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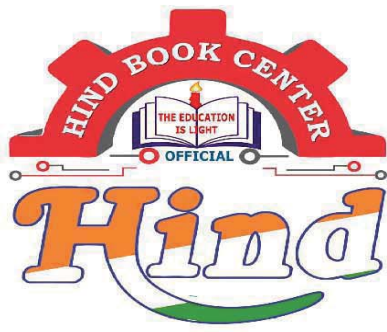
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Hydraulic Machines

(1)

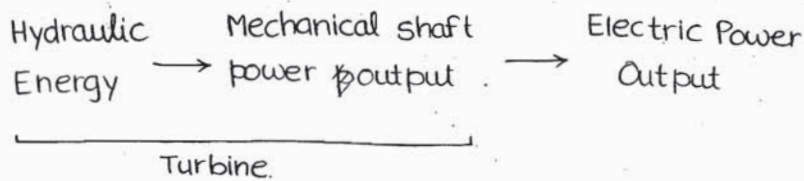
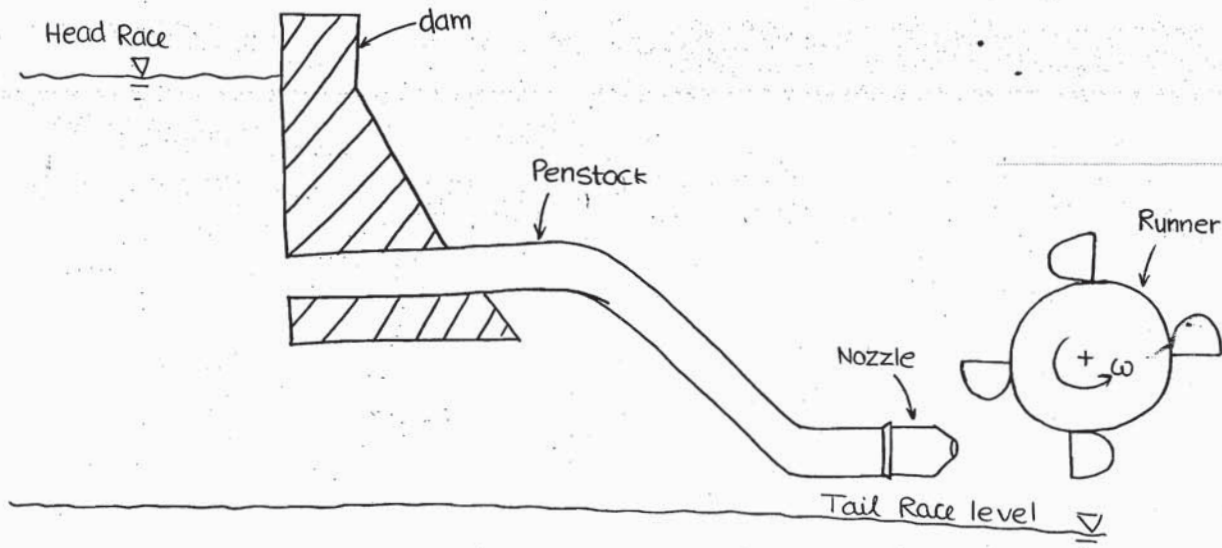
Flow in motion \longrightarrow Fluid dynamics

Classification of hydraulic Machines -

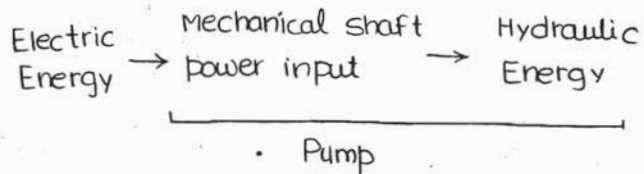
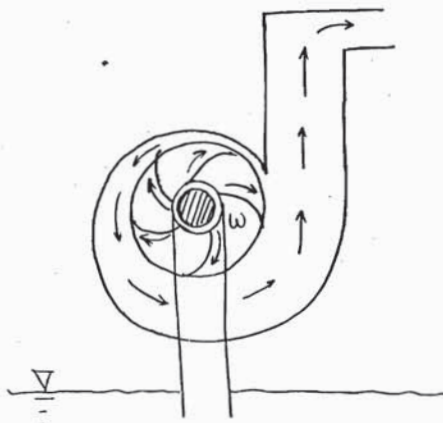
Work is done by the water (Ex- turbine)

