CBCS SCHEME

USN

BME502

Fifth semester B.E. Degree Examination, Jan/Feb 2025
Turbomachines

Time: 3 hrs. **Max. marks: 100**

Note: 1. Answer any five full questions, choosing ONE full question from each module.
2. Use of steam tables / Mollier chart is permitted.

Module-1

Q.1 a) Classify the turbomachines. (6)

b) Give the comparison between positive displacement machine and turbomachine. (6)

c) A model turbine 1 m diameter acting under a head of 2 m runs at 150 rpm. Estimate the scale ratio if the prototype develops 20 MW under a head of 225 m with a specific speed of 100. (8)

OR

Q.2 a) Define the following with the help of h-s diagram for power generating machine: (8)
i) Total to total efficiency, ii) Total to static efficiency, iii) Static to total efficiency, and iv) Static to static efficiency

b) Air flow through an air turbine where its stagnation pressure is decreased in the ratio 5:1. The total to total efficiency is 0.8 and the air flow rate is 5 kg/s. The inlet total temperature is 280 K. Calculate a) the actual power output, b) the actual exit total temperature, c) the actual exit static temperature if the exit flow velocity is 100 m/s, and d) the total to static efficiency of the device. (12)

Module-2

Q.3 a) Derive alternate forms of Euler's equation. (10)

b) Draw velocity triangles for the following degrees of reactions. (10)
When,
$R<0$, $R=50\%$, $R=0\%$

OR

Q.4 a) Derive the theoretical head- capacity relationship for the centrifugal pump. (10)

b) At a 50% reaction stage axial flow turbine, the mean blade diameter is 6 cm. The maximum utilization factor is 0.9, steam flow rate is 10 kg/s. Calculate the inlet and outlet absolute velocities and power developed if the speed is 2000 rpm. (10)

Module-3

Q.5 a) What is compounding? Explain with a neat sketch velocity compounded impulse turbine. (10)

b) Steam issues from the nozzle of a impulse turbine with a velocity 1200 m/s. The nozzle angle is 20^0 and the mean blade velocity is 400 m/s. Inlet and outlet angles are equal, for unit mass flow rate of steam calculate i) blade angles, ii) tangential force on blade, iii) power developed, and iv) blade efficiency, assume $k = 1$. (10)

OR

Q.6 a) Derive maximum blade efficiency equation for velocity compounded impulse steam turbine. (10)

b) In a Curtis steam turbine stage, there are two rows of moving blades with equiangular rotors. The steam enters 1st rotor with 29^0 each while second with 32^0 each. The absolute velocity of steam enters the first rotor at 530 m/s. The friction factor is 0.9 in 1st rotor, 0.91 in stator and 0.93 in 2nd rotor. If the discharge is axial, Find i) Mean blade speed and ii) power if m= 3.2 kg/s. (10)

Module-4

Q.7 a) Define heads and efficiencies of a Pelton when impulse turbine. (10)

b) A Pelton wheel is to be designed for the following specifications: (10)
shaft power = 5880 kW, Head = 300m, speed = 550 rpm, overall efficiency = 85%, jet diameter not to exceed 1/10 of wheel diameter, determine i) wheel diameter, ii) jet diameter iii) number of jets required, Take Cv = 0.98, $\phi = 0.46$.

OR

Q.8 a) Draw velocity triangles for the Francis turbine for i) Slow speed ii) Medium speed and iii) High speed runner. (10)

b) The external and internal diameter of the inward flow reaction turbine are 2m and 1m. The head on the turbine is 60m. The width of the vane at inlet and outlet are same and equal to 0.25. The runner vanes are radial at outlet and discharge is radial at outlet. The speed is 200 rpm and discharge is 6 m^3/s. Determine i) Vane angle at outlet and inlet ii) The hydraulic efficiency.

Module-5

Q.9 a) Derive an equation for the pressure rise in the impeller of a centrifugal pump when friction and other losses are neglected. (10)

b) A centrifugal pump delivers water against a net head of 14.5 m and a design speed of 1000 rpm, the vanes are curved back to an angle of 30^0 with the periphery. The impeller diameter is 300 mm and outlet width 50 mm. Determine the discharge of the pump if manometric efficiency is 95%. (10)

OR

Q.10 a) Explain the parts of a centrifugal pump with a neat sketch. (10)

b) A centrifugal pump is running at 1000 rpm. The outlet vane angle of the impeller is 45^0 and velocity of flow at outlet is 2.5m/s. The discharge through the pump is 200 liters/s when the pump is working against a total head of 20 m. If the manometric efficiency of the pump is 80%, determine i) the diameter of the impeller ii) the width of the impeller at outlet. (10)

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KLS - VDIT - Haliyal

VTU - QP - solution

Sub.: Turbomachines
code: BME502

Sem: V
Year: Jan/Feb 2025

Module - I

Q.1) a) Classification of turbomachines.

- Turbomachines
  - Fluid energy to Mechanical energy
    - Turbines
      - → Steam, Gas, water
      - Tagential → Pelton
      - Axial → Kaplan
      - Radial → Francis
      - Mixed → Modern Francis
  - Mechanical energy to fluid energy
    - → Pumps
    - → Fans
    - → compressors
    - → Blowers.
      - Axial
      - radial
      - mixed

b)

Positive displacement machine	Turbomachine.
→ These are especially of the reciprocating machine	→ Rotary machines
→ Low speed machine	→ High speed machines
→ Lower mechanical and volumetric efficiency	→ volumetric efficiency is close to 100%.
→ If reciprocating engine is stopped, the working gas trapped inside cylinder stays in the same state (cylinder is perfectly insulated).	→ The state of gas in turbomachine when whose motion is stopped, gas will experience changes in state dictated by the surrounding.
→ On account of much lower speeds, a reciprocating compressor can theoretically be made to work isothermally.	→ High speed turbocompressor is adiabatic m/c.
→ Due to low speed & limited displacement handle small flow rates.	→ Due to high speed, flow rate are higher.
→ Because of reciprocating masses, vibrations are more, heavy foundation is required.	→ Rotating masses can be easily balanced, light foundation is required.

c)

Model	Prototype
$D_m = 1m$	$P_p = 20 \times 10^6 W$
$H_m = 2m$	$H_p = 225 m$
$N_m = 150 rpm$	$N_s = 100.$

Scale ratio $D_m/D_p = ?$

$$\frac{\cancel{g} H_m}{N_m^2 D_m^2} = \frac{\cancel{g} H_p}{N_p^2 D_p^2} \quad \text{--- (i)}$$

Prototype: $N_s = \dfrac{N_p \sqrt{P \text{ in kW}}}{H_p^{5/4}}$

$$100 = \frac{N_p \sqrt{20 \times 10^3}}{(225)^{5/4}}$$

$N_p = 616.18$ rpm.

