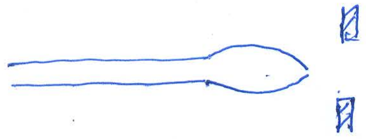
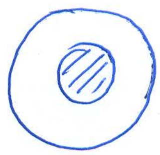
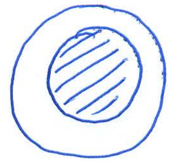
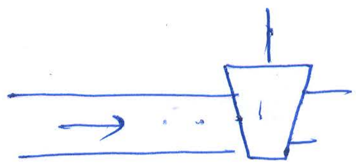




$$V_1 = C_v \sqrt{2gH}$$





Specific speed

Water hammer

$$N_s = \frac{N \sqrt{P}}{\sqrt{\rho}\,(gH)^{5/4}}$$

$P = W$

ρ ✗

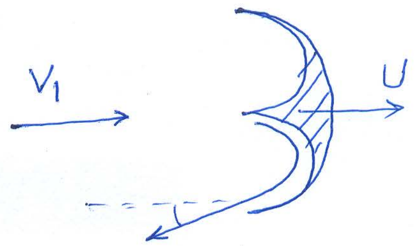
g ✗

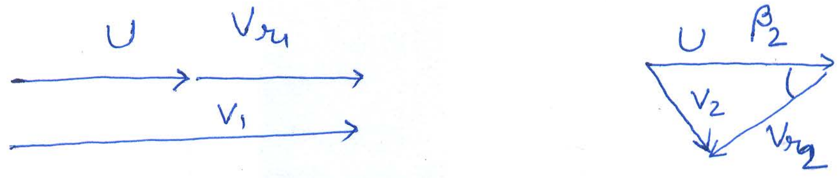
P kW

$$N_s = \frac{N \sqrt{P}}{H^{5/4}}$$

Engineering non-dimensional number

P ✓ H ✓ N





$$\omega = U(V_{u1} - V_{u2})$$

$$= U\{V_1 - (U - V_{r2}\cos\beta_2)\}$$

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

$$= U\{(V_1 - U) + C_b V_{r1}\cos\beta_2\}$$

C_b = blade friction factor

$$= U(V_1 - U)\{1 + C_b\cos\beta_2\}$$

$$= \frac{U}{V_1}\left(1 - \frac{U}{V_1}\right) V_1^2 \{1 + C_b\cos\beta_2\}$$

$$= \varphi(1-\varphi) V_1^2 \{1 + C_b\cos\beta_2\}$$

$$\eta_h = 2\varphi(1-\varphi)\{1 + C_b\cos\beta_2\}$$

ω_{max} = when $\varphi = \frac{1}{2}$

$$\eta_h = 2 \times 0.5 \times 0.5 \times \{1 + C_b\cos\beta_2\}$$

$\varphi = 0.46 \sim 0.47$

run away speed

14. What is the special feature of Kaplan turbine? Discuss the purpose of special feature. *(Refer Section 6.8.2)*
15. Discuss the governing of Kaplan turbine. *(Refer Section 6.8.2)*
16. Write a note on the need of the governing process of the hydraulic turbines. *(Refer Section 6.8)*
17. Discuss with a neat sketch the governing system with respect to hydraulic turbines. *(Refer Section 6.8.1)*
18. Discuss with a neat sketch the working of a governing system. *(Refer Section 6.8.2)*
19. Draw the typical operating characteristics of hydraulic turbines. Discuss their features. *(Refer Section 6.9)*
20. Draw the typical velocity triangles of the different types of hydraulic turbines. *(Refer Figs. 6.10, 6.15, 6.31)*