Work is done on the water (Ex- Pump)

Layout of hydro electric Power plant -



Pump:-



In General -

Energy (Joule)

$$= mgH$$

$$= \frac{1}{2} mV^2$$

$$= F \times X \quad (\text{workdone})$$

Power (Joule/sec)

$$= mgH$$

$$= \frac{1}{2} \dot{m}V^2$$

$$= F \times u \quad \left(\frac{\text{Workdone}}{\text{Sec}} \right)$$

$$= T \times \omega$$

Work done per sec per unit weight of water striking per Sec

$$= \frac{\text{Work done per sec}}{\dot{m}g} = H \text{ (m)}$$

In General -

Water

(System)

A/C to Newton's 2nd law of motion

$$\vec{F} = \dot{m} \vec{V}_2 - \dot{m} \vec{V}_1$$

Momentum of water leaving per sec. Momentum of water entering per sec.

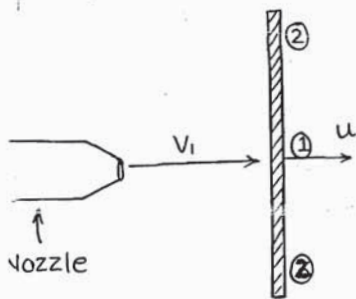
\dot{m} = mass flow rate actually striking over vane.

\vec{F} = Force applied on the water by the vane.

$$\text{Force applied by the water on the vane} = -\vec{F} \\ = \dot{m} \vec{V}_1 - \dot{m} \vec{V}_2$$

In General -

Notations :-



inlet of vane $\Rightarrow 1$

exit of vane $\Rightarrow 2$

\vec{V}_1 = absolute velocity of water at the inlet of vane

\vec{u}_1 = absolute " " vane " " " " "

\vec{V}_{r1} = Relative " " water " " " " "

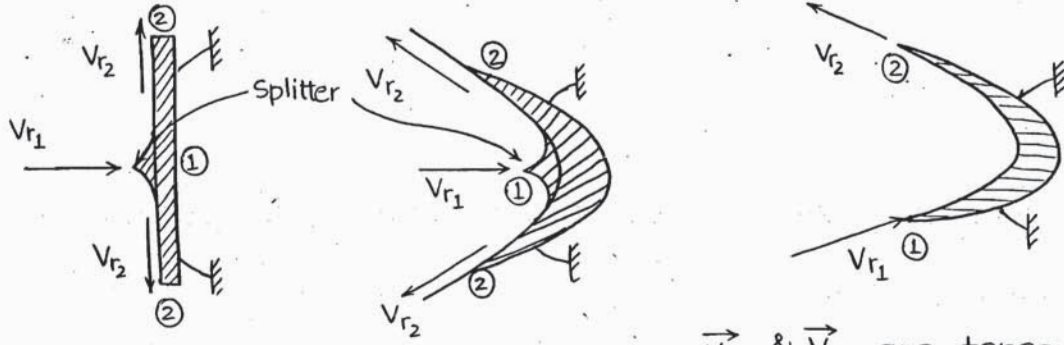
\vec{V}_2 = Absolute velocity of water at the exit of vane

\vec{u}_2 = Absolute " " vane " " " " "

\vec{V}_{r2} = Relative " " water " " " " "

No Shock condition :-

(2)



\vec{V}_{r1} & \vec{V}_{r2} are tangential to the vane geometry at inlet & exit respectively.