Substitute in equation (i)

$$\frac{2}{(150)^2 \times 1^2} = \frac{225}{(616.18)^2 \times D_p}$$

$\therefore D_p = 2.58 m$

$\therefore \dfrac{D_m}{D_p} = \dfrac{1}{2.58} = 0.387$

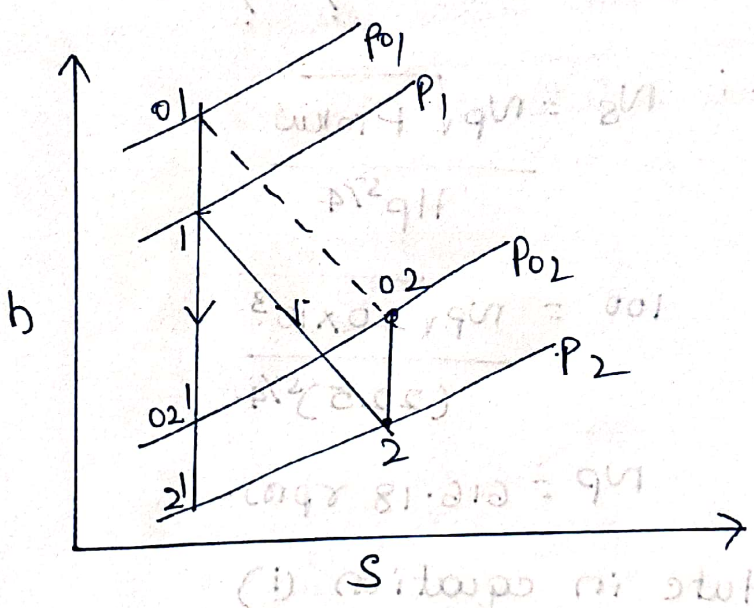
OR

Q.2) a) Power generating machines.

i) Total-to-total efficiency:

$$\eta_{t-t} = \frac{\text{Actual work output}}{\text{Total-to-total work output}}$$

$$= \frac{h_{01} - h_{02}}{h_{01} - h_{02'}}$$



ii) Total-to-static efficiency:

$$\eta_{t-s} = \frac{\text{Actual work output}}{\text{Total-to-static work output}}$$

$$= \frac{h_{01} - h_{02}}{h_{01} - h_{2'}}$$

iii) Static-to-total efficiency

$$\eta_{s-t} = \frac{\text{Actual work output}}{\text{static to total work output}}$$

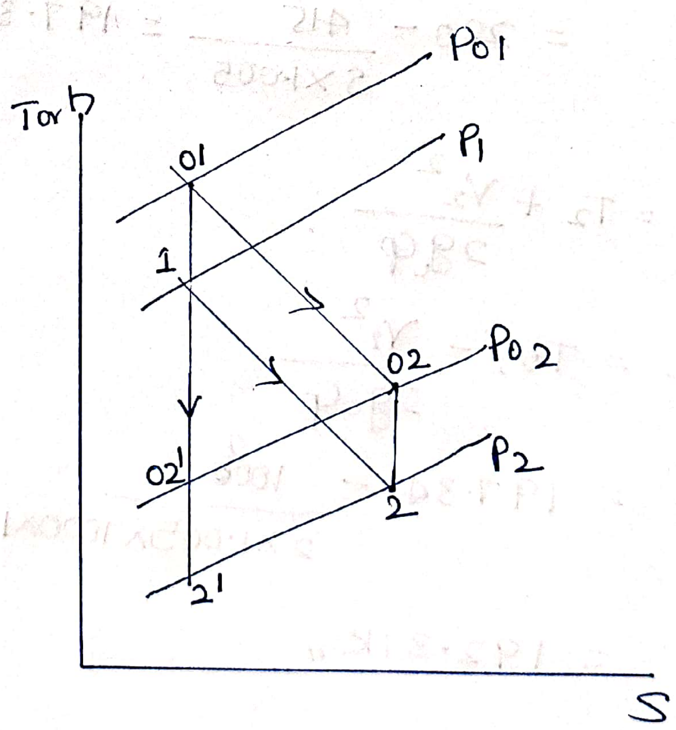
$$= \frac{h_{01} - h_{02}}{h_1 - h_{02}'}$$

iv) Static-to-static efficiency

$$\eta_{s-s} = \frac{\text{Actual work output}}{\text{Static-to-static work output}}$$

$$= \frac{h_{01} - h_{02}}{h_1 - h_2'}$$

b)



$\frac{P_{01}}{P_{02}} = \frac{5}{1}$, $\eta_{t-t} = 0.8$, $\dot{m} = 5\,kg/s$, $T_{01} = 280\,k$, $V_2 = 100\,m/s$.

For isentropic process :

$$\frac{T_{02}'}{T_{01}} = \left[\frac{P_{02}}{P_{01}}\right]^{\frac{\gamma-1}{\gamma}} = (5)^{\frac{0.4}{1.4}} = 0.631$$

$$\therefore T_{02}' = 176.68K.$$

a) $$\eta_{t-t} = \frac{P_a}{P_1} = \frac{\dot{m} c_p (T_{01} - T_{02})}{\dot{m} c_p (T_{01} - T_{02}')}$$

$$P_a = \dot{m} c_p (T_{01} - T_{02}') \eta_{t-t}$$

$$= 0.8 \times 5 \times 1.005 (280 - 176.68)$$

$$= 415\ kw.$$

b) $$P_a = m c_p (T_{01} - T_{02}) = 415\ kw.$$

or $$T_{02} = T_{01} - \frac{P_a}{m c_p}$$

$$= 280 - \frac{415}{5 \times 1.005} = 197.34k.$$

c) $$T_{02} = T_2 + \frac{V_2^2}{2 g_c c_p}$$

$$T_2 = T_{02} - \frac{V_2^2}{2 g_c c_p}$$

$$= 197.34 - \frac{100^2}{2 \times 1.005 \times 1000 \times 1}$$

$$= 192.37K_{\,//}$$

d) $T_{02}' = T_2' + \frac{V_2^2}{2 g_c C_p}$

$T_2' = T_{02}' - \frac{V_2^2}{2 g_c C_p}$

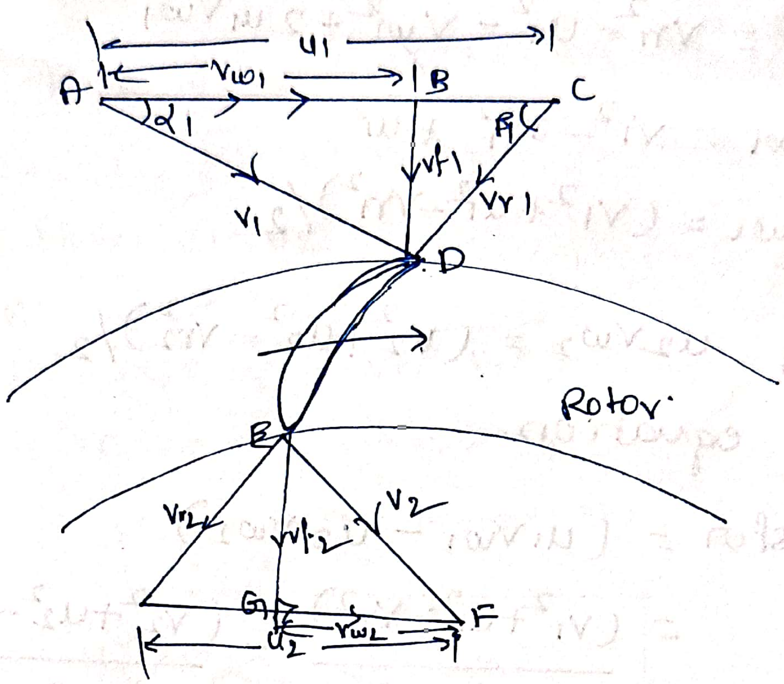
$= 176.68 - \frac{100^2}{2 \times 1 \times 1.005 \times 1000}$

$= 171.71 k.$

$\therefore \eta_{t-s} = \frac{h_{01} - h_{02}}{h_{01} - h_2'} = \frac{T_{01} - T_{02}}{T_{01} - T_2'}$

$= \frac{280 - 197.34}{280 - 171.71} = 0.76 = 76.33\%$ //

Q.3) a) Alternate forms of Euler's equation.



V = absolute velocity of fluid

V_r = relative "

V_f = flow velocity.

V_w = tangential velocity.

α = nozzle angle

u = rotor tangential speed.

B = Blade angle.