EXERCISES

1. As a small laboratory project, a table-top working model of a Pelton turbine is required to be designed. It may be assumed that water is available at a constant net head of 4 m from the over-head tank. A nozzle of 5 mm diameter is the starting point. Calculate the following parameters of the Pelton turbine with a proposed speed of 600 rpm, assuming a speed ratio of 0.46, nozzle velocity coefficient of 0.98, and an overall efficiency of 83%: (a) power, (b) diameter, (c) specific speed, (d) number of Pelton cups, (e) length of the cup and (f) breadth of the cup.
2. As a small laboratory project, a table-top working model of a Francis turbine is required to be designed. The water is available at a constant head of 4 m from the over-head tank. As a starting point, assume a specific speed of 120, a rotor speed of 800 rpm, and an overall efficiency of 75%. Also in standard notations, assume the following: $\phi_o = 0.75$, $\psi_0 = 0.36$, $\phi_1 = 0.68$. Calculate the following: (a) power, (b) flow rate, (c) inner diameter of guide-vane ring, (d) length of guide vanes, (e) breadth or height of guide vanes, (f) inlet diameter of runner, (g) breadth of runner inlet, (h) number of runner vanes, (i) guide-vane angle, (j) runner blade angle at the inlet, and (k) runner blade angle at outlet.
3. The net head at the nozzle of a Pelton turbine is 260 m of water and the flow rate available is estimated as 4.8 m^3/s. The speed ratio and the coefficient of velocity of nozzle are 0.46 and 0.96, respectively. The overall efficiency may be taken as 85%, as a starting point. The selected speed is 500 rpm. Calculate the (a) specific speed, (b) diameter of rotor, (c) number of jets, and (d) jet diameter.
4. A Pelton turbine is coupled to an alternator, running at 600 rpm. The output of the alternator is 4300 kW. At this output, the alternator is specified to have an overall efficiency of 88%. On the turbine side, the mechanical loss on the shaft is found to be 100 kW. The Pelton cups turn the jet through an angle of 160° ($\beta_2 = 20°$). The relative velocity of water experiences a loss of 10% due to friction, as the water moves in the cups. The head measured at the nozzle is 340 m of water. The nozzle efficiency is 0.975. Calculate the (a) output power of the turbine, (b) mechanical efficiency of the turbine, (c) hydraulic efficiency, (d) water flow rate, (e) specific speed, and (f) jet diameter.
5. The inlet blade angle of a Francis runner is 55°. The flow rate of water is 2.8 m^3/s at a net head of 65 m of water. The discharge of water from the runner is without any whirl component. The overall efficiency of the turbine is 82%. The outlet diameter of runner is 0.6 times the diameter at the inlet. The blade velocity at the inlet is 26 m/s. For the runner wheel, the diameter to width ratio is 8. The flow component of velocity of water remains constant in the runner. Calculate the (a) power of the turbine, (b) specific work, (c) the speed ratio of the runner ϕ_1, (d) runner inlet diameter, (e) runner width, (f) speed, (g) specific speed, (h) guide-vane angle, (i) guide wheel diameter, (j) guide wheel width, and (k) utilization factor.
6. A Francis turbine of a dam power house develops 450 kW of power at a speed of 1000 rpm when the head available is 85 m. An overall efficiency of 85% can be assumed. The runner wheel diameter is 12 times the width of the runner. The guide-vane angle is 20°. The runner diameter at the outlet is half that at the inlet. The flow component remains constant. The discharge of water is without any whirl component. Determine the (a) mass flow rate of water, (b) specific work, (c) diameter of runner at the inlet, (d) diameter of runner at the outlet, (e) blade width, (f) blade angle at the inlet, and (g) blade angle at the outlet.
7. For a Francis turbine, the net head available is 12.5 m of water, and the available flow rate is 0.35 m^3/s. The blades are radial at the inlet ($\beta_1 = 90°$). A velocity of flow, equal to 2.1 m/s, remains constant in the runner. The overall efficiency is 0.85 and the speed is 500 rpm. The diameter at the discharge is half that at the inlet, and the discharge is radial. Take the reduction in flow area due to the vane thickness as 10%. Overall efficiency is 85%. Calculate the (a) power, (b) specific speed, (c) specific work, (d) diameter of runner at the inlet, (e) diameter of runner at the outlet, (f) width of runner at the inlet, (g) width of runner at the outlet, (h) guide-vane angle, and (i) blade angle at the outlet in the rotor.
8. A run-of-the-river power house has a potential of a steady flow of 95 m^3/s, and the head that can be arranged is 5.5 m of water. Design a Kaplan turbine that can be assumed to have an overall efficiency of 87%. The speed ratio and flow ratio may be taken as 2.1 and 0.75, respectively. The hub diameter is 0.35 times the tip diameter of the runner. The flow component of velocity remains constant. Calculate the (a) power of the turbine, (b) tip diameter, (c) hub diameter, (d) speed, (e) specific speed, (f) specific work, (g) inlet blade angle at the tip, (h) inlet blade angle at the hub, (i) outlet blade angle at the tip, and (j) outlet blade angle at the hub.
9. A Kaplan turbine has a rated output of 2600 kW at 600 rpm, the head being 40 m of water. The speed ratio is 1.25. The overall and hydraulic efficiencies are 0.86 and 0.9, respectively. The hub diameter is 0.6 times the tip diameter. Calculate the (a) flow rate, (b) specific speed, (c) specific work, (d) tip diameter, (e) hub diameter, (f) blade inlet and outlet angles at the tip, and (g) blade inlet and outlet angles at the hub.
10. The flow rate of water in a reaction turbine is 3.4 m^3/s. The exit diameter of the turbine is 62 cm, which is also the inlet diameter of the draft tube connected to it. The diameter at the outlet of the draft tube is 92 cm. The length of the draft tube is 3 m. Calculate the head saved, due to the draft tube, if the efficiency of the draft tube is 90%. The end of the draft tube is 50 cm below the tailrace level. Take the atmospheric head as 10 m of water. If the saving in head is required to be 7.5 m, with the same efficiency and the same length, what should be the exit diameter of the draft tube? And in such a case, what is the half-cone-angle of the draft tube? If the atmospheric temperature is 33°C, is the cavitation likely to occur on the blade surfaces?

