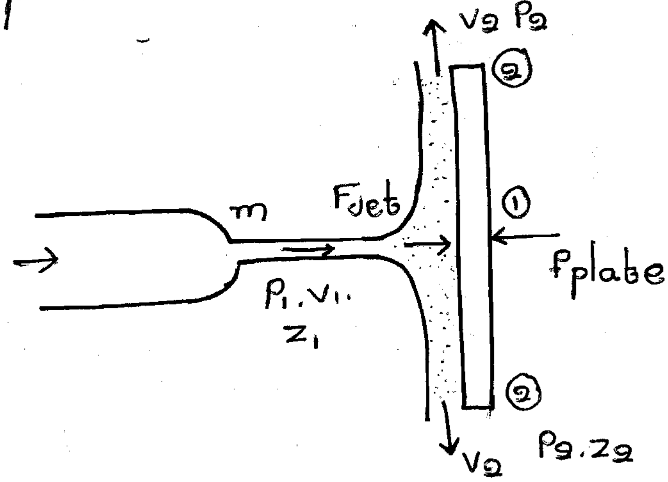
# Fluid Machinery

* Impact of Jet:-




1. Entry point
2. Exit point

Newtons $II^{nd}$ law:-

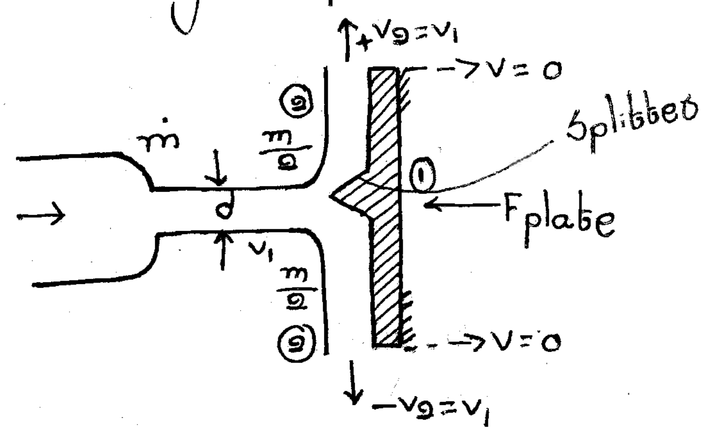
$F_{plate}$ = Rate of change in linear momentum
= [Final Momentum − Initial momentum] of water

$$\boxed{F_{Jet} = -F_{plate} = \dot{m}\bar{v}_1 - \dot{m}\bar{v}_2}$$

→ $\dot{m}$ = mass flow rate of water which strikes the plate.

Aim:-
To find out the impulse or impact force applied by the Jet over the plane.

* Jet strikes stationary flat plate in normal direction:-



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

$\boxed{P_1 = P_{atm} = P_2}$

$\boxed{z_1 = z_2}$

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

$Q = AV_1$

$\dot{m} = \rho a V_1 = \rho Q$

$\dot{n} = \rho a V_1$

$x = F_N = \dot{m} \times V_1 - [\frac{\dot{m}}{2} \times 0 + \frac{\dot{m}}{2} \times 0]$

$\boxed{x = F_N = \dot{m} V_1 = \rho a V_1^2 \ N}$

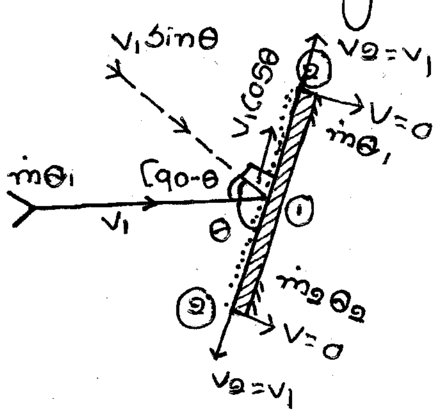
$y = F_T = \dot{m} \times 0 - [\frac{\dot{m}}{2} \times V_2 + \frac{\dot{m}}{2} \times (-V_2)]$

$\boxed{y = F_T = 0}$

ote:-

hen jet strikes over flat plate then it will apply the force nly in normal direction of plate, there will not be any force in angantial direction to plate.

Jet strikes stationary inclined plane:-




$\dot{m} = \dot{m}_1 + \dot{m}_2$

$Q = Q_1 + Q_2$ —①

$\boxed{\dot{m} = \rho a V_1}$

$F_N = \dot{m} \times V_1 \sin\theta - [\dot{m}_1 \times 0 + \dot{m}_2 \times 0]$

$\boxed{F_N = \dot{m} V_1 \sin\theta = \rho a V_1^2 \sin\theta}$

$F_x = F_N \sin\theta = \rho a V_1^2 \sin^2\theta \ N$

$\boxed{F_y = F_y \cos\theta = \rho a V_1^2 \sin\theta \cos\theta \ N}$

$\boxed{F_T = 0}$

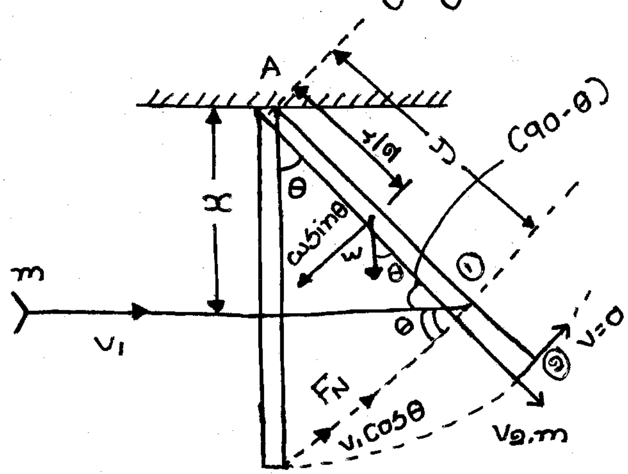
$\dot{m} \times V_1 \cos\theta - [\dot{m}_1 \times V_2 + \dot{m}_2 (-V_2)] = 0$

$\rho Q v_1 \cos\theta - \rho Q_1 v_1 + \rho Q_2 v_1 = 0$

$Q\cos\theta = Q_1 + Q_2 \quad -(ii)$

$\boxed{Q = Q_1 + Q_2} \quad -(i)$

## * Jet strikes vertical hanging plate:-




$l$ = length of pipe

$\omega$ = wt of plate = Mg

$\boxed{\Sigma M_A = 0}$

$F_N \cdot y = \omega \sin\theta \cdot \frac{l}{2}$

$\dot{m} = \rho a v_1$

$F_N = \dot{m} v_1 \cos\theta - \dot{m} \times 0$

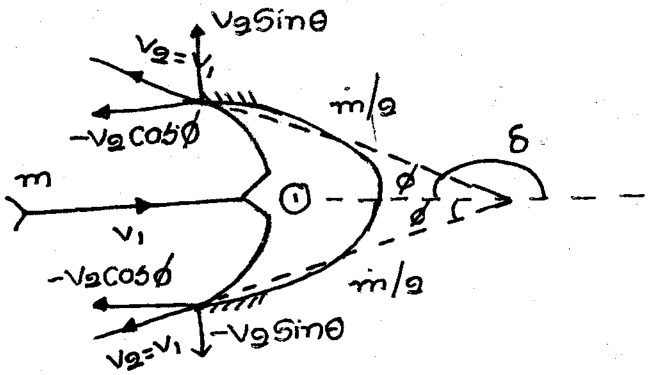
$F_N = \dot{m} v_1 \cos\theta = \rho a v_1^2 \cos\theta$

$\cos\theta = \frac{x}{y} \Rightarrow y = \frac{x}{\cos\theta}$

$\rho a v_1^2 \cancel{\cos\theta} \times \frac{x}{\cancel{\cos\theta}} = \omega \sin\theta \times \frac{l}{2}$

$$\boxed{\sin\theta = \frac{2\rho a v_1^2 x}{\omega l}}$$

## * Jet strikes at the Centre of stationary Curved plate/blade:-




$\phi$: Vane angle at exit

$\delta$ = Angle of Deflection

$\delta = [180 - \phi]$

$m = \rho a V_1$

$F_x = m \times V_1 - \left[\frac{m}{2}(-V_2\cos\phi) + \frac{m}{2}(-V_2\cos\phi)\right]$

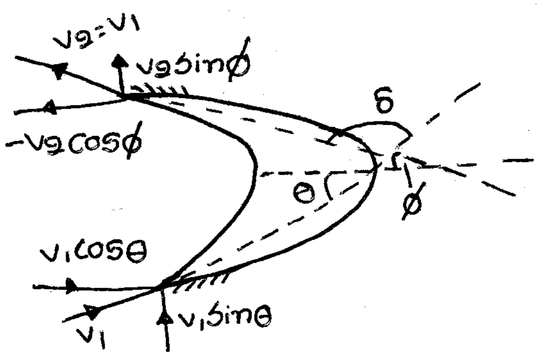
$F_x = \dot{m}V_1 + \dot{m}V_2\cos\phi$

$\boxed{F_x = \dot{m}V_1[1+\cos\phi]}$

$F_y = \dot{m}\times 0 - \left[\frac{\dot{m}}{2}V_2\sin\phi + \frac{\dot{m}}{2}(-V_2\sin\phi)\right]$

$\boxed{F_y = 0}$

## * Jet strikes at the tip of stationary Vane:-




· unsymmetrical vane $[\theta \neq \phi]$

· stationary vane $[\theta = \phi]$

$\theta$ = Vane angle at entry

$\phi$ = Vane angle at exit

$\delta$ = Angle of Deflection

$\delta = 180 - [\theta + \phi]$

$\dot{m} = \rho a V_1$

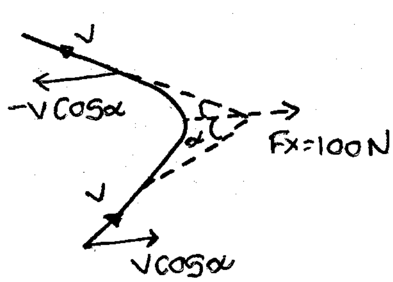
$F_x = \dot{m}V_1\cos\theta - \dot{m}(-V_2\cos\phi)$

$\boxed{F_x = \dot{m}V_1[\cos\theta + \cos\phi]}$

$F_y = \dot{m}V_1\sin\theta - \dot{m}V_2\sin\phi$

$\boxed{F_y = \dot{m}V_1[\sin\theta - \sin\phi]}$

).




$V = 20\,m/s$ $\quad m = 5\,kg/sec$

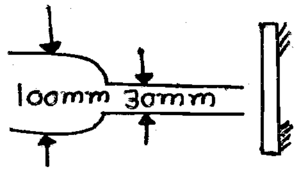
$F_x = \dot{m}V\cos\alpha - \dot{m}(-V\cos\alpha)$

$F_x = 2\dot{m}V\cos\alpha$

$100 = 2 \times 5 \times 20\cos\alpha$

$\boxed{\alpha = 60^\circ}$

67.




$Q = 15\,\text{lit/sec}$

$Q = \frac{\pi}{4} d^2 \times V_1$

$15 \times 10^{-3} = \frac{\pi}{4} (0.03)^2 \times V_1$

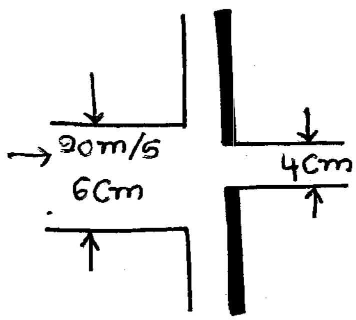
$V_1 = 21.22\,m/s$

$F = \rho a v_1^2$

$F = 1000 \times \left[\frac{\pi}{4} \times 0.03\right]^2 \times 21.22^2$

$\boxed{F = 318.3\,N}$

71.

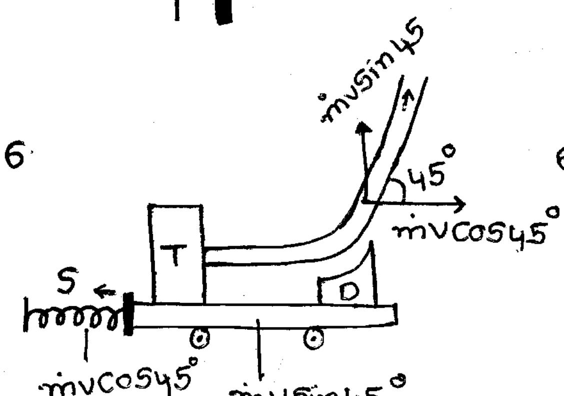



$F = \rho a v_1^2$

$= 1000 \times \left[\frac{\pi}{4} (0.06^2 - 0.04^2)\right] \times 20^2$

$\boxed{F = 628.3\,N}$

6.




$V = 4\,m/s$

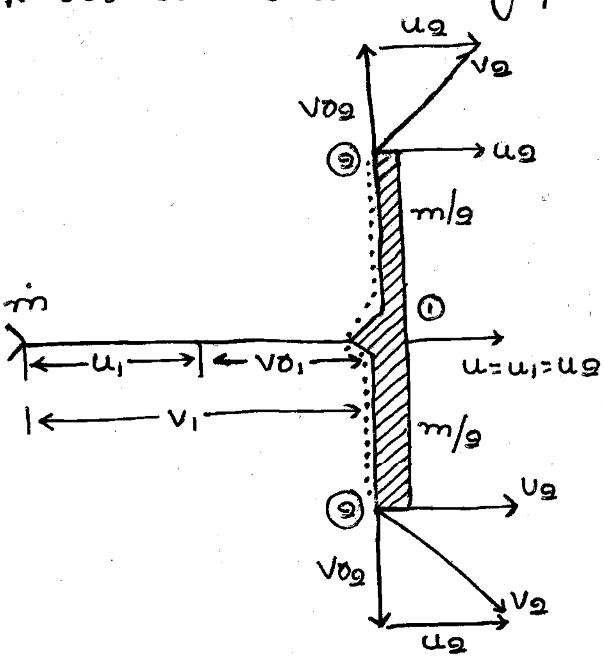
$Q = 0.1\,m^3/sec$

$F_{Spring} = F_{Trolley} = \dot{m} v \cos 45^\circ$

$= (1000 \times 0.1) \times 4 \times \frac{1}{\sqrt{2}}$

$= \frac{400}{\sqrt{2}} = 200\sqrt{2}\,N$

## * Jet strikes the moving flat plate:-




$\boxed{v_2 << v_1 \rightarrow \text{Due to impulse force}}$

$\boxed{P_1 = P_2 = P_{atm}}$ $\boxed{z_1 = z_2}$

$u$ = velocity of plate/vane

$v_r$ = Relative velocity of water w.r.t plate

$v_1, v_2$ = Absolute velocity of " " ground

$$\dot{m} = \rho a v_{r1} = \rho a [v_1 - u_1]$$

$$F_x = \dot{m} \times v_1 - \left[\frac{\dot{m}}{2} \times u_2 + \frac{\dot{m}}{2} \times u_2\right] \quad [\because u_2 = u_1]$$

$$F_x = \dot{m} v_1 - \dot{m} u_1 = \dot{m}(v_1 - u_1)$$

$$\boxed{F_x = \rho a [v_1 - u_1]^2 \, N}$$

$$F_y = \dot{m} \times 0 - \left[\frac{\dot{m}}{2} \times v_{r2} + \frac{\dot{m}}{2} \times (-v_{r2})\right]$$

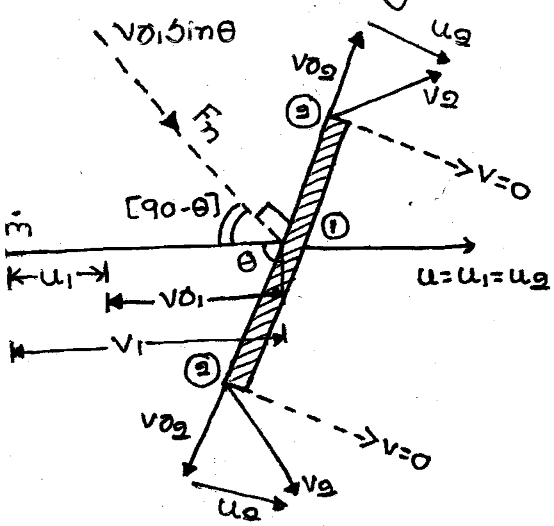
$$\boxed{F_y = 0}$$

$$\frac{WD}{Sec} = F_x \cdot u = Power = \rho a [v_1 - u_1]^2 \cdot u \text{ watt}$$

$$\cancel{\frac{P_1}{\rho g}} + \frac{v_{r1}^2}{2g} + \cancel{z_1} = \cancel{\frac{P_2}{\rho g}} + \frac{v_{r2}^2}{2g} + \cancel{z_2} + \underset{\neq 0}{\overset{+0}{h_f}}$$

$$\cancel{\frac{P_1}{\rho g}} + \frac{v_1^2}{2g} + \cancel{z_1} = \cancel{\frac{P_2}{\rho g}} + \frac{v_2^2}{2g} + \cancel{z_2} + \underset{\neq 0}{\underset{+0}{h_f}} + \frac{W.D}{mg}$$