From inlet velocity Δ^{le} ABD:

$$AD^2 = AB^2 + BD^2$$

$$V_1^2 = V_{w1}^2 + V_{f1}^2$$

$$V_{f1}^2 = V_1^2 - V_{w1}^2$$

from Δ^{le} BCD:

$$CD^2 = BC^2 + BD^2$$

$$V_{r1}^2 = (u_1 - V_{w1})^2 + V_{f1}^2$$

$$V_{f1}^2 = V_{r1}^2 - (u_1 - V_{w1})^2$$

$$= V_{r_1}^2 - (u_1^2 + V_{w_1}^2 - 2u_1V_{w_1})$$

$$= V_{r_1}^2 - u_1^2 - V_{w_1}^2 + 2u_1V_{w_1}$$

$$\therefore V_1^2 - \cancel{V_{w_1}^2} = V_{r_1}^2 - u_1^2 - \cancel{V_{w_1}^2} + 2u_1V_{w_1}$$

$$2u_1V_{w_1} = V_1^2 - V_{r_1}^2 + u_1^2$$

$$u_1V_{w_1} = (V_1^2 + u_1^2 - V_{r_1}^2)/2$$

Similarly $u_2V_{w_2} = (V_2^2 + u_2^2 - V_{r_2}^2)/2$

substituting equation.

$$\text{Energy transfer} = (u_1V_{w_1} - u_2V_{w_2})$$

$$= \frac{(V_1^2 + u_1^2 - V_{r_1}^2)}{2} - \frac{(V_2^2 + u_2^2 - V_{r_2}^2)}{2}$$

$$= \frac{(V_1^2 - V_2^2)}{2} + \frac{(u_1^2 - u_2^2)}{2} + \frac{(V_{r_2}^2 - V_{r_1}^2)}{2}$$

$$\therefore WD = \underbrace{\tfrac{1}{2}(V_1^2 - V_2^2)}_{\text{Dynamic head}} + \underbrace{\tfrac{1}{2}(u_1^2 - u_2^2)}_{\text{static head}} + \underbrace{\tfrac{1}{2}(V_{r_2}^2 - V_{r_1}^2)}_{\text{static head.}} \quad //$$

3) b) Velocity triangles for different degree of reaction.

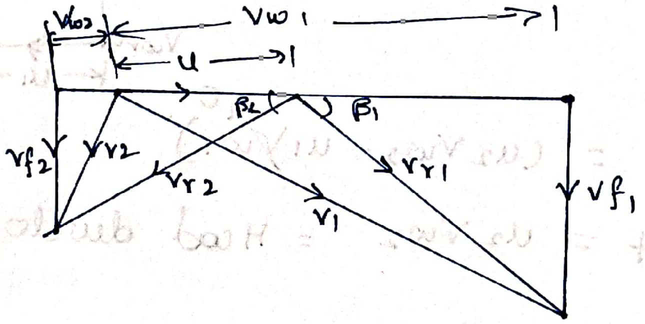
i) when $R < 0$

$$R = \frac{\cancel{\tfrac{1}{2}}\left[(\cancel{u_1^2} - \cancel{u_2^2}) + (V_{r_2}^2 - V_{r_1}^2)\right]}{\cancel{\tfrac{1}{2}}\left[(V_1^2 - V_2^2) + (\cancel{u_1^2} - \cancel{u_2^2}) + (V_{r_2}^2 - V_{r_1}^2)\right]}$$

Axial flow, $u_1 = u_2$

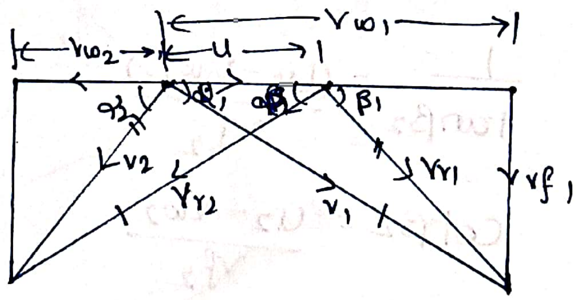
$$\therefore \quad R = \frac{(V_{r_2}^2 - V_{r_1}^2)}{(V_1^2 - V_2^2) + (V_{r_2}^2 - V_{r_1}^2)}$$

if R is to be −ve, $V_{r_1} > V_{r_2}$.

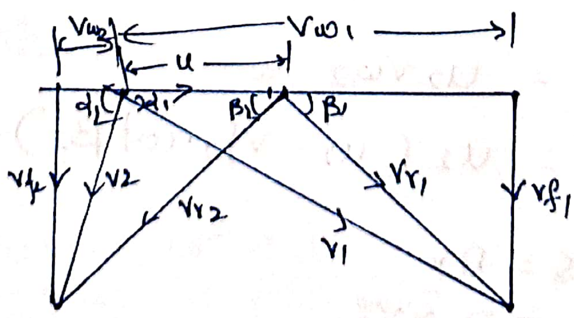


ii) $R = 50\%$, $\quad V_{r_2} = V_1 \quad \alpha_1 = \beta_2$

$V_{r_1} = V_2 \quad \alpha_2 = \beta_1$

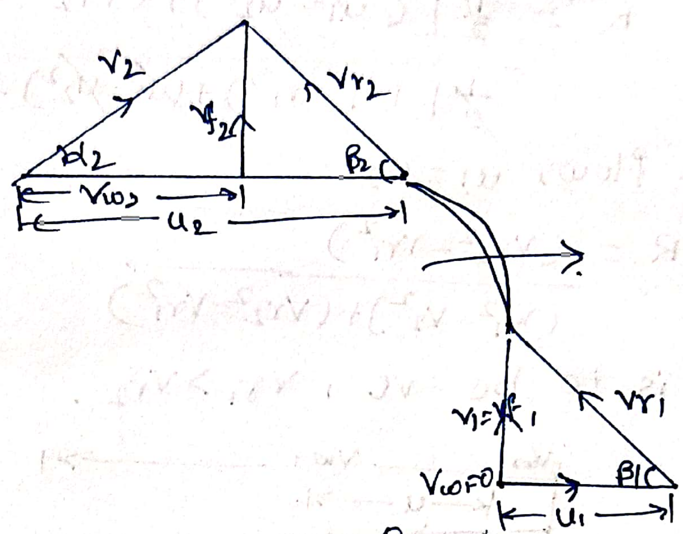


iii) $R = 0$. $\quad V_{r_1} = V_{r_2}$. $\beta_1 = \beta_2$



OR

Q.4) a) Theoretical head- capacity relationship:



$$w.D/\text{unit mass} = (u_2 V_{w2} - u_1 \cancel{V_{w1}}^{0})$$

$$H = u_2 V_{w2} \quad = \text{Head developed by pump.}$$

From outlet velocity Δ'C :

$$\tan\beta_2 = \frac{V_{f2}}{x} = \frac{V_{f2}}{(u_2 - V_{w2})}$$

$$\frac{1}{\tan\beta_2} = \frac{(u_2 - V_{w2})}{V_{f2}}$$

$$\cot\beta_2 = \frac{u_2 - V_{w2}}{V_{f2}}$$

$$V_{w2} = u_2 - V_{f2}\cdot\cot\beta_2 .$$

$$\therefore WD = H = u_2 V_{w2}$$

$$= u_2 (u_2 - V_{f2}\cdot\cot\beta_2)$$

discharge $Q = AV$

$$= A_2 \times V_{f2}$$

$$V_{f2} = Q/A$$

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$$\therefore H = u_2^2 - u_2 \frac{Q}{A} \cdot \cot \beta_2$$

$$H = u_2^2 - \frac{u_2}{A} \cdot \cot\beta_2 \cdot Q.$$

Q.4) b) $R = 50\%$.

