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Internal Assessment Test 3 – Jan 2023

Sub:	Turbomachines				Sub Code:	18ME54	Branch:	Mech
Date:		Duration:	90 min's	Max Marks: 50	Sem / Sec:	V		OBE

Answer all the Questions

		MARKS	CO	RBT
1	Show that the maximum efficiency of a Pelton wheel is given by $\eta_{b,max} = \frac{1+K\cos\beta_2}{2}$	[10]	CO4	L3
2	Derive an expression for minimum starting speed of Centrifugal pump.	[10]	CO5	L3
3	Define the following with respect to centrifugal pump. (i) Static head. (ii) Cavitation (iii) Priming (iv) Multistage centrifugal pumps.	[10]	CO5	L2
4.	A double jet Pelton wheel is required to generate 7500 kW, when the available head at the base of the nozzle is 400 m. The jet is deflected through 165° and the relative velocity of the jet is reduced by 15% in passing over the buckets. Determine (i) Diameter of the jet (ii) Total flow and (iii) Force exerted by the jet in the tangential direction.	[10]	CO4	L3
5.	The outer diameter of impeller of a centrifugal pump is 40 cm. Width of the impeller at the outlet is 5 cm. The pump is running at 800 rpm and is working a head of 15 m. The vane angle at the outlet is 40° and manometric efficiency is 75%. Determine: (i) Velocity of flow at outlet (ii) Velocity of water leaving the vane (iii) Angle made by absolute velocity at outlet with direction of motion at outlet (iv) Discharge.	[10]	CO5	L3

Solutions key

(1)

We have from Eq. (7.21),

$$\eta_H = \frac{2u(V_1 - u)(1 + K\cos\beta_2)}{V_1^2} \quad (7.21)$$

Differentiating Eq. (7.21) w.r.t. u and equating to 'zero' to get the condition for maximum efficiency, i.e. $d\eta_H/du = 0$, we have

$$\frac{d}{du}\left[\frac{2u(V_1 - u)(1 + K\cos\beta_2)}{V_1^2}\right] = 0$$

or
$$\frac{(1 + K\cos\beta_2)}{V_1^2}\frac{d}{du}(2uV_1 - 2u^2) = 0$$

or
$$\frac{d}{du}(2uV_1 - 2u^2) = 0$$

or
$$2V_1 - 4u = 0 \qquad \left[\because \frac{(1+\cos\beta_2)}{V_1^2} \neq 0\right]$$

$\therefore$
$$u = \frac{V_1}{2} \quad (7.22)$$

Equation (7.22) states that the condition for maximum hydraulic efficiency of a Pelton wheel is when the velocity of runner is half the velocity of the jet of water at inlet.

7.6.2 Maximum Efficiency of Pelton Wheel

Substituting Eq. (7.22) in (7.21),

$$\eta_{H\max} = \frac{2 \times \frac{V_1}{2}\left(V_1 - \frac{V_1}{2}\right)(1 + K\cos\beta_2)}{V_1^2}$$

$$= \frac{2 \times V_1 (2V_1 - V_1)(1 + K \cos \beta_2)}{2 \times 2 \times V_1^2}$$

$$= \frac{1 + K \cos \beta_2}{2} \tag{7.23}$$

Qns: 2

When the pump is started, there will be no flow until the pressure difference in the impeller is large enough to overcome the manometric head. If the impeller is rotating and if there is no flow, then the water is rotating in a forced vertex.

Centrifugal pressure head for no flow of water = $(u_2^2 - u_1^2)/2g$

Unless this pressure head is equal to or greater than the manometric head, the pump will not deliver water. By this the minimum speed can be determined.

The flow will commence only if $(u_2^2 - u_1^2)/2g \geq H_m$ (4.55)

i.e. $$\frac{1}{2g}\left[\frac{\pi d_2 N}{60}\right]^2 - \frac{1}{2g}\left[\frac{\pi d_1 N}{60}\right]^2 \geq H_m \qquad \left[\eta_{\text{mano}} = \frac{gH_m}{V_{w2}u_2}\right]$$

i.e. $$\frac{1}{2g}\left[\frac{\pi d_2 N}{60}\right]^2 - \frac{1}{2g}\left[\frac{\pi d_1 N}{60}\right]^2 \geq \eta_{\text{mano}} \frac{V_{w2}u_2}{g} \geq \eta_{\text{mano}} \frac{V_{w2}}{g}\left[\frac{\pi d_2 N}{60}\right]$$

