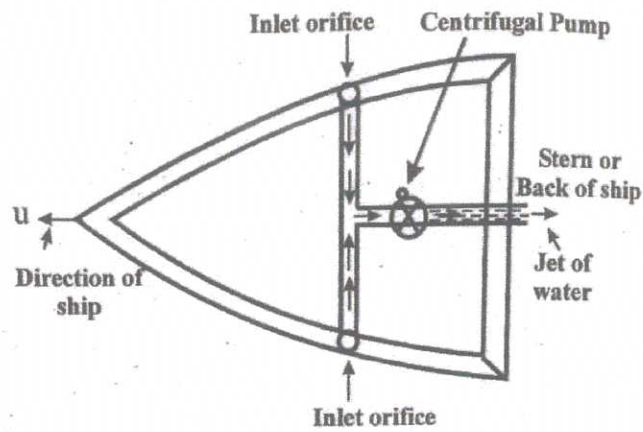


**SCHEME OF VALUATION**  
**(Scoring Indicators)**

Revision: 2015		Course Code: 6022		
Course Title: Hydraulic Machines				
Qst. No	Scoring Indicator	Spl it up sco re	S u b T ot al	T ot al
<b><u>PART A</u></b>				
I 1	Water jet mean the liquid comes out in the form of a jet from the outlet of a nozzle, which is fitted to a pipe through which the liquid is flowing under pressure. It will have maximum kinetic energy.	2	2	2
2	<b>Gross Head.</b> The difference between the head race level and tail race level when no water is flowing is known as Gross Head. It is denoted by $H_g$ . <b>Net Head.</b> It is the head effective head available at the inlet of the turbine. A loss of head is occurred in penstock. It is denoted by H.  $H = H_g - h_f$	1  1	2	2
3	The specific speed of a turbine is defined as the speed of a turbine which is identical in shape, geometrical dimensions, blade angles, gate opening etc with the actual turbine but of such a size that it will develop unit power when working under unit head. It is denoted by $N_s$ .	2	2	2
4	NPSH is defined as the total head required to make the liquid flow through the suction pipe to the pump impeller. It is also defined as the absolute pressure head at the inlet to the pump minus the vapour pressure head plus the velocity head.	2	2	2
5	$F_x = \rho AV^2$ $\rho$ = density A = area of cross section V = velocity of jet	2	2	2
<b><u>PART B</u></b>				
II 1	When a jet issues from a nozzle and strikes on a fixed vertical flat plate exerts a force on the plate which is equal to the momentum of the jet. The jet gives a reaction to the nozzle and is equal to the momentum of the issuing jet and will act opposite to the direction of the issuing jet. Jet propulsion is a principle used to utilize the reaction of a jet to propel the bodies such as ships, air crafts, rockets etc. Principle of jet propulsion is applied to propulsion of ships. The ship carries pumps, which take water from its surroundings. This water is discharged by	2	6	6

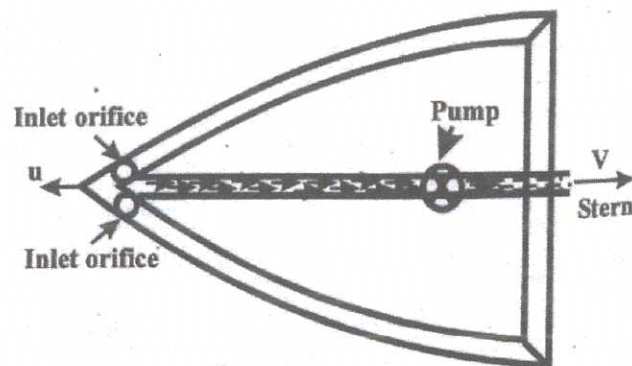
forcing through the orifice at the back of the ship. The efficiency of ship depends upon the direction of the inlet orifice. In general a ship may have;

1. Inlet orifices at right angles to the direction of its motion as shown in Fig below. ( known as AMID ship which means water is damn at the middle of the ship )



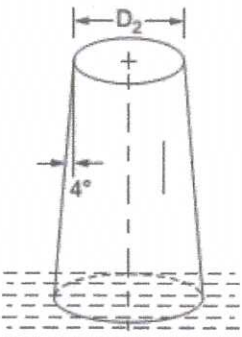
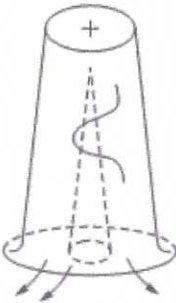
**(a) Inlet orifices are at right angles.**

2. Inlet orifices faces the direction of motion as shown in Fig below. A ship is steered through the water due to reaction of the force of the jet.