Axial flow turbine

$D = 60cm = 0.6m$

$\varepsilon_{max} = 0.9$

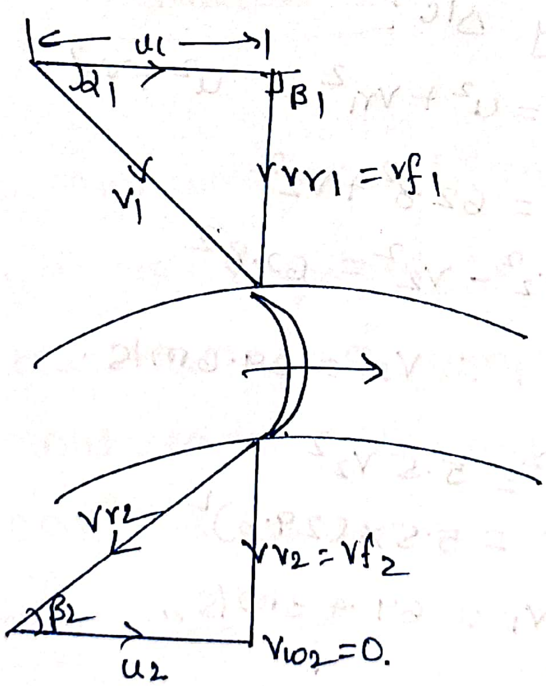
$\dot{m} = 10kg/s$

$V_1 = ?$

$V_2 = ?$

$P = ?$

$N = 2000rpm$



$u_1 = u_2 = u.$

$V_1, V_2 = ?$

$P = mu(V_{w1}u_1 \pm u_2 \cancel{V_{w2}})$

$= \dot{m}u(V_{w1})$

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$$u = \frac{\pi D N}{60} = \frac{\pi \times 0.6 \times 2000}{60} = 62.8 \, m/s.$$
$$= V_{w1}$$

$$\therefore P = 10 \times 62.8 \times 62.8 / 1000$$
$$= 39.44 \, kw.$$

To calculate V_1 & V_2:

$$E_{max} = \frac{V_1^2 - V_2^2}{V_1^2 - R V_2^2}$$

$$0.9 = \frac{V_1^2 - V_2^2}{V_1^2 - 0.5 V_2^2}$$

$$V_1^2 - 0.45 V_2^2 = V_1^2 - 0.9 V_1^2$$

$$\therefore V_1^2 = 5.5 V_2^2$$

From inlet velocity Δle:

$$V_1^2 = u^2 + V_{r1}^2 = u^2 + V_2^2 \quad (\because V_{r1} = V_2).$$

$$5.5 V_2^2 = 62.8^2 + V_2^2$$
$$5.5 V_2^2 - V_2^2 = 62.8^2$$

$$\therefore V_2 = 29.6 \, m/s.$$

$$\therefore V_1^2 = 5.5 V_2^2$$
$$= 5.5 \times (29.6)^2$$
$$V_1 = 69.43 \, m/s$$

$$u^2 = v_1^2 - v_2^2$$
$$= 6.38 v_2^2 - v_2^2$$
$$= 5.38 v_2^2$$
$$\therefore v_2^2 = \frac{u^2}{5.38} = \frac{(107.6)^2}{5.38}$$
$$v_2 = 46.39 \text{ m/s.}$$
$$v_1^2 = 0.38 v_2^2 = 0.38 \times (46.69)^2$$
$$v_1 = 118.03 \text{ m/s.}$$

ii) $P = m(u v_{w1} \pm u v_{w2})$ ($v_{w2} \to 0$)
$$= m u v_{w1}$$
$$= 15 \times 107.6 \times 107.6$$
$$= 173666.4 \text{ W,}$$

Module-3

Q.5)

a) In order to overcome the difficulties of higher speed, & demerits, it is required to reduce turbine speed by the method of compounding. The absorption of inlet energy in multiple rows of moving blades is known as compounding.

i) velocity compounding
ii) Pressure "
iii) Pressure & velocity "

Velocity compounded impulse turbine :

Here nozzle is fitted to a stationary casing. Each fixed blade rows are fitted between rotors.

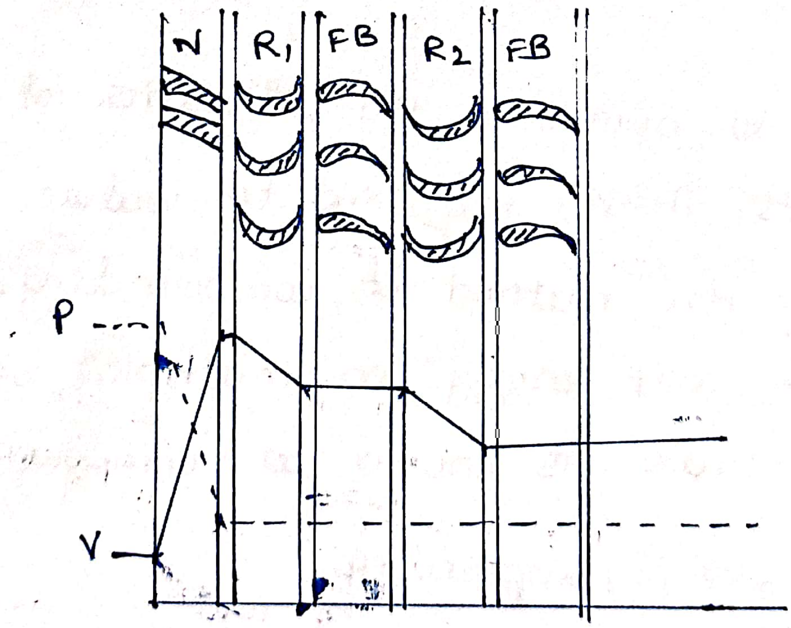
→ The high pressure steam expands in a nozzle blade rows generate high velocity of steam.

→ The high velocity steam transfers its energy in number of stages by employing many rotor blade rows separated by rows of fixed blade rows.

→ The decrease in velocity of fluid across two rotor blades rows is due to energy transfer.

→ Slight decrease in the fluid velocity in the fixed blade due to losses.

→ Due to multiple expansion the turbine speed reduces.



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b) $V_1 = 1200\, m/s$

$\alpha_1 = 22^\circ$

$\beta_1 = \beta_2$

$u = 400\, m/s$

i) $\beta_1, \beta_2 = ?$ ii) $F_t = ?$ iii) $P = ?$ iv) $\eta_b = ?$

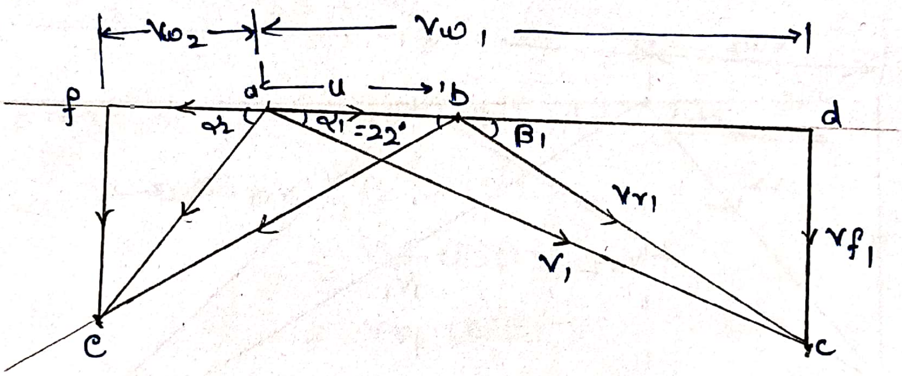
Scale:

$1\, cm = 150\, m/s.$ $\beta_1 = \beta_2$

& $V_{r_1} = V_{r_2}$

$\therefore u = \frac{400}{150} = 2.66\, cm$

$V_1 = \frac{1200}{150} = 8\, cm.$



$V_{w1} = 7.4\, cm \times 150 = 1110\, m/s$

$V_{w2} = 2.2\, cm \times 150 = 330\, m/s$

i) $\beta_1 = 31^\circ = \beta_2$

ii) $F_t = m(V_{w1} - V_{w2})$

$= 1\,(1110 - 330)$

$= 780\, N.$

iii) $P = \dot{m}\, u\,(V_{w1} + V_{w2})$ $\left\{ \because \overleftarrow{V_{w2}} + \overrightarrow{V_{w1}} \right.$

