UNIT –V

TURBINES

1. **Define volumetric efficiency? (Nov/Dec14), (Nov/Dec15)**

   It is defined as the volume of water actually striking the buckets to the total water Supplied by the jet

2. **Write short notes on Draft tube? (Nov/Dec15)**

   It is a gradually increasing area which connects the outlet of the runner to the tail race. It is used for discharging water from the exit of the turbine to the tail race.

3. **How are hydraulic turbine classified? (May/june14,April/May 11)**
   1. According to the type of energy
   2. According to the direction of flow
   3. According to the head at inlet
   4. According to the specific speed of the turbine

4. **What is mean by hydraulic efficiency of the turbine? (Nov/Dec13,12)**

   It is ratio between powers developed by the runner to the power supplied to the water jet

5. **Define specific speed of the turbine (April/may 08, May/June 07)**

   The speed at which a turbine runs when it is working under a unit head and develop unit power

6. **What is meant by governing of a turbine?**

   It is defined as the operation by which the speed of the turbine is kept constant under all conditions of working. It is done by oil pressure governor.

7. **List the important characteristic curves of a turbine**

   a. Main characteristics curves or Constant head curves

   b. Operating characteristic curves or Constant speed curves

   c. Muschel curves or Constant efficiency curves

8. Define gross head and net or effective head.

Gross Head: The gross head is the difference between the water level at the reservoir and the level at the tailstock.

Effective Head: The head available at the inlet of the turbine.

9. What is the difference between impulse turbine and Reaction turbine?

(April/May 2011,08)

S.No	Reaction turbine	Impulse turbine
1.	Blades are in action at all the time	Blades are only in action when they are in front of nozzle
2.	Water is admitted over the circumference the wheel	Water may be allowed to enter a part or whole of the wheel circumference

10. Give example for a low head, medium head and high head turbine

(Nov/Dec 09)

Low head turbine – Kaplan turbine

Medium head turbine – Modern Francis

High head turbine – Pelton wheel

11. Explain the type of flow in Francis turbine? (Nov/Dec 2016)

The type of flow in Francis turbine is inward flow with radial discharge at outlet.

12. How do you classify turbine based on flow direction and working medium? (April/May 2017)

According to the direction of flow turbines are classified into

(i) Tangential flow turbine

(ii) Radial flow turbine

(iii) Axial flow turbine

(iv) Mixed flow turbine

According to the working medium turbines are classified into

(i) Gas turbine

(ii) Water turbine

(iii) Steam turbine

PART-B

1. A Pelton wheel has a mean bucket speed of 10 metres per second. with a jet of water flowing at rate of 700 l/s. Under a head of 30 meters. The bucket deflect the jet through an angle 160°. Calculate power again by runner and hydraulic efficiency of turbine. Assume co. efficient of velocity as 0.98. (16)

[NOV/DEC - 2012]

Given:

$U = u_1 = u_2 = 10 m/s.$

$Q = 700 \ l/s = 0.7 \ m^3/s.$

$H = 30m$

$\phi = 180° - 160° = 20°$

$C_v = 0.98.$

Find:

(i) Power given to turbine (P) = ?

(ii) Hydraulic efficiency of turbine (η_h) = ?

formula:

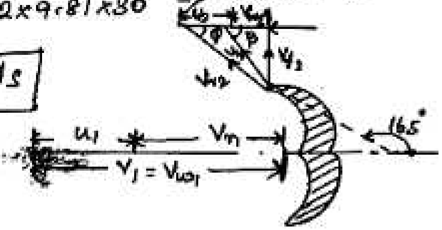
(i) Power $= \frac{\text{Work done by the jet / second}}{1000}$ kW

(ii) Hydraulic Efficiency (η_h) $= \frac{2[V_{w1} + V_{w2}] \times U}{(V_1^2)}$

Solution: (i) The velocity of jet $V_1 = C_v \sqrt{2gH}$.

