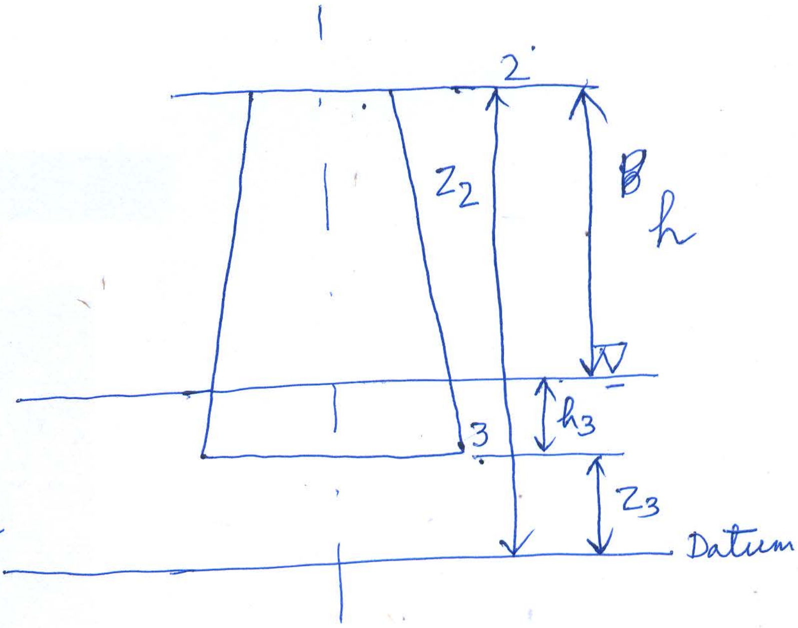
# Draft Tube



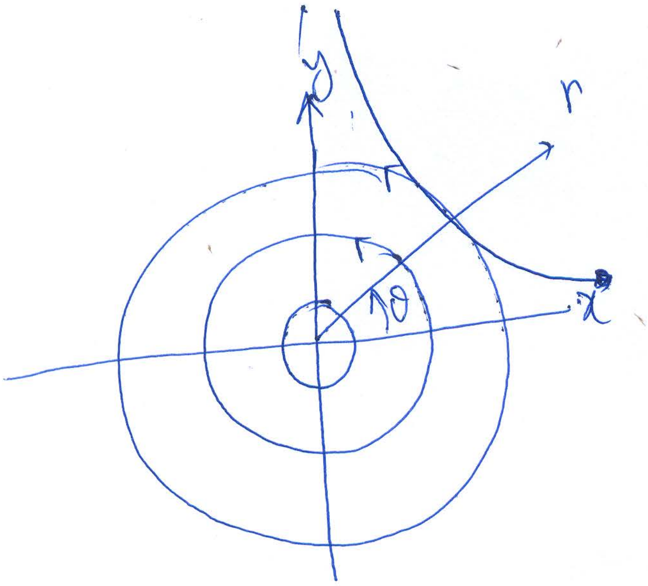

$$\frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

$$= \frac{p_3}{\rho g} + \frac{V_3^2}{2g} + z_3 + h_l$$

$$= \frac{p_a}{\rho g} + h_3 + \frac{V_3^2}{2g} + z_3 + h_l$$

$$\frac{p_2}{\rho g} = \frac{p_a}{\rho g} - (z_2 - z_3 - h_3) - \frac{V_2^2 - V_3^2}{2g} + h_l$$

$$= \frac{p_a}{\rho g} - h - (1-k)\frac{V_2^2 - V_3^2}{2g} \qquad h_l = k\,\frac{V_2^2 - V_3^2}{2g}$$