$= 1 \times 400 \times (1110 + 330)$

$= 456000\, W$

$= 456\, kW.$

iv) $\eta_b = \frac{WD}{KE} = \frac{2u(V_{w1}+V_{w2})}{V_1^2}$

$= \frac{2 \times 400(1110 + 330)}{1200^2}$

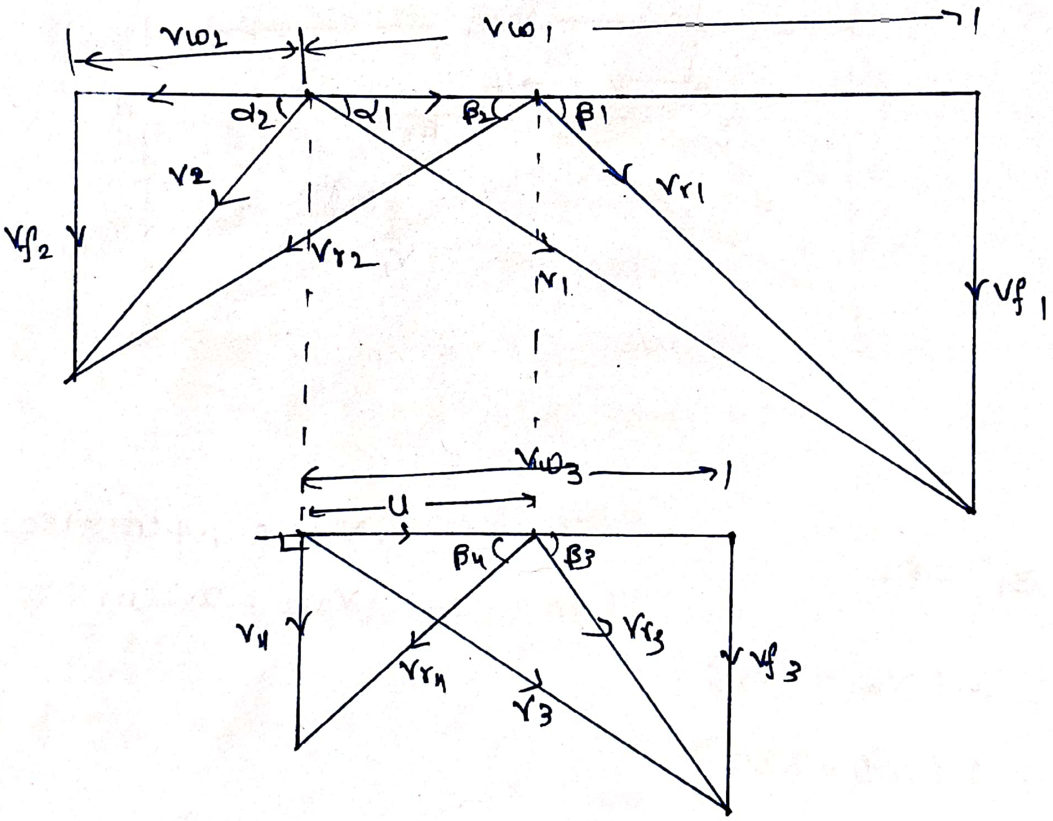
$= 0.8$

$= 80\%$ //

OR

Q.6)

a)



$V_2 = V_3$ & $\alpha_2 = \alpha_3$

$V_{r2} = V_{r1}$, $V_{r3} = V_{r4}$

$w_1 = (V_{w1} + V_{w2})u$

$= (V_{r1} \cdot \cos\beta_1 + V_{r2}\cos\beta_2)u$

if $\beta_1 = \beta_2$, $k = \frac{V_{r2}}{V_{r1}}$

$$W_1 = (2V_{r1}\cdot\cos\beta_1)\,u$$
$$= 2u(V_{r1}\cdot\cos\beta_1)$$
$$= 2u(V_1\cdot\cos\alpha_1 - u)$$

$$W_2 = (V_{w3} + \cancel{V_{w4}}^{\,\to 0})\,u$$
$$= u\,V_{w3}$$

$$V_{w3} = V_{r4}\cdot\cos\beta_4 + V_{r3}\cdot\cos\beta_3 \qquad \beta_3 = \beta_4$$
$$K_2 = \frac{V_{r4}}{V_{r3}} = 1$$
$$= 2V_{r3}\cdot\cos\beta_3$$
$$= 2(V_3\cdot\cos\alpha_3 - u)$$

$$W_2 = 2u(V_3\cdot\cos\alpha_3 - u)$$

if $\alpha_2 = \alpha_3$ & $V_2 = V_3$ then

$$V_3\cdot\cos\alpha_3 = V_2\cdot\cos\alpha_2$$
$$= V_{r2}\cdot\cos\beta_2 - u.$$
$$= V_{r1}\cdot\cos\beta_1 - u$$
$$= (V_1\cdot\cos\alpha_1 - u) - u.$$

$$\therefore W_2 = 2u(V_1\cdot\cos\alpha_1 - u - \cancel{2}u)$$
$$= 2u(V_1\cdot\cos\alpha_1 - 3u)$$

$$W_T = W_1 + W_2$$
$$= 2u(V_1\cdot\cos\alpha_1 - u) + 2u(V_1\cdot\cos\alpha_1 - 3u)$$
$$= 4u(V_1\cdot\cos\alpha_1 - 2u)$$

$$\therefore \eta_{b2s} = \frac{W_T}{KE} = W_T/\tfrac{1}{2}mV_1^2$$
$$= \frac{4u(V_1\cdot\cos\alpha_1 - 2u)}{\frac{1}{2}V_1^2}$$
$$= 8u\cancel{V_1}[\cos\alpha_1 - 2u/V_1)/\cancel{V_1}^{2}$$

$$= 8\phi\,(\cos\alpha_1 - 2\phi)$$

diffrentiating.

$$\frac{d\,q_{b2s}}{d\phi} = \frac{d}{d\phi}\left[8\phi\,(\cos\alpha_1 - 2\phi)\right] = 0$$

