$

$\eta_{mano} = 0.95$ $\quad \phi = 30^\circ$



$Q = \pi D_2 B_2 V_{f_2}$

$$\tan 30^\circ = \frac{V_{f_2}}{u_2 - V_{w_2}}$$

θ ∠β - guide
θ-φ - vane

$$\eta_{mano} = \frac{g H_m}{V_{w_2} u_2}$$

~~tan~~

$$u_2 = \frac{\pi D_2 N}{60}$$

$$u_2 = \frac{\pi \times 300\times10^{-3}\times1000}{60}$$

$= 15.7\,m$

$$V_{w_2} = \frac{9.81\times14.5}{0.95\times15.7}$$

$9.53\ m/s$

$$\tan 30^\circ = \frac{Vf_2}{15.7 - 9.53}$$

$$Vf_2 = 3.562 \text{ m/s}$$

$$Q = \pi D_2 B_2 Vf_2$$

$$= \pi \times 300 \times 10^{-3} \times 50 \times 10^{-3} \times 3.562$$

$$Q = 0.167 \text{ m}^3/\text{s}$$

2)

JR
KTU

A centrifugal pump having outer diam equal to 2 times the inner diam & running at 1000 rpm, works against a total head of 40m. The velocity of flow through the impeller is constant & equal to 2.5 m/s. The vanes are set back at angle of 40° at outlet. If the outer diam of impeller is 500mm & width at outlet is 50mm, determine
i) Vane angle at inlet
ii) Workdone by impeller on water per second.

999) η_{mano}

$D_2 = 2D_1$

$N = 1000\ rpm$

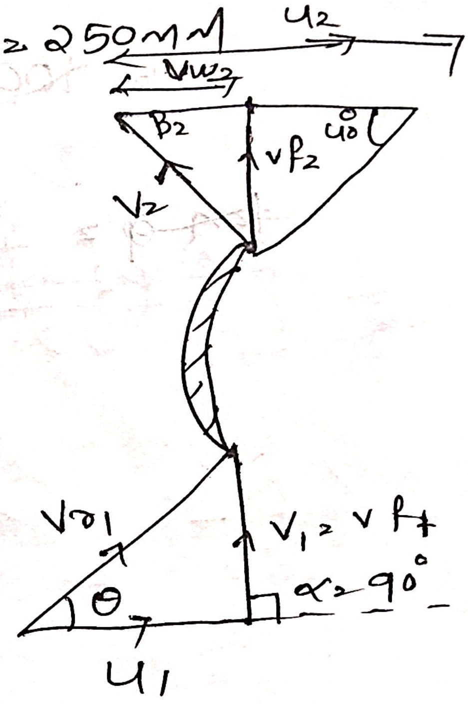
$H_m = 40\ m$

$V_{f_1} = V_{f_2} = 2.5\ m/s$

$\phi = 40^\circ$

$D_2 = 500\ mm$ $D_1 = 250\ mm$

$B_2 = 50\ mm$



$\tan\theta = \dfrac{V_{f_1}}{u_1}$

$u_1 = \dfrac{\pi D_1 N}{60}$

$= \dfrac{\pi \times 250 \times 10^{-3} \times 1000}{60}$

$u_1 = 13.08\ m/s$

$u_2 = \dfrac{\pi D_2 N}{60}$

$= \dfrac{\pi \times 500 \times 10^{-3} \times 1000}{60}$

$= 26.18\ m/s$

$\tan\theta = \dfrac{2.5}{13.08}$

i) $\theta = 10.8^\circ$

ii) $\rho a v_1 (V_{w_2} u_2)$

$a v_1 = Q = \pi D_2 B_2 V_{f_2}$

$= \pi \times 500\times10^{-3} \times 250\times10^{-3} \times 2.5$

$Q = 0.98$

$= 1000 \times 0.98 ($

$\cancel{\tan\phi} = \tan 40^\circ = \dfrac{V_{f_2}}{u_2 - V_{w_2}}$

$\tan 40^\circ = \dfrac{2.5}{26.18 - V_{w_2}}$

$V_{w_2} = \cancel{2.5}\ 23.2\ m/s$

iii) $WD/s = 1000 \times \overset{0.19}{\cancel{0.98}} \times 23.2 \times 26.18$

$= 118952.09$ kW

$= 118.95$

$$\eta_{man} = \frac{gH_m}{V_{w_2} u_2} = \frac{9.81 \times 40}{23.19 \times 26.17}$$

$$= 0.646$$

$$= 64\ \%$$

KTU

Minimum speed for starting a Centrifugal pump

The head available due to the pressure rise in impeller $= \frac{u_2^2}{2g} - \frac{u_1^2}{2g}$