$$rV_\theta = \text{constant}$$

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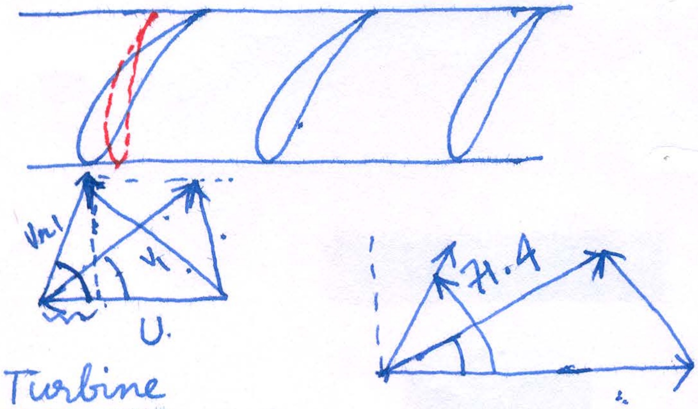
Chap6




## Kaplan Turbine

$P = 2600\ kW$ $\quad H = 40m$ $\quad N = 600\ rpm$

$\eta_0 = 0.86$ $\quad \phi = 1.25$

$N_S$ = Engineering specific speed.

$$= \frac{N\sqrt{P}}{H^{5/4}} \Rightarrow \frac{600\sqrt{2600}}{40^{5/4}} \qquad \frac{N\sqrt{P}}{\rho^{\frac{1}{2}}(gH)^{5/4}} \qquad P = W$$

$= 304.$

$Q = 7.7\ m^3/s$

$$2600 \times 10^3 = 10^3 \times Q \times 9.81 \times 40 \times 0.86$$
$$P_s = \rho \times Q \times g \times H \times \eta_0$$

$$\varphi = \frac{U.}{V_1} = 1.25$$

$$V_1 = \sqrt{2gH} = 28\ m/s$$

$$U = 1.25 \times 28 = 35\ m/s$$

$$U = \frac{\pi D_t N}{60} = 35 \qquad D_t = 1.11\ m \qquad \frac{D_h}{D_t} = 0.6$$

$$D_h = 0.666\ m/s$$

$$V_{n_1} = V_{n_2} = V_n = \frac{Q}{\frac{\pi}{4}(D_t^2 - D_h^2)} = \frac{7.7}{\frac{\pi}{4}(1.11^2 - 0.666^2)}\ m/s = 12.4\ m/s$$

$$\eta_h = 0.9 \qquad U_1 V_{t_1} = gH\eta_h \Rightarrow V_{t_1} = 10.1\ m/s$$

$$\beta_1 = \tan^{-1}\frac{V_n}{U - V_{t_1}} = 27.7^\circ \qquad \beta_2 = \tan^{-1}\frac{V_n}{U} = \tan^{-1}\frac{12.4}{35} = 19.5^\circ$$

## Free Vortex Design

| | $\beta_1$ | $\beta_2$ |
|---|---|---|
| tip | 26.6 | 19.5 |
| hub | 71.4 | |

$$r \times V_t = \text{constant}$$

$$(U_1 V_{t1})_h = (U_1 V_{t1})_t$$

$\beta_1$ and $\beta_2$ at hub

$$V_{t1} = \frac{35 \times 10.1}{21}$$

$$= 16.9$$

$$\beta_1 = \tan^{-1} \frac{12.4}{21 - 16.9} = 71.4^\circ$$

$$U_1 = \frac{\pi \times 0.666 \times 600}{60} \text{ m/s}$$

$$= 0.6 \times 35$$

$$= 21.0$$

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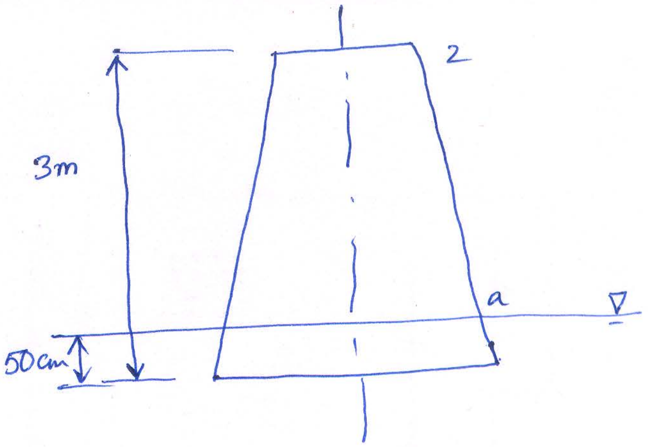
Chap 6