For minimum speed, using the equal sign,

$$\frac{\pi^2 N^2}{2g}\left[\frac{(d_2^2 - d_1^2)}{3600}\right] = \eta_{\text{mano}} \frac{V_{w2}}{g} \frac{\pi d_2 N}{60} \tag{4.56}$$

$$\therefore \qquad N = \frac{\overset{60}{\cancel{3600}} \times 2\eta_{\text{mano}} V_{w2} d_2}{\pi \times (d_2^2 - d_1^2) \times \cancel{60}} = \text{minimum speed for a centrifugal pump.}$$

QNo: 3

4.17.1 Static Head (H_S)

The static head is the sum of suction head (h_s) and delivery head (h_d), i.e.

$$H_S = h_s + h_d \tag{4.32}$$

Suction head (h_s): It is the vertical height between the centre line of the centrifugal pump and top surface of the liquid. See Figure 4.12.

Delivery head (h_d): It is the vertical height between the centre line of the pump and the water surface in the overhead tank to which water is delivered. See Figure 4.12.

4.22 MULTISTAGE PUMPS

We know that, the head developed by a centrifugal pump is proportional to the diameter and speed of the impeller. However, there is a limitation for the diameter and speed of the impeller. Therefore, maximum head developed with a single impeller is up to 50 m. For more head and discharge, a multistage pump is preferred. Figure 4.16 shows the different arrangements of multistage pumps.

The liquid leaves the suction pipe, enters the first impeller at inlet and is discharged at outlet with increased pressure. The liquid leaving from the first impeller enters the second impeller as shown in Figure 4.16(a). The pressure of the liquid leaving the second impeller is more than the pressure of the liquid leaving the first stage. This arrangement is called the series arrangement.

$$\text{Total head developed} = n_1 \times H_m \tag{4.57}$$

Figure 4.16(b) shows parallel arrangement of the pumps. The liquid leaving each pump is discharged into a common pipe. Each pump is dipped in the same sump. In this case, the discharge obtained is more against the same head.

$$\text{Total discharge} = n_2 \times Q$$

where, n_1 = number of identical impellers mounted on the same shaft, H_m = head developed by each impeller (pump), n_2 = number of identical pumps arranged in parallel and Q = discharge from each pump (impeller).

4.23 CAVITATION

Cavitation occurs on the suction side of the pump as lowest pressure exists just below the pump on the suction side. Due to height of installation of the pump above the sump, the pressure on the suction side is below the atmospheric value. The head drop across foot-valve and the frictional loss and also kinetic head all contribute to such sub-atmospheric pressures. If the pressure drops below the vapour pressure head, vaporization and bubble formations occur at the inlet to runner. Soon, energy is added, and therefore bubbles collapse. This results in water rushing to such spots. This causes mechanical failure too, cavities are formed on surfaces. This whole process is cavitation.

Qno: 4

Solution: Data:

Number of jets: $N_j = 2$

Head: $H = 400$ m

Power to generate: $P_g = 7500$ kW

$\beta_2 = 180° - 165° = 15°$

$V_{r2} = 0.85V_{r1}$, $\eta_g = 0.95$, $\eta_o = 0.$

$\phi = 0.47$, $C_V = 0.98$

To determine: d, Q, F_x

$$\text{S.P.} = \frac{P_g}{\eta_g} = \frac{7500}{0.95} = 7894.7 \text{ kW}$$

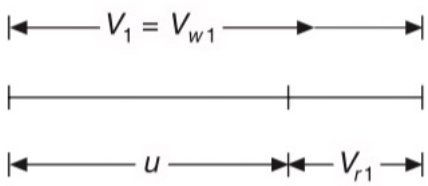
$$V_{w1} = V_1 = C_V\sqrt{2gH} = 0.98\sqrt{2 \times 9.81 \times 400} = 86.82 \text{ m/s}$$

$$u = \phi\sqrt{2gH} = 0.47\sqrt{2 \times 9.81 \times 400} = 41.64 \text{ m/s}$$

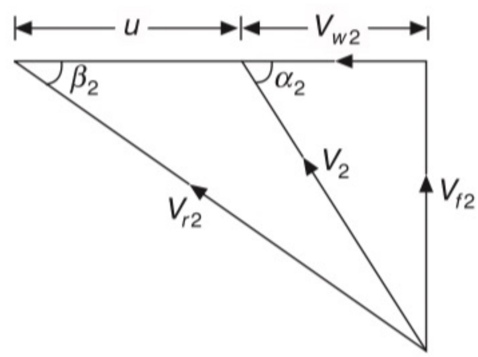
$$V_{r1} = V_{w1} - u = 86.82 - 41.64 = 45.18 \text{ m/s}$$

$$V_{r2} = 0.85V_{r1} = 0.85 \times 45.18 = 38.4 \text{ m/s}$$

$$V_{w2} = V_{r2} \cos \beta_2 - u = 38.4 \times \cos 15° - 41.64 = -4.55 \text{ m/s}$$

