Impulse Reaction turbine / Reaction turbine :-

 # Principle :- Water is supplied by penstock from reservior to turbine, then enters into casing. casing is always filled with water inside the casing a number of guide vane are present which converts the head available with water partialy into dynamic head $\left(H = \frac{V_1^2}{2g} + \frac{P_1}{\rho g}\right)$. As the water enters over the runner it has ~~got~~ both kinetic and pressure energy. As the water strikes moving vane it apply ~~large magnitude~~ impulse force due to K.E. same as the In pelton wheel.

As the water flows over the moving vane it creates a pressure differance across the vane due to aerofoil shape of the vane, due to which water applies a lift force. The lift force is also known as reaction force. The impulse and reaction both forces will rotate the runner therefore these turbine are known as impulse reaction turbine

⇒ | Entry | Exit |
|---|---|
| K.E. + Pr.E. | P_2, V_2 } min |
| $V_2 << V_1$ | |
| $P_2 << P_1$ | |

→ Smooth vane = $V_{r_2} >> V_{r_1} \Rightarrow V_{r_1} \neq V_{r_2}$

Component used in Reaction turbine :-

① Casing / spiral / volute / scroll casing :-

The casing is spiral in shape (gradually decreasing area), decreasing area help to maintain constant velocity of water at inlet to runner.

② Guide / Fixed vane / wicket Gate :

Guide are used to guide the water towards the runner in α - dir^n {α = guide vane angle}. Even though these vane are fixed but can rotate about their own axis ~~whi~~ with the help of governor to control the discharge by controlling flow area

