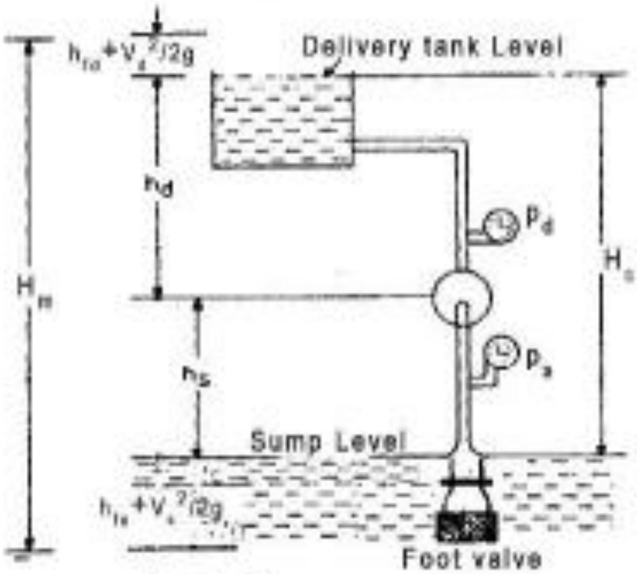
TURBOMACHINES (18ME54)
IAT-3
SOLUTIONS

1 Define Suction Head, Delivery Head, Static Head and Manometric Head with a neat diagram for a centrifugal pump.

(1) **Suction Head (h_S)**: It is the vertical height of the centre line of the pump above the water surface in the sump. This height is also called suction lift and is denoted as h_S

(2) **Delivery Head (h_d)**: It is the vertical height between the centre line of the pump and the water surface in the tank to which water is delivered. It is denoted as h_d

(3) **Static Head (H_s)**:
Static head is the vertical distance between the liquid level in the sump and the delivery tank. It is denoted by H_S. Therefore the static head, $H_S = h_S + h_d$



Manometric Head (H_m)
It is defined as the head against which a centrifugal pump has to work.
It includes all loses like frictional loses, leakage loses, etc.
If there are no loses in the impeller, then the manometric head will be equal to the head imparted to the liquid by the impeller (Euler's Head).

$\Rightarrow$ H_m = Head imparted by impeller − Head loses in the pump

$H_m = U_2 V_{w2}$ − Head loss.

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

h_{fs} = Frictional head loss in suction pipe.

h_{fd} = Frictional head loss in delivery pipe.

V_d = Velocity of water in delivery pipe.

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

2 Define i) Manometric Efficiency ii) Mechanical Efficiency iii) Voulmetric Efficiency iv) Overall Efficiency for a centrifugal pump

i) <u>Manometric Efficiency</u>

Ratio of manometric head developed by the pump to the head imparted by the impeller.

$$\eta_m = \frac{\text{manometric head}}{\text{Impeller head}} = \frac{gH_m}{H_e}$$

$$H_e = u_2 V_{w2}$$

$$\Rightarrow \eta_m = \frac{H_m}{u_2 V_{w2}}$$

But $H_m = H_e - \text{loss}$

$\Rightarrow H_e = H_m + \text{loss}$

$$\Rightarrow \eta_m = \frac{H_m}{H_m + \text{loss}}$$

ii) <u>Mechanical Efficiency</u>

Ratio of power actually delivered by the impeller to the power supplied at the shaft.

$$\eta_{mech} = \frac{\text{Impeller Power}}{\text{shaft Power}}$$

$$\eta_{mech} = \frac{U_2 V_{w2}}{U_2 V_{w2} + \text{Mechanical losses}}$$

(iii) Volumetric efficiency (η_{vol})

It is the ratio of amount of water delivered by the delivery pipe to the actual amount of water entering the impeller through suction pipe. Due to leakages, all the water sucked into the impeller does not pass through the delivery pipe.

$$\eta_{vol} = \frac{Q_d}{Q_s} = \frac{Q_d}{Q_d + Q_L}$$ where Q_L = amount of water leakage.