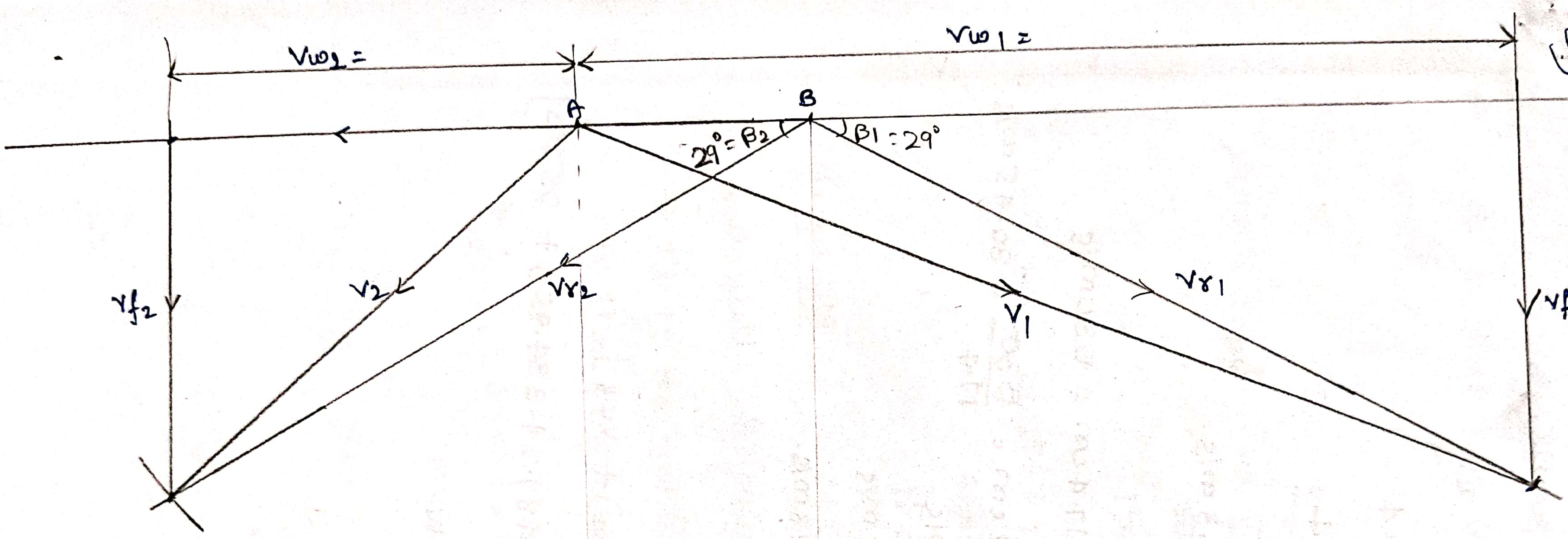
$$8\cos\alpha_1 - 16\times 2 = 0$$

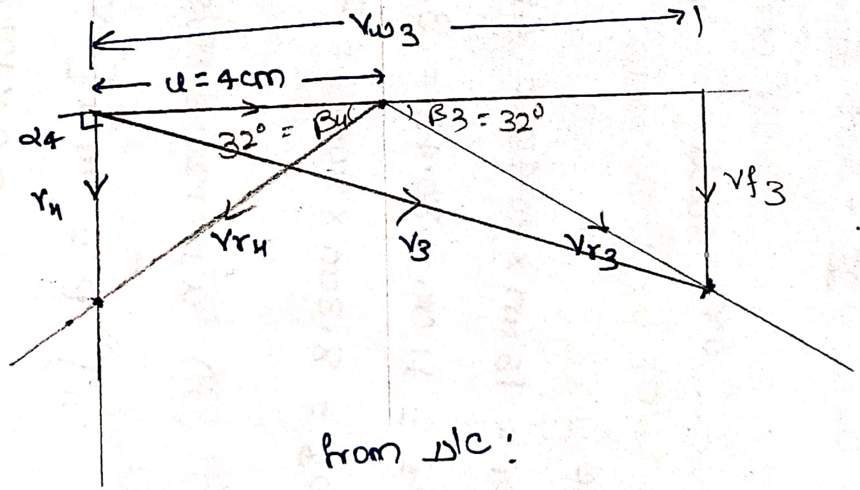
$$\therefore \quad \phi = \frac{\cos\alpha_1}{4}$$

$$\therefore \quad q_{b2s} = 8\phi\,(\cos\alpha_1 - 2\phi)$$

$$= -8\times\frac{\cos\alpha_1}{4}\left(\cos\alpha_1 - 2\times\frac{\cos\alpha_1}{4}\right)$$

$$q_{b2s_{max}} = \cos^2\alpha_1$$ //





$K_2 = \frac{V_3}{V_2} = 0.91$

$\therefore V_2 = \frac{V_3}{0.91} = \frac{8.6cm}{0.91}$

$= 9.45cm.$

$K_1 = \frac{V_{r2}}{V_{r1}} = 0.9$

$\frac{V_{r2}}{0.91} = V_{r1} = \frac{12.6cm}{0.91} = 13.8cm.$

$K_3 = \frac{V_{r4}}{V_{r3}} = 0.93$

$V_{r3} = \frac{V_{r4}}{0.93}$

$= \frac{4.7cm}{0.93}$

$= 5.05$

from D/C:

$V_{w1} = 160mm.$

$V_{w2} = 110mm$

$V_{w3} = 83mm$

$V_{f1} = 66mm$, $V_{f2} = 61mm.$

Scale :

$V_1 = 17.4\,cm = 530\,m/s.$

$4\,cm = ?\,x.$

$\therefore\ x \times 17.4 = 530 \times 4$

$x = \dfrac{530 \times 4}{17.4}$

$\underline{u} = x = 121.83\,m/s.$

$\therefore$ or. Scale : $V_1 = 17.4\,cm = 530\,m/s$

$\therefore\ 1\,cm = \dfrac{530}{17.4} = 30.45\,m/s.$

from s/c :

$\therefore\ V_{w01} = 16\,cm \times 30.45 = 487.2\,m/s$

$V_{w02} = 11\,cm \times 30.45 = 334.95\,m/s$

$V_{w03} = 8.3\,cm \times 30.45 = 252.73\,m/s.$

$\therefore$ i) $u = 121.8\,m/s.$

ii) $P = m\,u\,[(V_{w01} + V_{w02}) + V_{w03}]$

$= 3.2 \times 121.8\,[(487.2 + 334.95) + 252.73]$

$= 418945.22\,W.$

$= 418.94\,kW.$

Module-4

Q. 7)

a) Heads & efficiencies of hydraulic (Pelton wheel) turbine:

Heads:

i) Gross head : → It is the difference between head race and tail race level when there is no flow.

ii) Effective head: → Head available at inlet of the turbine.

$$H = H_g - H_f.$$

Efficiencies:

i) Hydraulic efficiency:

→ It is the ratio of power developed by the runner to the power available at inlet of turbine.

$$\rightarrow \eta_H = \frac{m \times WD}{\rho g Q H}$$

$$= \frac{\cancel{m}(u_1 V_{w1} \pm u_2 V_{w2})}{\cancel{\rho} g \cancel{Q} H}$$

$$= \frac{(u_1 V_{w1} \pm u_2 V_{w2})}{gH}.$$

ii) Volumetric efficiency:

→ It is the ratio of quantity of water actually striking on the runner to the quantity of water supplied to the runner.

→ $$\eta_{vol.} = \frac{Q_a}{Q_{th.}} = \frac{Q - \Delta Q}{Q_{th.}}$$

ΔQ = amount of water that slips directly to the tailrace = loss.

iii) Mechanical efficiency:

→ Ratio of shaft power output by the turbine to the power developed by runner.

→ $$\eta_{mech.} = \frac{SP}{m(u_1 V_{w_1} \pm u_2 V_{w_2})}$$

iv) Overall efficiency:

– $$\eta_o = \frac{\text{Shaft output power}}{\text{water power at inlet}}$$

$$= \frac{S.P}{\rho g Q H}$$

$$= \eta_H \times \eta_{vol.} \times \eta_{mech.}$$

//

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Q7) b) $P = 5880\,kW$

$H = 300\,m$

$N = 550\,rpm$

$\frac{d}{D} = \frac{1}{10}$

$\eta_o = 0.85$

$C_v = 0.98$

$\phi = 0.46$

$n = ?$

$d = ?$

$D = ?$

$Q = ?$

$$Q_T = n \times A \times V_1$$

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

$$= 0.98 \times \sqrt{2 \times 9.81 \times 300}$$

$$= 75.19\,m/s$$

$$u = \phi\sqrt{2gH}$$

$$= 0.46\sqrt{2 \times 9.81 \times 300}$$

$$= 35.29\,m/s.$$

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

$$35.29 = \frac{\pi \times D \times 550}{60}$$

$$\therefore \quad D = 1.22\,m.$$

$\therefore \frac{d}{D} = \frac{1}{10}$

$\therefore d = \frac{1}{10} \times 1.225$

$= 0.122 m.$

To find Q:

$$\eta_0 = \frac{S.P}{\rho g Q H}$$

$$0.85 = \frac{5880 \times 10^3}{1000 \times 9.81 \times Q \times 300}$$

$\therefore Q = 2.35 \ m^3/s.$

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

$2.35 = n \times \frac{\pi}{4} \times (0.122)^2 \times 75.19$

$\therefore n = 2.65$

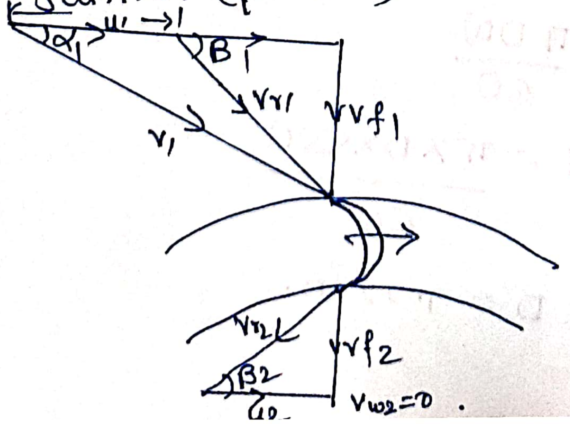
$n \simeq 3$

OR

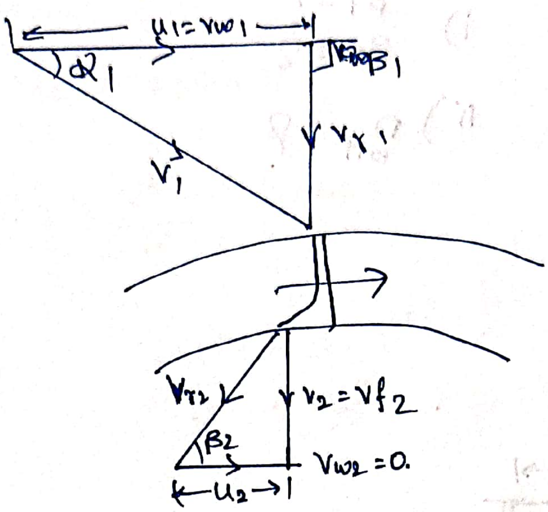
Q.8)

a) velocity dia for Francis turbine for

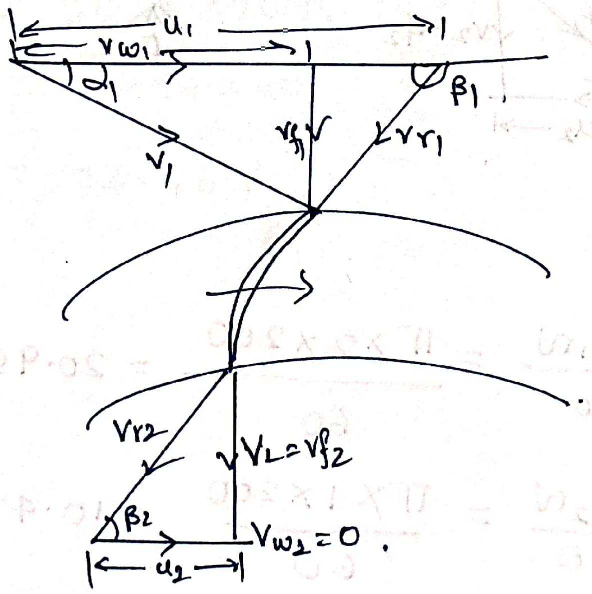
i) slow speed runner ($\beta_1 < 90°$)



ii) Medium speed runner ($\beta_1 = 90°$)



iii) High speed runner. ($\beta_1 > 90°$).



Q.8) b)

$D_1 = 2m$

$D_2 = 1m.$

$H = 60m$

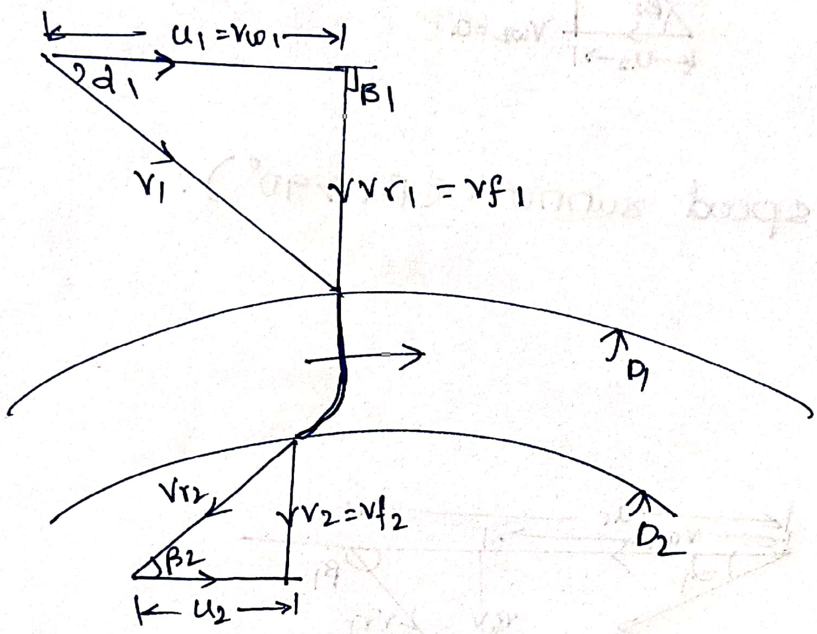
$B_1 = B_2 = 0.25m$

$N = 200rpm$

$Q = 6m^3/s.$

i) $\beta_1 = ?$
$\beta_2 = ?$

ii) $\eta_H = ?$



i) $\beta_1 = 90^\circ.$

$$u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 2 \times 200}{60} = 20.95 m/s = V_{w1}$$

$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 1 \times 200}{60} = 10.47 m/s.$$

$\therefore Q = \pi D_1 B_1 \times V_{f1}$

$6 = \pi \times 2 \times 0.25 \times V_{f1}$

$V_{f1} = 3.82 m/s$

$$Q_2 = \pi D_2 B_2 \times V_{f_2}$$

$$6 = \pi \times 1 \times 0.25 \times V_{f_2}$$

$$\therefore V_{f_2} = 7.64 \text{ m/s}.$$

$$\therefore \tan \beta_2 = \frac{V_{f2}}{u} = \frac{7.64}{10.47}.$$

$$\therefore \beta_2 = 36.11^\circ$$

$$\beta_1 = 90^\circ.$$

ii)

$$\eta_H = \frac{\cancel{m}(u_1 V_{w1} \pm u_2 \cancel{V_{w2}}^{\to 0})}{\cancel{\rho} g \cancel{Q} H}$$

$$= \frac{u_1 V_{w1}}{gH}$$

$$= \frac{20.95 \times 20.95}{9.81 \times 60}$$

$$= 74.56\%$$

Module-5

Q.9) a) Applying Bernoulli's equation at inlet and outlet of the impeller.

$$\left(\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+\cancel{Z_1}\right)=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+\cancel{Z_2}-\frac{u_2 V_{w2}}{g}$$

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}-\frac{u_2 V_{w2}}{g}$$

$$\left(\frac{P_2}{\rho g}-\frac{P_1}{\rho g}\right)=\frac{V_1^2}{2g}-\frac{V_2^2}{2g}+\frac{u_2 V_{w2}}{g} \quad \text{—— (i)}$$

$$V_1 = V_{f_1}$$

$$\tan\phi = \frac{V_{f_2}}{(u_2 - V_{w2})}$$

$$\therefore V_{w2} = u_2 - \frac{V_{f_2}}{\tan\phi} = u_2 - V_{f_2}\cdot\cot\phi$$

$$V_2^2 = V_{f_2}^2 + V_{w2}^2$$
$$= V_{f_2}^2 + (u_2 - V_{f_2}\cdot\cot\phi)^2$$
$$= V_{f_2}^2 + [u_2^2 - V_{f_2}^2\cot^2\phi - 2uV_{f_2}\cot\phi]$$
$$= V_{f_2}^2 + V_{f_2}^2\cot^2\phi + u_2^2 - 2u_2V_{f_2}\cot\phi$$
$$= V_{f_2}^2(1+\cot^2\phi) + u_2^2 - 2u_2V_{f_2}\cdot\cot\phi$$
$$= V_{f_2}^2\cdot\operatorname{cosec}^2\phi + u_2^2 - 2u_2V_{f_2}\cdot\cot\phi.$$

$$\therefore \Delta P = \frac{V_1^2}{2g} - \frac{V_2^2}{2g} + \frac{u_2 V_{w2}}{g}$$