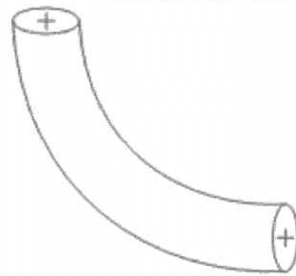


**(b) Inlet orifices facing the direction of ship.**

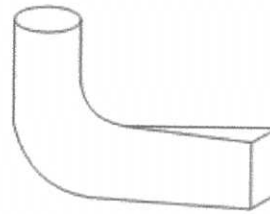


	<p><b>(4) Overall efficiency (<math>\eta_o</math>).</b> This is the ratio of power output at the shaft and power input by the water at the turbine inlet.</p> $\eta_o = \frac{\text{Power available at the turbine shaft}}{\text{Water power}}$	1.5		
4	<p><b>Classification of turbines:</b>  Hydraulic turbines may be classified according to the following factors:</p> <p><b>(i) According to the nature of energy possessed by water at inlet</b>  (a) Impulse turbines, and (b) Reaction turbines</p> <p><b>(ii) According to the direction of flow of water through runner</b>  (a) Tangential flow turbines (b) Radial flow turbines  (c) Axial flow turbines, and (d) Mixed flow turbines,</p> <p><b>(iii) According to the head and quantity of water available at the inlet</b>  (a) High head turbine (b) Medium head turbines, and  (c) Low head turbines</p> <p><b>(iv) According to the orientation of shaft</b>  (a) Horizontal shaft turbine, and (b) Vertical shaft turbine</p> <p><b>(v) According to the name of the originator</b>  (a) Pelton wheel (b) Francis turbine (c) Kaplan turbine, etc.</p> <p><b>(vi) According to the specific speed of the turbine</b>  (a) Low specific speed turbine  (b) Medium specific speed turbine, and  (c) High specific speed turbine.</p>	1 1 1 1 1 1	6	6
5	<p>Draft tube reduces the pressure loss as the pressure at the turbine outlet will be below atmospheric due to the arrangement. The loss in effective head is reduced by this arrangement. Also because of the diverging section of the tube the kinetic energy is converted to pressure energy which adds to the effective head. The draft tube thus helps to regain the lost static head due to higher level installation of the turbine and helps to recover part of the kinetic energy that otherwise may be lost at the turbine outlet.  Different types of draft tubes is shown in figure below.</p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;">  <p>Straight divergent tube</p> </div> <div style="text-align: center;">  <p>Moody's bell mouthed tube</p> </div> </div>	2	6	6

Each type 1 Mark 4 x 1 = 4



Simple elbow



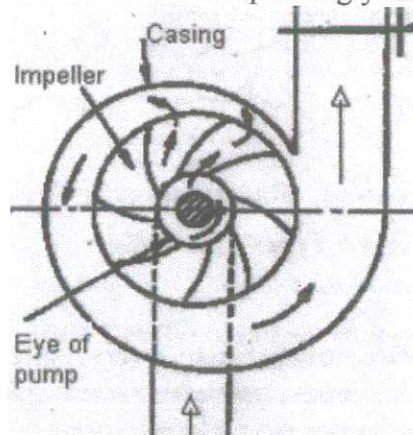
Elbow having square outlet and circular inlet

6 The casing of a centrifugal pump is very similar to the casing of a reaction turbine. It is an air tight passage surrounding the impeller and is designed in such a way that the kinetic energy of fluid discharged at the outlet of the impeller is converted into pressure energy before the fluid leaves the casing and enters the delivery pipe. The following are the three types of casings that are normally used.

1. Volute casing
2. Vortex casing
3. Casing with guide blades

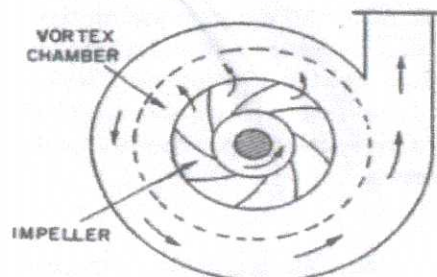
**1. Volute casing**

The figure below shows a volute casing. In this type, the impeller is surrounded by a spiral casing which provides a gradual increase in the area of flow, thus decreasing the velocity of water and correspondingly increasing the pressure.



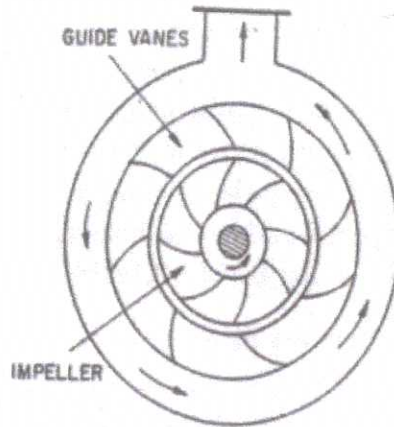
**2. Vortex casing or whirl pool chamber**

This is an improved form of volute casing designed by Professor James Thomson. In vortex casing, a circular chamber is introduced between the casing and the impeller as shown in Fig below. By introducing a circular chamber, the loss of energy due to formation of eddies is reduced to a considerable extent. Thus the efficiency is improved than that of a volute casing pump.



### 3. Casing with guide blades

In this type the impeller is surrounded by a series of guide blades mounted on a ring which is known as diffuser. Guide vanes are designed in such a way that the fluid from the impeller enters the guide vanes without shock. Also the area of the guide vanes increases, thus reducing the velocity of flow through guide vanes and consequently increasing the pressure of fluid. The fluid from the guide vanes then passes through the surrounding casing which is in most of the case concentric with the impeller as shown in Fig below.



2

7

### Cavitation

In any region of fluid flow, there is chance of formation of vapour bubbles. When the pressure of the flowing fluid is less than its vapour pressure, the fluid starts boiling and vapour bubbles are formed. When these vapour bubbles moves towards a zone of high pressure, they condense and finally collapse. Sudden collapsing of these vapour bubbles in a region of high pressure may create a very high pressure, thereby a tremendous shock (pitting action) on the adjacent wall. This may cause a local mechanical failure of the solid surface. The growth and decay of vapour bubbles adversely affect the performance of a hydraulic machine and the ultimate affect may be the break-down of the machine itself due to severe pitting and erosion of blade surface in region of cavitation. This phenomenon is called as cavitation.

6

6

6

PART C

III

a

$V$  = Velocity of the jet (absolute),  
 $a$  = Area of cross-section of the jet,  
 $u$  = Velocity of the flat plate.

In this case, the jet does not strike the plate with a velocity  $V$ , but it strikes with a relative velocity, which is equal to the absolute velocity of jet of water minus the velocity of the plate.