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

$$= 0.98 \sqrt{2 \times 9.81 \times 30} \Rightarrow 23.77 \text{ m/s}$$



$$\boxed{V_1 = 23.77 \text{ m/s}}$$

$$V_{r_1} = V_1 - u_1$$

$$V_{r_1} = 23.77 - 10 \Rightarrow 13.77 \text{ m/s}.$$

$$\boxed{V_{r_1} = 13.77 \text{ m/s}}$$

$$\boxed{V_{w_1} = V_1 = 23.77 \text{ m/s}}$$

From outlet velocity triangle,

$$V_{r_2} = V_{r_1} = 13.77 \text{ m/s}$$

$$V_{w_2} = V_{r_2} \cos\phi - u_2$$

$$= 13.77 \cos 20^\circ - 10.0$$

$$\boxed{V_{w_2} = 2.94 \text{ m/s}}$$

(ii) Work done by the jet per second on the runner is given by equation.

$$= \rho a V_1 [V_{w_1} + V_{w_2}] \times u$$

$$= 1000 \times 0.7 \times [23.77 + 2.94] \times 10$$

$$= 186970 \text{ Nm/s} \qquad [\because aV_1 = Q = 0.7 \text{ m}^3/\text{s}]$$

(iii) Power given to turbine $= \dfrac{\text{work done/sec}}{1000}$ kW

$$\Rightarrow \frac{186970}{1000}$$

$$\Rightarrow 186.97 \text{ kW}.$$

(iv) The hydraulic efficiency of the turbine (η_h) $\Big\} = \dfrac{2[V_{w_1}+V_{w_2}]\times u}{(V_1)^2}$

$$\Rightarrow \frac{2[28.77 + 2.94] \times 10}{(28.77)^2}$$

$$\Rightarrow 0.9454 \text{ (or) } 94.54\,\%$$

Result :

(i) Power given to turbine (P) } = 186.97 KW

(ii) The hydraulic efficiency of the turbine (η_h) = 94.54 %

2. In an Inward radial flow turbine, water enters at an angle of 22° to wheel tangent to outer rim and leaves at 3 m/s. Inner diameter 300mm & outer dia 600 mm. Speed is 300 rpm. The discharge through the runner radial.

Find the, (i) Inlet & outlet blade angles.
(ii) Taking Inlet width as 150mm. Find power developed by the turbine. (16)

[Apr/ may-2010]

Given:

Guide blade angles $\alpha = 22^\circ$.
Velocity of flow $V_{f_1} = V_{f_2} = 3$ m/s.
$D_1 = 300$mm ; 0.3m.
$D_2 = 600$ mm ; 0.6 m.
$N = 300$ rpm.
$\beta = 90^\circ$ & $V_{w_2} = 0$
Inlet width $(B_1) = 150$mm $= 0.15$ mm.

Find:

(i) Inlet & outlet blade angles.

(ii) Power developed by the turbine.

Formula :

(i) Inlet & outlet velocity triangles

Inlet velocity triangle $(\tan\theta) = \dfrac{V_{f1}}{V_{w1} - u_1}$

outlet velocity triangle $(\tan\phi) = \dfrac{V_{f2}}{u.}$

(ii) Power developed $(P) = \dfrac{\text{workdone per second}}{1000}$ kW.

Solu:

Tangential velocity of wheel at Inlet.

$$u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.3 \times 300}{60}$$

$$u_1 = 4.71 \text{ m/s}.$$

Tangential Velocity of wheel at outlet.

$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.6 \times 300}{60}$$

$$u_2 = 9.43 \text{ m/s}.$$

Absolute velocity of water at Inlet.

$$V_1 = \frac{V_{f1}}{\sin\alpha} = \frac{3}{\sin 22} = 8.0084 \text{ m/s}.$$

Velocity of wheel at Inlet.

$$V_{w1} = V_1 \cos\alpha = 8.0084 \times \cos 22$$

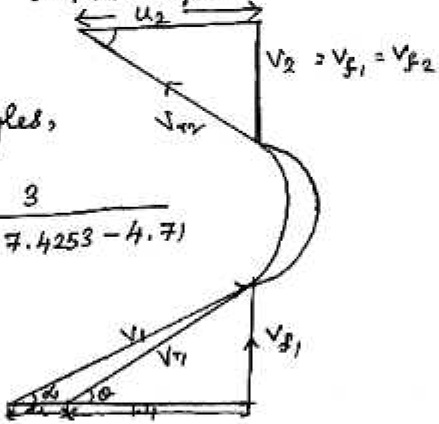
$$V_{w1} = 7.4253 \text{ m/s}.$$

The Discharge $Q = \pi D_1 B_1 V_{f_1}$

$$= \pi \times 0.3 \times 0.15 \times 3$$

$$= 0.4241 \ m^3/s .$$

For runner blade angles:



From Inlet Velocity triangles,

$$\tan\theta = \frac{V_{f_1}}{V_{w1} - u_1} = \frac{3}{7.4253 - 4.71}$$

$$\tan\theta = 1.1048$$

$$\theta = 47.85^\circ$$

From outlet Velocity triangles.

$$\tan\varphi = \frac{V_{f_2}}{u} = \frac{3}{9.43}$$

$$= 0.3181.$$

$$\varphi = \tan^{-1}(0.3181)$$

$$\varphi = 17.65^\circ .$$

Power developed,

$$P = \frac{\rho Q (V_{w_1} \times u_1)}{1000}$$

$$= \frac{1000 \times 0.4241 (7.4253 \times 4.71)}{1000}$$

$$\boxed{P = 14.83 \ KW}$$

Result:

(i) Inlet velocity triangle θ } $= 47.85^\circ$

Outlet velocity triangle φ $= 17.65^\circ$

(ii) Power developed $(P) = 14.83$ KW.

3. A Kaplan turbine working under a head of 20m developes 15MW brake. The hub diameter 1.5m. runner diameter is 4m. The guide blade angle $\eta_h = 0.9$ & $\eta_0 = 0.8$ Find runner vane angles & turbine speed. [16] [Apr/may-2010]

Solution:

$H = 20\,m.$

$P = 15MW = 15000\,KW.$

$D_0 = 4m.$

$D_b = 1.5m$

$\alpha = 30^\circ$

$\eta_h = 0.9 = 90\%.$

$\eta_0 = 0.8 = 80\%.$

$\beta = 90^\circ$ & $V_{w_2} = 0$

Find :

$\theta = ?$

vane angles $\phi = ?$

turbine speed $N = ?$

Formula :

(i) $\eta_0 = \frac{\text{Shaft power}}{\text{water power}} = \frac{S.P}{\rho g Q H}.$

$\eta_0 = 0.80$

(ii) Vane angles $\tan\alpha = \frac{V_{f_1}}{V_{w_1}}$

$\tan\phi = \frac{V_{f_2}}{u_2}$; $\tan\theta = \frac{V_{f_1}}{V_{w_1} - u_1}$

(iii) 'n' · Speed of the turbine $N = ?$

Solution:

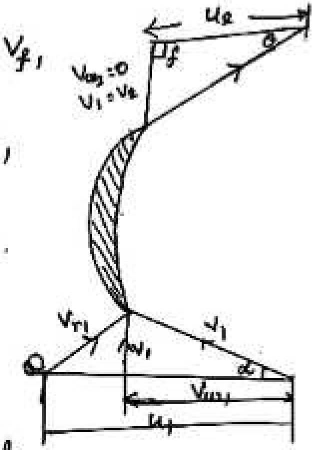
$$\eta_0 = \frac{S.P}{\rho g Q H}$$

We Know than

$$Q = \frac{\pi}{4}(D_a^2 - D_b^2) \times V_{f1}$$

$$95.56 = \frac{\pi}{4}(4^2 - 1.5^2) \times V_{f1}$$

$$\boxed{V_{f1} = 8.8487 \text{ m/s}}$$



From Inlet velocity triangle

$$\tan\alpha = \frac{V_{f1}}{V_{w1}}$$

$$\tan 30^\circ = \frac{8.8487}{V_{w1}}$$

$$\boxed{V_{w1} = 15.33 \text{ m/s}}$$

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

$$0.9 = \frac{15.33 \times u_1}{9.81 \times 20.}$$

$$\boxed{u_1 = 11.518 \text{ m/s}}$$

$$\tan\theta = \frac{V_{f1}}{V_{w1} - u_1}$$

$$= \frac{8.8487}{(15.33 - 11.5)}$$

$$= 2.3216$$

$$\tan\theta = 2.3216$$

$$\theta = \tan^{-1}(2.3216)$$

$$= 66.69$$

$$\boxed{\theta = 66.69^\circ}$$

For Kaplan turbine,

$$u_1 = u_2 = 11.518 \, m/s$$

$$V_{f_1} = V_{f_2} = 8.8487 \, m/s$$

$$\tan\varphi = \frac{V_{f_2}}{u_2} = 0.7682.$$

$$\varphi = \tan^{-1}(0.7682) = 37.53.$$

$$u_1 = \frac{\pi D N}{60}.$$

$$11.51 = \frac{\pi \times 4 \times N}{60}$$

$$\boxed{N = 54.997 \text{ rpm.}}$$

Result:

$$\theta = 66.69^\circ$$

$$\varphi = 37.53^\circ$$

$$N = 54.997 \text{ rpm.}$$

4. A Francis turbine developing 16120 KW under a head of 260 m runs at 600 rpm. The runner outside diameter is 1500 mm & the width is 135 mm. The flow rate is 7 m³/s. The exit velocity at the draft tube outlet is 16 m/s. Assuming zero whirl velocity at exit and neglecting blade thickness, determine the overall & hydraulic efficiency & rotor blade angle at inlet. Also find the guide vane outlet angle. (16) [Nov/Dec -2014]

Given:

$P = 16120\ KW$; $H = 260 m$; $N = 600 rpm$.

$D_2 = 1.5 m$; $B = 0.135 m$; $Q = 7 m^3/s$.

$V_2 = V_{f_2} = 16 m/s$; $V_{w_2} = 0$.

To Find:

$\eta_0 = ?$; $\eta_h = ?$

$\alpha = ?$; $\varphi = ?$

Solution:

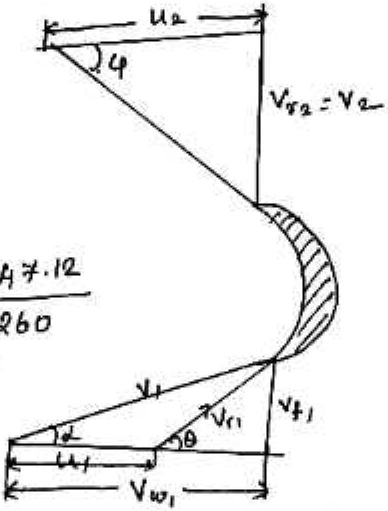
$$u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 1.5 \times 600}{60}$$

$$= 47.12\ m/s.$$

$$\text{Power developed } (P) = \frac{\rho Q V_{w_1} u_1}{1000}$$

$$\therefore\ 16120 = \frac{1000 \times 7 \times V_{w_1} \times 47.12}{1000}$$

$$\boxed{V_{w_1} = 48.86\ m/s}$$



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

$$= \frac{48.86 \times 47.12}{9.81 \times 260}$$

$$\boxed{\eta_h = 0.902}$$

$$\boxed{\eta_h = 90.2\%}$$

$$\eta_o = \frac{S.P}{W.P} = \frac{S.P}{\rho g Q H}$$

$$= \frac{16120}{1000 \times 9.81 \times 7 \times 260}.$$

$$\boxed{\eta_o = 90\%}$$

$$\tan\alpha = \frac{V_{f1}}{V_{w1}}$$

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

$$7 = \pi \times 1.5 \times 0.135 \times V_{f1}$$

$$\boxed{V_{f1} = 11 m/s}$$

$$\tan\alpha = \frac{11}{48.86} = 0.225$$

$$\alpha = \tan^{-1}(0.225) = 12.68^\circ$$

$D_1 = 2 D_2$ (Assume most of the case)

$$D_2 = \frac{1.5}{2} = 0.75$$

$$u_2 = \frac{\pi D N}{60} = \frac{\pi \times 0.75 \times 600}{60} = 23.56 \text{ m/s}$$

$$\tan\varphi = \frac{18}{23.56} = 0.679$$

$$\varphi = \tan^{-1}(0.679) = 34^\circ 18' \quad \boxed{\varphi = 34^\circ 18'}$$