(iv) Overall efficiency (η_O) :- It is the ratio of hydraulic energy output by the pump to the shaft power input to the pump

$$\eta_o = \frac{gH_m}{U_2 V_{u2}} \times \frac{U_2 V_{u2}}{\text{Input shaft power}} \times \frac{Q_d}{Q_s}$$

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

3 Derive an expression for Work Done for a centrifugal pump by drawing possible velocity triangles for the same

Work Done by a Centrifugal Pump.

Velocity triangle.

It is assumed that water enters the impeller radially.

$\Rightarrow V_{w_1} = 0$.

$\alpha_1 = 90°$.

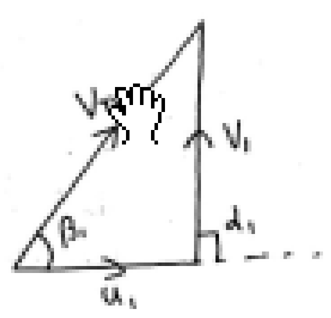
$V_1 = V_{f_1}$.

Possible Velocity triangles for Centrifugal Pump

~~Case I :-~~

Inlet velocity triangle

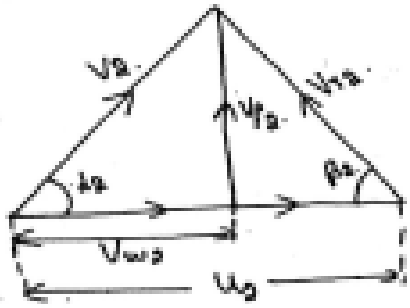
Following the assumptions, the inlet velocity triangle is drawn as below.



Outlet Velocity triangle.

Case 1: Backward Vane

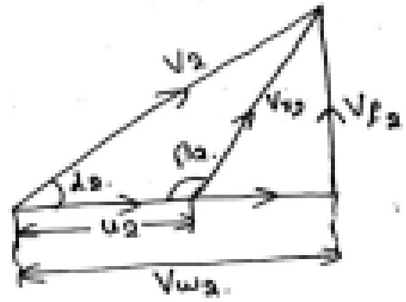
$\beta_2 < 90^\circ$



$u_2 > V_{w_2}$.

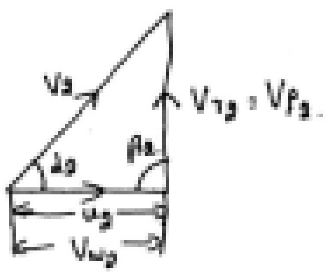
Case 2: Forward Vane

$\beta_2 > 90^\circ$



$U_2 < V_{w_2}$.

Case 3: Radial Blade



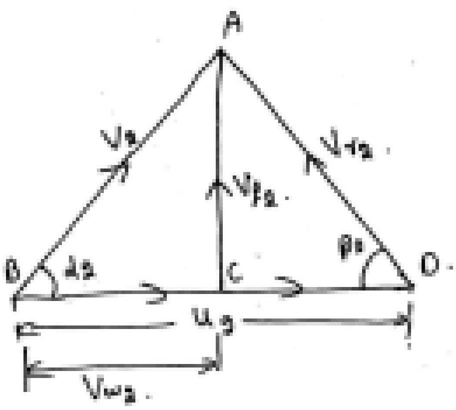
$u_2 = V_{w_2}$.

Considering Case-1 for the outlet velocity triangle.

Work Done by a centrifugal Pump is given by.

$$\frac{W.D}{\dot{m}} = V_{w_2} u_2 - V_{w_1} u_1$$

Since $V_{w_1} = 0 \Rightarrow \frac{W.D}{\dot{m}} = V_{w_2} u_2$.



From the outlet velocity Δ^{le},

$V_{w_2} = BC = BD - CD$

$BD = u_2$.

$\cot\beta_2 = \frac{CD}{V_{f_2}}$

$\Rightarrow CD = V_{f_2} \cot\beta_2$.