Hence relative velocity of the jet with respect to plate  
 $= (V - u)$

Mass of water striking the plate per sec

$$= \rho \times \text{Area of jet} \times \text{Velocity with which jet strikes the plate}$$

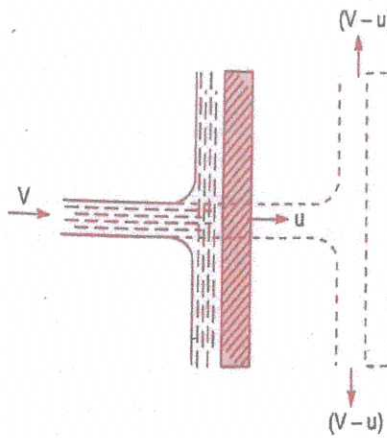
$$= \rho a \times [V - u]$$

$\therefore$  Force exerted by the jet on the moving plate in the direction of the jet,

$$F_x = \text{Mass of water striking per sec} \times [\text{Initial velocity with which water strikes} - \text{Final velocity}]$$

$$= \rho a (V - u) [(V - u) - 0] \quad (\because \text{Final velocity in the direction of jet is zero})$$

$$= \rho a (V - u)^2$$



2 Fig

3

8

8

b

Velocity of jet,  $V_1 = 20 \text{ m/s}$   
 Velocity of vane,  $u_1 = 10 \text{ m/s}$   
 Angle made by jet at inlet, with direction of motion of vane,  
 $\alpha = 20^\circ$

Angle made by the leaving jet, with the direction of motion  
 $= 130^\circ$

$\therefore \beta = 180^\circ - 130^\circ = 50^\circ$

In this problem,  $u_1 = u_2 = 10 \text{ m/s}$

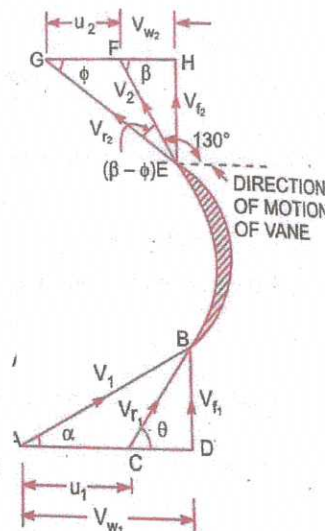
$$V_{r1} = V_{r2}$$

(i) **Vane Angles** means angle made by the relative velocities at inlet and outlet, i.e.,  $\theta$  and  $\phi$ .

From Fig. in  $\triangle ABD$ , we have  $\tan \theta = \frac{BD}{CD}$

$$= \frac{V_{f1}}{AD - AC} = \frac{V_{f1}}{V_{w1} - u_1} \quad \dots(i)$$

where  $V_{f1} = V_1 \sin \alpha = 20 \times \sin 20 = 6.84 \text{ m/s}$



1 Fig

7

7

$$V_{w_1} = V_1 \cos \alpha = 20 \times \cos 20 = 18.794 \text{ m/s.}$$

$$u_1 = 10 \text{ m/s}$$

$$\therefore \tan \theta = \frac{6.84}{18.794 - 10} = .7778 \text{ or } \theta = 37.875^\circ$$

$$\therefore \theta = 37^\circ 52.5'. \text{ Ans.}$$

From,  $\Delta ABC$ ,

$$\sin \theta = \frac{V_{f_1}}{V_{r_1}} \text{ or } V_{r_1} = \frac{V_{f_1}}{\sin \theta} = \frac{6.84}{\sin 37.875} = 11.14$$

$$\therefore V_{r_2} = V_{r_1} = 11.14 \text{ m/s.}$$

From,  $\Delta EFG$ , applying sine rule, we have

$$\frac{V_{r_2}}{\sin (180^\circ - \beta)} = \frac{u_2}{\sin (\beta - \phi)}$$

$$\text{or } \frac{11.14}{\sin \beta} = \frac{10}{\sin [\beta - \phi]} \text{ or } \frac{11.14}{\sin 50} = \frac{10}{\sin [50^\circ - \phi]} \quad (\because \beta = 50^\circ)$$

$$\therefore \sin (50^\circ - \phi) = \frac{10 \times \sin 50}{11.14} = 0.6876 = \sin 43.44^\circ$$

$$\therefore 50^\circ - \phi = 43.44^\circ \text{ or } \phi = 50^\circ - 43.44^\circ = 6.56^\circ$$

$$\therefore \phi = 6^\circ 33.6'. \text{ Ans.}$$

(ii) Work done per second per unit weight of the water striking the vane per second is given by equation

$$= \frac{1}{g} [V_{w_1} + V_{w_2}] \times u \text{ Nm/N (+ve sign is taken as } \beta \text{ is an acute angle)}$$

$$\text{where } V_{w_1} = 18.794 \text{ m/s, } V_{w_2} = GH - GF = V_{r_2} \cos \phi - u_2 = 11.14 \times \cos 6.56 - 10 = 1.067 \text{ m/s}$$

$$u = u_1 = u_2 = 10 \text{ m/s}$$

$\therefore$  Work done per unit weight of water

$$= \frac{1}{981} [18.794 + 1.067] \times 10 \text{ Nm/N} = 20.24 \text{ Nm/N. Ans.}$$

OR

**IV**

**a**

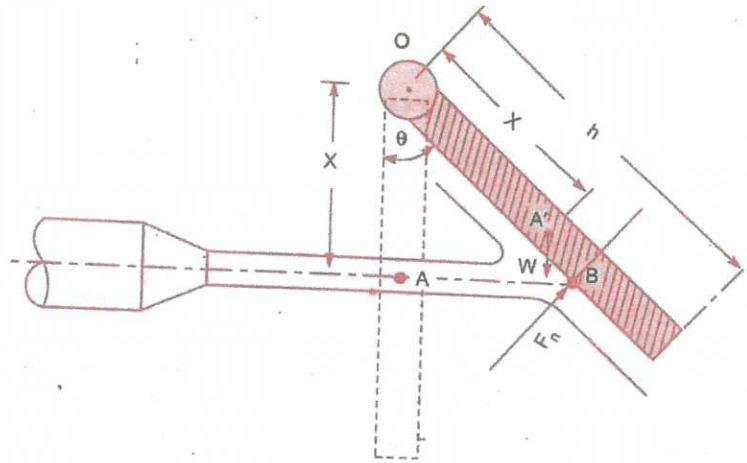
Consider a jet of water striking a vertical plate at the centre which is hinged at O. Due to the force exerted by the jet on the plate, the plate will swing through some angle about the hinge as shown in figure.

$x$  = distance of the centre of jet from hinge O,

$\theta$  = angle of swing about hinge,

$W$  = weight of plate acting at C.G. of the plate.