Impact of jet :-

In General -

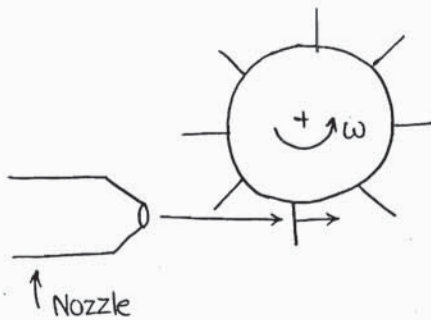
Level-1 :- Stationary surface :-



Level-2 :- Moving surface :-



Level-3 :- Impact of jet on series of flat plates -

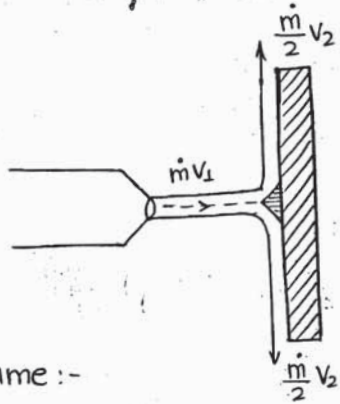


Alm -
 $F_x \Rightarrow \text{Max.}$
 $F_y \Rightarrow 0$

Level-1:- Stationary Plate :-

Assume smooth blade & if there is no energy loss in the flow because of impact of the fluid jet & the difference in elevation b/w incoming & outgoing jet is neglected, the Bernoulli eqⁿ indicates that the jet will move on & off the plate with same velocity.

1) Jet strikes normally :-



$d = \text{dia. of jet.}$
 $a = \text{c/s area of jet.}$

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

in x-direction

$$F_x = \dot{m} V_1 - 0$$

$$[F_x = \rho a V_1^2]$$

Resultant

in y-direction

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

$$F_y = 0$$

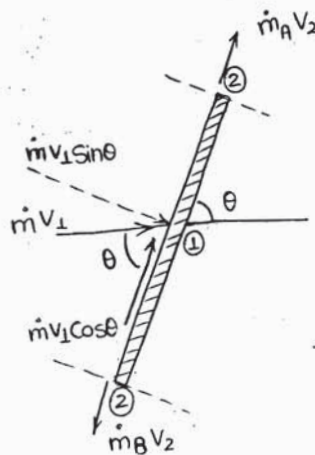
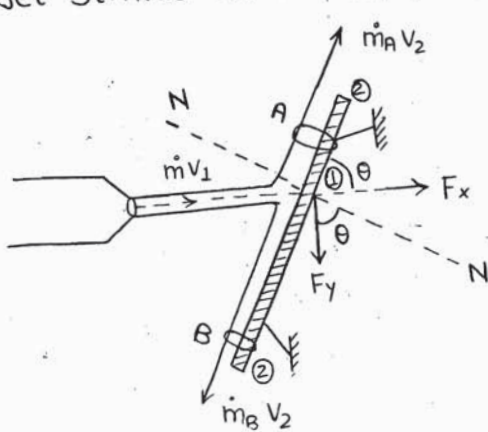
Assume :-

Smooth surface

$$V_2 = V_1$$

Note:- If the jet strikes the flat plate, then the resultant force always acts in the normal direction to the plate.

2) Jet Strikes on inclined plane :-



(Assume - smooth surface - $V_2 = V_1$)

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

in N-N direction -

$$F_N = \dot{m} V_1 \sin \theta - 0$$

$$[F_N = \rho a V_1^2 \sin \theta] \text{ (resultant)}$$

in x-direction -

$$F_x = F_N \sin \theta$$

$$[F_x = \rho a v_1^2 \sin^2 \theta]$$

in y-direction -

$$F_y = F_N \cos \theta$$

$$[F_y = \rho a v_1^2 \sin \theta \cos \theta]$$

(3)

Note:- There is no force acting in the tangential direction to the plate. So, F_N is the resultant dynamic thrust exerted by the jet

Force along the plate (tangential direction)

$$\dot{m} v_1 \cos \theta - [\dot{m}_A v_2 + (-\dot{m}_B v_2)] = 0$$

$$\rho Q v \cos \theta - (\rho Q_A v - \rho Q_B v) = 0$$

$$Q \cos \theta = Q_A - Q_B \quad \text{--- (1)}$$

$$\begin{cases} \dot{m} = \rho Q \\ \dot{m}_A = \rho Q_A \\ \dot{m}_B = \rho Q_B \end{cases}$$