## * Jet strikes moving inclined plate:-




$$\boxed{\dot{m} = \rho a v_{r1} = \rho a [v_1 - u_1]}$$

$$F_N = \dot{m} \times v_{r1} \sin\theta - [\dot{m}_1 \times 0 + \dot{m}_2 \times 0]$$

$$F_N = \dot{m} v_{r1} \sin\theta$$

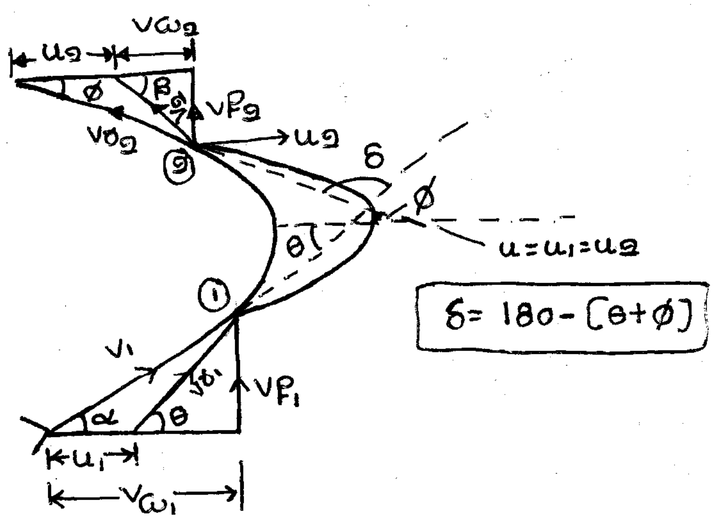
$$\boxed{F_N = \rho a [v_1 - u_1]^2 \sin\theta}$$

$$\boxed{F_x = F_N \sin\theta = \rho a [v_1 - u_1]^2 \sin\theta}$$

$$\boxed{F_y = F_N \cos\theta = \rho a [v_1 - u_1]^2 \sin\theta \cos\theta}$$

$$\frac{WD}{Sec} = F_x \cdot u = \rho a [v_1 - u_1]^2 \sin^2\theta \cdot u \quad \text{watt}$$

* Jet strikes the tip of moving vane:-




$\boxed{\delta = 180 - [\theta + \phi]}$

$\alpha \rightarrow$ Nozzle angle

$\beta \rightarrow$ Angle @ which water leaves the vane

$V_w$ - velocity of whirl

$V_F$ - velocity of flow

$\dot{m} = \rho a V_{r_1}$

$F_x = \dot{m} \times V_{w_1} - \dot{m} \times (-V_{w_2})$

$\boxed{F_x = \dot{m}[V_{w_1} + V_{w_2}] \ N}$

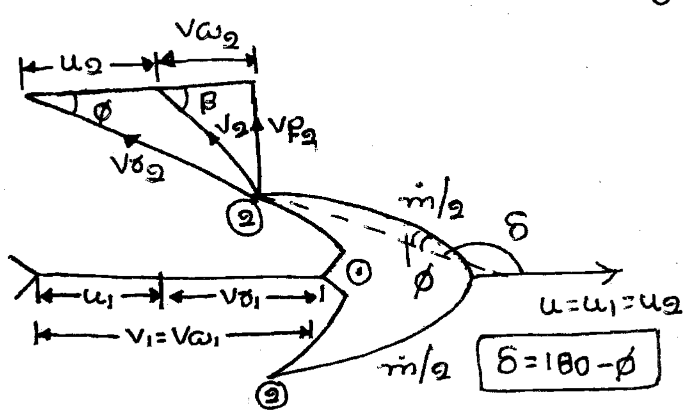
$F_y = \dot{m} \times V_{f_1} - \dot{m} \times V_{f_2}$

$\boxed{F_y = \dot{m}[V_{f_1} - V_{f_2}] \ N}$

Note:-
For shockless entry & exit the direction of $V_{r_1}$ & $V_{r_2}$ should be tangential to vane.

$\frac{W.D}{Sec} = F_x \cdot u = \dot{m}[V_{w_1} + V_{w_2}]u$ watts

* Jet strike at centre of moving vane:-




$\boxed{\delta = 180 - \phi}$

$\boxed{\dot{m} = \rho a V_{r_1} = \rho a [V_1 - u_1]}$

$F_x = \dot{m} \times V_{w_1} - \left[\frac{\dot{m}}{2}(-V_{w_2}) + \frac{\dot{m}}{2}(-V_{w_2})\right]$

$F_x = \dot{m} V_{w_1} + \dot{m} V_{w_2}$

$\boxed{F_x = \dot{m}[V_{w_1} + V_{w_2}]}$

$F_y = \dot{m} \times 0 - \left[\frac{\dot{m}}{2} \times V_{f_2} + \frac{\dot{m}}{2} \times (-V_{f_2})\right]$

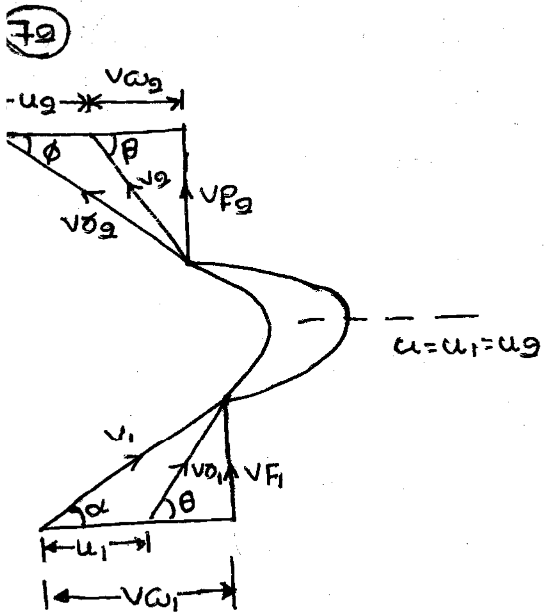
$\boxed{F_y = 0}$

$\frac{W.D}{Sec} = F \times u = \dot{m}[V_{w_1} + V_{w_2}]u$ watt

$\frac{WD}{\text{wt of water which strikes plate/vane}} \Rightarrow \frac{WD}{mg} = \frac{\overset{\rho a V_{r_1}}{\dot{m}}[V_{w_1} + V_{w_2}]u}{\underset{\rho a V_{r_1}}{\dot{m}} g}$

$\frac{WD}{mg} = \frac{[V_{w_1} + V_{w_2}]u}{g}$ m

72




$V_1 = 15 m/s$

$u = u_1 = u_2 = 5 m/s \quad [\because V_{r_2} = V_{r_1}]$

Symmetrical Vane $[\theta = \phi]$

$\delta = 120^\circ = 180 - (\theta + \phi)$

$\boxed{\theta = \phi = 30}$

$\alpha = ?$

$V_2 \cdot \beta = ?$

$\frac{WD}{mg} = ?$

$$\frac{V_1}{\sin(180-\alpha)} = \frac{V_{r_1}}{\sin\alpha} = \frac{u_1}{\sin(\theta-\alpha)}$$

$$\frac{15}{\sin 30^\circ} = \frac{V_{r_1}}{\sin\alpha} = \frac{5}{\sin(30-\alpha)}$$

$\boxed{V_{r_1} = 10.46 m/s}$

$\boxed{\alpha = 20.4^\circ}$

$$\frac{V_2}{\sin\phi} = \frac{[V_{r_2} = V_{r_1}]}{\sin[180-\beta]} = \frac{u_2}{\sin[\beta-\phi]}$$

$$\frac{V_2}{\sin 30^\circ} = \frac{10.46}{\sin[180-\beta]} = \frac{5}{\sin[\beta-30]}$$

$\boxed{V_2 = 6.62 m/s}$

$\boxed{\beta = 52.18^\circ}$

$$\frac{WD}{mg} = \frac{[V_{w_1} + V_{w_2}]u}{g}$$

$V_{w_1} = V_1 \cos\alpha = 15 \cos 20.4^\circ = 14.05 m/s$

$V_{w_2} = V_2 \cos\beta = 6.62 \cos 52.18^\circ = 4.05 m/s$

$$\frac{WD}{mg} = \frac{[14.05 + 4.05] \times 5}{9.81}$$

$$\boxed{\frac{WD}{mg} = 9.22 m}$$

*

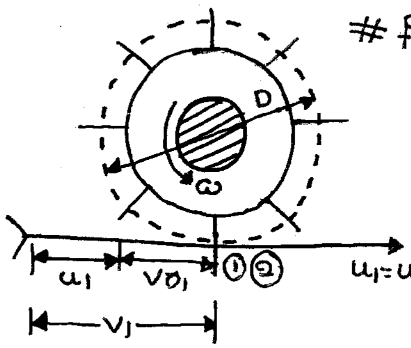
$$\eta = \frac{WD}{\frac{1}{2} m v_1^2}$$

$$\eta = \frac{\underset{\rho a v_{r1}}{\dot{m}}\,[V_{w1} + V_{w2}]}{\frac{1}{2}\underset{\rho a v_1}{\dot{m}}\, v_1^2}$$

∴ To increase the 'η' of system

## * Tangential flow runner:-

# Front view




$u_1 = u_2 = U = \frac{\pi D N}{60} = \omega r$

$(\because r_1 = r_2 = r)$

D: wheel dia

N: speed [rpm]

$$\dot{m} = \rho a v_1$$

$$F_x = \dot{m} \times v_1 - \left[\frac{\dot{m}}{2} \times u_2 + \frac{\dot{m}}{2} \times u_2\right]$$

$[\because u_1 = u_2 = u]$

$$F_x = \dot{m} v_1 - \dot{m} u_1 = \dot{m}[v_1 - u_1]$$

$$\boxed{F_x = \rho a v_1 [v_1 - u_1]\ N}$$

$$\boxed{F_y = 0}$$

$$W.D = F_x \cdot u = \rho a v_1 [v_1 - u_1] \cdot u \text{ watt}$$

$$\eta = \frac{\rho \cancel{a} v_1 [v_1 - u_1] u}{\frac{1}{2} \cancel{\dot{m}} v_1^2}$$

$$\eta = \frac{2(v_1 - u_1) u}{v_1^2}$$

$$\eta = f_n(v_1, u)$$

if $v_1 = $ const

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

$$\frac{d}{du}\left[\frac{2(v_1 - u_1) u}{v_1^2}\right] = 0$$

$$\frac{d}{du}[(v_1 - u_1) u] = 0$$

$$v_1 - 2u = 0$$

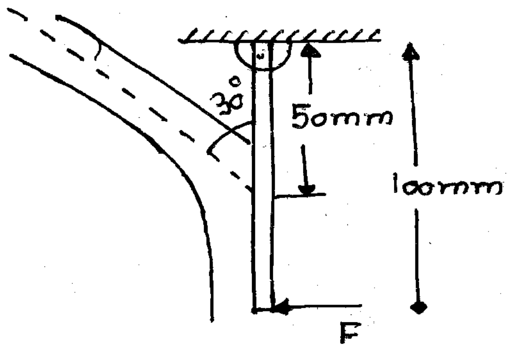
$$\boxed{u = \frac{v_1}{2}} \ ***$$

$$\eta_{max} = \frac{2\left[v_1 - \frac{v_1}{2}\right]\frac{v_1}{2}}{v_1^2}$$

$$\boxed{\eta_{max} = \frac{1}{2} = 5 \ldots}$$

1 - Gate
\ Civil

$V = 30m/s$
$d = 10mm$



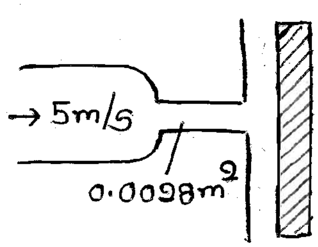

Sol:- Force exerted in x-direction

$$F_x = \dot{m}[V\sin\theta - 0]$$
$$= \rho AV[V\sin\theta]$$
$$= \rho AV^2 \sin\theta$$
$$= 1000 \times \frac{\pi}{4}(0.01)^2 \times (30)^2 \sin 30$$
$$F_x = 35.34N$$

Taking moment about hinge

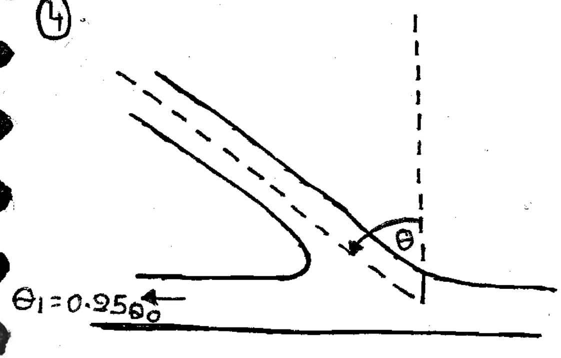
$$F_x \times 0.05 = F \times 0.1$$
$$35.34 \times 0.05 = F \times 0.1$$
$$F = 17.67N$$

2)




$$F_x = \rho AV^2$$
$$= 1000 \times 0.0028 \times [5]^2$$
$$F_x = 70N$$

4.




$Q_0 = Q_1 + Q_2$

$Q_0 = 0.25Q_0 + Q_2$

$Q_2 = 0.75Q_0$

Impact losses are neglected. So velocity will remains unchanged in $Q_1$ & $Q_2$

$V_0 = V_1 = V_2$

Impulse momentum equ

$\rho Q_0 V_0 \sin\theta = \rho Q_2 V_2 - \rho Q_1 V_1$

$Q_0 \sin\theta = 0.75Q_0 - 0.25Q_0$

$\sin\theta = \frac{1}{2}$

$\theta = 30$

5.

larger discharge would be

$Q_1 = \frac{Q}{2}[1+\cos\theta]$

Smaller discharge would be

$Q_2 = \frac{Q}{2}[1-\cos\theta]$

$$\frac{Q_1}{Q_2} = \frac{\frac{Q}{2}[1+\cos\theta]}{\frac{Q}{2}[1-\cos\theta]}$$

$$\frac{1+\cos\theta}{1-\cos\theta} = \frac{1+\cos[90+30]}{1-\cos[90-30]} = 3$$

68.

$\rho A(V-U)^2$

$= 1000 \times \frac{\pi}{4} \times (0.075)^2 \times [20-5]^2$

$F_x = 994.01 N$

$\frac{W.D}{sec} = F_x \times U$

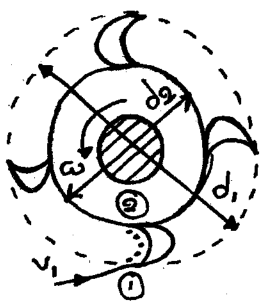
$= 994.01 \times 5$

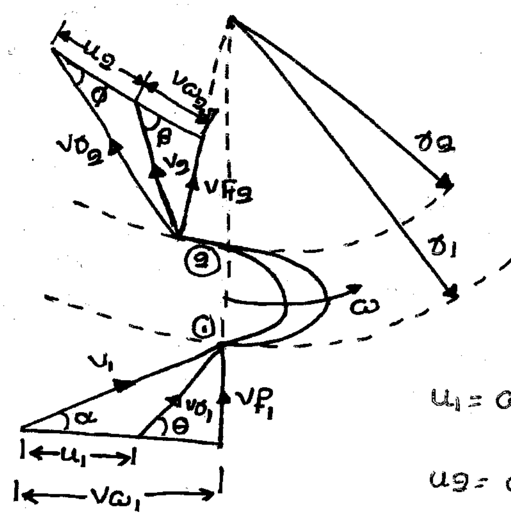
$= 4970.09$ N-m

25/9/18

## * Radial Flow runner:-

- Inward radial flow




$r_2 < r_1$

$u_2 < u_1$

$u_1 \neq u_2$

$u_1 = \omega r_1 = \frac{\pi d_1 N}{60}$

$u_2 = \omega r_2 = \frac{\pi d_2 N}{60}$

$$\boxed{\dot{m} = \rho a v_1 = \rho Q}$$

$\frac{WD}{sec} = T \cdot \omega =$ Runner/Rotor power [RP]

T = Rate of change in Angular moment

Angular moment = Moment of momentum

linear momentum of water at entry $= \dot{m} \times V_{w_1}$

Angular momentum of water at entry $= \dot{m} \times V_{w_1} \times r_1$

linear momentum of water at exit $= \dot{m}(-V_{w_2})$

Angular momentum of water at exit $= -\dot{m} V_{w_2} \times r_2$

$T = \dot{m} V_{w_1} r_1 - [\dot{m} V_{w_2} r_2]$

$T = \dot{m}[V_{w_1} r_1 + V_{w_2} r_2]$ N-m

$RP = T \cdot \omega = \dot{m}[V_{w_1} r_1 + V_{w_2} r_2]\omega$

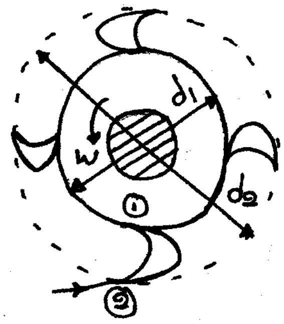
$\boxed{RP = \rho Q [V_{w_1} u_1 + V_{w_2} u_2]}$ watt

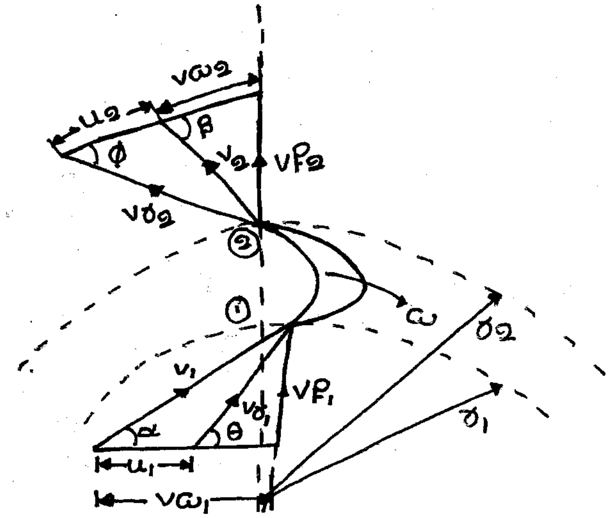
$F_y = \dot{m} V_{f_1} - \dot{m} V_{f_2}$ [Radial force on Runner]

$F_y = \dot{m}[V_{f_1} - V_{f_2}]$

to get $F_y = 0 \Rightarrow [\therefore V_{f_1} = V_{f_2}]$

- outward Radial Flow:-



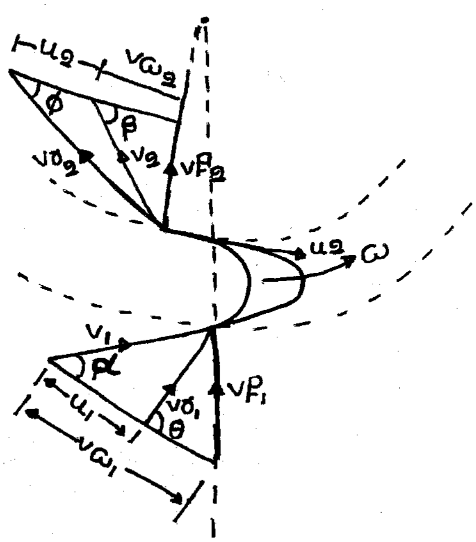

$r_2 > r_1$
$u_2 > u_1$
$u_1 \neq u_2$

[∵ Same as inward Radial Flow]

$$\boxed{\begin{aligned} \frac{Rp}{\dot{m}g} &= \frac{\rho Q\,[V_{w1}u_1 + V_{w2}u_2]}{[\dot{m}g = \rho Q g]} \\ \frac{RP}{\dot{m}g} &= \frac{[V_{w1}u_1 + V_{w2}u_2]}{g}\,m = H_e \end{aligned}}$$

* $H_e$ → Euler's head

73.