The dotted lines shows the position of the plate, before the jet strikes the plate. The point A on the Plate will be at A' after the jet strikes the plate.



2  
Fig

The distance  $OA = OA' = x$ . Let the weight of the plate is acting at  $A'$ . When the plate is in equilibrium after the jet strikes the plate, the moment of all the forces about the hinge must be zero. Two forces are acting on the plate. They are:

1. Force due to jet of water, normal to the plate,

$$F_n = \rho a V^2 \sin \theta'$$

where  $\theta' = \text{Angle between jet and plate} = (90^\circ - \theta)$

2. Weight of the plate,  $W$

Moment of force  $F_n$  about hinge  $= F_n \times OB = \rho a V^2 \sin (90^\circ - \theta) \times OB = \rho a V^2 \cos \theta \times OB$

$$= \rho a V^2 \cos \theta \times \frac{OA}{\cos \theta} = \rho a V^2 \times OA = \rho a V^2 \times x$$

Moment of weight  $W$  about hinge  $= W \times OA' \sin \theta = W \times x \times \sin \theta$

For equilibrium of the plate,  $\rho a V^2 \times x = W \times x \times \sin \theta$

$$\therefore \sin \theta = \frac{\rho a V^2}{W}$$

1.5

1.5

3

b	Diameter of jet,	$d = 50 \text{ mm} = 0.05 \text{ m}$	2	7	7
	$\therefore$ Area,	$a = \frac{\pi}{4} (.05)^2 = .001963 \text{ m}^2$			
	Angle,	$\theta = 30^\circ$			
	Force in the direction of jet, $F_x = 1471.5 \text{ N}$				
	Force in the direction of jet is given by equation $F_x = \rho a V^2 \sin^2 \theta$				
	As the force is given in Newton, the value of $\rho$ should be taken equal to $1000 \text{ kg/m}^3$				
	$\therefore$	$1471.5 = 1000 \times .001963 \times V^2 \times \sin^2 30 = .05 V^2$			
	$\therefore$	$V^2 = \frac{150}{.05} = 3000.0$			
		$V = 54.77 \text{ m/s}$	2		
	$\therefore$ Discharge,	$Q = \text{Area} \times \text{Velocity}$			
		$= .001963 \times 54.77 = 0.1075 \text{ m}^3/\text{s} = 107.5 \text{ liters/s. Ans.}$	3		

V

a

4 Fig

4

When the turbine is running at normal load, piston in the distribution valve and actuator occupies their normal positions as shown in the figure. In this positions as the ports A and B are closed the oil supplied by the gear pump remains in the middle portion of the distribution valve and thus gears of the pump go on rotating without developing further pressure. As the load on the turbine decreases, speed increases correspondingly. As the actuator is connected to the turbine shaft, its speed also increases and balls fly off. Therefore, the sleeve moves upward, the lever rod inclined and the bell crank lever moves downwards. When bell crank lever moves downwards, the jet deflector will operate and divert whole or part of the jet away from the buckets. With the downwards movement of the bell

crank lever, the roller on the cam rises. In the mean time the distribution valve also works as follows:

When the lever rod inclined then sleeve control valve rod is pushed down in the distribution valve. Downward movement opens the port *B* and keeps port *A* still closed. As soon as port *B* opens, the oil from the middle port of the distribution valve goes to the servomotor on the left side of the piston. This oil of high pressure forces the piston to move towards right side, thus forcing the spear to reduce the area of jet and hence the rate of flow. The spear occupies its final position, jet deflector occupies its original position and does not obstruct jet as the speed again becomes normal.

When the load on the turbine increases, the speed reduces. This causes the fly balls of the actuator to come down and thus sleeve also move downward causing the lever rod to move upward and to open port *A* to the right side of the piston. The piston moves towards left, causing the spear to move away from the nozzle and increases the area of flow, which in turn increases the amount of water striking the buckets and brings the speed to come normal. In this case the deflector moves up but the deflector plate is not able to obstruct the jet at normal speed. As soon as the speed becomes normal, the actuator balls occupy normal position and port *A* and *B* closed.

**b**

Speed of bucket,  $u = u_1 = u_2 = 10 \text{ m/s}$   
 Discharge,  $Q = 700 \text{ litres/s} = 0.7 \text{ m}^3/\text{s}$ , Head of water,  $H = 30 \text{ m}$   
 Angle of deflection  $= 160^\circ$   
 $\therefore$  Angle,  $\phi = 180 - 160 = 20^\circ$   
 Co-efficient of velocity,  $C_v = 0.98$ .

The velocity of jet,  $V_1 = C_v \sqrt{2gH} = 0.98 \sqrt{2 \times 9.81 \times 30} = 23.77 \text{ m/s}$

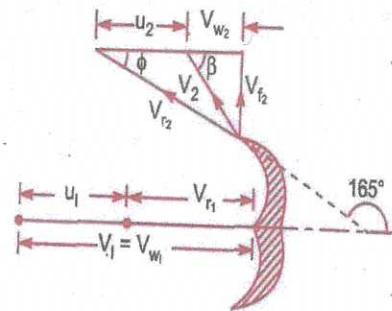
$\therefore$   $V_{r1} = V_1 - u_1 = 23.77 - 10$   
 $= 13.77 \text{ m/s}$

$V_{w1} = V_1 = 23.77 \text{ m/s}$

From outlet velocity triangle,

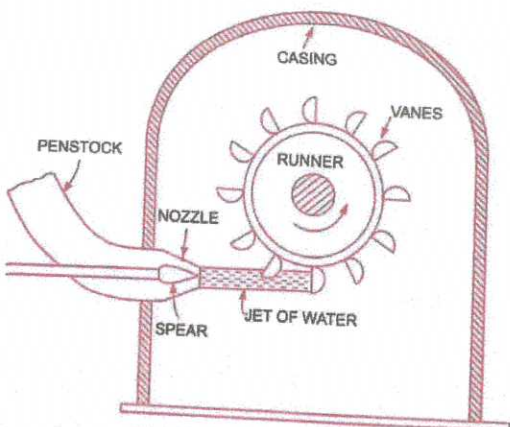
$V_{r2} = V_{r1} = 13.77 \text{ m/s}$

$V_{w2} = V_{r2} \cos \phi - u_2$   
 $= 13.77 \cos 20^\circ - 10.0 = 2.94 \text{ m/s}$