Result :

$$\eta_o = 90\% \ ; \ \eta_h = 90.2\% \ ; \ \alpha = 12.68'$$

$$\varphi = 34^\circ 18'$$

5. With a neat sketch, explain the construction and working of Pelton wheel. **[APR./MAY 2008]**

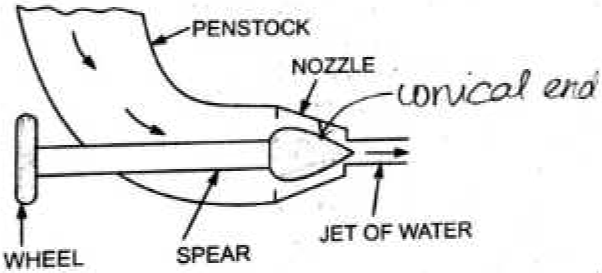
Pelton turbine is a tangential flow impulse turbine. It is named after L.A.Pelton, an American engineer. This turbine is used for high heads.

MAIN PARTS:

1. Nozzle and flow regulating valve
2. Runner and buckets
3. Casing
4. Breaking jet

1. Nozzle and flow regulating valve

The nozzle increases the kinetic energy of water flowing through the penstock. At the outlet of the nozzle, the water comes out in the form of jet and strikes the bucket of the runner. The amount of water striking the buckets of the runner is controlled by providing a spear in the nozzle. The spear is a conical needle which can be operated manually. When the spear is pushed forward or backward into



the nozzle the amount of water striking the runner is reduced or increased.

2. Runner and buckets

The runner consists of a circular disc with a number of bucket evenly spaced round its periphery. The shape of the bucket is of semi ellipsoidal cups. Each bucket is divided into two symmetrical parts by a dividing which is known as splitter. The splitter divides the jet into two equal parts and the jet comes out at the outer edge of the bucket.

The bucket is made up of cast iron, cast steel bronze or stainless steel depending upon the head at the inlet of the turbine.

3. Casing:

The function of casing is to prevent the splashing of the water and to discharge water to tail race. It also acts as a safeguard against accident.

It is made up of cast iron or fabricated steel plates.

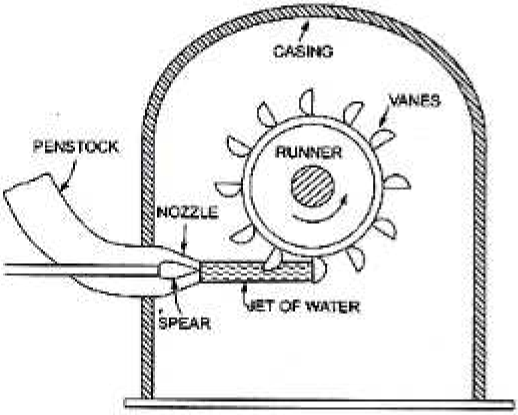
4. Breaking jet:

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 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.

Working:

The water from the reservoir flows through the penstocks at the outlet of which a nozzle is fitted. The nozzle increases the kinetic energy of water flowing through the penstock. At the outlet of the nozzle, the water comes out in the form of jet and strikes the bucket of the runner.

The water flows along the tangent to the path of rotation of the runner. The runner revolves freely in air. The water is in contact with only a part of the runner at a time, and throughout its action on the runner and in its subsequent flow to the tail race, the water is at atmospheric pressure. Casing is to prevent the splashing of the water and to discharge water to tail race.



Pelton turbine.

6. Draw the characteristic curves of the turbines. Explain the significance?

Characteristics curves of a hydraulic turbine are the curves, with the help of which the exact behavior and performance of the turbine under different working conditions can be obtained. These curves are plotted from the results of the tests performed on the turbine.