Ex 1 / Chap6

Pelton turbine

$H = 4m$

d = Nozzle dia

$= 5mm$

$N = 600$ rpm

$\phi = \frac{U}{V_1} = 0.46$

$C_v = 0.98$

$\eta_o = 83\%$

$V_1 = C_v \sqrt{2gH}$

$= 0.98 \sqrt{2 \times 9.81 \times 4}$ m/s

$= 8.7$ m/s

$U = .46 \times 8.7$ m/s

$= 4$ m/s

$Q = \frac{\pi}{4} \times \left(\frac{5}{1000}\right)^2 \times 8.7$ m^3/s

$= 0.17$ lps

Power $= \rho Q g H \times \eta_o$

$= 1000 \times 0.17 \times 10^{-3} \times 9.81 \times 4 \times 0.83$

$= 5.54W$

$U = \frac{\pi D N}{60} \Rightarrow \frac{\pi \times D \times 600}{60} = 4 \rightarrow D = \frac{4}{10 \times \pi} m = 0.127m$

$N_s = \frac{N\sqrt{P}}{H^{5/4}} = \frac{600 \times \sqrt{5.54 \times 10^{-3}}}{4^{5/4}} = 7.9$

3. $H = 260 m$

$Q = 4.8 m^3/s$

$\phi = 0.46$

$C_v = 0.96$

$\eta_o = 0.85$

$N = 500$ rpm

$V_1 = C_v\sqrt{2gH}$

$= 0.96\sqrt{2 \times 9.81 \times 260}$ m/s

$= 68.6$ m/s

$U = \phi V_1 = 0.46 \times 68.6$

$= 31.5$ m/s

$P = \rho Q g H \times \eta_o = 10^3 \times 4.8 \times 9.81 \times 260 \times 0.85$

$= 10406$ kW

$N_s = \frac{N\sqrt{P}}{H^{5/4}} = \frac{500 \times \sqrt{10406}}{260^{5/4}} = 49$

$U = \frac{\pi D N}{60} = 31.5 \Rightarrow D = \frac{31.5 \times 60}{\pi \times 500} = 1.2 m$

Number of jets = 2.

$Q = 2.4 m^3/s$ per jet.