$Q = 3.4\ m^3/s$

$D_2 = 62\ cm$

$D_3 = 92\ cm$

$(1-k) = 0.9$




$$V_2 = \frac{Q}{\frac{\pi}{4} D_2^2} = \frac{3.4}{\frac{\pi}{4} \times 0.62^2}\ m/s$$

$= 11.26\ m/s$

$$V_3 = \frac{Q}{\frac{\pi}{4} D_3^2} = \frac{3.4}{\frac{\pi}{4} \times (.92)^2}\ m/s = 5.11\ m/s$$

$$\frac{p_2}{\rho g} = \frac{p_a}{\rho g} - (3 - 0.5) - 0.9 \times \frac{11.26^2 - 5.11^2}{2 \times 9.81}$$

$= 10 - 2.5 - 4.62$

$= 2.88\ m$

Saving in head $= 10 - 2.88 = 7.12\ m$

If saving to be 7.5 m, then

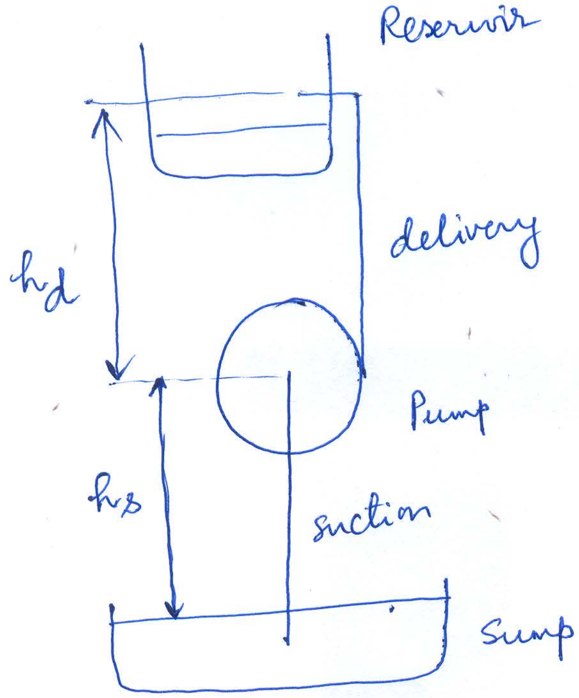
$$7.5 = 2.5 + 0.9\ \frac{11.26^2 - V_3^2}{2g}$$

$V_3 = 4.21\ m/s$

$d_3 = 1.016\ m$

Half cone angle $= \tan^{-1}\left(\frac{1.016 - 0.62}{2 \times 3.000}\right) = 3.776^0$

7/11/17




$$\require{cancel}\cancel{q}\,|-w| = \left(p + \frac{v^2}{2} + gz\right)_2 - \left(p + \frac{v^2}{2} + gz\right)_1$$