Applying continuity -

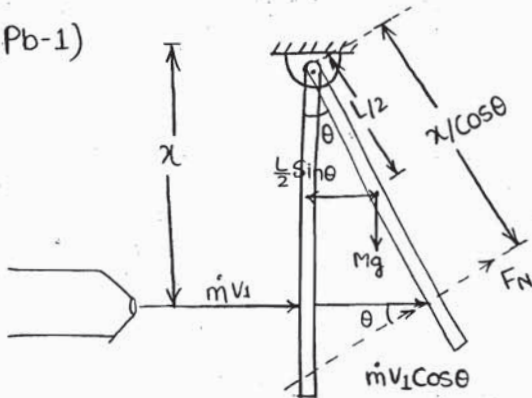
$$\dot{m} = \dot{m}_A + \dot{m}_B$$

$$Q = Q_A + Q_B \quad \text{--- (2)}$$

By eq-(1) & (2)

$$\begin{cases} Q_A = \frac{Q}{2} [1 + \cos \theta] \\ Q_B = \frac{Q}{2} [1 - \cos \theta] \end{cases}$$

Pb-1)



Taking Moments about hinge O -

$$Mg \times \frac{L}{2} \sin \theta = F_N \times \frac{x}{\cos \theta}$$

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

$$F_N = \rho a v_1^2 \cos \theta$$

$$Mg \times \frac{L}{2} \sin \theta = \rho a v_1^2 \cos \theta \times \frac{x}{\cos \theta}$$

$$\theta = \sin^{-1} \left[\frac{2 \rho a v_1^2 x}{Mg L} \right]$$

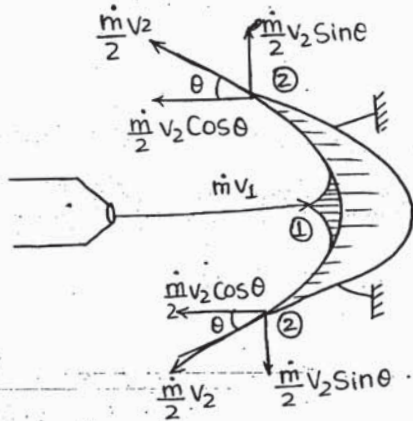
Given -

$$\text{wt. of Plate} = Mg$$

$$\text{Length of plate} = L$$

3) Curved Surface (Symmetrical)

(Attack at centre)



assume - Smooth surface
 $V_2 = V_1$

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

In x-direction-

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

$$F_x = \dot{m} V_1 (1 + \cos\theta)$$

$$[F_x = \rho a V_1^2 (1 + \cos\theta)]$$

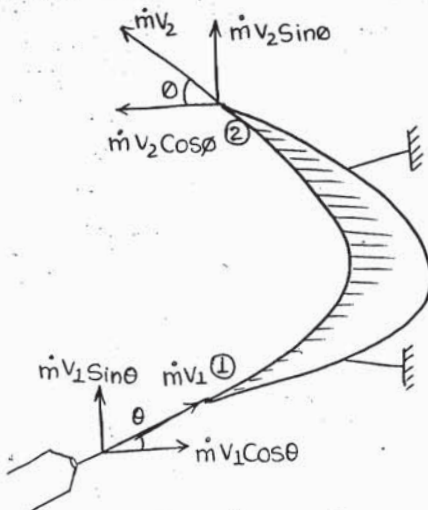
In y-direction-

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

$$[F_y = 0]$$

4) Curved surface (unsymmetrical) :-

(Attack at tip)



Assume - Smooth surface - $V_2 = V_1$

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

In x-direction:-

$$F_x = \dot{m} V_1 \cos\theta - [-\dot{m} V_2 \cos\theta]$$

$$[F_x = \dot{m} V_1 (\cos\theta + \cos\theta) = \rho a V_1^2 (\cos\theta + \cos\theta)]$$