③ Runner / Rotor :- according to flow of water

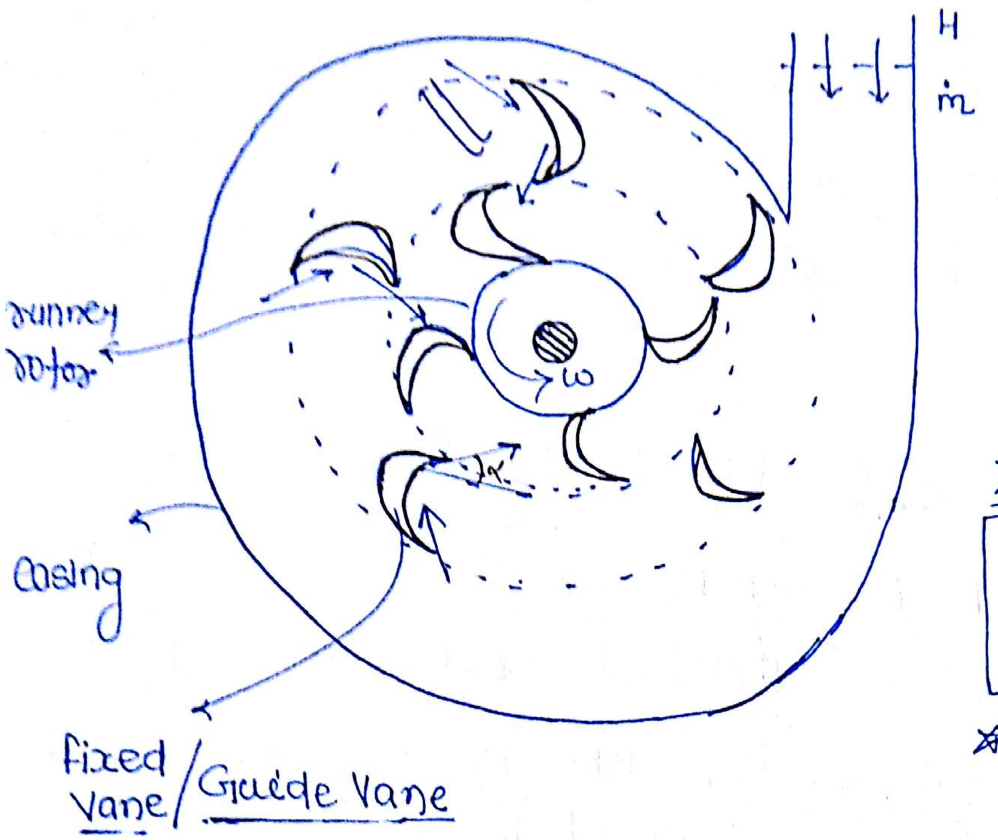
- Radial
- Axial
- Mixed

→ Moving Vane Angle → θ, ϕ

④ Draft tube :-

Radial Flow reaction turbine:-

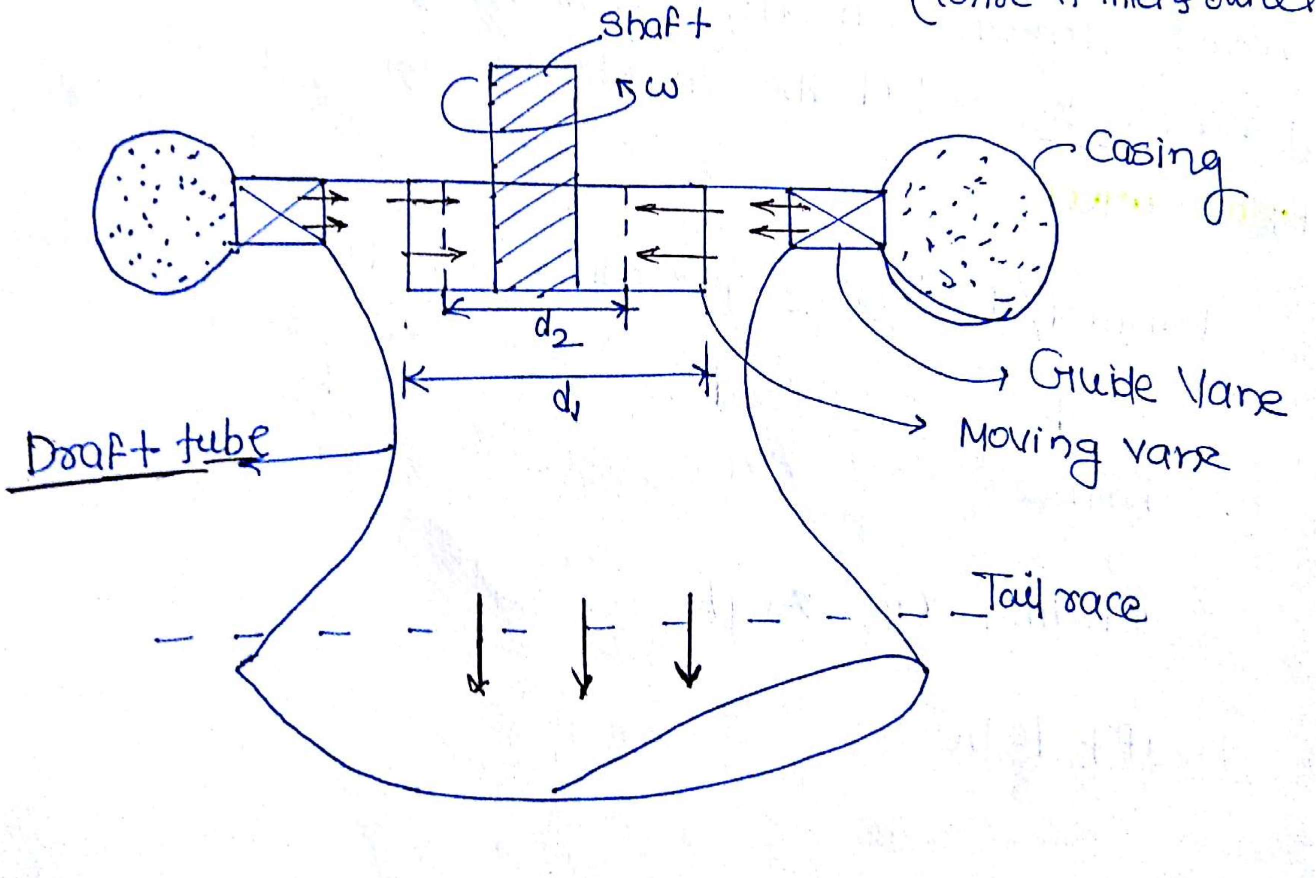
Top View:-



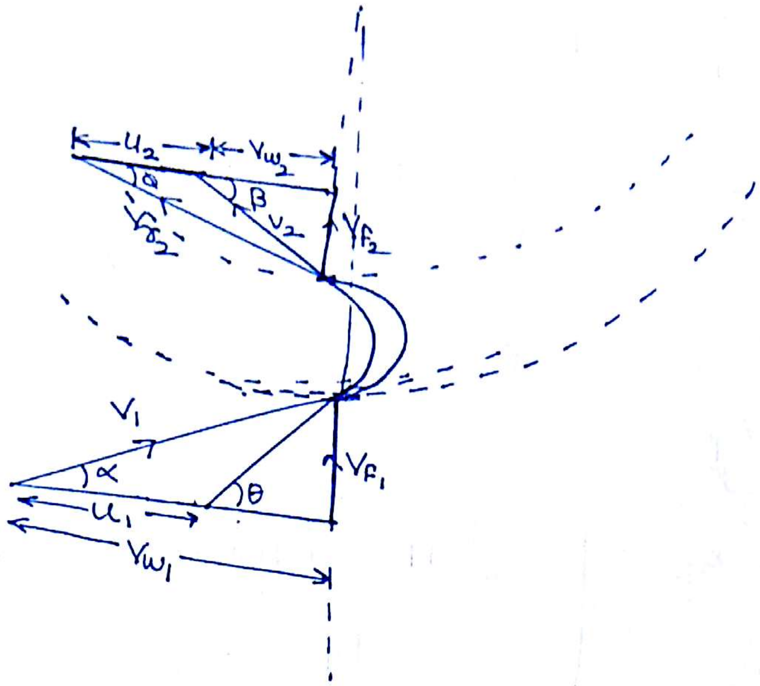
casing Gradually ↓ area

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

* V_1 should not be taken as $\sqrt{2gH}$ (centre से inlet & outlet diff.)



Velocity diagram :-



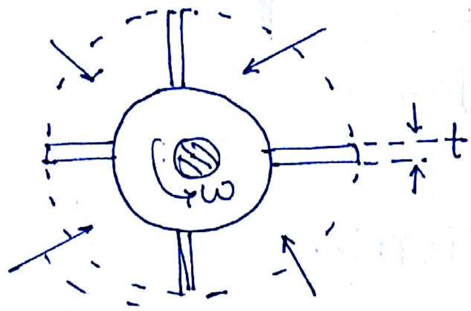
$$u_1 = \omega r_1 = \frac{\pi d_1 N}{60}$$

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

$d_1 > d_2$

$u_1 > u_2$

Area of Flow :-



crossectional area of flow dir^n

water flow in circumfrential area

$$A_f = \pi d b$$

$$A_{f_1} = \pi d_1 b_1 , \quad A_{f_2} = \pi d_2 b_2$$

$b_1, b_2 \rightarrow$ width of vane at entry & exit.

$\rightarrow$ t = thickness of vane

n = no. of Vane

Actual $\boxed{A_f = (\pi d - nt) \times b}$

Actual $\boxed{A_f = k . \pi d b}$

k = Coefficient of Vane thickness

discharge:-

$$Q = A_f \times V_f$$

$$Q = A_{f_1} \times V_{f_1} = A_{f_2} V_{f_2}$$

to get $F_y = 0$ (No radial force on runner)

$$\therefore V_{f_1} = V_{f_2}$$

$$\therefore A_{f_1} = A_{f_2}$$

$$\Rightarrow \pi d_1 b_1 = \pi d_2 b_2$$

$$d_1 b_1 = d_2 b_2$$

* $d_1 > d_2$

$b_2 > b_1$

if Given

$$b_1 = b_2$$

$$V_{f_1} \neq V_{f_2}$$

Degree of Reaction:-

$$\frac{RP}{\dot{m}g} = \Delta KE \text{ head} + \Delta Pr. \text{ head}$$

$$R = \frac{\text{Contribution of pr. head in to } RP/\dot{m}g}{\text{total contribution of KE \& Pr. heat into } RP/\dot{m}g}$$