2 Fig

7 7

	<p>Work done by the jet per second on the runner is given by equation (18.9) as</p> $= \rho a V_1 [V_{w_1} + V_{w_2}] \times u$ $= 1000 \times 0.7 \times [23.77 + 2.94] \times 10 \quad (\because aV_1 = Q = 0.7 \text{ m}^3/\text{s})$ $= 186970 \text{ Nm/s}$ <p><math>\therefore</math> Power given to turbine = <math>\frac{186970}{1000} = 186.97 \text{ kW. Ans.}</math></p> <p>The hydraulic efficiency of the turbine is given by equation (18.12) as</p> $\eta_h = \frac{2[V_{w_1} + V_{w_2}] \times u}{V_1^2} = \frac{2[23.77 + 2.94] \times 10}{23.77 \times 23.77}$ $= 0.9454 \text{ or } 94.54\% \text{ Ans.}$	2.5	
	OR		
<b>VI</b>			
a	<p>The main parts of the Pelton turbine are:</p> <ol style="list-style-type: none"> <li>1. Nozzle and flow regulating arrangement (spear),</li> <li>2. Runner and buckets,</li> <li>3. Casing, and</li> <li>4. Breaking jet.</li> </ol> <p><b>1. Nozzle and flow Regulating Arrangement.</b> The amount of water striking the buckets (vanes) of runner is controlled by providing a spear in the nozzle as shown in Fig. The spear is a conical needle which is operated either by a hand wheel or automatically in an axial direction depending upon size of the unit. When the spear is pushed forward into the nozzle the amount of water striking the runner is reduced. On the other hand, if the spear is pushed back, the amount of water striking the runner increases.</p> <p><b>2. Runner with Buckets:</b> Fig shows the runner of a <u>Pelton wheel</u>. It consists of a circular disc on the periphery of which a number of buckets are fixed. The shape of buckets are of double hemispherical shape.</p> <div style="text-align: center;">  </div> <p><b>3. Casing.</b> Fig. shows a Pelton turbine with a casing. The function of the casing is to prevent the splashing of the water and to discharge water to tail race. It also acts as safeguard against accidents. It is made of cast iron or fabricated steel plates. The casing of the Pelton wheel does not perform any hydraulic function.</p> <p><b>4. Breaking Jet.</b> When the nozzle is completely closed by moving the spear in the forward direction, the amount of water striking the runner reduces to zero. But the runner due to inertia goes on revolving for a long time. To stop the</p>	1.5 1.5 2 1.5 1.5	8 8

	runner in a short time, a small nozzle is provided which directs the jet of water on the back of the vanes. This jet of water is called breaking jet.			
<b>b</b>	<p>Shaft power, S.P. = 11,772 kW  Head, H = 380 m  Speed, N = 750 r.m.p.</p> <p>Overall efficiency, <math>\eta_0 = 86\%</math> or 0.86</p> <p>Ratio of jet dia. to wheel dia. <math>= \frac{d}{D} = \frac{1}{6}</math></p> <p>Co-efficient of velocity, <math>K_{v_1} = C_v = 0.985</math>  Speed ratio, <math>K_{u_1} = 0.45</math></p> <p>Velocity of jet, <math>V_1 = C_v \sqrt{2gH} = 0.985 \sqrt{2 \times 9.81 \times 380} = 85.05 \text{ m/s}</math></p> <p>The velocity of wheel, <math>u = u_1 = u_2</math>  <math>= \text{Speed ratio} \times \sqrt{2gH} = 0.45 \times \sqrt{2 \times 9.81 \times 380} = 38.85 \text{ m/s}</math></p> <p>But <math>u = \frac{\pi DN}{60} \therefore 38.85 = \frac{\pi DN}{60}</math>  <math>D = \frac{60 \times 38.85}{\pi \times 750} = \frac{60 \times 38.85}{\pi \times 750} = 0.989 \text{ m. Ans.}</math></p> <p>But <math>\frac{d}{D} = \frac{1}{6}</math>  <math>\therefore \text{Dia. of jet, } d = \frac{1}{6} \times D = \frac{0.989}{6} = 0.165 \text{ m. Ans.}</math></p> <p>Discharge of one jet, <math>q = \text{Area of jet} \times \text{Velocity of jet}</math>  <math>= \frac{\pi}{4} d^2 \times V_1 = \frac{\pi}{4} (.165)^2 \times 85.05 \text{ m}^3/\text{s} = 1.818 \text{ m}^3/\text{s}</math></p> <p>Now <math>\eta_0 = \frac{\text{S.P.}}{\text{W.P.}} = \frac{11772}{\frac{\rho g \times Q \times H}{1000}}</math>  <math>0.86 = \frac{11772 \times 1000}{1000 \times 9.81 \times Q \times 380}</math>, where Q = Total discharge</p> <p><math>\therefore \text{Total discharge, } Q = \frac{11772 \times 1000}{1000 \times 9.81 \times 380 \times 0.86} = 3.672 \text{ m}^3/\text{s}</math></p> <p><math>\therefore \text{Number of jets} = \frac{\text{Total discharge}}{\text{Discharg of one jet}} = \frac{Q}{q} = \frac{3.672}{1.818} = 2 \text{ jets. Ans.}</math></p>	7	7	
		1		
		2		
		2		
		2		

**VII**

**a**

**Selection of turbines**

The selection of turbine is generally based upon the following two factors

- (i) Selection based on specific speed, and
- (ii) Selection based on head of water.