$V_1 = 30\,m/s$
$N = 2000\,rpm$
$\alpha = 20^\circ$
$V_2 = 5\,m/s$

$\theta, \phi = ?$
$\frac{WD}{mg}, \eta = ?$

Inward Radial Flow

| | |
|---|---|
| $r_1 = 0.5m$ | $d_1 = 1m$ |
| $r_2 = 0.25m$ | $d_2 = 0.5m$ |

$$\boxed{\tan\theta = \frac{V_{f1}}{V_{w1} - u_1}}$$

$V_{f1} = V_1 \sin\alpha = 30\sin 20^\circ = 10.26\,m/s$
$V_{w1} = V_1 \cos\alpha = 30\sin 20^\circ = 28.19\,m/s$

$u_1 = \frac{\pi d N}{60} = 10.47\, m/s$

$\tan\theta = \frac{10.26}{28.19 - 10.47}$

$\boxed{\theta = 30.07^\circ}$

$\boxed{\tan\phi = \frac{V_{f2}}{u_2 + V_{\omega 2}}}$

$V_{f2} = V_2 \sin\beta = 5 \sin 50^\circ = 3.83\, m/s$

$V_{\omega 2} = V_2 \cos\beta = 5 \cos 50^\circ = 3.2\, m/s$

$u_2 = \frac{\pi d_2 N}{60} = 5.23\, m/s$

$\tan\phi = \frac{3.83}{5.23 + 3.2}$

$\boxed{\phi = 24.4^\circ}$

$\frac{\omega \cdot D}{mg} = \frac{RP}{mg} = \frac{[V_{\omega 1} u_1 + V_{\omega 2} u_2]}{g}$

$\boxed{\frac{RP}{mg} = 31.80 m}$

$\eta = \frac{\cancel{g\theta}[V_{\omega 1} u_1 + V_{\omega 2} u_2]}{\frac{1}{2} \cancel{m} v_1^2}$

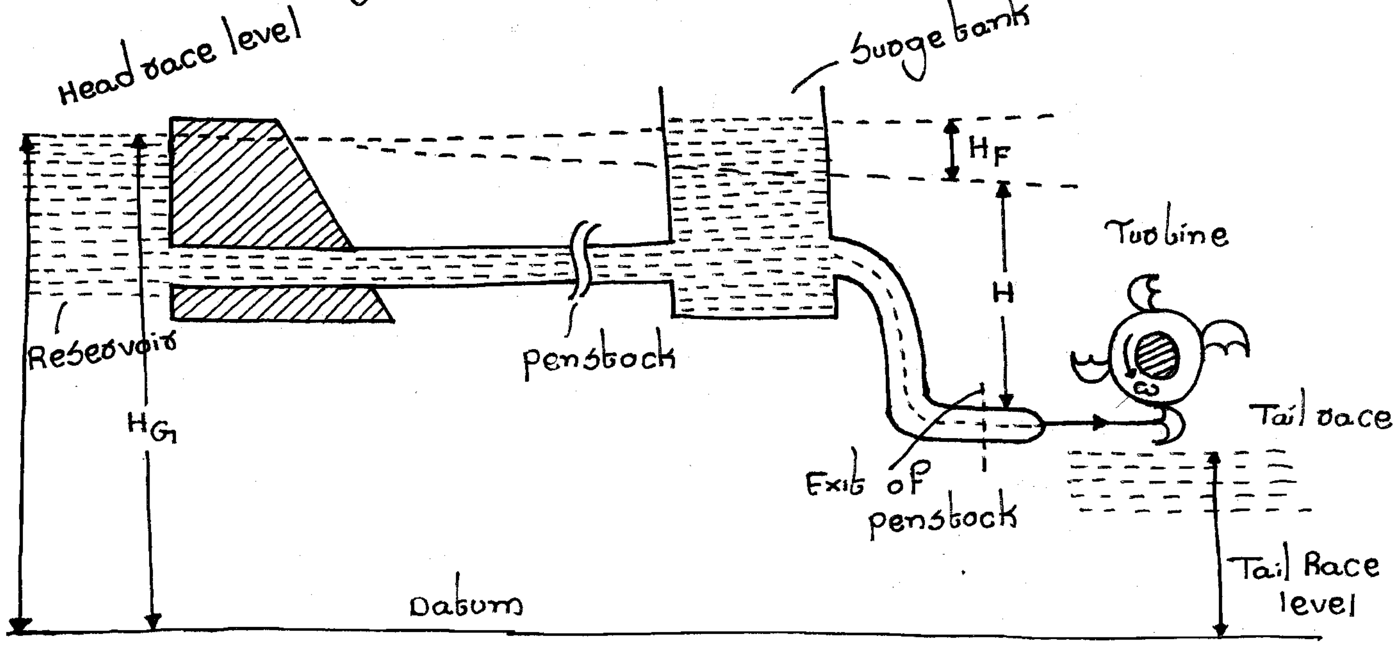
$\boxed{\eta = 69.32\%}$

$$\boxed{\begin{aligned} \frac{v_1^2}{2g} &= 45.87 m \\ \frac{v_2^2}{2g} &= 1.27 m \\ &= 45.87 - 1.27 \\ &= 44.6 \end{aligned}}$$

## * layout of Hydro power plant:-

• Aim:-

produce electricity, Flood Control




## * Components:-

- Reservoir — lake [Natural] / artificial [Dam]
- penstock → large dia. pipe
- Surge tank
- Turbine
- Tail race
- Generator

$$\boxed{H_F = \text{Head loss in penstock} = \frac{FLV^2}{2gD}}$$

$$\boxed{H = H_G - H_F}$$

## * Types of Head:-

• Gross head [$H_G$]:-

it is defined as the head under which hydro power plant is working or it is difference b/w Head race level & Tail race level.

• Net head [H]:-

it is head available with water at entry to turbine or it is head under which turbine is working.

* Serge tank:-

it is the reservoir of water placed near to turbine & used to avoid the water hammering penstock.

* power:-

$\frac{WP}{HP}$ :- $mgH = \rho gQH$ watt

RP :- $\rho Q[V_{w_1}u_1 + V_{w_2}u_2]$

SP :- RP − Mech. loss

GP :- SP − loss in Generator

* Efficiency:-

$\eta_H$ :- $\frac{RP}{WP}$

$\eta_m$ :- $\frac{SP}{RP}$

$\eta_o$ :- $\frac{SP}{WP} = \frac{SP}{RP} \times \frac{RP}{WP}$

$\eta_o$ :- $\eta_H \times \eta_m$

$\eta_G$ :- $\frac{GP}{SP}$

* Impulse turbine:-

principle:-

water is supplied by penstock from reservoir to turbine, at the exit of penstock a nozzle is fitted which is used to convert the head available with water fully into kinetic energy. therefore water leaves the nozzle in the form of jet. As the jet strikes over the vane it will applying impulse force due to "K.E" of water & rotates the runner.

Therefore this turbine is known as impulse turbine. In this only "K.E" of water is contributing into runner power.

Entry [only K.E] | Exit
---|---
$P_1 = P_{atm} = P_2$ | $P_2 = P_{atm}$

Due to impulse force $\Rightarrow V_2 <<< V_1$ | $V_2 \rightarrow min$

- Smooth vane $V_{r2} = V_{r1}$
- Rough vane $V_{r2} < V_{r1}$

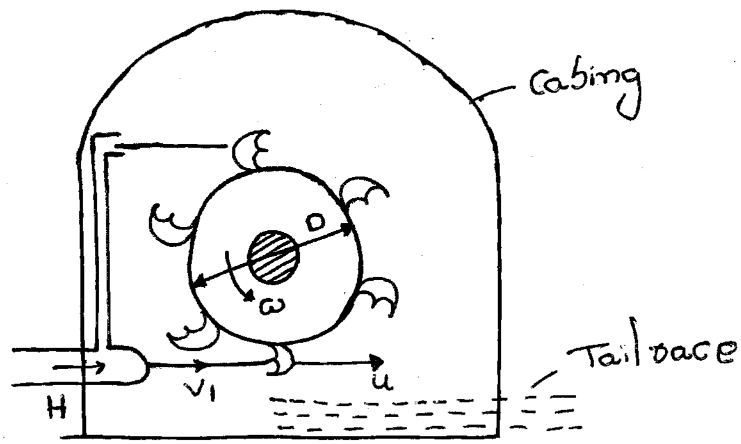
$\boxed{V_{r2} = k V_{r1}}$

K → Coefficient of Vane friction

*** pelton wheel:-**

- Components:-

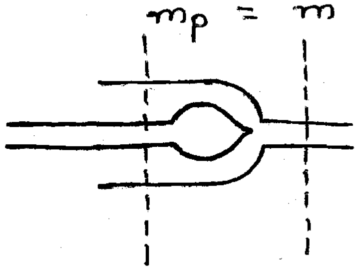
i. Casing:-




No hydraulic function & used to avoid the splashing of water

ii. Nozzle & Spear:-

$\dot{m}_p = \dot{m}$



if $\eta_{nozzle} = 100\%$

$$\frac{V_1^2}{2g} = H$$

$$V_1 = \sqrt{2gH}$$

if $\eta_{nozzle} < 100\%$

$$\frac{V_1^2}{2g} < H$$

$$V_1 = C_v\sqrt{2gH}$$

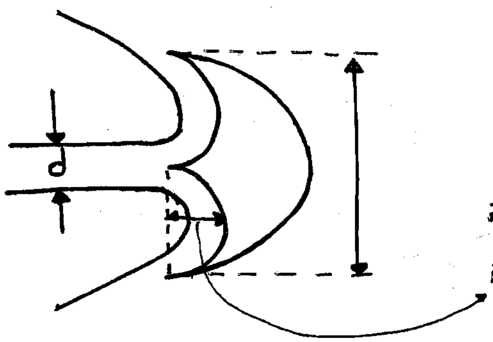
To Control the discharge through nozzle a spear is provided which can move forward & backward with the help of governer in order to '↑' (or) '↓' flow area through nozzle.

ii. Braking Jet:-

It is used to stop the runner as quickly as possible & also to avoid the critical speed of the shaft.

v. Runner/Rotor:-

It is the rotating wheel over which a number of vanes are installed



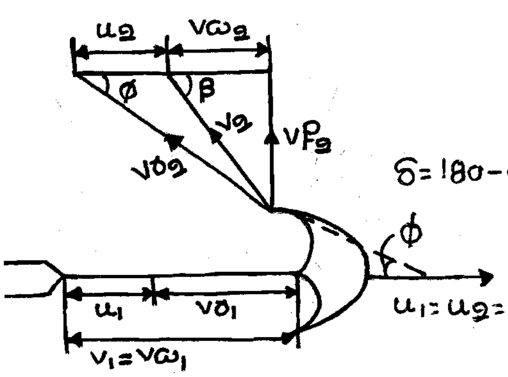

• Design parameters of pelton:-

i. Jet ratio:- $m = \frac{D}{d}$

ii. No of Vanes:- $\frac{m}{2} + 15$

iii. Width:- $5d$

iv. Depth:- $1.2d$




$\delta = 180 - \phi$

$u_1 = u_2 = u = \frac{\pi D N}{60}$

$[\because r = r_1 = r_2]$

Discharge:-

$$\boxed{Q = aV_1 = \frac{\pi}{4} d^2 \times V_1}$$

$$\frac{WP}{Hp} = \rho g Q H \text{ watt}$$

$$RP = F_x \cdot u$$

$$F_x = \dot{m} \times V\omega_1 - \left[\frac{\dot{m}}{2} \times (-V\omega_2) + \frac{\dot{m}}{2}(-V\omega_2)\right]$$

$$F_x = \dot{m} V\omega_1 + \dot{m} V\omega_2$$

$$= \dot{m}[V\omega_1 + V\omega_2]$$

$$RP = \rho Q [V\omega_1 + V\omega_2] u$$

$$\eta_H = \frac{RP}{WP} = \frac{[V\omega_1 + V\omega_2] u}{gH}$$

• Blade efficiency:-

$$\boxed{\eta_{Blade} = \frac{RP}{\frac{1}{2} \dot{m} V_1^2}}$$

$$\eta_H = \frac{\cancel{\rho Q}[V\omega_1 + V\omega_2]u}{[\rho g Q H = \frac{1}{2}\cancel{m}v_1^2]}$$

if $\eta_{nozzle} = 100\%$

$$\rho g Q H = \frac{1}{2} m v_1^2$$

$$\eta_H = \frac{2[V\omega_1 + V\omega_2]u}{v_1^2}$$

$V\omega_1 = v_1$

$V\omega_2 = vo_2 \cos\phi - u_2$

$vo_2 = K vo_1 = K[v_1 - u_1]$

$$\eta_H = \frac{2[v_1 + K[v_1 - u_1]\cos\phi - u_2]u}{v_1^2} \qquad [\because u = u_1 = u_2]$$

$$\eta_H = \frac{2[v_1 - u_1][1 + K\cos\phi)u}{v_1^2}$$

$\eta_H = fn[v, u]$

if $v$ = constant

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

$$\frac{d}{du}\left[\frac{2(v_1 - u_1)[1 + K\cos\phi]u}{v_1^2}\right] = 0$$

$$\frac{d}{du}\left[(v_1 - u_1)u\right] = 0$$

$v_1 - 2u = 0$

$$\boxed{u = \frac{v_1}{2}}$$

$$\eta_{max} = \frac{2[v_1 - \frac{v_1}{2}][1 + k\cos\phi]\frac{v_1}{2}}{\frac{v_1^2}{2}}$$

$$\boxed{\eta_{max} = \frac{1 + K\cos\phi}{2}}$$

Assume

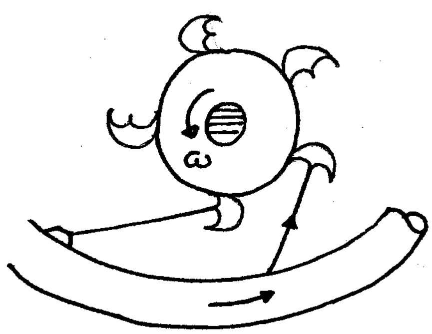
$K=1$ , $\phi=15^\circ$

$$\boxed{\eta_{max} = 98.29\%}$$

$\phi \rightarrow [10^\circ - 20^\circ]$

$\delta \rightarrow [160^\circ - 170^\circ]$

* Multijet pelton:-



$$\boxed{n = \text{no of Jet} = \frac{\text{total Q supplied by penstock}}{Q/\text{Jet}} \ngtr 6}$$

Frequency $f_{(Hz)} = \frac{PN}{120}$

P = no of poles

N = speed [rpm]

Imp. Ratio

① Speed ratio $K_u = \frac{u_1}{\sqrt{2gH}}$

Spouting velocity

⑨.

$H = H_G - H_F$

$= H_G - \frac{FLV^2}{2gD}$

$H = 300 - \frac{[4 \times 0.0098] \times 400 \times 5^2}{2 \times 9.81 \times 1}$

$\boxed{H = 280\,m} \approx \boxed{295}$

(76).