$\Rightarrow V_{w_2} = BC = u_2 - V_{f_2} \cot\beta_2$.

$$\frac{W.D}{\dot{m}} = (u_2 - V_{f_2} \cot\beta_2)\, u_2$$

In a centrifugal pump, the volume flow rate,

$$Q = A_2 V_{f_2}$$

$$A_2 = \pi D_2 B_2$$

$$V_{f_2} = \frac{Q}{A_2}$$

$$W.D = \left(u_2 - \frac{Q}{A_2} \cot\beta_2\right) u_2$$

$$\boxed{W.D = u_2^2 - \frac{u_2 Q}{A_2} \cot\beta_2}$$

4 Explain minimum starting speed by deriving the expression for the same for a centrifugal pump

Minimum Starting Speed

When the pump is started, there will be no flow untill the pressure difference in the impeller is large enough to overcome the manometric head. This implies that the centrifugal head should be greater than the manometric head.

The centrifugal head is given by the alternate forms of Euler's equation.

$$\text{Centrifugal head} = \frac{u_2^2 - u_1^2}{2}$$

For the flow to commence,

$$\frac{u_2^2 - u_1^2}{2} \geq H_m$$

So the minimum condition to start the speed is

$$\frac{u_2^2 - u_1^2}{2} = H_m \quad \text{—— (a)}$$

$$\text{Manometric efficiency, } \eta_m = \frac{H_m}{H_e}$$

$$\Rightarrow H_m = \eta_m H_e$$

$$u_2 = \frac{\pi D_2 N}{60} \qquad u_1 = \frac{\pi D_1 N}{60}$$

$$\frac{u_2^2 - u_1^2}{2} = \left(\frac{\pi N}{60}\right)^2 \frac{(D_2^2 - D_1^2)}{2} \quad \text{—— (b)}$$

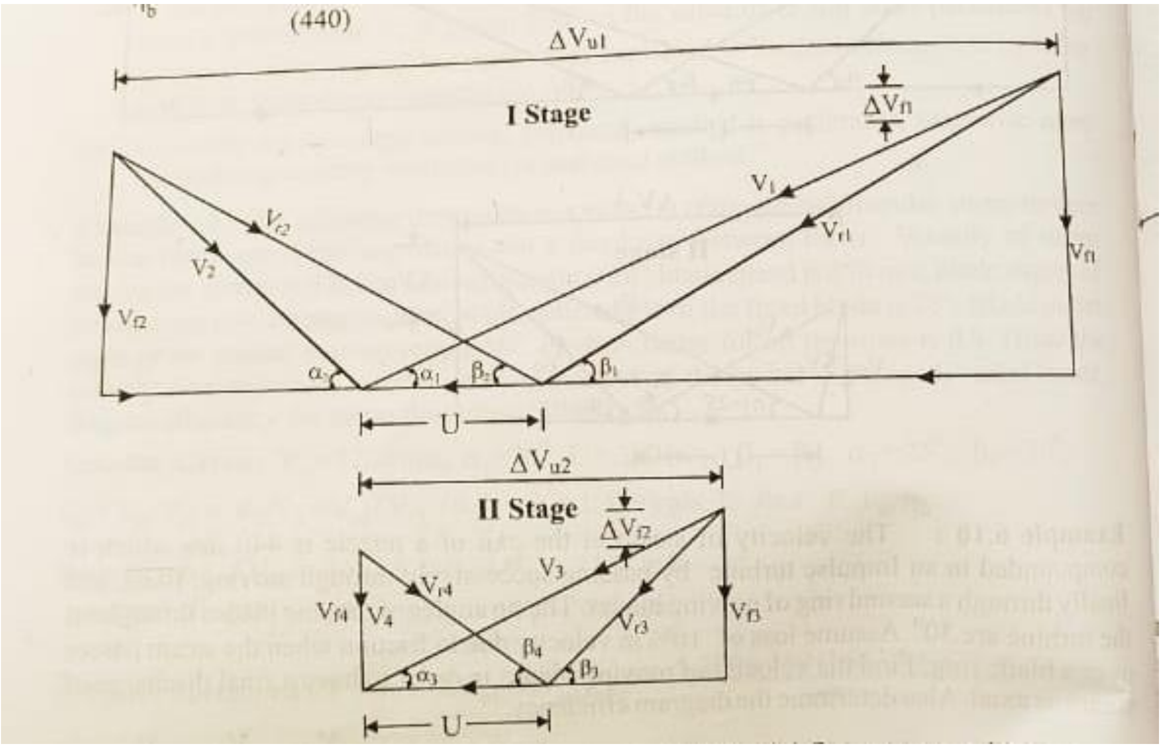
Substituting (6) in (5).