**(i) Selection based on specific speed.**

Specific speed plays an important role for selecting the type of turbine. Selection based on specific speed is a scientific method, and gives precise information. By knowing the specific speed of a turbine the performance of the turbine can also be predicted. If a runner of high specific speed is used for given head and power output, the overall cost of installation is lower. The runner of too high specific speed with high available head increases the cost of turbine. The runner of too low specific speed with low available head increases the cost of generator due to the low turbine speed. The following table shows the specific speed ranges of various types of turbines.

S.No	Range of specific speed (in SI units)	Type of turbine selected
1.	Less than 30	Single jet pelton wheel
2.	30-50	Multi-jet pelton wheel
3.	50 - 260	Francis turbine
4.	260 - 860	Kaplan turbine

**(ii) Selection based on head of water.**

Selection based on head of water is based on experience and observational factors only. Following table shows the type of turbine, to be used, for corresponding head of water.

S.No	Head of turbine in m	Type of turbine selected
1.	Less than 15	Kaplan turbine
2.	30-60	Kaplan turbine or Francis turbine (Preferably Kaplan turbine)
3.	60- 150	Francis turbine or Kaplan turbine (Preferably Francis turbine)
4.	150-240	Francis turbine or Pelton wheel (Preferably Francis turbine)

8 8

4

4

5.	240 - 300	Pelton wheel or Francis turbine (Preferably Pelton wheel)
6.	Above 300	Pelton wheel turbine

b

Overall efficiency	$\eta_o = 75\% = 0.75$
Power produced,	S.P. = 148.25 kW
Head,	$H = 7.62$ m
Peripheral velocity,	$u_1 = 0.26 \sqrt{2gH} = 0.26 \times \sqrt{2 \times 9.81 \times 7.62} = 3.179$ m/s
Velocity of flow at inlet,	$V_{f1} = 0.96 \sqrt{2gH} = 0.96 \times \sqrt{2 \times 9.81 \times 7.62} = 11.738$ m/s.
Speed,	$N = 150$ r.p.m.
Hydraulic losses	= 22% of available energy
Discharge at outlet	= Radial
	$V_{w2} = 0$ and $V_{f2} = V_2$

Hydraulic efficiency is given as

$$\eta_h = \frac{\text{Total head at inlet} - \text{Hydraulic loss}}{\text{Head at inlet}}$$

$$= \frac{H - .22 H}{H} = \frac{0.78 H}{H} = 0.78$$

But

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

$\therefore$

$$\frac{V_{w1} u_1}{gH} = 0.78$$

$\therefore$

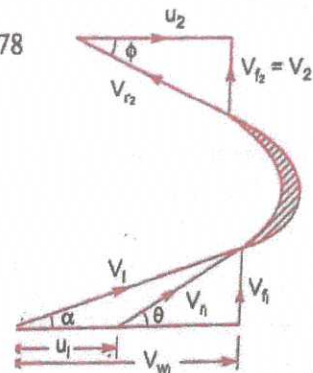
$$V_{w1} = \frac{0.78 \times g \times H}{u_1} = \frac{0.78 \times 9.81 \times 7.62}{3.179} = 18.34 \text{ m/s.}$$

(i) The guide blade angle, i.e.,  $\alpha$ . From inlet velocity triangle,

$$\tan \alpha = \frac{V_{f1}}{V_{w1}} = \frac{11.738}{18.34} = 0.64$$

$\therefore$

$$\alpha = \tan^{-1} 0.64 = 32.619^\circ \text{ or } 32^\circ 37'. \text{ Ans.}$$



1 Fig

1.5

(ii) The wheel vane angle at inlet, i.e.,  $\theta$

$$\tan \theta = \frac{V_{f1}}{V_{w1} - u_1} = \frac{11.738}{18.34 - 3.179} = 0.774$$

$$\therefore \theta = \tan^{-1} .774 = 37.74 \text{ or } 37^\circ 44.4'. \text{ Ans.}$$

(iii) Diameter of wheel at inlet ( $D_1$ ).

Using the relation,

$$u_1 = \frac{\pi D_1 N}{60}$$

$$D_1 = \frac{60 \times u_1}{\pi \times N} = \frac{60 \times 3.179}{\pi \times 50} = 0.4047 \text{ m. Ans.}$$

(iv) Width of the wheel at inlet ( $B_1$ )

$$\eta_o = \frac{\text{S.P.}}{\text{W.P.}} = \frac{148.25}{\text{W.P.}}$$

But

$$\text{W.P.} = \frac{WH}{1000} = \frac{\rho \times g \times Q \times H}{1000} = \frac{1000 \times 9.81 \times Q \times 7.62}{1000}$$

$\therefore$

$$\eta_o = \frac{148.25}{\frac{1000 \times 9.81 \times Q \times 7.62}{1000}} = \frac{148.25 \times 1000}{1000 \times 9.81 \times Q \times 7.62}$$

or

$$Q = \frac{148.25 \times 1000}{1000 \times 9.81 \times 7.62 \times \eta_o} = \frac{148.25 \times 1000}{1000 \times 9.81 \times 7.62 \times 0.75} = 2.644 \text{ m}^3/\text{s}$$

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

$$2.644 = \pi \times .4047 \times B_1 \times 11.738$$

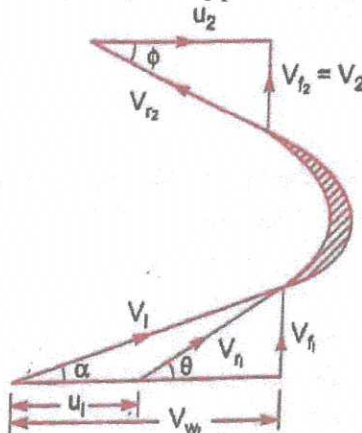
$$B_1 = \frac{2.644}{\pi \times .4047 \times 11.738} = 0.177 \text{ m. Ans.}$$

OR

## VIII

a

The inward flow reaction turbine having radial discharge at outlet is known as Francis Turbine, after the name of J.B. Francis an American engineer who in the beginning designed inward radial flow reaction type of turbine. In the modern Francis turbine, the water enters the runner of the turbine in the radial direction at outlet and leaves in the axial direction at the inlet of the runner. Thus the modern Francis Turbine is a mixed flow type turbine.