In y-direction:-

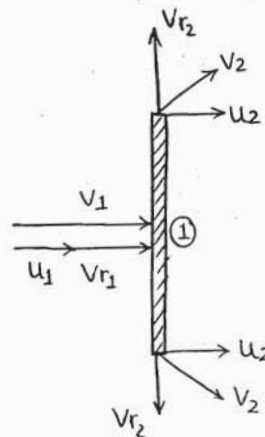
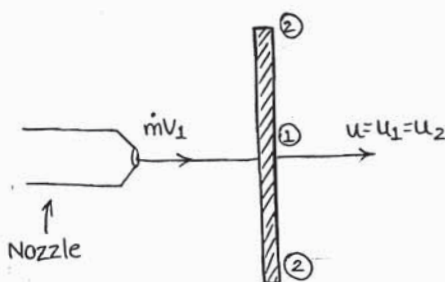
$$F_y = \dot{m} V_1 \sin\theta - \dot{m} V_2 \sin\theta$$

$$F_y = \dot{m} V_1 (\sin\theta - \sin\theta)$$

$$[F_y = \rho a V_1^2 (\sin\theta - \sin\theta)]$$

Level-2 :- Moving Surface :-

1) Jet Strikes normally:-



Assume -
Smooth surface -
($V_2 = V_1$)

$$\dot{m} = \rho a V_{r1}$$

(4)

In x-direction:-

$$F_x = \dot{m} V_1 - \left(\frac{\dot{m}}{2} u_2 + \frac{\dot{m}}{2} u_2 \right)$$