$$H_m = h_s + h_{sf} + h_d + h_{df} + \frac{V_2^2}{2g}$$

$$\eta_h = \frac{H_m}{H_n} = \frac{H_m}{\frac{u_2 V_{u2}}{g}}$$

Chapter 7

## Exercises

1. The diameters of the impeller of a centrifugal pump are 20 cm and 40 cm at the inlet and outlet, respectively. The blades of the impeller are bent backward at an angle of 40° at the outlet. The radial velocity of flow is constant at 6.8 m/s. The water enters the impeller in the radial direction. The total head to overcome is 61.5 m of water. The speed is 1440 rpm. Calculate the following: (a) Blade angle at the inlet, (b) angle and magnitude of outlet velocity, (c) specific work, (d) manometric efficiency, and (e) power required to drive the pump if the width of the impeller passage at the outlet is 2 cm and the overall efficiency is 88%.
2. The blades of the impeller of a centrifugal pump are bent backward at 35° to the tangent of the wheel rim. The outer diameter of the impeller is 30 cm and the speed is 980 rpm. The measured head across the inlet and outlet of the pump is 15 m. Find (a) loss of head in the impeller (b) hydraulic efficiency. (c) Also calculate the power required to drive the pump if the flow rate is 15 kg/s. The entry of water is radial and the flow velocity remains constant at 3.5 m/s.
3. In a performance test of a centrifugal pump, it was found that the maximum efficiency occurred when the flow rate was 45 lps, at a head of 30 m, while running at 1440 rpm. The impeller diameter of the pump was 28 cm. Calculate the number of similar stages and the diameter of the impeller of a multi-stage unit to deliver 85 lps against a head of 130 m at a speed of 960 rpm.
4. The vertical height of the outlet of the delivery pipe of a centrifugal pump is 22 m, above the centerline of the pump. The length of the delivery pipe is 32 m, including the effective lengths of all the pipe fittings, and its diameter is 7.5 cm. The suction side head and the losses are negligible. A flow rate of 1500 lpm is required. The overall efficiency is estimated as 80%. Calculate the power output of the motor driving the pump, if $f = 0.009$, and the specific speed of the pump if the speed is 1440 rpm.
5. The diameters of the impeller of a centrifugal pump are 0.4 and 1.0 m at the inlet and outlet, respectively. The speed is 300 rpm. The outlet angle of the blades is 30°. The radial component of velocity is constant and is equal to 6.5 m/s. The head across the impeller is 6 m, and the flow rate of water is 1 $m^3$/s. Calculate (a) hydraulic efficiency, (b) power required to drive the pump. (c) Also determine the minimum starting speed.
6. The head measured at the outlet flange of a centrifugal pump is 20 m of water above that at the inlet. The flow rate is 0.09 $m^3$/s. The impeller diameters are 20 and 40 cm. The blades are bent backward with an angle of 40° at the outlet. The width of the impeller at the outlet is 20 mm. The losses in the impeller are 1.5 m, and the gain in the diffuser blades is 3.5 m. The entry of water is radial. The flow velocity remains constant in the impeller. Calculate the following: (a) Head at the outlet of the impeller, (b) head developed by the impeller, (c) hydraulic or manometric efficiency, (d) speed, and (e) angle of the diffuser blades.
7. A pump is required to be designed for a flow of 0.1 $m^3$/s at a manometric head of 60 m. A manometric efficiency of 85% and a mechanical efficiency of 95% can be assumed. The effect of the vane thickness is to reduce the flow area by 10%. The proposed speed is 1500 rpm. The velocity of flow remains constant at 2.5 m/s and the blade angle at the outlet is 55°. If a three-stage unit is preferred, calculate the following: (a) Impeller diameter, (b) width of impeller at the outlet, and (c) overall powe required to drive the pump.