The velocity triangle at inlet and outlet of the Francis turbine are drawn in the same way as in case of inward flow reaction turbine. As in case of Francis

	<p>turbine, the discharge is radial at outlet, the velocity of whirl at outlet (i.e., <math>V_{w2}</math>) will be zero. Hence the work done by water on the runner per second will be</p> $= \rho Q [V_{w1} u_1]$ <p>work done per second per unit weight of water striking/s</p> $= \frac{1}{g} [V_{w1} u_1]$ <p>Hydraulic efficiency will be given by</p> $\eta_h = \frac{V_{w1} u_1}{gH}$	2		
b	<p>Power developed, <math>P = 9100 \text{ kW}</math></p> <p>Net available head of turbine, <math>H = 5.6 \text{ m}</math></p> <p>Speed ratio, <math>K_u = 2.09</math></p> <p>Flow ratio, <math>K_f = 0.68</math></p> <p>Overall efficiency, <math>\eta_o = 86\% = 0.86</math></p> <p>Boss diameter of wheel, <math>D_b = \frac{1}{3} D_0</math></p> <p>Using the relations for speed ratio and flow ratio, i.e.,</p> <p>Speed ratio, <math>K_u = \frac{u}{\sqrt{2gH}}</math></p> <p>Peripheral velocity of the wheel, <math>u = K_u \sqrt{2gH}</math></p> $= 2.09 \times \sqrt{2 \times 9.81 \times 5.6} = 21.91 \text{ m/s}$ <p>Flow ratio, <math>K_f = \frac{V_f}{\sqrt{2gH}}</math></p> <p>Velocity of flow, <math>V_f = K_f \sqrt{2gH} = 0.68 \times \sqrt{2 \times 9.81 \times 5.6}</math></p> $= 7.13 \text{ m/s}$ <p>We know that, overall efficiency of a turbine,</p> $\eta_o = \frac{P}{\rho g Q H} = \frac{P}{\rho g Q H}$ <p>Discharge of the turbine,</p> $Q = \frac{P}{\rho g H \eta_o} = \frac{9100}{1 \times 9.81 \times 5.6 \times 0.86} = 192.61 \text{ m}^3/\text{s}$	1	7	7

We also know that,

Discharge of the turbine,  $Q = \text{Area of flow} \times \text{Velocity of flow}$

$$= \frac{\pi}{4} (D_o^2 - D_b^2) \times V_f$$

Substituting the values in the above equation, we get

$$192.61 = \frac{\pi}{4} \times \left( D_o^2 - \left( \frac{1}{3} D_o \right)^2 \right) \times 7.13$$

$$= \frac{\pi}{4} \times D_o^2 \left( 1 - \left( \frac{1}{3} \right)^2 \right) \times 7.13$$

$$= \frac{\pi}{4} \times D_o^2 \times \frac{8}{9} \times 7.13$$

$\therefore$  Diameter of the turbine runner,

$$D_o = \sqrt{\frac{4 \times 9 \times 192.61}{\pi \times 8 \times 7.13}} = 6.22 \text{ m} \quad (\text{Ans})$$

$\therefore$  Diameter of the turbine runner boss,  $D_b = \frac{1}{3} D_o$

$$= \frac{1}{3} \times 6.22 = 2.07 \text{ m} \quad (\text{Ans})$$

We also know that peripheral velocity of the runner,

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

$$\text{Speed of the turbine runner, } N = \frac{60u}{\pi D_o} = \frac{60 \times 21.91}{\pi \times 6.22}$$

$$= 67.27 \text{ rpm} \quad (\text{Ans})$$

**IX**

**a Multistage centrifugal pump**

If a centrifugal pump consists of two or more impellers, the pump is called a multistage centrifugal pump. The impellers may be mounted on the same shaft or on different shafts. So, a multistage pump is having the following two important functions.

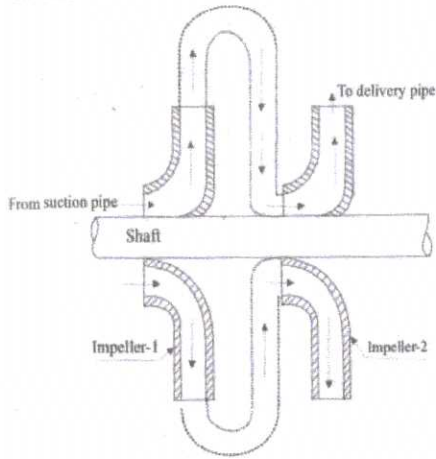
1. To produce a high head, and
2. To discharge a large quantity of liquid.

If a high head is to be obtained, the impellers are connected in series (or on the same shaft) while for discharging large quantity of liquid, the impellers (or pumps) are connected in parallel.

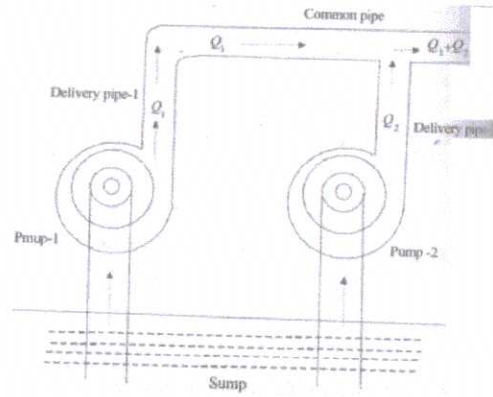
**a) Multistage centrifugal pump for high head**

As discussed above, for getting high heads, a number of impellers are mounted on the same shafts shown in the figure. The water from the suction pipe enters

the first impeller at inlet and is discharged at outlet with increased pressure. The water with increased pressure from the outlet of the first impeller is taken to the inlet of the second impeller. At the outlet of the second impeller, the pressure of water will be more than the pressure of water at the outlet of the first impeller. Thus if more impellers are mounted on the same shaft, the pressure at the outlet will be increased further.