$$\frac{RP}{\dot{m}g} = \frac{V_{w_1} U_1 + V_{w_2} U_2}{g}$$

$\Rightarrow$ $\underline{\underline{V_{w_1} u_1}}$

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

$$V_{w_1} - u_1 = V_{r_1} \cos\theta = \sqrt{V_{r_1}^2 - V_{f_1}^2}$$

$$(V_{w_1} - u_1)^2 = V_{r_1}^2 - V_{f_1}^2 = V_{r_1}^2 - (V_1^2 - V_{w_1}^2)$$

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

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

$\Rightarrow$ $\underline{\underline{V_{w_2} u_2}}$

$$V_{w_2} = V_{r_2} \cos\phi - u_2$$

$$(V_{w_2} + u_2) = V_{r_2} \cos\phi = \sqrt{V_{r_2}^2 - V_{f_2}^2}$$

$$(V_{w_2} + u_2)^2 = V_{r_2}^2 - V_{f_2}^2$$

$$V_{w_2} + u_2 + 2 V_{w_2} u_2 = V_{r_2}^2 - (V_2^2 - V_{w_2}^2)$$

$$V_{w_2} u_2 = \frac{-V_2^2 - u_2^2 + V_{r_2}^2}{2}$$

$$\Rightarrow \frac{RP}{\dot{m}g} = \frac{V_{w_1} u_1 + V_{w_2} u_2}{g} = \frac{V_1^2 - V_2^2}{2g} + \frac{u_1^2 - u_2^2}{2g} + \frac{V_{r_2}^2 - V_{r_1}^2}{2g}$$

$$\frac{RP}{\dot{m}g} = \Delta K \text{ Head} + \Delta Pr \text{ Head}$$

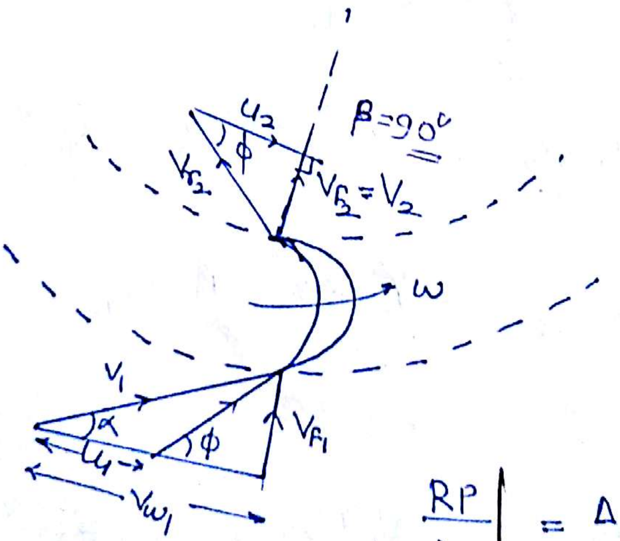
So degree of reaction

$$R = \frac{\frac{u_1^2 - u_2^2}{2g} + \frac{V_{r_2}^2 - V_{r_1}^2}{2g}}{RP/\dot{m}g}$$

$$R = \frac{RP/\dot{m}g - \left(\frac{V_1^2 - V_2^2}{2g}\right)}{RP/\dot{m}g}$$

$$\boxed{R = 1 - \frac{\left(V_1^2 - V_2^2\right)}{2g\left(RP/\dot{m}g\right)}}$$