The important parameters which are varied during a test on a turbine:

1.Speed (N) 2.Head(H) 3. Discharge(Q) 4.Power(P)

5.overall deficiency(η_o) 6. Gate opening

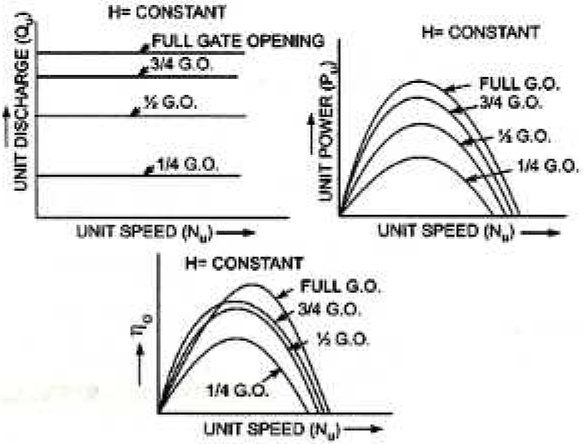
Speed (N), Head(H), Discharge(Q) are independent parameters. One of the parameters are kept constant and the variation of the other four parameters with respect to any one of the remaining two independent variables are plotted and various curves are obtained. These curves are called characteristics curves. The following are the important characteristic curves of a turbine.

1. Main characteristics curves or constant head curves.
2. Operating characteristics curves or constant speed curves
3. Muschel curves of constant efficiency curves

MAIN CHARACTERISTICS CURVES OR CONSTANT HEAD CURVES.

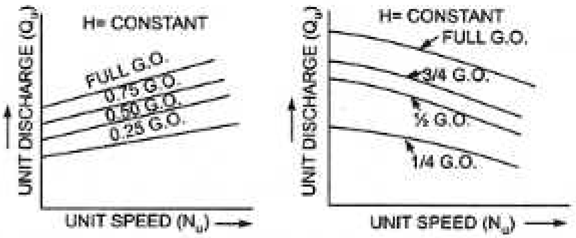
Main characteristics curves are obtained by maintaining a constant head and a constant gate opening on the turbine. The speed of the turbine is varied by changing load on the turbine. For each value of the speed , the corresponding values of the power (P) and discharge(Q) are obtained. Then the overall efficiency (η_o) for each value of the speed is calculated. From these readings the values of unit speed (N_u), unit power (P_u),and unit discharge (Q_u) are determined.

Main characteristics curves of a Pelton wheel as shown below.

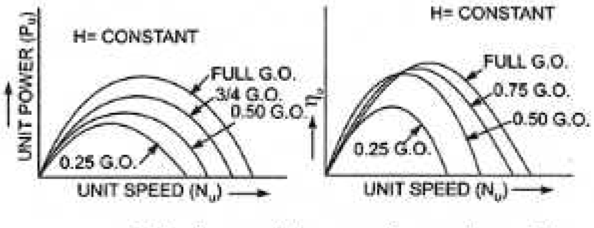


Main characteristic curves for a Pelton wheel.

Main characteristics of a Kaplan and reaction turbine as shown below.



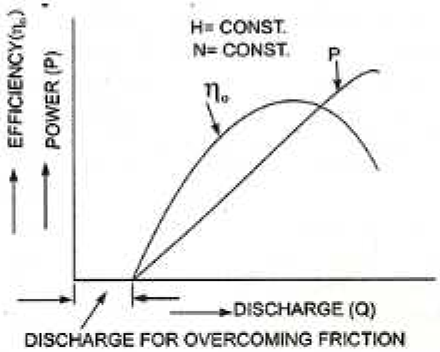
(a) FOR KAPLAN TURBINE (b) FOR FRANCIS TURBINE



Main characteristic curves for reaction turbine.

OPERATING CHARACTERISTICS CURVES OR CONSTANT SPEED CURVES :

Operating Characteristics Curves are plotted when the speed on the turbine is constant. There are three independent parameters namely N, H and Q. For operating characteristics N and H are constant and hence the variation of power and efficiency with respect to discharge Q are plotted. The power curve for turbines shall not pass through the origin because certain amount of discharge is needed to produce power to overcome initial friction. Hence the power and efficiency curves will be slightly away from the origin on the x-axis as to overcome initial friction certain amount of discharge will be required.