$\frac{\pi}{4} d^2 \times V_1 = 2.4$

$\frac{\pi}{4} \times d^2 \times 68.6 = 2.4$

$d = 0.2 m$

$N_s = \frac{49}{\sqrt{2}} = 34.6$

4. $N = 600$ rpm

Output of alternator $= 4300$ kW, alternator $\eta = 88\%$

Output of turbine $P_s = \dfrac{4300}{0.88}$ kW

$= \underline{\underline{4886 \text{ kW}}}$

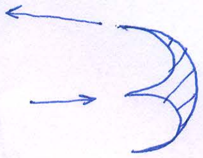
Mech loss $= 100$ kW

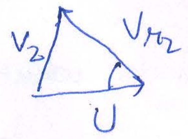
$\beta_2 = 20^0$

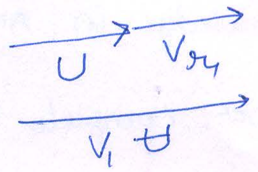
$V_{r_2} = 0.9 V_{r_1}$, $C_b = 0.9$

$H = 340$ m

η_n = nozzle efficiency $= \dfrac{V_1^2/2}{gH} = 0.975$







$$\omega = U(V_1 - V_{u_2})$$

$$= U\{V_1 - (U - V_{r_2}\cos\beta_2)\}$$

$$= U\{V_1 - (U - C_b V_{r_1})\cos\beta_2\}$$

$$= U\{(V_1 - U) + C_b V_{r_1}\cos\beta_2\}$$

$$= U\cdot(V_1 - U)\{1 + C_b\cos\beta_2\}$$

$$= \varphi(1-\varphi)V_1^2\{1 + C_b\cos\beta_2\}$$

$V_1 = C_v\sqrt{2gH} = 0.975 \times \sqrt{2 \times 9.81 \times 340}$ m/s $= 79.6$ m/s

$P_r = P_s +$ mech loss $= 4886 + 100 = 4986$ kW

$\eta_m = \dfrac{P_s}{P_r} = \dfrac{4886}{4986} = 98\%$

$\eta_h = \dfrac{1 + C_b\cos\beta_2}{2} = \dfrac{1 + 0.9 \times \cos 20}{2} = 0.923$

Power input to turbine $= \dfrac{4986}{0.923} = 5402 \times 1000 = \rho Q g H \eta_n$

$Q = \dfrac{5402 \times 1000}{1000 \times 9.81 \times 340 \times 0.975}$ m³/s $= 1.66$ m³/s

$N_s = \dfrac{N\sqrt{P}}{H^{5/4}} = \dfrac{600 \times \sqrt{4886}}{340^{5/4}} = 28.7$

$\frac{\pi}{4}d^2 \times V_1 = Q \Rightarrow d = \sqrt{\dfrac{4 \times Q}{\pi \times V_1}} = \sqrt{\dfrac{4 \times 1.66}{\pi \times 79.6}} = 0.163$ m

5. $\beta_1 = 55^0$

$Q = 2.8 m^3/s$

$H = 65 m$

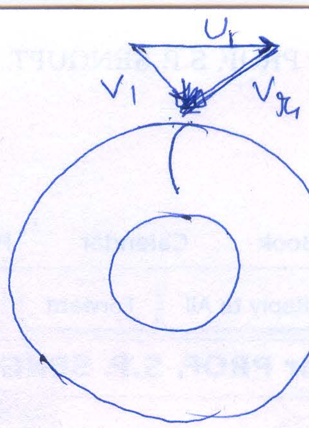
$\eta_o = 82\%$

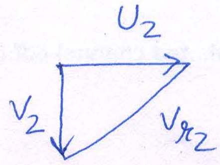
$D_2/D_1 = 0.6$

$U_1 = 26 m/s$

$D/b = 8$

$V_{n_1} = V_{n_2} = V_2$



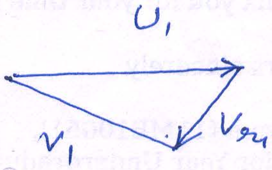


$P_s = \rho Q g H \eta_o$

$= 10^3 \times 2.8 \times 9.81 \times 65 \times 0.82$

$= 1464 kW$

$\pi D_1 b_1 V_{n_1} = \pi D_2 b_2 V_{n_2} = Q$



$$w = \frac{P_s}{\rho Q} = \frac{1464 \times 10^3}{10^3 \times 2.8} J/kg = 522.8 J/kg$$