Francis turbine :-



$$\left.\frac{RP}{\dot{m}g}\right|_{max} = \Delta K\ Heat\Big|_{max} + \Delta Pr\ head\Big|_{max}$$

$$\left.\frac{RP}{\dot{m}g}\right|_{max} \Rightarrow \Delta K \text{ Head}\Big|_{max} \Rightarrow \left.\frac{V_1^2 - V_2^2}{2g}\right|_{max} \Rightarrow V_2 = min$$

$$V_2 = \sqrt{V_{w_2}^2 + V_{f_2}^2}$$

for V_2 min, $V_{w_2} = 0$

Conditions for Francis turbine

$$\boxed{V_{w_2} = 0 \;,\; V_2 = V_{f_2} \;,\; \beta = 90^\circ}$$

Francis turbine is an inward flow reaction turbine with radial discharge.

$$R_{Francis} = 1 - \frac{V_1^2 - V_2^2}{2g\left[\frac{\rho Q (V_{w_1} U_1)}{\dot{m} g}\right]}$$

$$R_{Francis} = 1 - \frac{V_1^2 - V_2^2}{2 V_{w_1} U_1}$$

$\because V_1^2 = V_{w_1}^2 + V_{f_1}^2$

$\because V_2 = V_{f_2}$

$$R_{Francis} = 1 - \frac{V_{w_1}^2 + V_{f_1}^2 - V_{f_2}^2}{2 V_{w_1} U_1}$$

$$\boxed{R_{Francis} = 1 - \frac{V_{w_1}}{2 U_1}}$$

degree of reaction for Francis turbine

$$\boxed{R_{impulse} = 0}$$

degree of reaction for impulse turbine.

Power

$\rightarrow WP/HP = \rho g Q H$

$\rightarrow RP = \rho Q (V_{w_1} U_1 + V_{w_2} U_2)$

$RP = \rho Q (V_{w_1} U_1) \rightarrow$ francis turbine

$\rightarrow SP = RP - \text{Mech. loss}$

Efficiency:

$$\rightarrow \eta_{vol} = \frac{Q - \Delta Q}{Q}$$

$$\rightarrow \eta_H = \frac{RP}{WP} = \frac{(V_{w_1} U_1 + V_{w_2} U_2)}{gH}$$

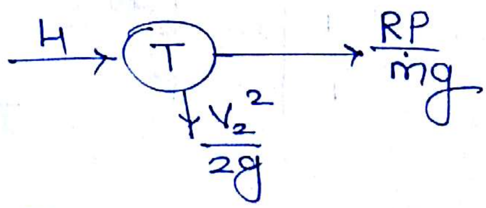
$$\eta_H = \frac{V_{w_1} U_1}{gH} \quad \text{(Francis turbine)}$$

$$\rightarrow \eta_m = \frac{SP}{RP}$$

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

Most Approximated eqn

Assumption



① No friction loss

② $V_{w_2} = 0$

$$H = \frac{V_2^2}{2g} + \frac{RP}{\dot{m} g} \qquad H = \frac{V_2^2}{2g} + \frac{V_{w_1} U_1}{g}$$

→ Width ratio $= \frac{b_1}{d_1} = (0.1 - 0.4)$

→ Diameter ratio $= \frac{d_1}{d_2} = 2$

→ Speed ratio$(k_u) = \frac{U}{\sqrt{2gH}}$

→ Flow ratio$(k_f) = \frac{V_{f_1}}{\sqrt{2gH}}$

Q. T5

$d_1 = 1m$ $A_f = 0.25 m^2$ $V_2 = V_{f_2}$ $V_{w_2} = 0$

$V_{w_1} = 25 m/s$ $N = 400 rpm$ $H = 65 m$ $\beta = 90'$

$V_1 = 8 m/s$

$$\eta_H = \frac{RP}{WP} = \frac{\rho Q(V_{w_1} U_1)}{\rho Q g H} = \frac{25 \times 20.943}{9.81 \times 65}$$