Turbines = 5

Runners = $5\times2=10$

Nozzles = $10\times4=40$

Total $Q = 40\,m^3/sec$

$C_v = 0.985$

$H = 250\,m$

$\boxed{d = ?}$

$Q = a v_1 = \frac{\pi}{4}d^2 \times v_1$

$v_1 = C_v\sqrt{2gH} = 68.98\,m/s$

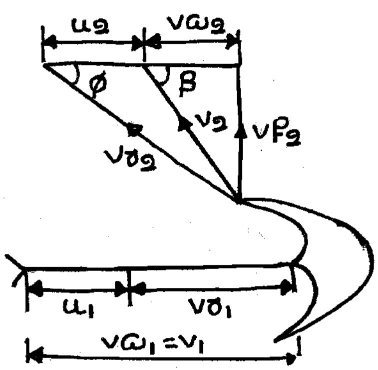
$n = 40 = \frac{\text{total } Q}{Q/\text{Jet}} = \frac{40}{Q/\text{Jet}}$

$Q/\text{Jet} = 1\,m^3/sec$

$1 = \frac{\pi}{4}d^2 \times 68.98$

$\boxed{d = 0.1358\,m}$

(75).




$H_G = 400\,m$

Penstock → $L = 4\,km$, $D = 1\,m$

$\boxed{RP,\ SP,\ \eta_H,\ \eta_o = ?}$

$f = 0.008$

$d = 150\,m$

$\delta = 165^\circ = 180-\phi$

$\boxed{\phi = 15^\circ}$

$V_{r2} = 0.85 V_{r1}$

$u = 0.45\times V_1$

$\eta_m = 85\%$

$RP = \rho Q[V_{w1}+V_{w2}]u$

$Q = a v_1 = \frac{\pi}{4}d^2\times v_1$ $[\because C_v = 1]$

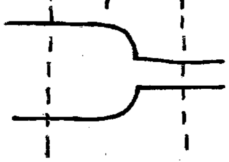
$V_1 = \sqrt{2gH}$

$$H = H_G - \frac{FLv^2}{2gD}$$

$$H = 400 - \frac{[4 \times 0.008] \times 4000 \times v_p^2}{2 \times 9.81 \times 1}$$

$$H = 400 - 6.523\, v_p^2 \quad \text{—(i)}$$

$$\dot{m}_p = \dot{m}$$



$$\cancel{\rho} \times \left[\cancel{\tfrac{\pi}{4}} D^2\right]_p \times V_p = \cancel{\rho} \times \left[\cancel{\tfrac{\pi}{4}} d^2\right] \times V$$

$$1^2 \times v_p = 0.15^2 \times V_1$$

$$v_p = 0.15^2 \times \sqrt{2gH} \quad \text{—(ii)}$$

From equ (i) & (ii)

$$H = 400 - 6.523 \left[0.15^2 \times \sqrt{2gH}\right]^2$$

$$\boxed{H = 375.65}$$

$V_1 = 85.85\ m/s = V_{\omega_1}$

$Q = 1.517\ m^3/sec$

$$\boxed{u = u_1 = u_2 = 0.45 \times V_1 = 38.63\ m/s}$$

$$\omega_2 = V_{r_2} \cos\phi - u_2$$

$$= K[V_1 - u_1]\cos\phi - u_2$$

$$\omega_2 = 0.85[85.85 - 38.63] \cos 15^\circ - 38.63$$

$$\omega_2 = 0.14\ m/s$$

$$RP = 1000 \times 1.517 [85.85 + 0.14] \times 38.63$$

$$\boxed{RP = 5.039\ MW}$$

$$\eta_m = \frac{SP}{RP} \Rightarrow SP = 4.283\ MW$$

$$\eta_H = \frac{RP}{\rho g Q H} = \frac{5.039 \times 10^6}{1000 \times 9.81 \times 375.65 \times 1.517} \quad \boxed{= 90.13\%}$$

$$\boxed{\eta_o = \eta_H \times \eta_M = 76.6\%}$$

## * Impulse - Reaction Turbine/ Reaction Turbine :-

· principle :-

water is supplied by penstock from reservoir to turbine. they enters into the casing. The casing is always filled with the water. Inside the casing a no. of vanes are present which permanently fixed with the casing. called as the fixed vane. These vanes are used to convert the head available with the water partially into "K·E". therefore water enters over the runner with kinatic & stationary.

As the water strikes over the moving vane it will apply impulse force due to "K·E" of water same as the pelton wheel turbine. As the water flows over the moving vane it create the pressure difference across the vane surface due to aerodynamic shape of the vane. due to which water will apply lift force [also known as reaction force]. Due to pressure energy of water the impulse & reaction force rotate the runner. therefor this turbine is known as impulse reaction turbine.

In a Reaction turbine both kinatic & pressure energy of water is contributing into runner power.

Entry [K·E + Pr·E] Exit

Due to implose force → $V_2 << V_1$ $P_r \cdot e, V_2 \rightarrow min$

Due to Reaction force ↗ $P_2 << P_1$

$V_{r2} >>> V_{r1}$

$V_{r1} \neq V_{r2}$

Inward radial flow reaction turbine:-

* Components:-

· Casing:- Spiral/volute/Scroll casing

The casing is spiral in shape [i.e gradually '↓' in area]. '↓' area help to maintain constant velocity of water at inlet to runner.

· Guid vane / Fixed vane:-

The Guid vanes are used to guide the water towards runner in 'α'- direction. Even though the vanes are fixed but they can rotate about their own bivot with the help of Governor in order to control the discharge through turbine by controlling flow area in b/w adjacent guide vane.

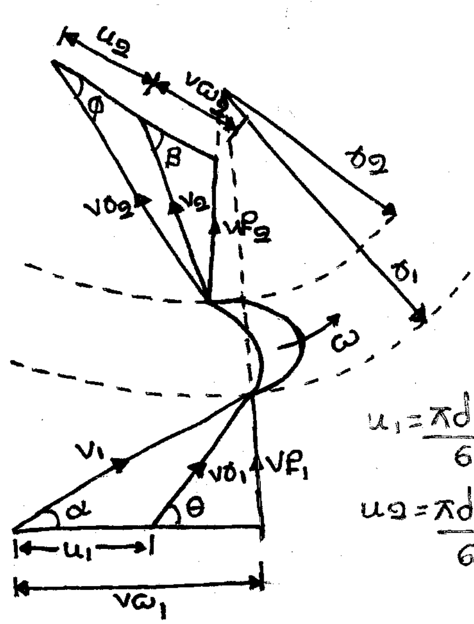
$\boxed{\alpha = \text{Guide Vane Angle / Fixed Vane Angle}}$

∴ Runner / Rotor:-

- Radial → Francis
- Axial → Kaplan propeller
- Mixed → Modern Francis

$\boxed{\theta, \phi \to \text{Moving / Runner Vane Angle}}$

1. Draft tube:-




$u_1 = \frac{\pi d_1 N}{60}$ $\quad r_2 < r_1$

$u_2 = \frac{\pi d_2 N}{60}$ $\quad u_2 < u_1$

Area of flow (AF):-

water flows in circumferential area

$AF_1 = \pi d_1 \times b_1$

$AF_2 = \pi d_2 b_2$

$b_1 b_2 \Rightarrow$ width of vane

Discharge:-

$\dot{m}_{Entry} = \dot{M}_{Exit}$

$\rho \times AF_1 \times VF_1 = \rho \times AF_2 \times VF_2$

$Q = AF_1 VF_1 = AF_2 VF_2$

$Q = \pi d_1 b_1 VF_1 = \pi d_2 b_2 VF_2$

to get $F_y = 0 \Rightarrow [\because V_{F_1} = V_{F_2}]$

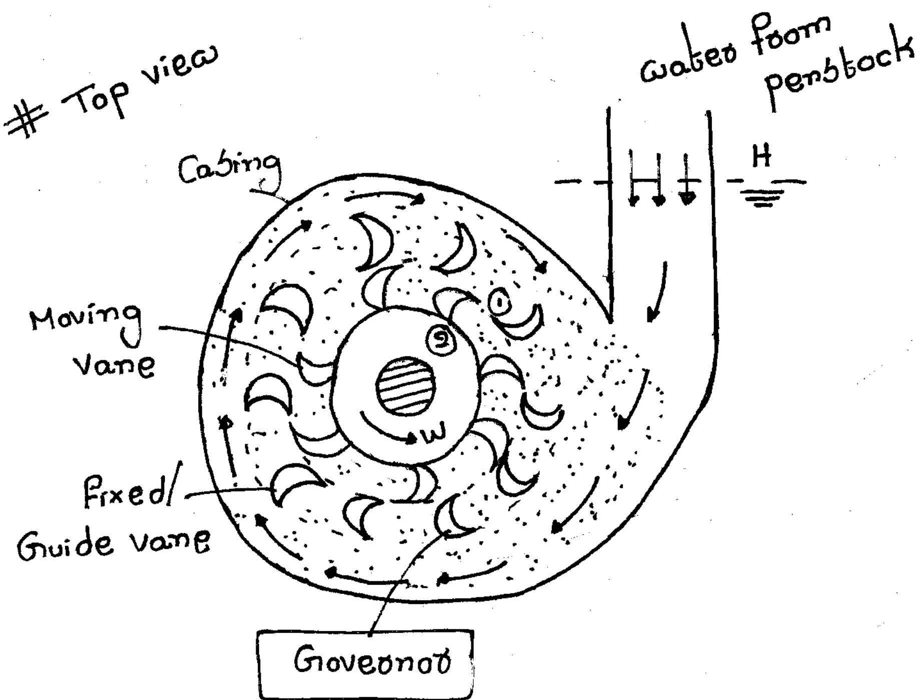
$\because A_{F_1} = A_{F_2}$

$\pi d_1 b_1 = \pi d_2 b_2$

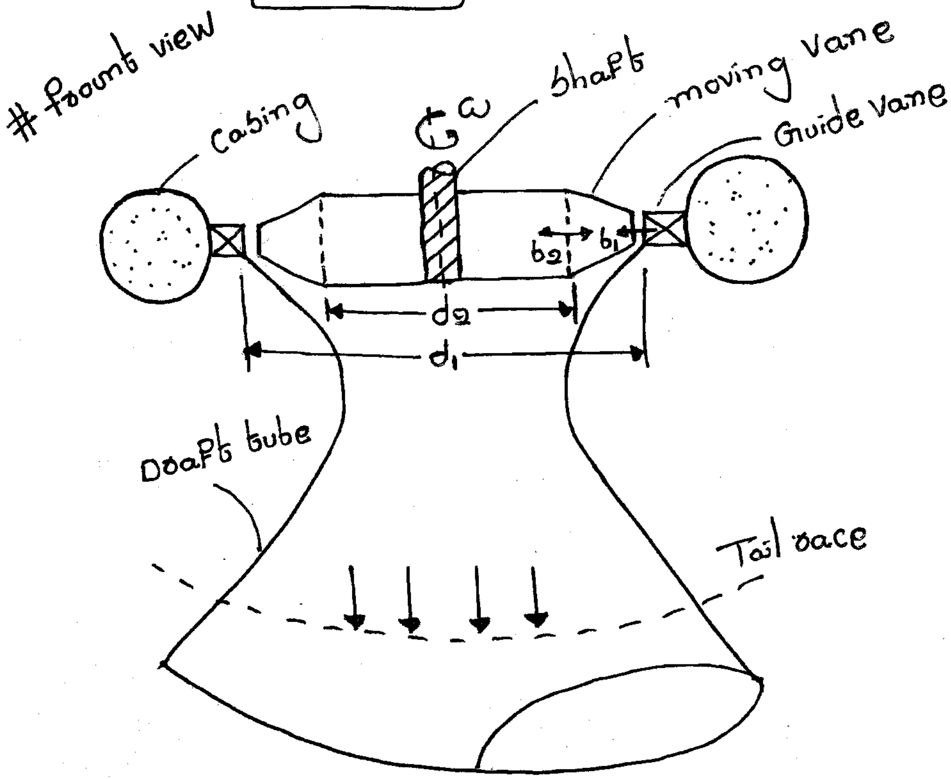
$d_1 b_1 = d_2 b_2$

$d_1 > d_2$ | if Given in problem
$b_2 > b_1$ | $\therefore b_1 = b_2$
$V_{F_1} \neq V_{F_2}$

# Top view




# front view



* Degree of reaction:-

$$\frac{RP}{mg} = \frac{[V_{w_1}u_1 + V_{w_2}u_2]}{g} = \text{Contribution of K.E head} + \text{Contribution of P.E head}$$

$$R = \frac{\text{Contribution of Pr.E head into } \frac{RP}{mg}}{\text{Total Contribution of K.E + Pr.E head into } \frac{RP}{mg}}$$

$$V_{w_1} = u_1 + V_{r_1}\cos\theta$$

$$[V_{w_1} - u_1]^2 = V_{r_1}\cos\theta = \left(\sqrt{V_{r_1}^2 - V_{f_1}^2}\right)^2$$

$$[V_{w_1} - u_1]^2 = V_{r_1}^2 - V_{f_1}^2 = V_{r_1}^2 - [V_1^2 - V_{w_1}^2]$$

$$\cancel{V_{w_1}^2} + u_1^2 - 2V_w u_1 = V_{r_1}^2 - V_1^2 + \cancel{V_{w_1}^2}$$

$$+V_1^2 + u_1^2 - V_{r_1}^2 = 2V_w u_1$$

$$V_w u_1 = \frac{V_1^2 + u_1^2 - V_{r_1}^2}{2}$$

Similarly $V_{w_2}u_2 \rightarrow \dfrac{-V_1^2 - u_2^2 + V_{r_2}^2}{2}$

$$\frac{RP}{mg} = \frac{[V_{w_1}u_1 + V_{w_2}u_2]}{g} = \underbrace{\frac{V_1^2 - V_2^2}{2g}}_{\text{Contribution of K.E head}} + \underbrace{\frac{u_1^2 - u_2^2}{2g} + \frac{V_{r_2}^2 - V_{r_1}^2}{2g}}_{\text{Contribution of P.E head}}$$

$$R = \frac{\left[\frac{u_1^2 - u_2^2}{2g} + \frac{V_{r_2}^2 - V_{r_1}^2}{2g}\right]}{RP/mg} \Rightarrow \frac{\frac{RP}{mg} - \frac{V_1^2 - V_2^2}{2g}}{\frac{RP}{mg}}$$

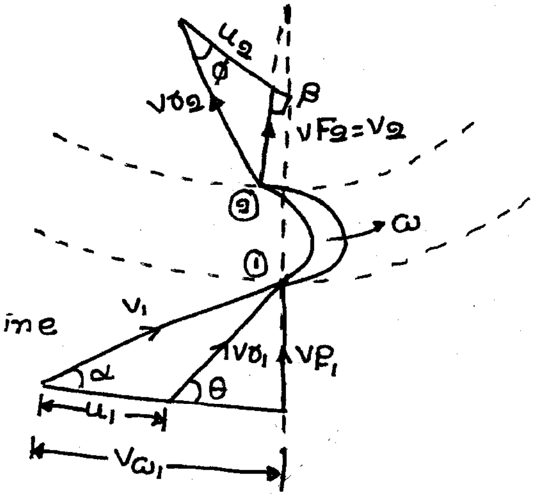
$$\boxed{R = 1 - \frac{V_1^2 - V_2^2}{2g\left[\frac{RP}{mg}\right]}}$$

- Francis turbine:-

$$\frac{RP}{mg}\bigg|_{max} \Rightarrow \frac{V_1^2 - V_2^2}{2g}\bigg|_{max} \Rightarrow V_2 \to min$$

$$V_2 = \sqrt{\cancelto{0}{V_{\omega_2}^2} + V_{F_2}^2}$$

$$\boxed{V_{\omega_2} = 0,\ V_2 = V_{F_2},\ \beta = 90^\circ}$$




Francis turbine is inward flow reaction turbine with radial discharge.

$$R_{Francis} = 1 - \frac{V_1^2 - V_2^2}{2\cancel{g}\left[\frac{\rho \cancel{Q} V_{\omega_1} u_1}{\cancel{m}\cancel{g}}\right]}$$

$$R = 1 - \frac{V_1^2 - V_2^2}{2V_{\omega_1} u_1}$$

$$V_2 = V_{F_2}$$

$$V_1^2 = V_{\omega_1}^2 + V_{F_1}^2$$

$$R = 1 - \frac{V_{\omega_1}^2 + V_{F_1} - V_{F_2}^2}{2V_\omega u_1}$$

To get $F_y = 0 \Rightarrow [V_{F_1} = V_{F_2}]$ $[\because b_2 > b_1]$

$$R = \frac{1 - V_{\cancel{\omega_1}}^{\cancel{2}}}{2V_{\cancel{\omega_1}} u_1}$$

[∵ For impulse turbine $R = 0$]

$$\boxed{R_{Francis} = 1 - \frac{V_{\omega_1}}{2u_1}}$$

*

$$\frac{WP}{HP} = \rho g Q H$$

$$RP = \rho Q[V_{\omega_1}u_1 + V_{\omega_2}u_2]$$

$$RP = \rho Q[V_{\omega_1}u_1] \quad \text{Francis}$$

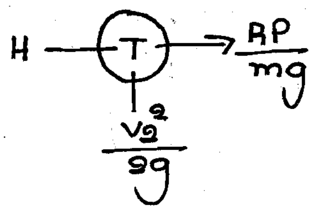
$$\eta_H = \frac{[V_{\omega_1}u_1 + V_{\omega_2}u_2]}{gH}$$

$$\eta_H = \frac{V_{\omega 1} u_1}{gH} \quad [\text{Francis}]$$

Blade efficiency:-

$$\eta_{Blade} = \frac{RP}{K\cdot E + P_r\cdot E} = \frac{RP}{\rho g Q H}$$

Most approximate Equ




Assumptions:-

1. No friction loss
2. $V_{\omega 2} = 0$

$$H = \frac{V_2^2}{2g} + \frac{RP}{mg}$$

$$\boxed{H = \frac{V_2^2}{2g} + \frac{V_{\omega 1} u_1}{g}}$$

* Imp ratio:-

width ratio $\rightarrow \frac{b_1}{d_1} = [0.1 - 0.4]$

dia ratio $\rightarrow d_1/d_2 = 2$

Speed ratio $\rightarrow k_u = u_1/\sqrt{2gH}$

Flow ratio $\rightarrow k_f = \frac{V_{f1}}{\sqrt{2gH}}$

(10).

$$\text{Speed ratio} = \frac{U}{\sqrt{2gH}}$$

$$0.48 = \frac{U}{\sqrt{2\times 9.81\times 256}}$$

$$U = 34.01\ m/s$$

$$U = \frac{\pi D N}{60}$$

$$D = \frac{2040.6}{\pi \times 630}$$

$$D = 1.031 m$$

Q. A Francis turbine is working under a head of 30m & discharge of 10m3/s. The speed of the runner is 300rpm. the speed ratio & flow ratio for the runner is 0.9 or 0.3 respectively. The overall 'η' & hydraulic 'η' for the turbine is 80% & 90% respectively. Find
i) shaft power ii) dia & width of runner at inlet iii) Guide blade angle
iv) runner Vane angle at inlet.