$$\left(\frac{\pi N}{60}\right)^2 \frac{(D_2^2 - D_1^2)}{2} = \eta_m H_e$$

$$\left(\frac{\pi N}{60}\right)^2 = \frac{2\eta_m H_e}{D_2^2 - D_1^2}$$

$$N^2 = \frac{60^2 \times 2\eta_m H_e}{\pi(D_2^2 - D_1^2)} \Rightarrow \boxed{N = \frac{120\,\eta_m H_e}{\pi(D_2^2 - D_1^2)}} \text{ rpm}$$

5 The velocity of steam at the exit of the nozzle is 440 m/s, which is compounded in an impulse turbine. The tip angles of the moving blades throughout the turbine are 30°. Assume loss of 10% in velocity due to friction when the steam passes over a blade ring. Find the velocity of moving blades in order to have a final discharge of steam as axial. Also determine the diagram efficiency.



Note: As we have to find out the tangential speed of rotors for the axial discharge at last row, we have to proceed from the 2nd stage by assuming a suitable length for U. We assumed U = 3cm, Finally from Graph we get, $V_1 = 13.6$cm.

Also, $V_1 = 440$ m/s = 13.6 cm ($\because$ $V_1 = 440$ m/s given)

$\therefore$ Scale ratio = 1 : 32.35 i.e., 1 cm = 32.35 m/s

(i) Tangential velocity of rotor (U)

$\therefore$ U = 3cm x 32.35 = 97.06 m/s

(ii) Diagram efficiency (η_b):

From Graph:

$\Delta V_{u1} = 579$ m/s

$\Delta V_{u2} = 204.8$ m/s

$$\eta_b = \frac{2U(\Delta V_{u1} + \Delta V_{u2})}{V_1^2}$$

$$\eta_b = \frac{2 \times 97.06\,[579 + 204.8]}{(440)^2} = 78.6\%$$

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Internal Assessment Test 3 – Jan 2022

Sub:	TURBO MACHINES					Sub Code:	18ME54	Branch:	MECHANICAL	
Date:	24/01/2021	Duration:	90 min's	Max Marks:	50	Sem/Sec:	5th Sem A &B		OBE	

		MARKS	CO	RBT
	Answer all questions			
1.	Define Suction Head, Delivery Head, Static Head and Manometric Head with a neat diagram for a centrifugal pump.	[10]	CO5	L1
2.	Define i) Manometric Efficiency ii) Mechanical Efficiency iii) Voulmetric Efficiency iv) Overall Efficiency for a centrifugal pump	[10]	CO5	L1
3.	Derive an expression for Work Done for a centrifugal pump by drawing possible velocity triangles for the same	[10]	CO5	L1
4.	Explain minimum starting speed by deriving the expression for the same for a centrifugal pump	[10]	CO5	L1
5.	The velocity of steam at the exit of the nozzle is 440 m/s, which is compounded in an impulse turbine. The tip angles of the moving blades throughout the turbine are 30°. Assume loss of 10% in velocity due to friction when the steam passes over a blade ring. Find the velocity of moving blades in order to have a final discharge of steam as axial. Also determine the diagram efficiency.	[10]	CO3	L3

[CI] [CCI] [HOD]