$$U_1 = \frac{\pi \times 1 \times 400}{60}$$

$U_1 = 20.943 m/s$ $\eta_H = 82.11\%$

$$P = \rho Q (V_{w_1} U_1)$$

$$Q = AV$$

$$P = 1000 \times 0.25 \times 8 \times 25 \times 20.943$$

~~P = 10.471~~ MW

$$P = 1047.150 kW$$

Q.64

$H = 30\,m$ $\quad u_1 = 0.9\sqrt{2gH}$

$Q = 10\,m^3/s$ $\quad V_{f_1} = 0.3\sqrt{2gH}$

$N = 300\,rpm$

$$\eta_o = \frac{SP}{WP} = 0.80$$

$$\eta_H = \frac{RP}{WP} = 0.90$$

$WP = \rho Q g H$

$SP = 0.80 \times 10^4 \times 9.81 \times 30 = 2354.4\,kW$

$RP = 0.90 \times 10 \times 1000 \times 9.81 \times 30$

$RP = 2.648700\,MW$

$$u_1 = \frac{\pi D N}{60} \qquad u_1 = 21.83\,m/s$$

$$0.9\sqrt{2 \times 9.81 \times 30} = \frac{\pi d_1 \times 300}{60}$$

$$\boxed{d_1 = 1.390\,m}$$

~~$\frac{u_1}{V_1} = \frac{u}{\sqrt{2gH}} = 0.9$~~

$V_{f_1} = 0.3\sqrt{2 \times 9.81 \times 30}$

$V_{f_1} = 7.27\,m/s$

~~$V_1 = \frac{u}{0.9} = \sqrt{2 \times 9.81 \times 30} = 24.26\,m/s$~~

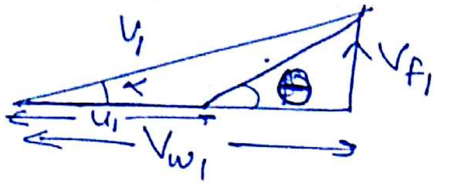
~~26.95~~

~~$V_1 = 24.26$~~

$$\left\{ \begin{array}{l} Q = AV \\ 10 = \pi d b V_{f_1} \end{array} \right\}$$

$b = \frac{10}{\pi \times 1.390 \times 7.27}$