$H = 30m$ $Q = 10m^3/s$ $N = 300rpm$

i) $S.P = RP - \eta_{mec}$

$\boxed{RP =}$

$$\eta_0 = \frac{SP}{\rho Q g H}$$

$$0.8 = \frac{SP}{\rho Q g H}$$

$$SP = 0.8\times 1000\times 10\times 9.81\times 30$$

$$\boxed{SP = 2.354\ MW}$$

ii. $$\text{Speed ratio} = \frac{U}{\sqrt{2gH}}$$

$$0.9 = \frac{U}{\sqrt{2\times 9.81\times 30}}$$

$$U = 21.83\ m/s$$

$$U = \frac{\pi D N}{60}$$

$$D = \frac{60\times 21.83}{\pi\times 300}$$

$$\boxed{D = 1.38 m}$$

$\theta = \pi d_1 b_1 VF_1$

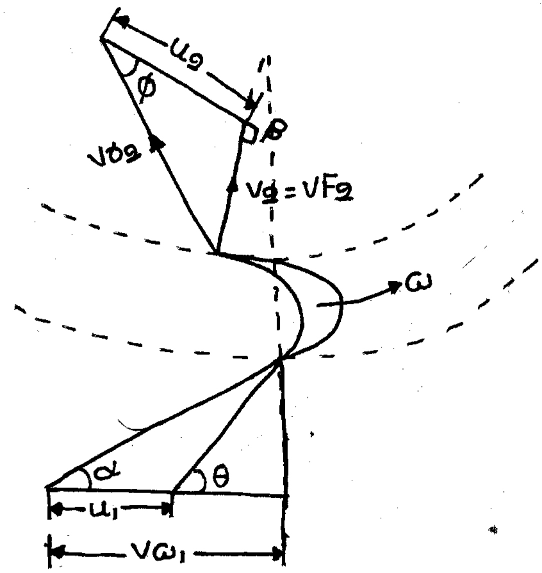
$VF_1 = \dfrac{10}{\cancel{\pi \times 13}}$

$10 = \pi \times 1.39 \times b_1 \times 7.27$

$\boxed{b_1 = 0.314m}$

$KF = 0.3 = \dfrac{VF_1}{\sqrt{2gH}}$

$VF_1 = 7.27 m/s$




$\tan\alpha = \dfrac{VF_1}{V\omega_1}$

$\eta_H = \dfrac{V\omega_1 u_1}{gH}$ [$\because V\omega_2 = 0$]

$0.9 = \dfrac{V\omega_1 \times 21.83}{9.81 \times 30}$

$V\omega_1 = 12.13 m/s$

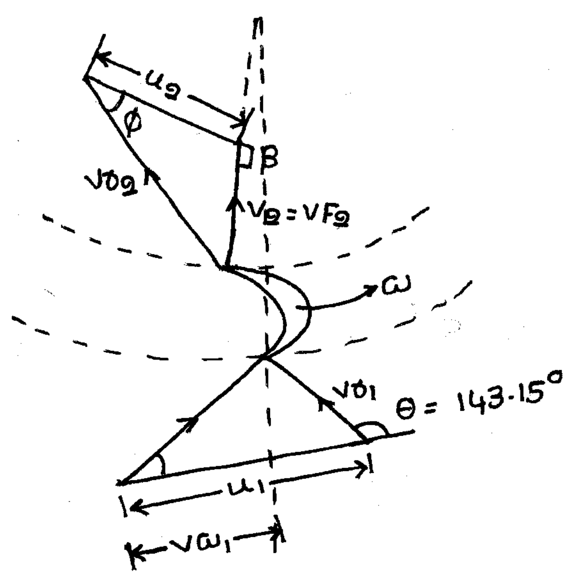
$\tan\alpha = \dfrac{7.27}{12.13}$

$\boxed{\alpha = 30.96}$

$\tan\theta = \dfrac{VF_1}{V\omega_1 - u_1}$

$= \dfrac{7.27}{12.13 - 21.83}$

$\boxed{\theta = -36.85^\circ = 143.15^\circ}$



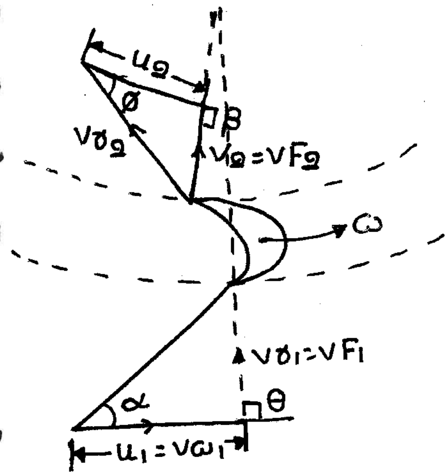
77.

$H = 40m, \quad d_1 = 1.0m \quad d_2 = 0.5m, \quad \theta = 90^\circ \quad \alpha = 15^\circ \quad V\omega_2 = 0$

$VF_1 = VF_2 \; [\because b_2 > b_1]$

loss = 0

$\boxed{N, \phi = ?}$




$\tan\alpha = \frac{VF_1}{u_1} = \tan 15^\circ$ — (i)

$H = \frac{V_2^2}{2g} + \frac{V\omega_1 u_1}{g}$

$V_2 = VF_2 = VF_1$

$V\omega_1 = u_1$

$40 = \frac{VF_1^2}{2g} + \frac{u_1^2}{g}$ — (ii)

From equ (i) & (ii)

$VF_1 = 5.21 m/s = VF_2$

$u_1 = 19.46 m/s = \frac{\pi d_1 N}{60}$

$\boxed{N = 371.7 \, rpm}$

$\tan\phi = \frac{VF_2}{u_2} = \frac{VF_1}{u_2} = \frac{5.21}{9.73}$

$\boxed{\phi = 28.18^\circ}$

$u_2 = \frac{\pi d_2 N}{60} = 9.73 m/s$

78.

$H = 160m \quad Q = 80 m^3/s \quad d_1 = 4m \quad d_2 = 2m \quad \theta = 120^\circ$

$V_2 = VF_2 = 15 m/s \; [\because V\omega_2 = 0, \; \beta = 90^\circ]$

$b_1 = b_2 \; [\therefore VF_1 \neq VF_2]$

$\eta_H = 90\%$

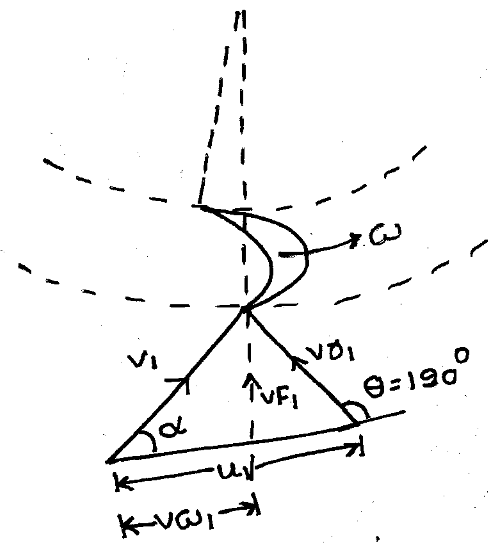
$\boxed{HP = 125.568\,MW}$

$N = ?$

$$\eta_H = \frac{V_{w1}u_1}{gH} \quad [\because V_{w2} = 0]$$

$$0.9 = \frac{V_{w1}u_1}{9.81 \times 160}$$

$$V_{w1}u_1 = 1412.64 \quad \text{—(i)}$$




$$\tan(180-\theta) = \frac{V_{f1}}{u_1 - V_{w1}}$$

$$Q = \cancel{\pi d_1 b_1} V_{f1} = \cancel{\pi d_2 b_2} V_{f2}$$

$$4 \times V_{f1} = 2 \times 15$$

$$V_{f1} = 7.5\,m/s$$

$$\tan 60^\circ = \frac{7.5}{u_1 - V_{w1}}$$

$$u_1 - V_{w1} = 4.33 \quad \text{—(ii)}$$

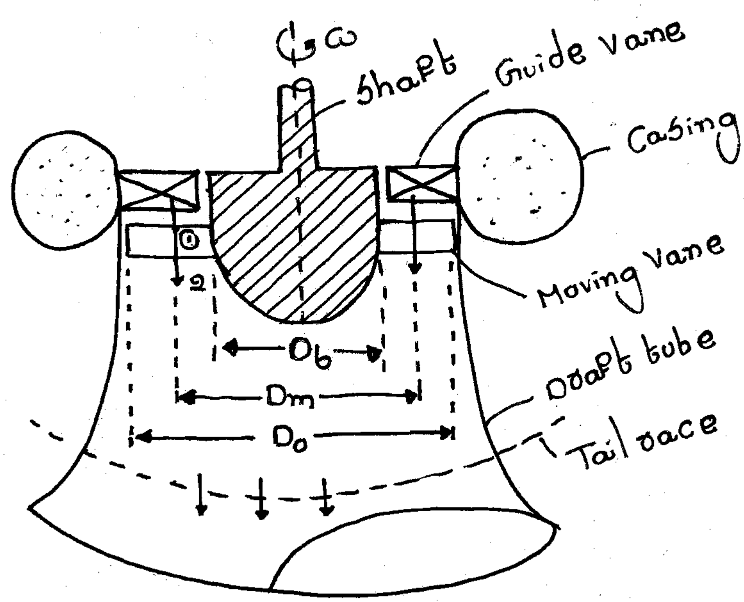
From equ I–II

$$u_1 = 39.8\,m/s = \frac{\pi d_1 N}{60}$$

$\boxed{N = 190.12\,rpm}$

# Axial flow Reaction turbine:-

Kaplan, propeller, Bulb, Tubular, Tidal plant



$D_o \rightarrow$ tip / Extreme / outer dia

$D_b \rightarrow$ Hub / Boss dia

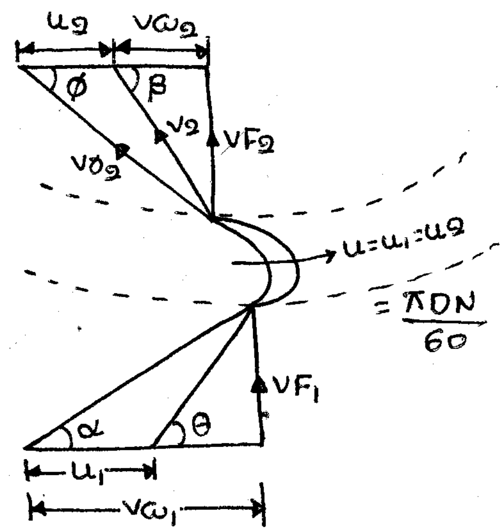
$D_m \rightarrow$ Mean dia $= \dfrac{D_o + D_b}{2}$

$$\boxed{u_1 = u_2 = u = \omega r = \frac{\pi D N}{60}}$$

• Area of flow:-

water flows in cross sectional Area

$$A_f = \frac{\pi}{4}\left[D_o^2 - D_b^2\right] = A_{f_1} = A_{f_2}$$




• Discharge:-

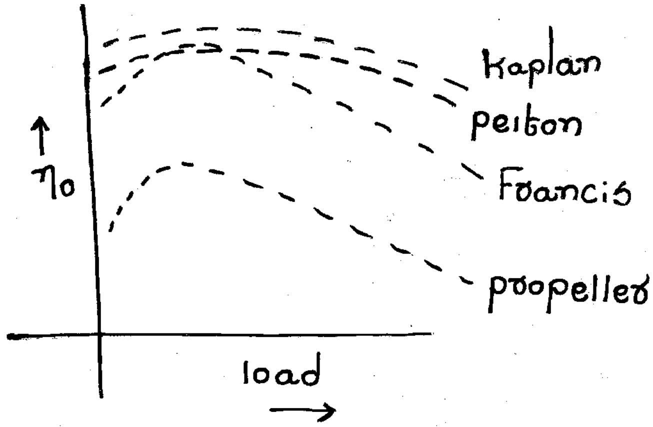
$Q = A_1 F_1 V_{F_1} = A_{F_2} V_{F_2}$

$\therefore A_{F_1} = A_{F_2}$

$$\boxed{\therefore V_{F_1} = V_{F_2}}$$

* Important points:-

- This vanes are twisted. Therefore vane angle changes as the runner dia changes.
- In axial flow turbine generally '3' to '8' vanes are used which is less compared to radial flow turbine [16-24 vanes]. Therefore less frictional losses.
- In propeller turbine the moving vanes are rigid fixed with the hub. Therefore orientation cannot be adjusted, whereas in kaplan turbine the orientation of moving vane can be adjusted. The remaining calculations & equ are same as radial flow turbine.




∴ least effected is "Kaplan".
More effected is "propeller".

79.

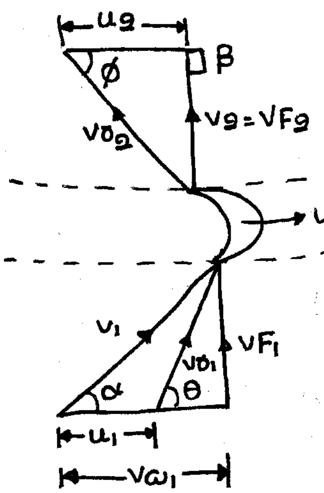
$H = 5.5m$, $\eta_o = 88\%$, $\eta_g = 93\%$, $D_o = 4.5m$, $D_b = 2m$, $\eta_H = 94\%$

$GP = 5MW$, $N = 150rpm$, $V_{\omega 2} = 0$

$\boxed{\theta, \phi \rightarrow D_M = ?}$

$D_M = \frac{4.5+2}{2}$

$\boxed{D_M = 3.25m}$




$u = u_1 = u_2 = \frac{\pi D_M N}{60}$

$= \frac{\pi \times 3.25 \times 150}{60}$

$\boxed{u_1 = 25.52}$

$\tan\theta = \frac{V_{f1}}{V_{\omega 1} - u_1}$

$u_1 = \frac{\pi D_M N}{60} = 25.52 \, m/s$

$\boxed{\eta_H = \frac{V_{\omega 1} u_1}{gH}}$

$0.94 = \frac{V_{\omega 1} \times 25.52}{9.81 \times 5.5}$

$\boxed{V_{\omega 1} = 1.98 m/s}$

$Q = \frac{\pi}{4}[D_o^2 - D_b^2] \times V_{f1}$

$\boxed{\eta_o = \frac{SP}{\rho g Q H}}$

$\eta_G = \frac{GP}{SP} \Rightarrow S.P = \frac{5}{0.93}$

$\boxed{Sp = 5.376 MW}$

$\eta_o = 0.88 = \frac{5.376 \times 10^6}{1000 \times 9.81 \times Q \times 5.5}$

$$Q = 113.22\ m^3/sec = \frac{\pi}{4}\left[4.5^2 - 2^2\right] \times V_{f_1}$$

$$\boxed{V_{f_1} = 8.87\ m/s = V_{f_2}}$$

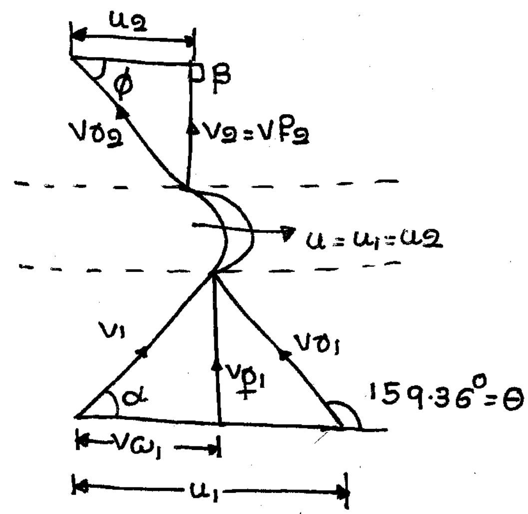
$$\tan\theta = \frac{8.87}{1.98 - 25.52}$$

$$\boxed{\theta = -20.64^\circ = 159.36^\circ}$$

$$\boxed{\tan\phi = \frac{V_{f_2}}{u_2} = \frac{V_{f_1}}{u_1}}$$

$$\tan\phi = \frac{8.87}{25.52}$$

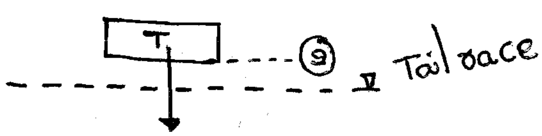
$$\boxed{\phi = 19.16^\circ}$$




## * Draft tube:-

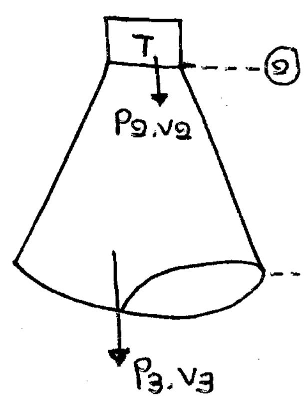
It is the diverging tube fitted at the exit of runner & used to utilize the "K.E" of water available at the exit of runner.