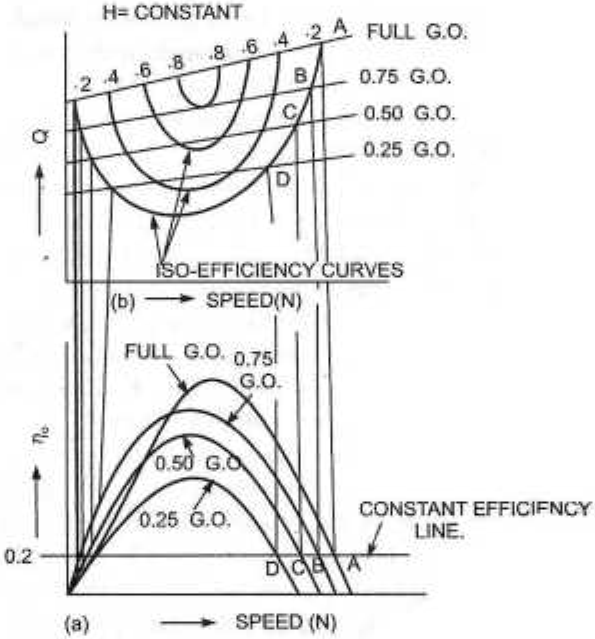
Operating characteristic curves.

MUSCHEL CURVES OF CONSTANT EFFICIENCY CURVES :

These curves are obtained from the speed Vs efficiency and speed Vs discharge curves for different gate openings. For a given efficiency, from the N_u vs η_u curves, there are two speeds. From the N_u vs Q_u curves, corresponding to two values of speeds there are two values of discharge. If the efficiency is maximum there is only one value. These two values of speed and two values of discharge corresponding to a particular gate opening are plotted.

The procedure is repeated for different gate opening and the curve Q vs N are plotted. The points having the same efficiency are iso-efficiency curves. These curves are useful to determine the zone of constant efficiency and for predicting the performance of the turbine at various efficiencies.

Horizontal lines representing the same efficiency are drawn on the η_o speed curves. The points at which these lines cut the efficiency curves at various gate opening are transferred to the corresponding Q- speed curves. The points having the same efficiency are then joined by smooth curves. These smooth curves represent the iso-efficiency curve.



Constant efficiency curve.

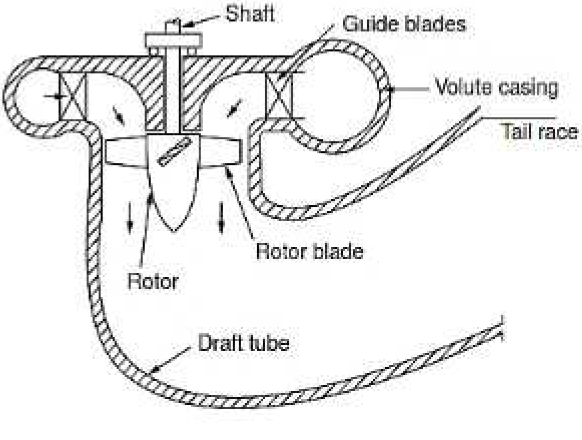
7. Explain the working of Kaplan turbine. Construct its velocity triangles.

(Nov/Dec 2016)

The popular axial flow turbines are the Kaplan turbine and propeller turbine. In propeller turbine the blades are fixed. In the Kaplan turbines the blades are mounted in the boss in bearings and the blades are rotated according to the flow conditions by a servomechanism maintaining constant speed. In this way a constant efficiency is achieved in these turbines. The system is costly and where constant load conditions prevail, the simpler propeller turbines are installed. There are many locations where large flows are available at low head. In such a case the specific speed increases to a higher value. In such situations axial flow turbines are gainfully employed. A sectional view of a kaplan turbines in shown in figure. These turbines are suited for head in the range 5 – 80 m and specific speeds in the range 350 to 900. The water from supply pipes enters the spiral casing as in the case of Francis turbine. Guide blades direct the water into the chamber above the blades at the proper direction. The speed governor in this case acts on the guide blades and rotates them as per load requirements.