$$(u_2 = u_1)$$

$$= \dot{m} (V_1 - u_1)$$

$$= \rho a V_{r1} (V_1 - u_1)$$

$$V_{r1} = (V_1 - u_1)$$

$$\left[F_x = \rho a (V_1 - u_1)^2 \right]$$

In y-direction:-

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

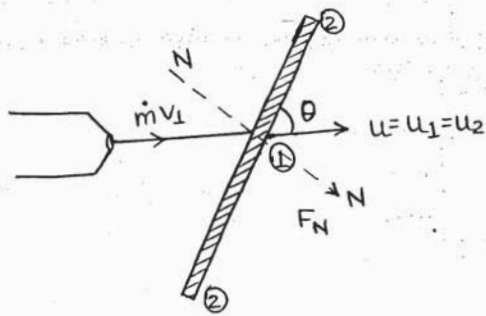
$$F_y = 0$$

- work done per sec by the jet on the plate

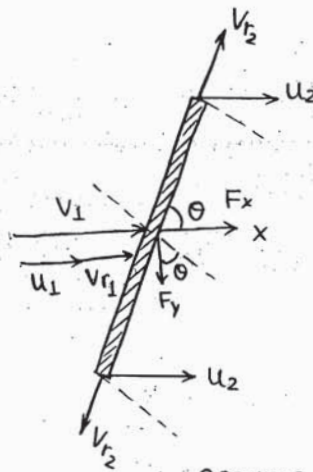
$$= F_x \times u_1$$

$$= \rho a (V_1 - u_1)^2 u_1$$

2) Jet strikes at inclined plate:-



$$\dot{m} = \rho a V_{r1}$$



Assume - Smooth surface

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

In N-N direction:-

$$F_N = \dot{m} V_1 \sin \theta - [\dot{m} u_2 \sin \theta]$$

$$(u_2 = u_1)$$

$$= \dot{m} (V_1 - u_1) \sin \theta$$

$$= \rho a V_{r1} (V_1 - u_1) \sin \theta$$

$$(V_{r2} = V_1 - u_1)$$

$$\left[F_N = \rho a (V_1 - u_1)^2 \sin \theta \right]$$

In x-direction-

$$F_x = F_N \sin \theta$$

$$F_x = \rho a (V_1 - u_1)^2 \sin^2 \theta$$

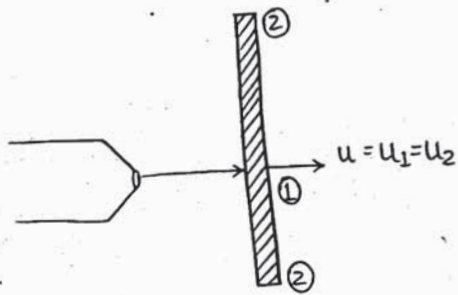
In y-direction-

$$F_y = F_N \cos \theta$$

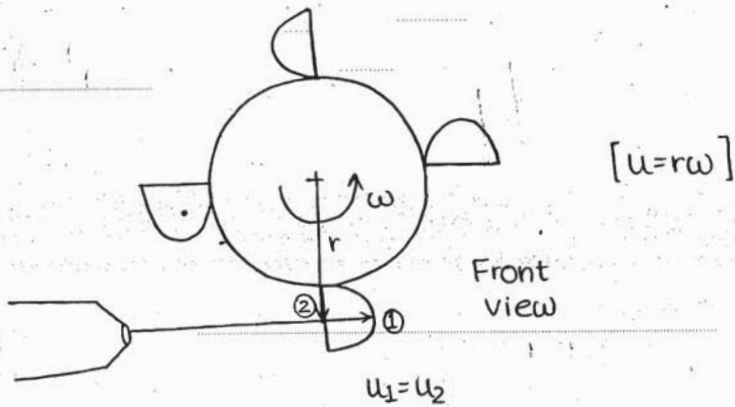
$$F_y = \rho a (V_1 - u_1)^2 \sin \theta \cos \theta$$

In General -

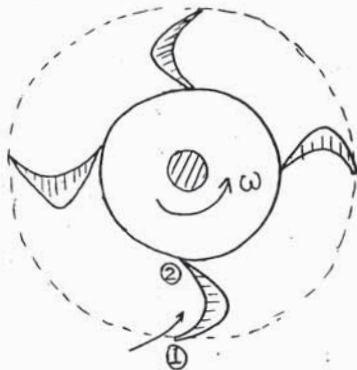
Single plate :-



Pelton wheel :-



Inward Radial flow runner :-



Top view

$$R_1 > R_2$$

$$u_1 = \omega R_1$$

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

$$u_2 = \omega R_2$$

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

$$u_1 > u_2$$

Single Surface :-

(5)

θ } Vane Angle
 ϕ }

α = the angle at which jet strikes the vane at inlet.

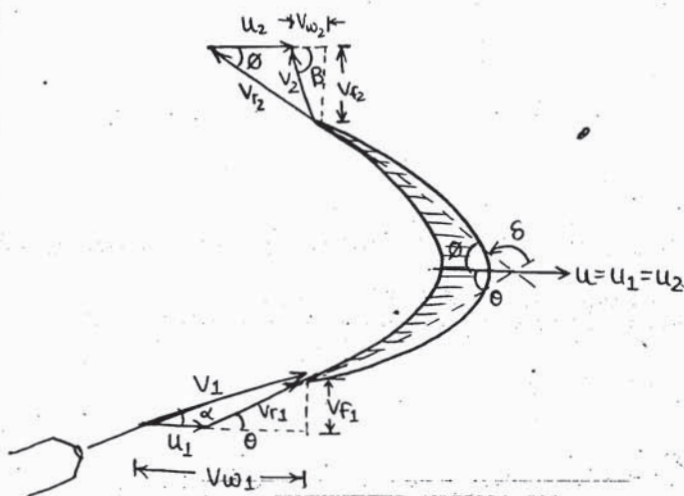
Note: - for Reaction turbine

α = Guide vane angle

δ = Angle of deflection

V_w = velocity of whirl

V_f = velocity of flow.