$\boxed{b_1 = 94.39\,mm}$



~~cos α~~ $\sin\alpha = \frac{7.27}{24.26}$

~~$\alpha = 17.43^\circ$~~

$V_{w_1} = 24.26 \sin 17.43$

~~$V_{w_1} = 7.26$~~

~~cos~~ $\tan\phi = \frac{V_{f_1}}{24 - V_{w_1}}$

$= \frac{7.27}{21.83 -}$

$\tan\alpha = \frac{V_{f_1}}{V_{w_1}}$

0.9 $\eta_H = \frac{V_{w_1} U_1}{gH}$

$0.9 = \frac{V_{w_1} \times 21.83}{9.81 \times 30}$

$V_{w_1} = 12.13$ m/s

$\tan\alpha = \frac{7.27}{12.13}$ $\alpha = 30.95^\circ$

$\theta = ?$

$$\tan\theta = \frac{V_F}{V_{w_1} - U} = \frac{7.27}{12.13 - 21.83}$$

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

→ $d_2 = ?$

$$U_2 = \frac{\pi d_2 N}{60}$$

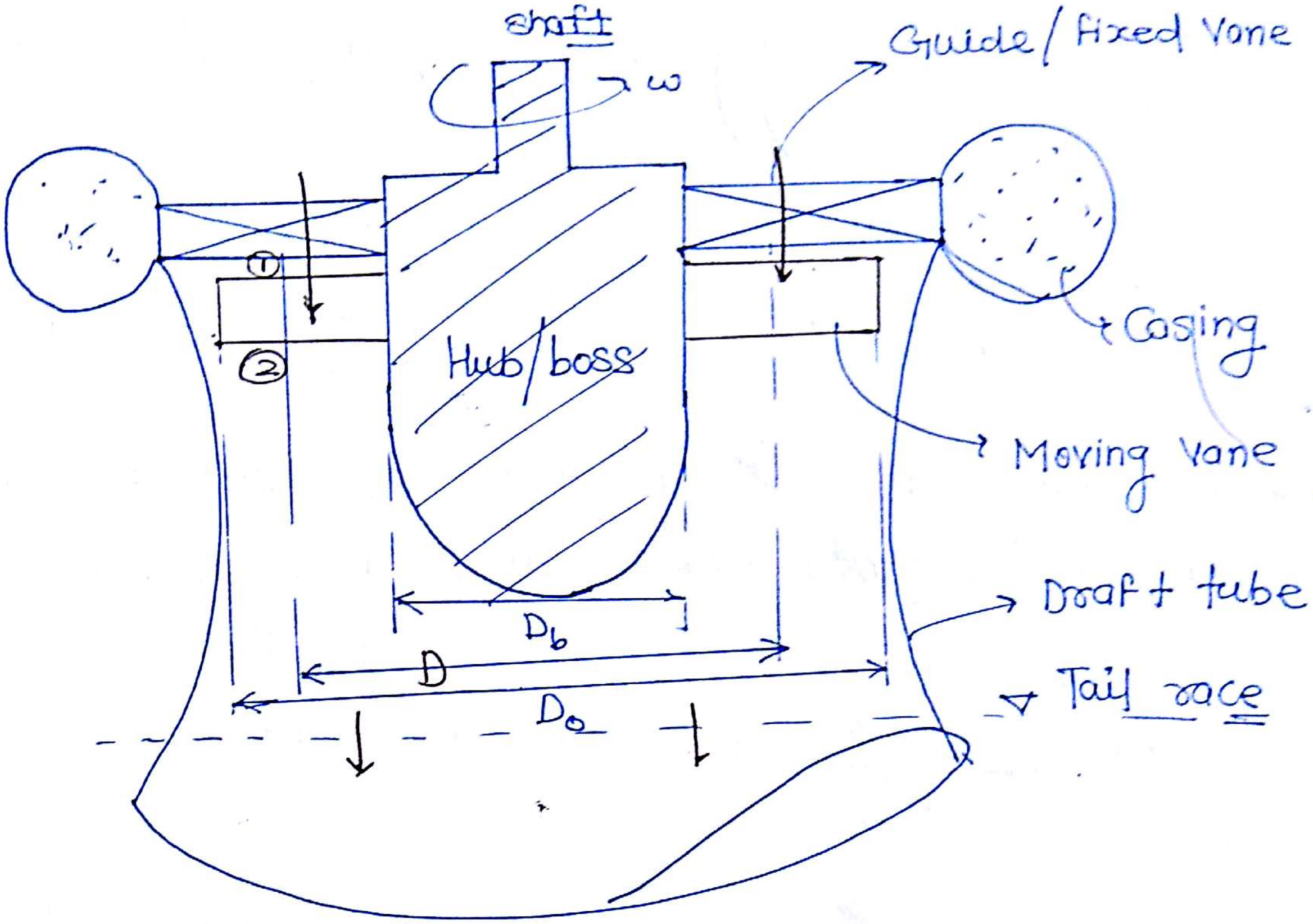
$$Q = \pi d_2 b_2 V_{F_2}$$

$$d_1 / d_2 = 2$$

$$d_2 = \frac{1.39}{2} = 0.695 \text{ m}$$

Kaplan turbine model are manufactured for individual power production with a little as two feet of head

Axial flow turbine (kaplan & propeller)



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

Area of flow

water flows in cross sectional area.

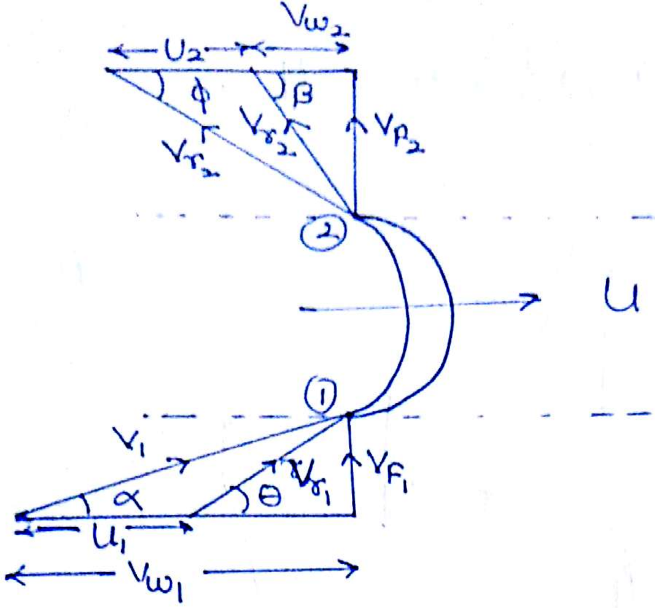
$$A_f = \frac{\pi}{4}\left(D_o^2 - D_b^2\right) = A_{f_1} = A_{f_2}$$