$$w = U_1 V_{u_1} \Rightarrow V_{u_1} = \frac{522.8}{26} m/s = 20.1 m/s$$

$$V_{n_1} = (U - V_{u_1}) \tan\beta_1 = (26 - 20.1) \tan 55 = 8.43 m/s$$

$$\pi D_1 b_1 V_{n_1} = Q \Rightarrow \pi \times 8 b_1 \times b_1 \times V_{n_1} = Q \Rightarrow b_1 = \sqrt{\frac{Q}{\pi \times 8 \times V_{n_1}}} = \sqrt{\frac{2.8}{\pi \times 8 \times 8.43}}$$

$$= 0.115 m.$$

$$D_1 = 8 b_1 = 8 \times 0.115 m = 0.92 m$$

$$\frac{\pi D N}{60} = U_1 \Rightarrow N = \frac{60 U_1}{\pi D_1} = \frac{60 \times 26}{\pi \times 0.92} rpm = 540 rpm$$

$$N_s = \frac{N\sqrt{P}}{H^{5/4}} = \frac{540\sqrt{1464}}{65^{5/4}} = 112$$

$$V_1 = \sqrt{V_{u_1}^2 + V_{n_1}^2} = \sqrt{20.1^2 + 8.43^2} = 21.8 m/s$$

$$\tan\alpha_1 = \frac{V_{n_1}}{V_{u_1}} = \frac{8.43}{20.1} \quad \alpha_1 = 22.7^0$$

6. $P = 450 kW$

$N = 1000$ rpm

$H = 85 m$

$\eta_o = 0.85$

$\frac{D_1}{b_1} = 12$

$\alpha_1 = 20^\circ$

$\frac{D_2}{D_1} = \frac{1}{2}$

$V_{n_1} = V_{n_2} = V_2$

$P = \rho Q g H \eta_o$

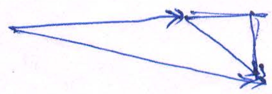
$450 \times 10^3 = 10^3 \times Q \times 9.81 \times 85 \times 0.85$

$Q = 0.635 \, m^3/s.$

$\frac{V_{n1}}{V_{u1}} = \tan 20$

$V_{u1} = \frac{V_{n1}}{\tan 20}$

$w = \frac{P}{\rho Q} = \frac{450 \times 10^3}{10^3 \times 0.635} = 708.7 \, J/kg$



$u = \frac{\pi D_1 N}{60}$ $\quad V_{n_1} = \frac{Q}{\pi D_1 b_1} = \frac{Q}{\pi D_1 \times \frac{D_1}{12}}$

$w = u V_{u_1}$

$= \frac{u V_{n1}}{\tan 20}$

$= \frac{\pi D_1 N}{60} \times \frac{Q}{\pi D_1 \times \frac{D_1}{12}} \times \frac{1}{\tan 20}$

$D_1 = \frac{N \times Q \times 12}{60 \times \tan 20 \times w} = \frac{1000 \times 0.635 \times 12}{60 \times \tan 20 \times 708.7} m = 0.492 \, m$

$D_2 = \frac{D_1}{2} = \frac{0.492}{2} = 0.246 \, m$ $\quad V_{n_1} = \frac{0.635 \times 12}{\pi \times 0.492^2} = 10 \, m/s$

$V_{u1} = \frac{V_{n1}}{\tan 20} = \frac{10}{\tan 20} = 27.5 \, m/s$

$u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.492 \times 1000}{60} m/s = 25.8 \, m/s$

$\beta_1 = \tan^{-1} \frac{V_{n1}}{u_1 - V_{u1}} = \tan^{-1} \frac{10}{25.8 - 27.5} = -80.2^\circ.$