$$= \frac{V_{f_1}^2}{2g} - \frac{1}{2g}\left[V_{f_2}^2\cdot\operatorname{cosec}^2\phi + u_2^2 - 2u_2V_{f_2}\cot\phi\right] + \frac{(u_2 - V_{f_2}\cdot\cot\phi)\,u}{g} \times 2.$$

$$= \frac{1}{2g}\left[V_{f_1}^2 - V_{f_2}^2 \cdot \operatorname{cosec}^2\phi - u_2^2 + 2u_2 V_{f_2}\cdot\cot\phi + 2u_2^2 - 2u_2 V_{f_2}\cdot\cot\phi \right]$$

$$= \frac{1}{2g}\left[V_{f_1}^2 - V_{f_2}^2 \operatorname{cosec}^2\phi + u_2^2 \right]$$

b) $H_m = 14.5\,m$

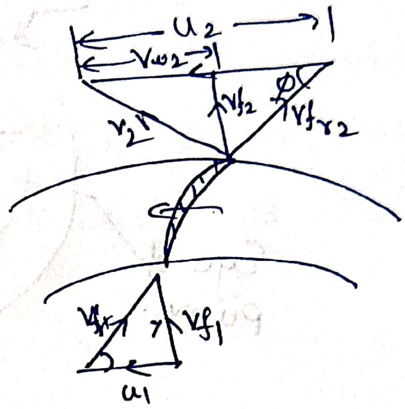
$N = 1000\,rpm$

$\phi = 30^\circ$

$D_2 = 300\,mm = 0.3\,m$

$B_2 = 50\,mm = 0.05\,m$

$\eta_{man} = 95\% = 0.95$



$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.3 \times 1000}{60} = 15.7\,m/s.$$

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

$$0.95 = \frac{9.81 \times 14.5}{V_{w_2} \times 15.70}$$

$$V_{w_2} = 9.54\,m/s$$

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

$$\therefore V_{f_2} = \tan\phi\,(u_2 - V_{w_2})$$

$$= 6.16 \times \tan 30^\circ$$

$$= 3.55\,m/s.$$

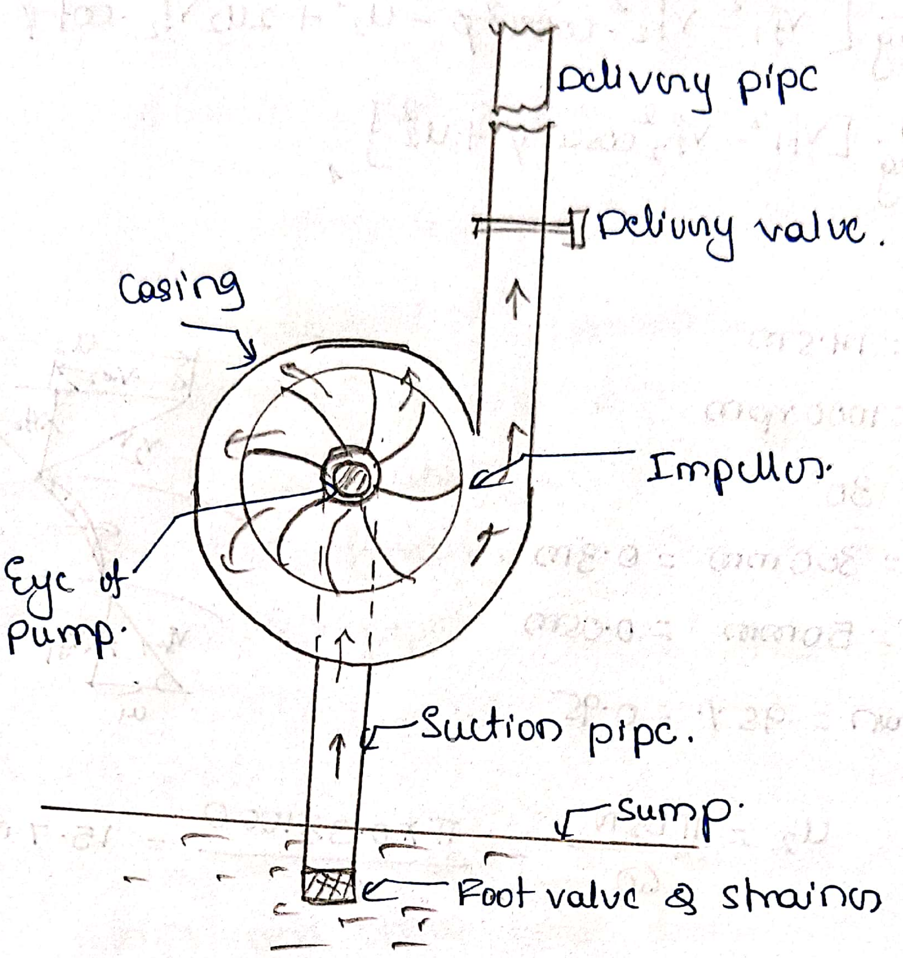
$$\therefore Q = \pi D_2 B_2 \times V_{f_2}$$

$$= \pi \times 0.30 \times 0.05 \times 3.55$$

$$= 0.167\,m^3/s$$

OR

Q.10) a)



i) Impeller :

The rotating part of a centrifugal pump. It consists of series of a backward curved vanes. This is connected to a shaft of an electric motor.

ii) Casing :

It is an air tight passage surrounding the impeller and is designed in such a way that the kinetic energy of the water discharged at the outlet of the impeller is converted into pressure energy before water leaves the casing & enters the delivery pipe.

→ Volute casing
→ Vortex "
→ Casing with guide blades

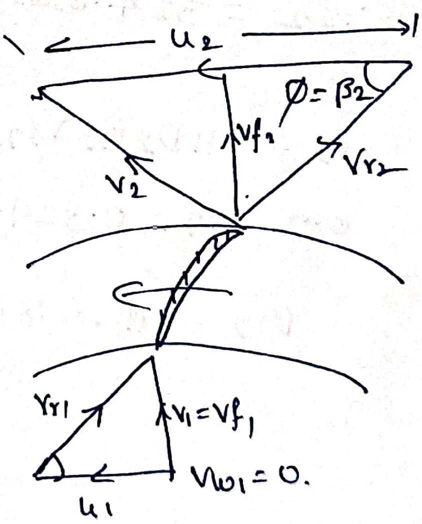
iii) Suction pipe with a foot-valve and strainer.

A pipe whose one end is connected to the inlet of the pump and other end dips into water in a sump. A foot valve which is a non-return valve or one-way type of valve is fitted at the lower end of the suction pipe.

iv) Delivery pipe

A pipe whose one end is connected to the outlet of the pump and other end delivers the water at a required height.

b) $N = 1000 \, rpm$



$\beta_2 = 45^0 = \phi$

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

$Q = 200 \, litres/s.$

$H_m = 20m$

$\eta_{man} = 80\% = 0.8$

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

$$u_2 - V_{w_2} = \frac{V_{f_2}}{\tan\phi} = \frac{2.5}{\tan 45} = 2.5$$

$$V_{w_2} = u_2 - 2.5$$

$$\eta_{man} = \frac{gH_m}{u_2 V_{w2}}$$

$$0.8 = \frac{9.81 \times 20}{u_2 V_{w2}}$$

$$u_2 V_{w2} = 245.25$$

$$\therefore (u_2 - 2.5) u_2 = 245.25$$

$$u_2^2 - 2.5 u_2 - 245.25 = 0.$$

Solution for quadratic equation,

$$u_2 = 16.96$$

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

$$16.96 = \frac{\pi \times D_2 \times 1000}{60}$$

$$\therefore D_2 = 324 \text{ mm}.$$

ii) $Q = \pi D_2 B_2 V_{f2}$

$$0.2 = \pi \times 0.324 \times B_2 \times 2.5$$

$$B_2 = 0.0786 \text{ m} = 78.6 \text{ mm}$$

x —— x

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