| Without Draft tube | With Draft tube |
|---|---|




$$\boxed{P_2 \geq P_{atm}}$$

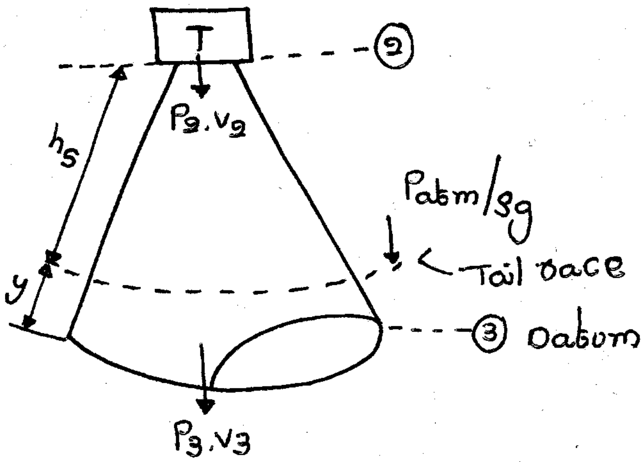
$$\frac{V_2^2}{2g} \rightarrow \text{waste}$$




$$\boxed{P_2 < P_{atm}}$$

$$P_3 \geq P_{atm}$$

$$V_2^2/2g > \frac{V_3^2}{2g} \rightarrow \text{waste}$$




Energy equ ② & ③

$$\frac{P_2}{\rho g} + \frac{V_2^2}{2g} + h_s + y = \underbrace{\frac{P_3}{\rho g}}_{\left(\frac{P_{atm}}{\rho g} + y\right)} + \frac{V_3^2}{2g} + 0 + h_f$$

$$\frac{P_2}{\rho g} = \frac{P_{atm}}{\rho g} + \cancel{y} + \underbrace{\frac{V_3^2}{2g} - \frac{V_2^2}{2g}}_{} + h_f - h_s - \cancel{y}$$

$[\because V_3 < V_2]$

$$\frac{P_2}{\rho g} = \frac{P_{atm}}{\rho g} - \left[\frac{V_2^2}{2g} - \underbrace{\frac{V_3^2}{2g} - h_f + h_s}_{(+ve)}\right]$$

$$\frac{P_2}{\rho g} < \frac{P_{atm}}{\rho g}$$

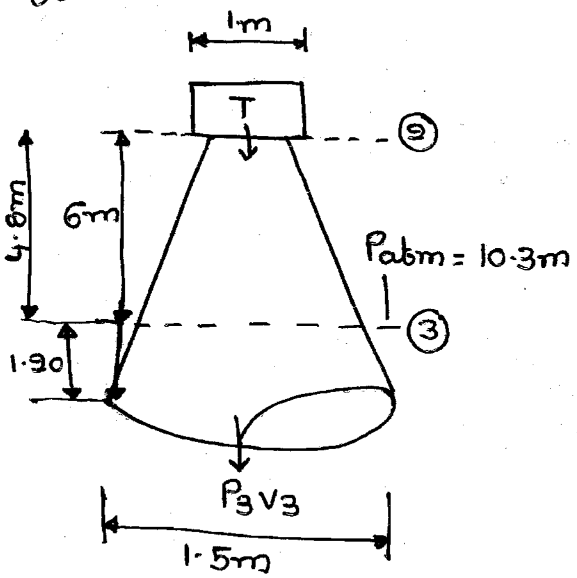
$$\left.\frac{P_2}{\rho g}\right|_{min} > \frac{P_v}{\rho g} \quad \text{[To avoid Cavitation]}$$

* Efficiency of Draft tube:-

$$\eta_{DT} = \frac{\frac{V_2^2}{2g} - \frac{V_3^2}{2g} - h_f}{\left(\frac{V_2^2}{2g}\right)}$$

| To avoid Flow Separation | => | Diverging Angle | $\not> 5^\circ - 7^\circ$ |
|---|---|---|---|

80.




$d_1 = 1m \qquad V_3 = 2.5 m/s$

$d_2 = 1.5m \qquad h = 6m, \; y = 1.90$

$P_{atm} = 10.3m$

$h_F = 0.2 \times \frac{2.5^2}{2g} = 0.063$

Energy equ (2) & (3)

$$\boxed{\frac{P_2}{\rho g} + \frac{V_2^2}{2g} + h_s + y = \frac{P_3}{\rho g} + \frac{V_3^2}{2g} + 0 + h_F}$$

$A_2V_2 = A_3V_3$

$$\left[\frac{\pi}{4} d_1^2\right] \times V_2 = \left[\frac{\pi}{4} d_2^2\right] \times V_3$$

$$1^2 \times V_2 = 2.5^2 \times 2.5$$

$$\boxed{V_2 = 5.625 m/s}$$

$$\frac{P_3}{\rho g} = 10.3 + 1.2 = 11.5m$$

$$\frac{P_2}{\rho g} + \frac{5.625^2}{2g} + 4.8 + 1.2 = 11.5 + \frac{2.5^2}{2g} + 0.063$$

$$\boxed{\frac{P_2}{\rho g} = 4.269m}$$

$$\eta_{DT} = \frac{\frac{5.625^2}{2g} - \frac{2.5^2}{2g} - 0.064}{\frac{5.625^2}{2g}}$$

$$\boxed{\eta_{DT} = 76.3\%}$$

* Specific Speed:-

It is defined as the speed at which the turbin would produce unit power when working under unit head. It is independent of size & used for selection of type of turbine.

$$\boxed{Sp = P = \eta_o \times \rho g Q H}$$

$P \propto QH$

$P \propto (D^2\sqrt{H})H$

$u = \frac{\pi D N}{60}$

$u \propto DN \propto \sqrt{H}$

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

$\therefore Q = A_F \times V_F$

$A_F \propto D^2$

$V_F \propto \sqrt{H}$

$Q \propto D^2\sqrt{H}$

$\therefore u \propto \sqrt{H}$

• Area $\propto \Delta^2$

• velocity $\propto \sqrt{H}$

$P \propto \left[\left(\frac{\sqrt{H}}{N}\right)^2 \sqrt{H}\right] H$

$P = \frac{k \cdot H^{5/2}}{N^2}$

Def :- H = unit head = 1m

P = unit power

N = NS

P = 1 Kw [SI]

P = 1 Hp [MKS]

$1 = \frac{k \cdot 1^{5/2}}{NS^2}$

$\boxed{K = NS^2}$

$P = \frac{NS^2 \cdot H^{5/2}}{N^2}$

$$\boxed{NS = \frac{N\sqrt{P}}{H^{5/4}} \text{ [MLT]}}$$

$$\boxed{\begin{aligned} NS &= 200 \text{ (SI)} \\ &= 200 \text{ [MKS]} \end{aligned}}$$

| NS | | Turbine |
|---|---|---|
| 0 – 60 | → | pelton wheel |
| 0 – 30 | → | single jet |
| 30 – 60 | → | Multi jet |
| 60 – 300 | → | francis |
| 300 – 1000 | → | propeller, kaplan |
| 300 – 600 | → | propeller |
| 600 – 1000 | → | Kaplan |

* Model prototype:-

i. Head Coefficiant:-

$$\frac{U \propto DN \propto \sqrt{H}}{H \propto D^2N^2}$$

$$\boxed{\left.\frac{H}{D^2N^2}\right|_M = k = Const = \left.\frac{H}{D^2N^2}\right|_P}$$

ii. Discharge coefficiant:-

$$Q \times D^2 \sqrt{H} \propto D^2 \cdot DN \propto D^3 N$$

$$\boxed{\left.\frac{Q}{D^3N}\right|_M = k = Const = \left.\frac{Q}{D^3N}\right|_P}$$

iii. power coefficiant:-

$$P \propto Q \cdot H \propto D^3N \cdot D^2N \propto D^5N^3$$

$$\boxed{\left.\frac{P}{D^5N^3}\right|_M = \left.\frac{P}{D^5N^3}\right|_P}$$

iv. Specific speed:-

$$\boxed{Ns|_M = Ns|_P}$$

* unit quantity:-

It is the parameter of the turbine which is defined by turbine operates under unit head & gives Max $\eta$. unit quantities are used to find out the performane ~~paratet~~ parameter [N, Q, P] for same turbine under different different head.

- Unit Speed [$N_u$]:-

$U \propto DN \propto N \propto \sqrt{H}$

Can take as Constant

$\frac{N}{\sqrt{H}} = k = $ Constant

Def:- $H = 1m$, $N = N_u$

$\frac{N_u}{\sqrt{1}} = k \Rightarrow k = N_u$

$$\boxed{\frac{N_1}{\sqrt{H_1}} = N_u = \frac{N_2}{\sqrt{H_2}}}$$

Unit power [$P_u$]:-

$P \propto QH \propto \sqrt{H} \cdot H \propto H^{3/2}$

$\frac{P}{H^{3/2}} = $ Const $= k$

Def:- $H = 1m$, $P = P_u$

$$\boxed{k = P_u}$$

$$\boxed{\frac{P_1}{H_1^{3/2}} = P_u = \frac{P_2}{H_2^{3/2}}}$$

- Unit Discharge [$Q_u$]:-

$Q \propto D^2 \cdot \sqrt{H} \propto \sqrt{H}$

$\frac{Q}{\sqrt{H}} = k = $ Constant

Def:- $H = 1m$ $Q = Q_4$

$k = Q_4$

$$\boxed{\frac{Q_1}{\sqrt{H_1}} = Q_u = \frac{Q_2}{\sqrt{H_2}}}$$

23.

$N_S = \frac{N\sqrt{P}}{H^{5/4}}$

$= \frac{145\sqrt{7000}}{25^{5/4}}$

$$\boxed{N_S = 217, \text{Francis}}$$

26. $\left.\frac{1000}{40^{3/2}}\right|_1 = \left.\frac{P_2}{20^{3/2}}\right|_2$

$$\boxed{P_2 = 354 \text{ kW}}$$

28.

| P | M |
|---|---|
| $P = 300 kw$ | $H = 10 m$ |
| $N = 1000 rpm$ | $P = ?$ |
| $H = 40 m$ | $N = ?$ |

$$\frac{D_M}{D_P} = \frac{1}{4}$$

$$\left.\frac{H}{D^2N^2}\right|_P = \left.\frac{H}{D^2N^2}\right|_M \longrightarrow \boxed{\left.\frac{N\sqrt{P}}{H^{5/4}}\right|_m = \left.\frac{N\sqrt{P}}{H^{5/4}}\right|_P}$$

$$N_M^2 = \frac{H_m}{H_P} \times \left[\frac{D_P}{D_M}\right]^2 \times N_P^2$$

$$N_m^2 = \frac{10}{40} \times (4)^2 \times 1000^2$$

$$\boxed{N_m = 2000 rpm}$$

$$\left.\frac{2000\sqrt{P}}{10^{5/4}}\right|_M = \left.\frac{1000\sqrt{300}}{40^{5/4}}\right|_P$$

$$\boxed{P_M = 2.34 kw}$$

Note:-

i. Runaway Speed:-

When the load on the turbine '↓' to '0' suddenly when then the speed of the runner '↑' to "1.5-3" times of normal speed called runaway speed. The runner is design to remain safe at runaway speed.

ii. The turbine also can be classified based upon head & discharge

| | H | Q | Turbine |
|---|---|---|---|
| | High | low | pelton |
| $wp = \rho g Q H$ | Medium | Medium | Francis |
| $Q = A_F V_F$ | low | High | Kaplan, propeller |

iii. For discharge/power kaplan turbine can be compact in size then Francis & then pelton.

iv.

$N_s \propto \sqrt{nP}$

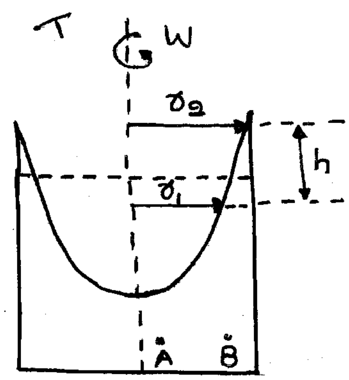
$n \rightarrow$ no of jets

$\boxed{N_s \propto \sqrt{n}}$

# centrifugal pump

* principle:-

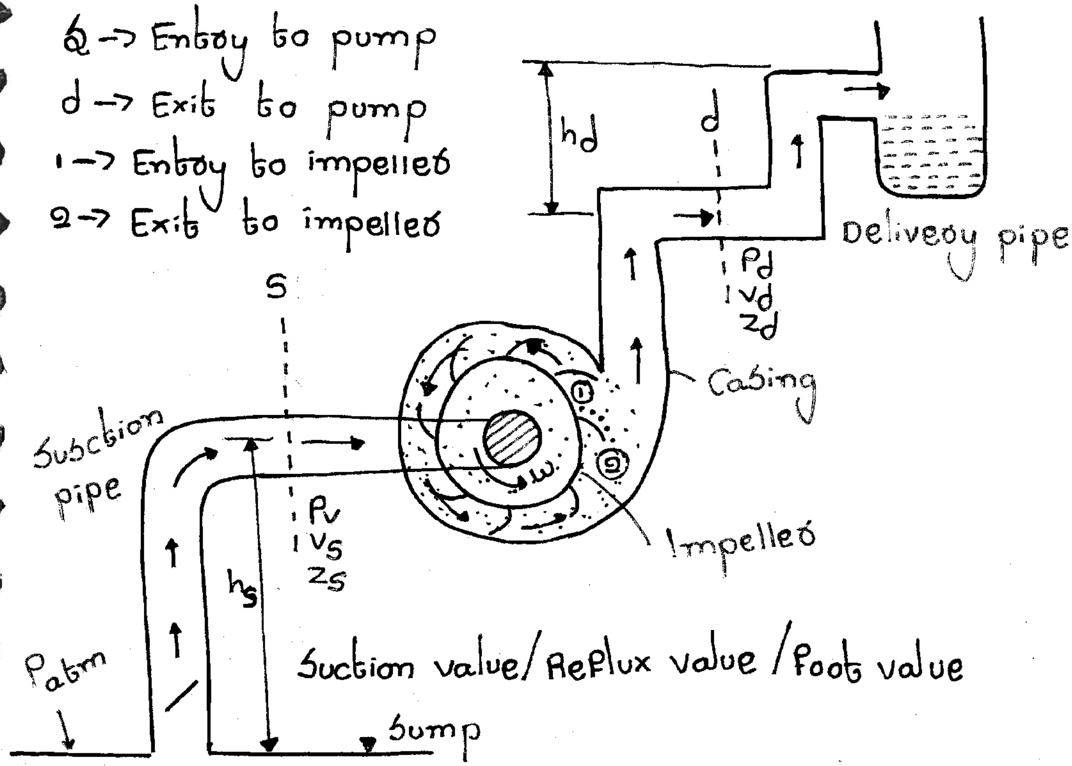
The centrifugal pump works on the principle of force vortex which says when a mass of water is rotating about the axis then the raising pressure is radially outward direction & pressure '↓' in the inward direction. The rise in pressure is directly propotional to square of the speed.




$$h = \frac{P_2 - P_1}{\rho g} = \frac{\omega^2 [r_2^2 - r_1^2]}{2g}$$

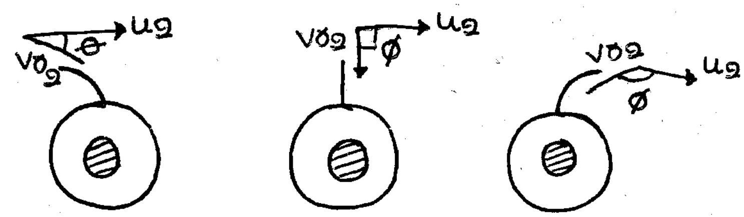
$$\boxed{\Delta P \propto \omega^2}$$

s → Entry to pump
d → Exit to pump
1 → Entry to impeller
2 → Exit to impeller



## * Components:-

i. Casing:- Spiral/volute/Scroll casing

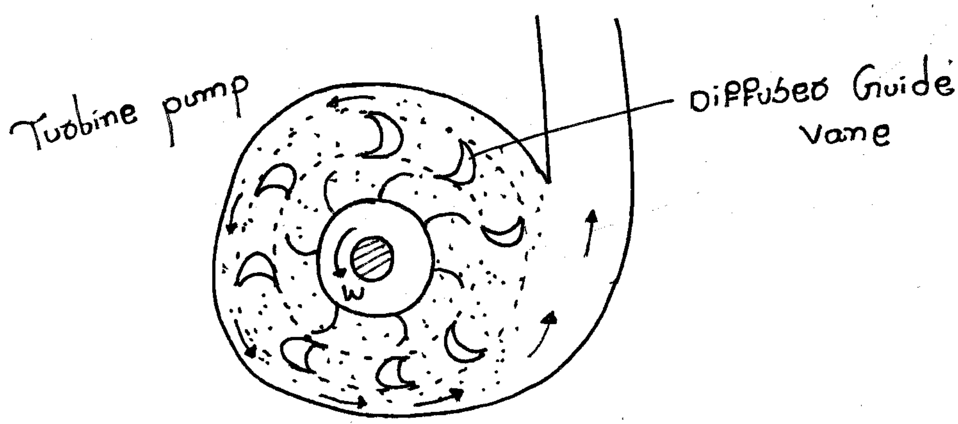



$\phi < 90^\circ$ [Backward vane]

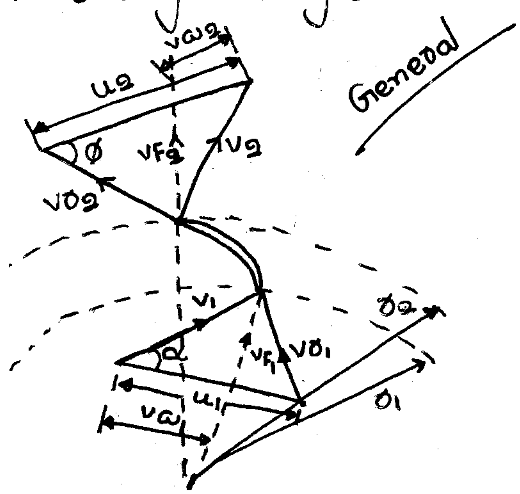
$\phi = 90^\circ$ [Radial Vane]

$\phi > 90^\circ$ [Forward Vane]

- Most preferred vane.