It will be always greater than the working head

ie. $\frac{u_2^2}{2g} - \frac{u_1^2}{2g} > H_m$

$$\boxed{H_m = \frac{u_2^2}{2g} - \frac{u_1^2}{2g}} \rightarrow (1)$$

we have $\eta_{mano} = \frac{g H_m}{V_{w_2} u_2}$

$$H_m = \frac{\eta_{mano} V_{w_2} u_2}{g} \rightarrow (2)$$

Compare ① & ②

$$\frac{u_2^2}{2g} - \frac{u_1^2}{2g} = \frac{\eta_{mano} \times V_{w_2} \times u_2}{g}$$

$$\frac{1}{2g}\left[\left(\frac{\pi D_2 N}{60}\right)^2 - \left(\frac{\pi D_1 N}{60}\right)^2\right] = \frac{\eta_{man} \times V_{w_2}}{g} \frac{\pi D_2 N}{60}$$

$\div$ throughout $\frac{\pi N}{60 g}$

$$\frac{1}{2}\left[\frac{\pi D_2^2 N}{60} - \frac{\pi D_1^2 N}{60}\right] = \eta_{mano} V_{w_2} D_2$$

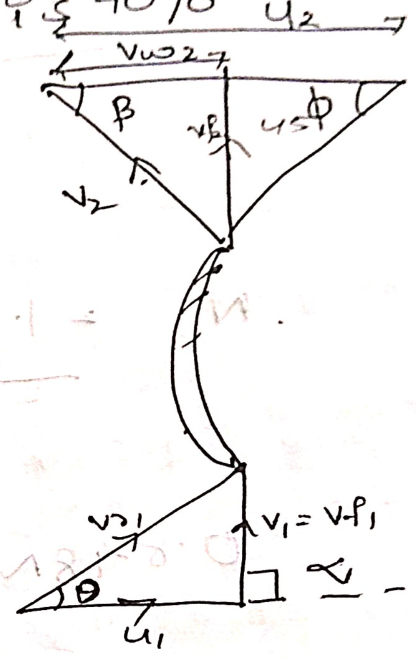
$$\frac{\pi N}{120}\left[D_2^2 - D_1^2\right] = \eta_{mano} V_{w_2} D_2$$

$$\boxed{N = \frac{120 \times \eta_{man} V_{w_2} D_2}{\pi \left[D_2^2 - D_1^2\right]}}$$

$N = \frac{120\, \eta_{ma} V_{w_2} u_2}{\pi}$

$N = \frac{120\, \eta_m V_{w_2} u_2}{\pi}$

Q) The diam of impeller of a centrifugal pump at inlet & outlet are 30 cm & 60cm respectively. velocity of flow at outlet is 2m/s & vanes are set back at an angle of 45°. Determine the minimum speed of pump if the manometric effic is 70%.



$D_1 = 30cm$

$D_2 = 60cm$

$V_{f_2} = 2m/s$

$\phi = 45^0$

$\eta_{mano} = 70\%$

~~$V_{w_2} = gHm$~~ $\tan 45 = \frac{V_{f_2}}{u_2 - V_{w2}}$

$u_2 = \frac{\pi D_2 N}{60}$

$u_2 = \frac{\pi \times 60 \times 10^{-2} \times N}{60}$

$u_2 = 0.0314 \times N$

$V_{w_2} = 0.0314\ N - 2$

$$N = \frac{120 \times \eta_{ma} \, V_{w_2} \, D_2}{\pi \left[D_2^2 - D_1^2 \right]}$$

$$= \frac{120 \times 0.7 \times (0.0314 N - 2) \times 60 \times 10^{-2}}{\pi \left[0.6^2 - 0.3^2 \right]}$$

$$N = \frac{1.5825 N - 100.8}{0.848}$$

$$0.848 N = 1.5825 N - 100.8$$

$$- 0.734 N = -100.8$$

$$\underline{N = 137.32} \text{ rpm}$$

⇒ <u>Specific speed of pump</u>

It is the speed of a geometrically similar pump which would deliver unit discharge against unit head.

we have discharge, $Q = \pi D B V_f$

Let $D = B$

$Q \propto D^2 V_f \rightarrow (1)$

Peripheral velocity, $u = \frac{\pi D N}{60}$

$u \propto DN$

Similarly $u = n\sqrt{2gH_m}$

where n - Speed ratio.

$u \propto \sqrt{H_m}$

$\therefore DN \propto \sqrt{H_m}$

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

Also flow velocity, $V_f = C_V\sqrt{2gH_m}$

$V_f \propto \sqrt{H_m}$

$(1) \Rightarrow Q \propto \frac{H_m}{N^2}\sqrt{H_m}$

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

when $Q = 1$, $H = 1$, $N = N_s$

$\therefore (2) \Rightarrow 1 = \frac{K}{N_s^2}$

$K = N_s^2$

Put this value in ②

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

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

$$\boxed{N_s = \frac{N\sqrt{Q}}{H^{3/4}}}$$

⇒ Cavitation in hydraulic machines.

To find the rate of cavitation, introduce a term called Thoma's cavitation factor (σ)

For a turbine, $\sigma = \frac{H_a - H_v - H_s}{H}$

where H_a - atmospheric head (10.3 m of water)

H_v - Vapour pressure head (0.5 m of water)

H_s - Suction head

H - Net head $= H_g - h_f$

$\Rightarrow$ For a pump, $\sigma = \dfrac{H_a - H_v - H_s - H_{fs}}{H_m}$

where H_m - manometric head.