$$\dot{m} = \rho a V_{r1}$$

In x-direction :-

$$F_x = \dot{m} V_1 \cos \alpha - (-\dot{m} V_2 \cos \beta)$$

$$= \dot{m} (V_1 \cos \alpha + V_2 \cos \beta)$$

$$\downarrow \quad \downarrow$$

$$V_{w1} \quad V_{w2}$$

$$[F_x = \dot{m} (V_{w1} + V_{w2})]$$

In y-direction :-

$$F_y = \dot{m} V_1 \sin \alpha - \dot{m} V_2 \sin \beta$$

$$= \dot{m} (V_1 \sin \alpha - V_2 \sin \beta)$$

$$[F_y = \dot{m} (V_{f1} - V_{f2})]$$

Work done per second by the water jet on the vane = $F_x \cdot u_1$

$$= \dot{m} (V_{w1} + V_{w2}) u_1$$

Work done per sec per unit weight of water striking per sec

$$= \frac{\dot{m} (V_{w1} + V_{w2}) u_1}{\dot{m} g}$$

$$\downarrow$$

$$\rho a V_{r1}$$

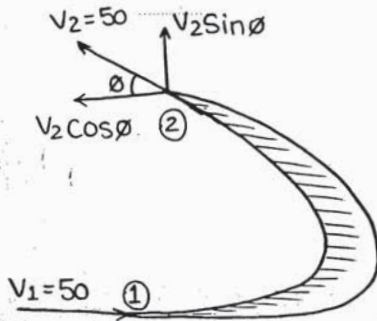
Efficiency (η):-

$$\eta = \frac{\text{Work done per sec}}{\text{input water power}}$$

$$= \frac{\dot{m} (V_{w1} + V_{w2}) u_1}{\frac{1}{2} \dot{m}_{\text{nozzle}} V_1^2}$$

\uparrow
 $f_a V_1$

T-1)
Pg-62)



$$F_x = \dot{m} V_1 - (-\dot{m} V_2 \cos 25^\circ)$$

$$\frac{F_x}{\dot{m} g} = \frac{\dot{m} (50 + 50 \cos 25^\circ)}{\dot{m} g} \text{ N/N/S}$$

$$= 9.72 \text{ N/N/S}$$

$$F_y = 0 - \dot{m} V_2 \sin 25^\circ$$

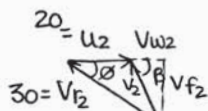
$$\frac{F_y}{\dot{m} g} = \frac{-\dot{m} (50 \sin 25^\circ)}{\dot{m} g}$$

$$F_y = -2.15 \text{ N/N/S}$$

Assume -

Smooth surface

$$V_2 = V_1$$

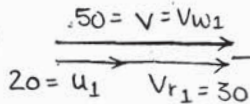


$$F_x = \dot{m} (V_{w1} + V_{w2})$$

$$\frac{F_x}{\dot{m} g} = \frac{\dot{m} (50 + 7.19)}{\dot{m} g}$$

$$= 5.83 \text{ N/N/S}$$

$$\left\{ \begin{aligned} V_{w2} &= V_{r2} \cos \theta - u_2 \\ &= 30 \cos 25^\circ - 20 \\ &= 7.19 \text{ m/s} \end{aligned} \right.$$



$$F_y = \dot{m} (V_{f1} - V_{f2})$$

$$\frac{F_y}{\dot{m} g} = \frac{\dot{m} (-12.68)}{\dot{m} g}$$

$$= -1.29 \text{ N/N/S}$$

$$\left\{ \begin{aligned} V_{f2} &= V_{r2} \sin \theta \\ &= 30 \sin 25^\circ \\ &= 12.68 \text{ m/s} \end{aligned} \right.$$

assume - smooth
Surface

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

Q-75)

Pg-61)

$V_1 = 15 \text{ m/s}$, frictionless vane ($V_{r2} = V_{r1}$)

(6)

$$u_1 = u_2 = 5 \text{ m/s}$$

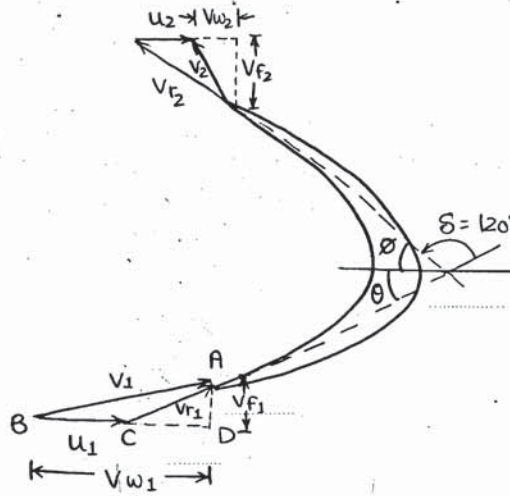
$$\theta = 0$$

$$\delta = 120^\circ$$

determine -

$$\alpha = ? , V_2 = ?$$

$$\frac{\text{Work done per sec}}{mg} = ?$$



at inlet

- ΔABC

- Sine rule

$$\frac{V_1}{\sin 150^\circ} = \frac{u_1}{\sin(180 - (150 + \alpha))} \Rightarrow$$