Two-stage pumps with impeller in series



Pumps in parallel

2  
Fig

Let

$n$  = the number of identical impellers mounted on the same shaft

$H_m$  = the head developed by each impeller measured in meter

Then **total head developed** =  $n \times H_m$

The discharge passing through each impeller is same.

**b) Multistage centrifugal pump for high discharge**

For getting high discharge, the pumps should be connected in parallel as shown in figure. Each of the pumps lifts the water from a common sump and discharges water to a common pipe to which delivery pipe of each pump is connected. Each of the pumps working against the same head. Let  $n$  is the number of identical pumps arranged in parallel and  $Q$  is the discharge from one pump

Then **Total discharge** =  $n \times Q$

2

**b**

**Centrifugal pump:**

1. Flow is smooth and even
2. Weight of the pump is less for given delivery rate
3. It is compact and occupies less floor space for a given delivery rate.
4. Initial cost is less
5. No air vessel is required
6. It requires priming.
7. It is suitable for large discharge and small head.
8. It can handle viscous liquids like paper pulp, muddy water
9. The pump can run at high speed because cavitation does not depend speed of the pump.
10. Uniform torque acts on the impeller Shaft.
11. Maintenance cost is less
12. Efficiency of low head pump is high
13. Installation is easy

**Reciprocating pump**

1. Flow is intermittent
2. Weight of the pump is more for the same delivery rate.

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ma  
rk  
each

3.  
5

7

	<ol style="list-style-type: none"> <li>3. Floor space required is more than centrifugal pump.</li> <li>4. Initial cost is more.</li> <li>5. Air vessel is required.</li> <li>6. It does not require priming.</li> <li>7. It is suitable for low discharge high head.</li> <li>8. It cannot handle viscous liquids because valves cause trouble.</li> <li>9. The pump cannot run at high speed because greater the speed, greater the risk of cavitation.</li> <li>10. Torque on the pump shaft is non-uniform.</li> <li>11. Maintenance cost is more because parts like valves require constant attention.</li> <li>12. Efficiency of low head pump is low, because higher losses.</li> <li>13. Installation is difficult.</li> </ol>	(7 No .s) 0.5 ma rk eac h	3. 5
OR			
<b>X</b>			
<b>a</b>	<p><b>Hydraulic ram</b> Hydraulic ram is a pump which can be used to lift small quantity of water to a larger height. So, it is suitable where large quantity of water available at low head. It does not require any prime mover or any external power. It works on the principle of water hammer.</p> <p><b>Working</b> It consists of a valve box or chamber connected to a low level water source through an inclined supply pipe. At the other end of the supply pipe is fitted with a gate valve. The valve box is fitted with a waste valve and delivery valve. Both valves are non-return type which allows the flow only in one direction. The delivery valve is fitted to an air vessel.</p> <div data-bbox="331 1160 1326 1675" data-label="Diagram"> </div> <p style="text-align: right;">Fig 3</p> <p>At starting, the gate valve and the delivery valve remains closed and the waste valve remains open. Now the gate valve is opened and the water from the source starts flowing into the valve box through the supply pipe and the level of water rises in the chamber and the waste valve begins to rise upward to close it. It may be noted that some water escape through the waste valve opening. Due to increase in pressure, at one stage, the waste valve closes suddenly. But supply from the source is continuing. This produces water hammering due to the inertia of flowing water. So, a thrust is produced in the valve box which is sufficient to open the delivery valve. Now the water is forced into the air vessel through the</p>	2	8 8
		Wo rki ng 3	

delivery valve. The water entering the air vessel compresses the air already present in the air vessel. In this way the pressure in the air vessel rises and ultimately closes the delivery valve. Now the water in the air vessel is forced by the compressed air to flow through the delivery pipe, Under this condition both the delivery and waste valves are closed. When water in the chamber loses its momentum, the waste valve opens and water from the chamber goes out through the waste valve. Now the flow through the supply pipe begins again and the operation repeats.

**b**

**Jet pump**

It is a pumping device works under the principle of Bernaulli's theorem. The figure below shows a line sketch of a jet pump. In this device water under high pressure is passed through a pipe containing a nozzle at its end. The nozzle is placed in a venturi pipe as shown in the figure.

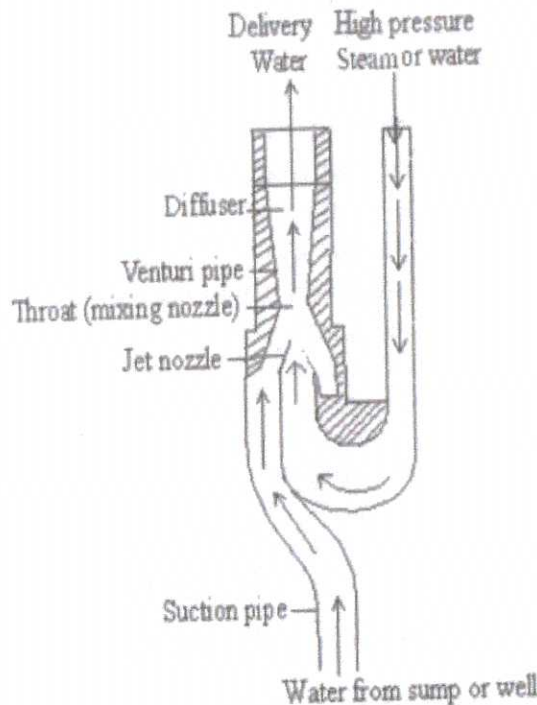


Fig 3

While passing through the nozzle, most of the pressure energy of working medium (water or steam) is converted into kinetic energy. As a result, pressure around the nozzle drops much below atmospheric pressure. This causes flow water to flow through the suction pipe. The two flows meet in the throat of the venturi pipe. This portion is known as mixing nozzle. The mixing of the two flows in the mixing nozzle results in increase in pressure. There is further increase in pressure in the diffuser due to the decrease in velocity in the diffuser.

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