## * velocity triangle:-




$$IP = T\omega$$

$$T = \dot{m} \times V_{w2} \times r_2 - \dot{m} \times V_{w1} \times r_1$$

$$T = \dot{m}\,[V_{w2} r_2 - V_{w1} r_1] \text{ N-m}$$

$$IP = T\omega = \dot{m}\,[V_{w2} r_2 - V_{w1} r_1]\,\omega$$

$$IP = \rho Q\,[V_{w2} u_2 - V_{w1} u_1]\,\omega$$

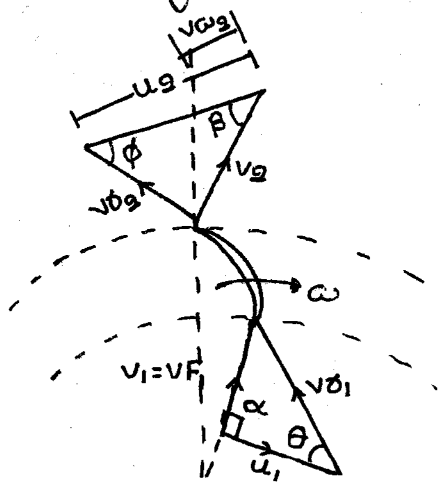
$$\frac{IP}{\dot{m} g} = \frac{[V_{w2} u_2 - V_{w1} u_1]}{g}\ m = H_e$$

$$u_1 = \omega r_1 = \frac{\pi d_1 N}{60}$$

$$u_2 = \omega r_2 = \frac{\pi d_2 N}{60}$$

$r_2 > r_1 \mid u_2 > u_1$

Centrifugal pump:-




| Francis | CP |
|---|---|
| $V_2 = V_{F2}$ | $V_1 = V_{F1}$ |
| $V_{w2} = 0$ | $V_{w1} = 0$ |
| $\beta = 90^\circ$ | $\alpha = 90^\circ$ |

$$I_p = \rho Q[V_{w2} u_2]$$

$$\frac{I_p}{mg} = \frac{V_{w2} u_2}{g}$$

* Types of head:-

1. Static head [HS]:-

$$\boxed{H_S = h_s + h_d}$$

2. Manometric head [Hm]:-

i. If no loss in pump:-

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

ii. If loss in pump:-

$$H_m = \frac{V_{w2} u_2}{g} - [\text{loss in impeller} + \text{loss in casing}]$$

iii.

$$H_m = \left[\frac{P_d}{\rho g} + \frac{V_d^2}{2g} + z_d\right] - \left[\frac{P_s}{\rho g} + \frac{V_s^2}{2g} + z_s\right]$$

$$z_s \approx z_d$$

$$H_m = \frac{P_d - P_s}{\rho g} + \frac{V_d^2 - V_s^2}{2g}$$

$$\dot{m}_{suction} = \dot{m}_{delivery}$$

$$\rho \times \left[\frac{\pi}{4} d_s^2\right] \times V_s = \rho \times \left[\frac{\pi}{4} d_d^2\right] \times V_d$$

If Given in prob $\therefore d_s = d_d$

$\because V_s = V_d$

$$\boxed{\Rightarrow H_m = \frac{P_d - P_s}{\rho g}}$$

iv.

$$H_m = H_s + H_F + \frac{V_d^2}{2g}$$

$$H_s = h_s + h_d$$

$$\boxed{H_F = H_{Fs} + H_{Fd}}$$

Manometric head :-

it is defined as the net energy given by Pump to water are it is the head against the which pump is working or head developed by the pump.

Area of Flow :-

$AF_1 = \pi d_1 b_1$

$AF_2 = \pi d_2 b_2$

Discharge :-

$Q = AF_1 VF_1 = AF_2 VF_2$

$Q = \pi d_1 b_1 VF_1 = \pi d_2 b_2 VF_2$

$\frac{WP}{MP} = \dot{m} g H_m = \rho g Q H_m$

$IP = \rho Q [Vw_2 u_2 - Vw_1 u_1]$

$IP = \rho Q [Vw_2 u_2]$ Cp

$SP = IP + \text{Mech-loss}$

Motor power $= SP + \text{loss in motor}$

$\eta_{mano} = \frac{WP}{IP} = \frac{g H_m}{Vw_2 u_2}$

$\eta_{mech} = \frac{IP}{SP}$

- $\eta_o = \frac{WP}{SP} = \frac{WP}{IP} \times \frac{IP}{SP}$

- $\eta_o = \eta_{mano} \times \eta_{mech}$

* Imp ratio:-

- width ratio – $\frac{b}{d}$
- dia ratio – $\frac{d_1}{d_2} = 0.5$
- Speed ratio $K_u = \frac{u_2}{\sqrt{2gH}}$
- Flow ratio $K_F = \frac{V_{F2}}{\sqrt{2gH_m}}$

(34)

$\eta = 90\%$

$H_S = 155m$

$Q = 7.5 m^3/s$

$H_F = 13m$

$S.P = ?$

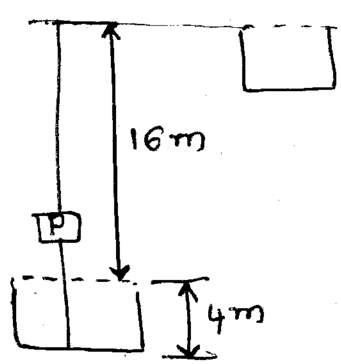
$\eta_o = \frac{WP}{SP}$

$S.P = \frac{\rho g Q H_m}{\eta_o} = \frac{1000 \times 9.81 \times 7.5 \times 168}{0.9} = \boxed{13.734}$ //

$H_m = H_S + H_F$

$H_m = 155 + 13 = 168m$

36.




$Q = 0.025 m^3/s$

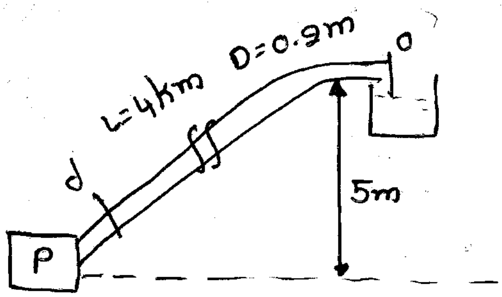
$\eta = 65\%$

$SP = \frac{\rho g Q H_m}{\eta_o}$

$SP = \frac{1000 \times 9.81 \times 0.025 \times 20}{0.65}$

$SP = 7.54 kW$

50.




$$\frac{P_d}{\rho g}+\cancel{\frac{V_d^2}{2g}}+\cancel{Z_d} = \frac{P_o}{\rho g}+\cancel{\frac{V_o^2}{2g}}+\cancel{Z_o}+h_p$$

(or) 10.3, 5

Head given by pump to water $= H_s + \frac{FLV^2}{2gD}\Big|_{pipe}$

$$= 5 + \frac{0.01\times4000\times2^2}{2\times9.81\times1}$$

$$\frac{P}{\rho g} = 45.77m$$

$P_g = 4.49$ bar (gauge)

$P_{abs} = 4.49+1.013 = 5.503$ bar (absolute)

35.

$Q = 0.118 m^3/s$

$N = 1450$ rpm

$H = 25m$

$d_2 = 25cm$

$b_2 = 5cm$

$\eta_m = 75\%$

$\phi = ?$

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

$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi\times0.25\times1450}{60} = 19m/s$$

$$Q = \pi d_2 b_2 V_{f2}$$

$$V_{f2} = \frac{Q}{\pi d_2 b_2} = \frac{0.118}{\pi\times0.25\times0.05} = 3m/s$$

$$\eta_m = \frac{gH_m}{V_{w2}u_2}$$

$$V_{w2} = \frac{9.81\times25}{0.75\times19} = 17.237 m/s$$

$$\phi = \tan^{-1}\left[\frac{3}{19-17.237}\right]$$

$$\boxed{\phi = 59.55°}$$

33. $V = \frac{\pi D N}{60} = \frac{\pi \times 0.5 \times 1200}{60} = 10\pi \ m/s$

T6. $d_1 = 1.0m$  $N = 400rpm$  $AF_1 = 0.25m^2$  $H = 65m$  $VF_1 = 8.0m/s$
$V\omega_1 = 25.0m/s$

$\eta_h = \frac{R.P}{\omega.p}$

$u_1 = \frac{\pi d_1 N}{60} = \frac{\pi \times 1.0 \times 400}{60} = 20.94$

$\omega.p = \rho g Q H$

$Q = AF_1 \times VF_1$
$= 0.25 \times 8.0 = 2 \ m^3/s$

$\omega.p = 1000 \times 9.81 \times 2 \times 65$

$\omega.P = 1275.3 \ k\omega$

$RP = \rho Q [V\omega_1 u_1]$
$= 1000 \times 2 [25.0 \times 20.94]$

$RP = 1047 k\omega$

$\eta_h = \frac{1275.3}{1047} = 82.11\%$

T7. $H = 12m$  $D_b = 0.35 D_o$  $N = 100rpm$  $\phi = 15^\circ$  $k_p = 0.6$

$k_p = \frac{VF_1}{\sqrt{2gH}}$

$0.6 = \frac{VF_1}{\sqrt{2 \times 9.81 \times 12}}$

$VF_1 = 9.206$

$\tan\phi = \frac{VF_2}{u_2} = \frac{VF_1}{u_1}$

$\tan(15) = \frac{9.206}{u_1}$

$u_1 = 34.35$

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

$34.35 = \frac{\pi \times D_o \times 100}{60}$

$D_o = 6.56m$

$D_b = 0.35 \times 6.56 = 2.296$

$Q = \frac{\pi}{4} (D_o^2 - D_b)^2 VF_1$

$Q = \frac{\pi}{4} [6.56^2 - 2.296^2] \times 9.206$

31.

$Q = 0.6\,m^3/sec$

$H_m = 15m$

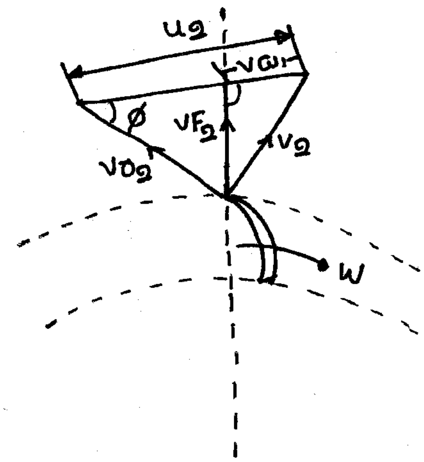
$N = 750\,rpm$

$\eta_{mano} = 80\%$

$loss = 0.027 V_2^2\, m$

$V_f = 3.2\, m/s$

$d_2, A_{F2}, \phi = ?$




$Q = A_{F2} V_{F2}$

$0.6 = A_{F2} \times 3.2$

$\boxed{A_{F2} = 0.1875 m^2}$

$$\eta_{mano} = \frac{gH_m}{V_{\omega 2} u_2}$$

$$0.8 = \frac{9.81 \times 15}{V_{\omega 2} u_2}$$

$V_{\omega 2} u_2 = 183.93$ — (1)

$$H_m = \frac{V_{\omega 2} u_2}{g} - \text{loss in pump}$$

$$15 = \frac{183.93}{9.81} - 0.027 V_2^2$$

$\boxed{V_2 = 11.78\, m/s}$

$V_2^2 = V_{\omega 2}^2 + V_{F2}^2$

$1.78^2 = V_{\omega 2}^2 + 3.2^2$

$\boxed{V_{\omega 2} = 11.33\, m/s}$

$1.33 \times u_2 = 183.93$

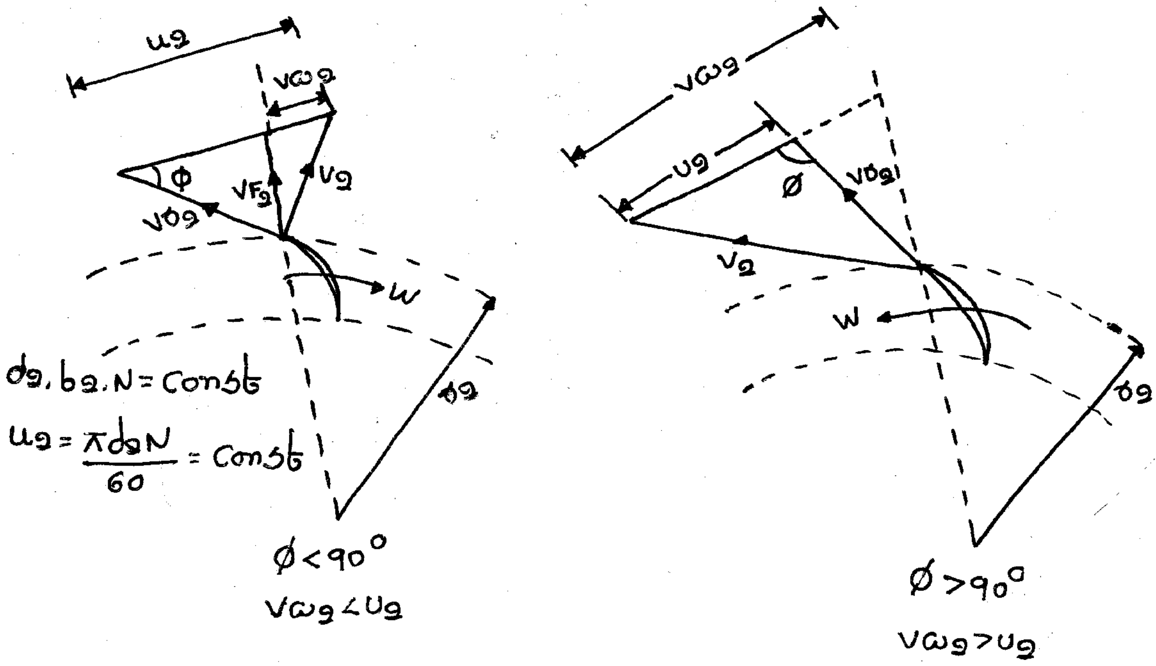
$$u_2 = 16.23\, m/s = \frac{\pi d_2 N}{60}$$