8. In a centrifugal pump, the width of the impeller passage is 2.5 cm at the outer diameter of 45 cm. The thickness of blades in the impeller accounts for 10% reduction in the flow area. The manometric efficiency is 82%, and the overall efficiency is 78%. The whirl velocity at the exit is 24 m/s. The speed is 1440 rpm. Calculate the following: (a) Head generated, (b) flow rate, (c) exit vane angle, and (d) power required to drive the pump.
9. The following observations were recorded during a trial in a centrifugal pump installation. Static suction head = 5.3 m, static delivery head = 26 m, frictional loss of head in suction pipe = 1 m, frictional loss of head in delivery pipe = 6.3 m, diameter of suction pipe = 10 cm, diameter of delivery pipe = 7.5 cm, flow rate = 0.045 $m^3$/s, manometric efficiency = 82%, overall efficiency = 76%, room temperature = 29°C, and barometer reading = 10.01 m of water. Calculate the following: (a) Manometric head, (b) head developed in the impeller, (c) power drawn by the pump, and (d) NPSH.
10. A centrifugal pump delivers 0.04 $m^3$ of water per second through a vertical height of 35 m. The suction and delivery pipes are of equal diameter of 10 cm, and their total length inclusive of effects of pipe fittings is 55 m. The pipe friction coefficient $f$ is 0.006. In the impeller, the blade width at the outlet is 1/10th of the diameter, and the thickness of blades accounts for 8% of loss of flow area. The blades are bent backward, making an angle of 65° with the wheel tangent. The hydraulic efficiency is 80% and the specific speed is 30. Calculate the following: (a) Manometric head, (b) speed, and (c) impeller diameter.

## Project-Oriented Questions

ON WEB Solutions Available

1. This is a small project having three parts: Part (a), Part (b) and Part (c).
   **Part (a):** Enlist the design parameters and performance parameters of a centrifugal pump. Explain, to the extent possible, the effects of variation of such parameters (e.g., in the impeller, the width of the blade, B2, affects the flow rate; higher the width, higher is the flow rate; and hence higher power; also, it does not affect the head created, … .).
   **Part (b):** Prepare a table which shows the values of parameters [as in Part (a) above] in the solved examples and the exercise problems of this chapter. If some values are not available in the problems (either as part of data or part of answers), calculate them wherever possible.
   **Part (c):** Make an attempt to reinforce your explanations of Part (a), citing the table of Part (b), wherever possible.
2. Two pumps are required to be designed: one for a fire hose and another for pumping water to a town water supply scheme in a remote place where electrical power supply is snapped. Both require power supply from mobile units and therefore the power of the prime mover is limited to an upper limit of 60 kW. Discuss the parameters which distinguish the design of the two pumps. Substantiate your discussion with some numerical values that you might use in the design.

## Answers

### Multiple-Choice Questions

1. (c)
2. (b)
3. (b)
4. (d)

Ex 1
Chap 7 Pai

$D_1 = 20\,cm,\ D_2 = 40\ cm$

$\beta_2 = 40^\circ$

$V_{n_1} = V_{n_2} = 6.8\ m/s$

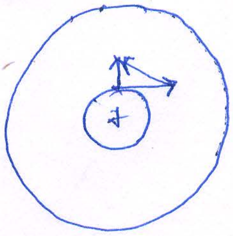
$H = 61.5\,m$

$N = 1440\ rpm$

$$U_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.2 \times 1440}{60}\ m/s$$

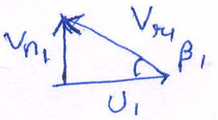
$= 15\ m/s$

$U_2 = 2 \times U_1 = 30\ m/s$



$$\tan\beta_1 = \frac{V_{n_1}}{U_1} = \frac{6.8}{15}$$

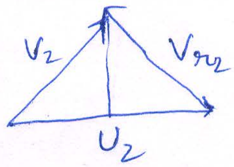
$\beta_1 = 24.4^\circ$




$V_{u_2} = U_2 - V_{n_2} \cot\beta_2$

$= 30 - 6.8 \times \cot 40$

$= 21.9\ m/s$




$$\tan\beta_2 = \frac{V_{n_2}}{V_{u_2}} = \frac{6.8}{21.9} = 0.31 \Rightarrow \beta_2 = 17.2^\circ$$

$$\frac{V_{n_2}}{V_2} = \sin\beta_2 \Rightarrow V_2 = \frac{V_{n_2}}{\sin\beta_2} = \frac{6.8}{\sin 17.2} = 23\ m/s$$