Discharge

$$Q = A_{f_1} V_{f_1} = A_{f_2} V_{f_2}$$

$$V_{f_1} = V_{f_2}$$

At D



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

D = dia at which problem has to solved

→ The runner is a large diameter shaft is called hub/boss over which generally (3–8) vane are installed which is less compare to francis turbine (16–24) Therefore less frictional losses.

→ The blade are twisted therefore vane angle changes ~~or~~ as runner dia. change.

→ In propeller turbine the blades are permanently fixed with the hub. whereas in kaplan turbine the blades are adjustable therefore under variable load condition The kaplan turbine offers maximum efficiency.

→ All the other calculation and relations are same as Redial flow turbine.

Q 65

$H = 20\,m$ $\alpha = 35°$

$SP = 11772\,kW$ $\eta_H = 88\%$

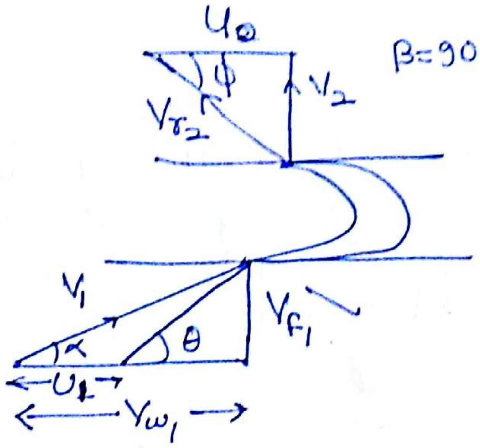
$D_o = 3.5\,m$ $\eta_o = 84\%$

$D_b = 1.75\,m$ $V_{w_2} = 0$

$V_{f_2} = V_2$

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

$u_o = \frac{\pi D N}{}$



θ & ϕ

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

$WP = \frac{11772}{0.84}$ $\eta_H = \frac{RP}{WP}$

$WP = 14014.28\,kW$

$RP = 12332.57\,kW$

$RP = \rho Q (V_{w_1}) . u$

$WP = \rho Q g H = 14014.28$

$Q = 71.42\,m^3/s$

$12332.57 = 1000 \times 71.42 \times V_{w_1} \cdot u$

$\Rightarrow Q = A_{f_1} \times V_{f_1} = 71.42$

$\frac{\pi}{4} \times (3.5^2 - 1.75^2) \times V_{f_1} = 71.42$

$V_{f_1} = 9.89\,m/s$

$$\tan\theta = \frac{V_{f_1}}{V_{w_1} - u} \qquad \tan\alpha = \frac{V_{f_1}}{V_{w_1}}$$

$$\tan\theta = \frac{9.89}{V_{w_1} - u} \qquad V_{w_1} = \frac{9.89}{\tan 30^\circ}$$

$$V_{w_1} = 14.13$$

Now

$$12332.57 \times 10^3 = 1000 \times 71.42 \times 14.13 \cdot u$$

$$u = 12.22 \text{ m/s}$$

$$\tan\theta = \frac{9.89}{14.13 - 12.22}$$

$$\theta = 79.01^\circ$$

$\phi = ?$

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

$$\tan\phi = \frac{9.89}{12.22}$$

$$\phi = 39^\circ$$

$$u = \frac{\pi D_0 N}{60} \Rightarrow N = \frac{12.21 \times 60}{\pi \times 3.5}$$

$$N = 66.62 \text{ rpm}$$