$\boxed{d_2 = 0.413 m}$

$$\tan\phi = \frac{V_{F2}}{u_2 - V_{\omega 2}} = \frac{3.2}{16.23 - 11.33}$$

$\boxed{\phi = 33.1°}$

* why Backward vanes are most preferred vanes:-




· For Radial Vanes $[\phi = 90^\circ] \Rightarrow [u_2 = V\omega_2]$

$$V\omega_2|_F > V\omega_2|_R > V\omega_2|_B$$

$$Ip|_F > Ip|_R > Ip|_B$$

$$Sp|_F > Sp|_R > Sp|_B$$

$$\boxed{\eta_o = \frac{\omega P}{SP}}$$

$$\boxed{\eta_o|_B > \eta_o|_R > \eta_o|_F}$$

* Effect of Vane Angle $[\phi]$ over head & discharge:-

$$H_m = \frac{V\omega_2 u_2}{g}$$

$$V\omega_2 = u_2 - V_{F_2}\cot\phi$$

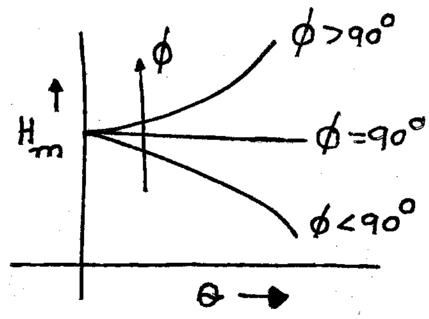
$$H_m = \frac{(u_2 - V_{F_2}\cot\phi)u_2}{g}$$

$$H_m = \underbrace{\frac{u_2^2}{2g}}_{A} - \underbrace{\frac{u_2}{g\,AF_2}}_{B}\underbrace{(AF_2)}_{Q}\cot\phi$$

$d_2, N, b_2 = \text{const}$

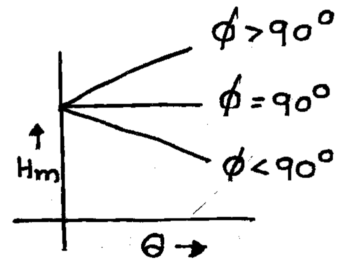
$u_2 = \frac{\pi d_2 N}{60} = \text{const}$

$AF_2 = \pi d_2 b_2 = \text{const}$




$H_m = A - BQ\cot\phi$

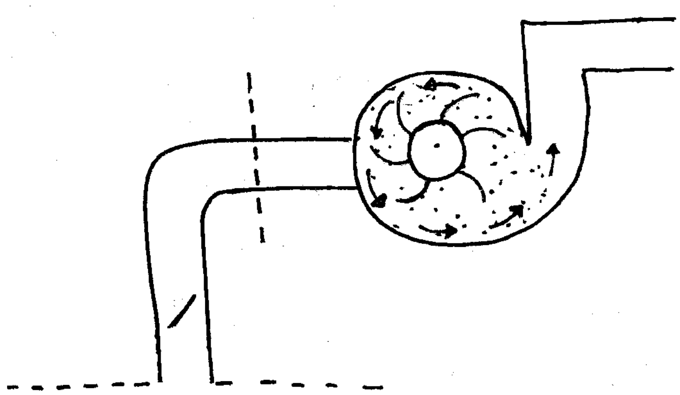
- $\phi < 90^\circ$ — $\cot\phi \rightarrow (+ve)$
- $\phi = 90^\circ$ — $\cot\phi \rightarrow 0$
- $\phi > 90^\circ$ — $\cot\phi \rightarrow (-ve)$




[Assuming no loss]

## * Priming of pump:-

The process of manually filling the water or removing the air from casing & suction pipe is known as priming of pump. The priming is done to ensure that the impeller does the work directly over the water.



• Priming of pump:-

$$I_p = T\omega = \underbrace{\rho}_{\rho_{water}\ \rho_{air}} Q\,[V_{w2} u_2]$$

$$\underbrace{H_m}_{\text{very less}} = \frac{IP}{mg}$$

$$\rho_{air} <<<<< \rho_{water}$$

## * Minimum starting speed of pump:-

$$\frac{P_2 - P_1}{\rho g} = \frac{\omega^2 [r_2^2 - r_1^2]}{2g} \geq H_m$$

$$\frac{2\pi N}{60} = \omega = \sqrt{\frac{2gH_m}{[r_2^2 - r_1^2]}}$$

## * Specific speed [Ns]:-

it is defined as the speed at which the pump would deliver unit discharge when working against unit head.

$$Q = A_F \times V_F$$

$$Q \propto D^2 . \sqrt{H_m}$$

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

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

Area $\propto D^2$

$V_F \propto \sqrt{H_m}$

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

$$Q \propto \left[\frac{\sqrt{H_m}}{N}\right]^2 . \sqrt{H_m}$$

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

Def:- $H_m$ = unit head = 1m

$Q$ = unit discharge

$$\boxed{N = N_S}$$

$Q = 1 m^3/sec$

$= 1$ lit/sec

$$1 = \frac{K \cdot 1^{3/2}}{N_S^2} \Rightarrow \boxed{K = N_S^2}$$

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

$$\boxed{N_S = \frac{N\sqrt{Q}}{H_m^{3/4}} \quad [M^0 L T]}$$

| NS | pump |
|---|---|
| 0-80 | Radial |
| 80-160 | Mixed |
| 160-300 | Axial |

* Model- prototype:-

1. Head Coefficient:-

$$\left.\frac{Hm}{D^2N^2}\right|_M = \left.\frac{Hm}{D^2N^2}\right|_P$$

1. Discharge Coefficient:-

$$\left.\frac{Q}{D^3N}\right|_M = \left.\frac{Q}{D^3N}\right|_P$$

3. power Coefficient:-

$$\left.\frac{P}{D^5N^3}\right|_M = \left.\frac{P}{D^5N^3}\right|_P$$

4. Specific Speed:-

$$Ns|_M = Ns|_P$$

* Multiple pump:-

$n$ = no of pumps

| i. Series | ii. parallel |
|---|---|
| total $Hm = n \times Hm$ | $Hm$ = Constant |
| $Q$ = Constant | total $Q = n \times Q$ |

16.

$$\left.\frac{Q}{D^3\cancel{N}}\right|_M = \left.\frac{Q}{D^3\cancel{N}}\right|_P$$

[Speed is same]

$$\left.\frac{13.2}{20^3}\right|_M = \left.\frac{Q}{15^3}\right|_P$$

$$\boxed{Q = 5.57 lps}$$

38.

$$\frac{2\pi N}{60} = \sqrt{\frac{2gHm}{(r_2^2 - r_1^2)}}$$

$$\frac{2\pi N}{60} = \sqrt{\frac{2 \times 9.81 \times 15.3}{(0.4^2 - 0.2^2)}}$$

$$\boxed{N = 477 rpm}$$

$d_2 = 80cm$

$r_2 = 40cm$

$$\frac{d_1}{d_2} = \frac{r_1}{r_2} = 0.5$$

$r_1 = 20cm$

69.

$H_m = 150\,m$

$N_s = 30$

$N = 1450\,rpm$

$Q = 0.2\,m^3/sec$

$n = ?$

$N_s = \dfrac{N\sqrt{Q}}{H_m^{3/4}}\Bigg|_{\text{Each pump}}$

$30 = \dfrac{1450\sqrt{0.2}}{H_m^{3/4}}$

$H_m\big|_{\text{each pump}} = 60.21\,m$

$150 = n \times 60.21$

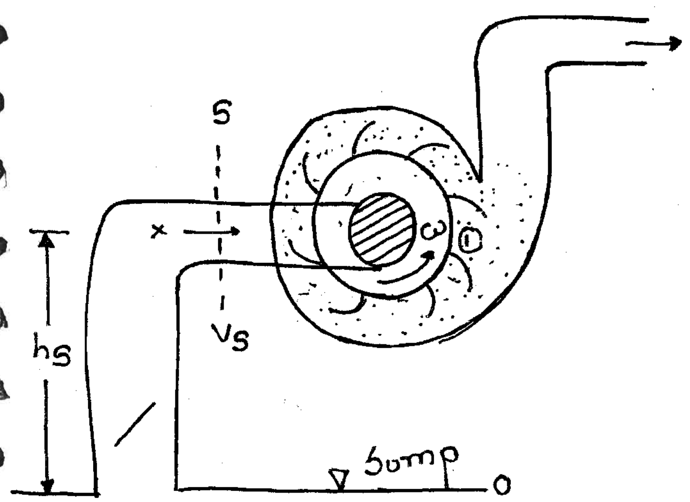
$\boxed{n = 2.49 \approx 3 \text{ pumps}}$

series :-

total $H_m = 150 = n \times H_m$

$Q = \text{const} = 0.02\,m^3/sec$

* Suction height of cp :- — (20-22 feet)




Energy equ 0-1

$\dfrac{P_{atm}}{\rho g} + 0 + 0 = \dfrac{P_1}{\rho g} + \dfrac{v_1^2}{2g} + h_s + h_f$ $[\because v_s \approx v_1]$

$\underset{3m}{\dfrac{P_1}{\rho g}} = \underset{10.3}{\dfrac{P_{atm}}{\rho g}} - \underbrace{\left[\overset{0.3}{\dfrac{V_s^2}{2g}} + h_s + h_f\right]}_{+ve}$

very less

$\dfrac{P_1}{\rho g} < \dfrac{P_{atm}}{\rho g}$

$\dfrac{P_1}{\rho g}\Bigg|_{min} > \dfrac{P_v}{\rho g}$ [To avoid cavitation]

* Area affected by Cavitation:-

- In Reaction tube:- At the exit of runner or entry to draft tube
- In Centrifugal pump:- At the entry to impeller or pump.

* Net positive suction head [NPSH]:-

it is defined as the difference b/w pressure head entry to impeller to the vapour pressure of fluid at operating temp. it help us to avoid the cavitation.

$$\boxed{NPSH = \frac{P_1}{\rho g} - \frac{P_V}{\rho g}\, m = \frac{P_{atm}}{\rho g} - h_s - h_F - \frac{P_V}{\rho g}\, m}$$

| | |
|---|---|
| 0.36 < | 0.5 m/min |
| 0.79 > | |

$\sigma = 0 \rightarrow NPSH \rightarrow 0$

if NPSH is '0'

$P_1 = P_V$

* Thoma's Cavitation factor/Cavitation Coefficient [$\sigma$]:-

$$\sigma = \frac{NPSH}{H} = \frac{H_{atm} - h_s - h_F - h_v}{H}$$

H:
- pump (Hm)
- Turbine: H = Net head

$$\begin{Bmatrix} \sigma > \sigma_c & \text{[No Cavitation]} \\ \sigma < \sigma_c & \text{[Cavitation occurs]} \end{Bmatrix}$$

$\sigma_c \rightarrow$ Critical factor

## * Reciprocating pump:-

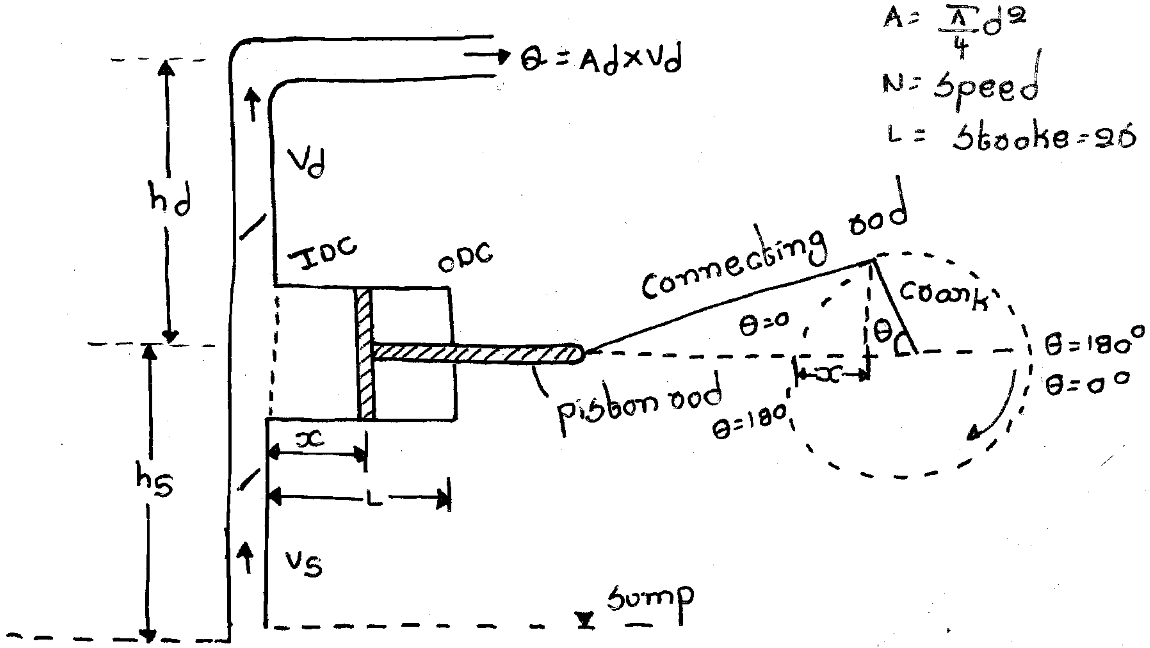
r: Crank radius

D = Bore/piston dia

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

N: Speed

L = Stroke = 2r




$\theta = \omega t$

$X = r - r\cos\theta$

$x = r - r\cos\omega t$

$V_p = \frac{dx}{dt} = 0 - r\omega - \sin\omega t$

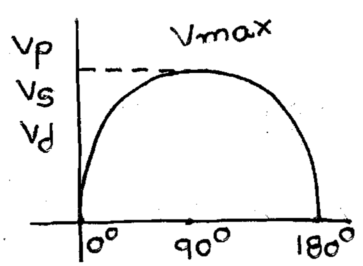
$V_p = +r\omega\sin\theta$

$\dot{m}_{suction} = \dot{m}_{pump} = \dot{m}_{delivery}$

$\underbrace{\rho \times A_s \times V_s = \rho \times A}\underbrace{\times V_p = \rho \times A_d} \times V_d$

$V_s = \frac{A}{A_s} \cdot V_p$

$V_d = \frac{A}{A_d} \cdot V_p$




## * characteristic of R.P.:-

- pulsating discharge
- variable discharge
- $H_F = \frac{fLV^2}{2gD} \Big|_{pipe}$

$V_s, V_d \rightarrow max$

$H_F \rightarrow max$

Consumes more power

- low discharge

→ High head

• Theoritical dischaoge

$$Q_{th} = \frac{A \times LN}{60} \ m^3/sec$$

• $Slip = Q_{th} - Q_{act}$

if $Q_{act} > Q_{th}$

"Negative slip condition" ***

• High speed

• Shoot Delivery pipe

• Coff of dischaoge $C_d = \frac{Q_{act}}{Q_{th}}$

$$\% \ slip = \frac{Q_{th} - Q_{act}}{Q_{th}} = 1 - C_d$$

* Aio vessel:-

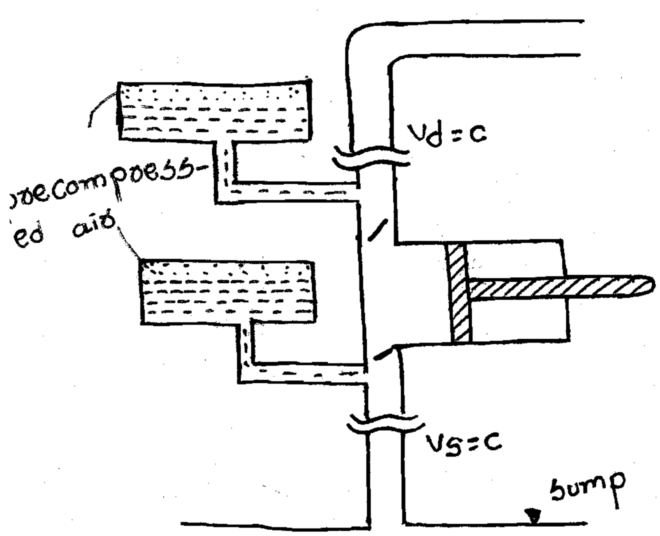
it is the reseovoio of water placed near to pump in suction & delivery pipe.

Adv:-

To maintain constant dischaoge

To reduce power input by avoiding acceleration & de-acceleration of water

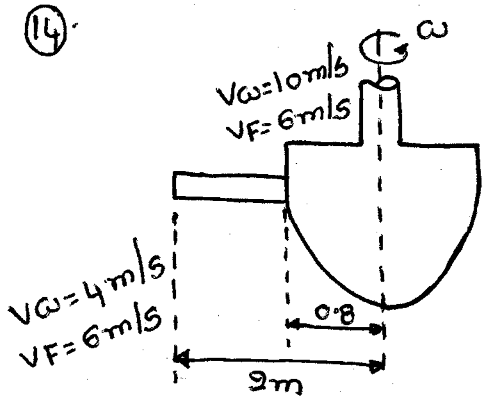
The speed of the pump can be increased. Therefore it can handle more dischaoge.



| Machine | Dimensionless $N_S$ |
|---|---|
| Turbine | $N_S = \dfrac{N\sqrt{\frac{P}{\rho}}}{(gH)^{5/4}}$ |
| pump | $N_S = \dfrac{N\sqrt{Q}}{(gH_m)^{3/4}}$ |

— Shape Factor

14.




$\eta_H|_o = \eta_H|_b = \eta_H|_M$

$\dfrac{V_{\omega_1} u_1}{\cancel{gH}}\Big|_o = \dfrac{V_{\omega_1} u_1}{\cancel{gH}}\Big|_b$

$V_{\omega_1} r_1 \cancel{\omega}|_o = V_{\omega_1} r_1 \cancel{\omega}|_b$

$V_{\omega_1} r_1|_o = V_{\omega_1} r_1|_b$

$V_{\omega_1} \times 2|_o = 10 \times 0.8|_b$

$V_{\omega_1} = 4\,m/s$

66.