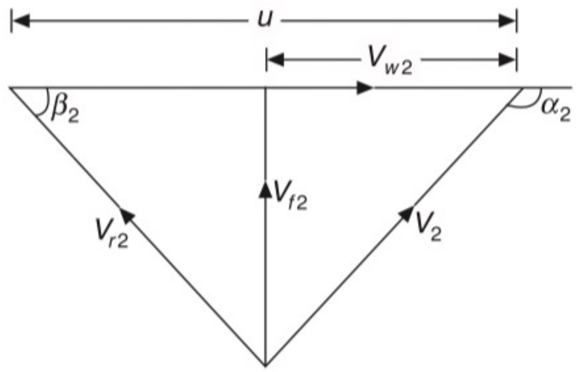


Inlet velocity triangle



Outlet velocity triangle

$\therefore$ V_{w2} is –ve, hence the outlet velocity triangle changes to as given below:



(a) **Total discharge (*Q*):**

$$\eta_o = \frac{\text{S.P}}{\rho g Q H} = \frac{7894.7 \times 1000}{1000 \times 9.81 \times Q \times 400} = 0.8$$

$\therefore$ $Q = 2.515\ \text{m}^3/\text{s}$ **Ans.**

(b) **Jet diameter (*d*):**

$$q = \text{discharge from each jet} = \frac{Q}{N_j} = \frac{2.515}{2} = 1.257\ \text{m}^3/\text{s}$$

$$q = 1.257 = \frac{\pi}{4} d^2 V_1 = \frac{\pi}{4} \times d^2 \times 86.82$$

$\therefore$ $d = 0.1357$ m **Ans.**

(c) **Force in the *x* direction (F_x):**

$F_x = \rho Q(V_{w1} \pm V_{w2}) = 1000 \times 2.515\ (86.82 - 4.55) = 1206.91$ kN **Ans.**

Qno: 5

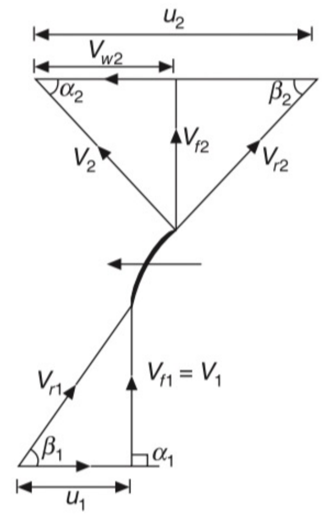
Solution: Data:

Speed:	$N = 800$ rpm
Outer diameter of impeller:	$d_2 = 40$ cm
Width of outlet:	$b_2 = 5$ cm
Head:	$H_m = 15$ cm

Vane angle at outlet: $\beta_2 = 40°$

Manometric efficiency: $h_{\text{man}} = 75\%$

To determine: V_{f2}, V_2, α_2, Q



$$u_2 = \frac{\pi d_2 N}{60} = \frac{\pi \times 0.4 \times 800}{60} = 16.75 \text{ m/s}$$

$$\eta_{\text{man}} = \frac{gH_m}{V_{w2}\, u_2} = \frac{9.81 \times 15}{V_{w2} \times 16.75} = 0.75$$

$$V_{w2} = 11.71 \text{ m/s}$$

(a) **Velocity of flow at outlet (V_{f2}):**

$$\tan \beta_2 = \frac{V_{f2}}{u_2 - V_{w2}} = \frac{V_{f2}}{16.75 - 11.71} = \tan 40°$$

$\therefore$ $V_{f2} = 4.23$ m/s **Ans.**

(b) **Velocity of water leaving the vane (V_2):**

$$V_2 = \sqrt{V_{f2}^2 + V_{w2}^2} = \sqrt{4.23^2 + 11.71^2} = 12.45 \text{ m/s}$$ **Ans.**

(c) **Angle made by absolute velocity at outlet (α_2):**

$$\tan \alpha_2 = \frac{V_{f2}}{V_{w2}} = \frac{4.23}{11.71} = 0.36$$

$\therefore$ $\alpha_2 = 19.8°$ **Ans.**

(d) **Discharge (Q):**

$$Q = \pi d_2 b_2 V_{f2} = \pi \times 0.4 \times 0.05 \times 4.23$$

$\therefore$ $Q = 0.265 \text{ m}^3/\text{s}$