$w = U_2 V_{u_2}$

$= 30 \times 21.9$

$= 657\ m\ kJ/kg$

$$\eta_m = \eta_h = \frac{61.5}{657/9.81} = 91.8\%$$

$Q = \pi D_2 b_2 \times V_{n_2}$

$= \pi \times 0.4 \times 0.02 \times 6.8\ m^3/s$

$= 0.171\ m^3/s$

$P = \rho Q g H / \eta_o$

$= 1000 \times 0.171 \times 9.81 \times 61.5 / 0.88$

$= 117.2\ kW$

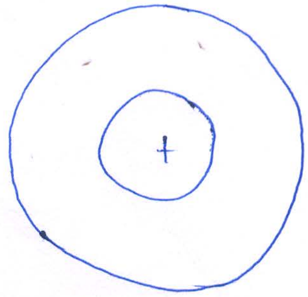
Chap7 Pai

$\beta_2 = 35^\circ$

$D_2 = 30\ cm$

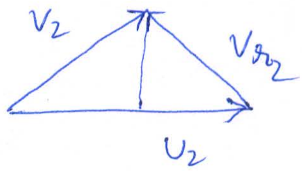
$N = 980\ rpm$

$H_m = 15\ m$



$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.3 \times 980}{60}\ m/s$

$= 15.4\ m/s$




$V_{n_2} = 3.5\ m/s$

$V_{u_2} = u_2 - V_{n_2} \cot \beta_2$

$= 15.4 - 3.5 \times \cot 35$

$= 10.4\ m/s$

$H_n = \frac{u_2 V_{u2}}{g} = \frac{15.4 \times 10.4}{9.81} = 16.3\ m.$

(a) loss of head $= 16.3 - 15 = 1.3\ m$

(b) $\eta_h = \frac{15}{16.3} = 92\%$

(c) Power $= \dot{m} g H_n$

$= 15 \times 9.81 \times 16.3\ W$

$= 2.4\ kW$

3
chap 7 Pri

Performance test of the pump gave:

$Q = 45$ lps $= 0.045\ m^3/s$

$H = 30\ m$

$N = 1440$ rpm

$D = 28$ cm

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}} = \frac{1440 \times \sqrt{0.045}}{30^{3/4}} = 23.83$$

Pumps are in series. specific speed same.

$N = 960$ rpm, $Q = 85$ lps $= 0.085\ m^3/s$

$$N_s = 23.83 = \frac{960\sqrt{0.085}}{H_s^{3/4}} \Rightarrow H_s^{3/4} = \frac{960\sqrt{0.085}}{23.83} = 11.74\ m.$$

$H_s = 26.68$ m.

$$\text{Number of stages} = \frac{130}{26.68} = 4.87 \Rightarrow 5$$

Diameter of new pump

$$\frac{Q_1}{N_1 D_1^3} = \frac{Q_2}{N_2 D_2^3}$$

$$D_2^3 = D_1^3 \times \frac{Q_2}{Q_1} \times \frac{N_1}{N_2}$$

$$= 28^3 \times \frac{85}{45} \times \frac{1440}{960}$$

$$= 62197.3$$

$D_2 = 39.62$ cm

4 / Chap7 Pai  $h_d = 22m$ , $Q = 1500\,lpm = 25\,lps$

$l_e$ = equivalent length = 32m

$$V = \frac{25 \times 10^{-3}}{\frac{\pi}{4} \times (0.075)^2} = 5.66\ m/s$$

$$h_{fd} = 0.036 \times \frac{32}{0.075} \times \frac{5.66^2}{2 \times 9.81}\ m$$

$$= 25.08\ m$$

$$H_m = h_d + h_{fd} + V_d^2/2g = 22 + 25.08 + \frac{5.66^2}{2 \times 9.81} = 48.7\ m$$

Power required, $P = \frac{\rho Q g H}{1000 \times 0.8}$ kW

$$= 14.93\ kW$$

specific speed of pump

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}} = \frac{1440 \times \sqrt{25 \times 10^{-3}}}{48.7^{3/4}}$$

$$= 12.35$$