$$\frac{15}{\sin 150} = \frac{5}{\sin(30 - \alpha)}$$

$$[\alpha = 20.4^\circ] \text{ Ans}$$

$$V_{w1} = V_1 \cos \alpha$$

$$= 15 \cos 20.4^\circ$$

$$V_{w1} = 14.06 \text{ m/s}$$

$$V_{f1} = V_1 \sin \alpha$$

$$= 15 \sin 20.4$$

$$= 5.23 \text{ m/s}$$

$$V_{r1} = \frac{V_{f1}}{\sin \theta}$$

$$= \frac{5.23}{\sin 30}$$

$$V_{r1} = 10.46 \text{ m/s}$$

At Exit :-

$$\begin{aligned}V_{f_2} &= V_{r_2} \sin \theta \\ &= 10.46 \sin 30^\circ \\ &= 5.23 \text{ m/s}\end{aligned}$$

$$\begin{aligned}V_{w_2} &= V_{r_2} \cos \theta - u_2 \\ &= 10.46 \cos 30^\circ - 5 \\ &= 4.06 \text{ m/s}\end{aligned}$$

$$\begin{aligned}V_2 &= \sqrt{V_{w_2}^2 + V_{f_2}^2} \\ &= \sqrt{(4.06)^2 + (5.23)^2} \\ V_2 &= 6.62 \text{ m/s}\end{aligned}$$

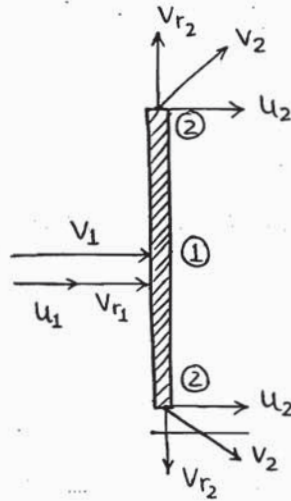
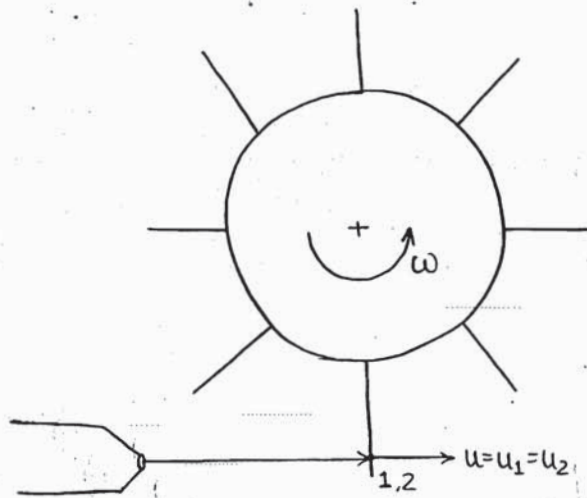
Work done per sec per unit weight of water striking per sec.

$$\begin{aligned}&= \frac{\dot{m} (V_{w_1} + V_{w_2}) u_1}{\dot{m} g} \\ &= \frac{(14.06 + 4.06) \times 5}{9.81} \\ &= 9.23 \text{ m Ans.}\end{aligned}$$

Impact of jet on a series of flat plate

(7)

or
Runner



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

$$F_x = \dot{m} V_1 - \left(\frac{\dot{m}}{2} u_2 + \frac{\dot{m}}{2} u_2 \right) \Rightarrow$$

$$(u_2 = u_1)$$

$$F_x = \dot{m} (V_1 - u_1)$$

Work done per sec

$$\text{or} \quad = F_x u_1$$

Runner power

$$= \dot{m} (V_1 - u_1) u_1$$

Efficiency (η):-

$$\eta = \frac{\text{Work done per sec}}{\text{input water power}}$$

$$= \frac{\rho a V_1 \dot{m} (V_1 - u_1) u_1}{\frac{1}{2} \dot{m}_{\text{Nozzle}} V_1^2}$$

$$\eta = \frac{2(V_1 - u_1) u_1}{V_1^2}$$

for Max η -

$$\frac{d\eta}{du_1} = 0$$

$$\frac{d}{du_1} \left[\frac{2(V_1 - u_1) u_1}{V_1^2} \right] = 0$$