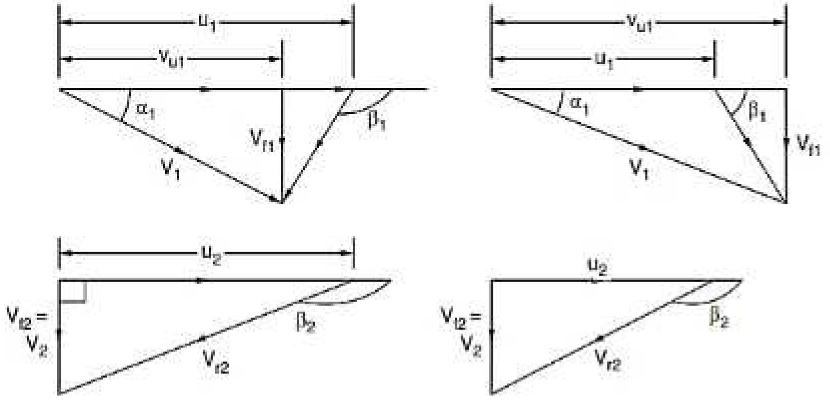
The flow rate is changed without any change in head. The water directed by the guide blades enters the runner which has much fewer blades (3 to 10) than the Francis turbine. The blades are also rotated by the governor to change the inlet blade angle as per the flow direction from the guide blades, so that entry is without shock. As the head is low, many times the draft tube may have to be elbow type. The important dimensions are the diameter and the boss diameter which will vary with the chosen speed. At lower specific speeds the boss diameter may be higher.

The number of blades depends on the head available and varies from 3 to 10 for heads from 5 to 70 m. As the peripheral speed varies along the radius (proportional to the radius) the blade inlet angle should also vary with the radius. Hence twisted type or Airfoil blade section has to be used. The speed ratio is calculated on the basis of the tip speed as $\emptyset = \frac{u}{\sqrt{2gH}}$ and varies from 1.5 to 2.4. The flow ratio lies in the range 0.35 to 0.75.



Sectional view of Kaplan turbine

Velocity triangles



(a) At Tip (b) At Hub

PART-C

1. The head available at a location was 1500 m. It is proposed to use a generator to run at 750 rpm. The power available is estimated at 20,000 kW. Investigate whether a single jet unit will be suitable. Estimate the number of jets and their diameter. Determine the mean diameter of the runner and the number of buckets.

Solution:

The specific speed is calculated to determine the number of jets,

$$N_S = \frac{750}{60} \frac{\sqrt{20{,}000 \times 10^3}}{1500^{5/4}}$$

$$N_S = 5.99$$

So a single jet will be suitable

The overall effeciency is assumed as 0.87.

$$20{,}000 \times 10^3 = 0.87 \times Q \times 1000 \times 9.81 \times 1500$$

$$\Rightarrow \boxed{Q = 1.56225 \ m^3/s}$$

To determine the jet velocity, the value of C_v is required. It is assumed as 0.97.

$$V = 0.97\sqrt{2gH}$$
$$= 0.97\sqrt{2\times 9.81\times 1500}$$
$$\boxed{V = 166.4\ m/s}$$

We know, $Q = A.V$

$$1.56225 = \frac{\pi}{4} d^2 \times 166.4$$
$$\Rightarrow \boxed{d = 0.1093\ m}$$

Assume, $\phi = 0.46$

$$u = 166.4 \times 0.46$$

Also, $u = \frac{\pi D N}{60}$

$$\Rightarrow D = \frac{60u}{\pi N}$$
$$= \frac{60 \times 166.4 \times 0.46}{\pi \times 750}$$
$$\boxed{D = 1.95\ m}$$

Number of buckets, $= z.\frac{D}{2d} + 15$

$$= \frac{1.95}{2\times 0.1093} + 15$$
$$= 24$$

2. At a location selected to install a hydroelectric plant, the head is estimated as 550 m. The flow rate was determined as 20 m 3m/s. The plant is located at a distance of 2 m from the entry to the penstock pipes along the pipes. Two pipes of 2 m diameter are proposed with a friction factor of 0.029. Additional losses

amount to about 1/4th of frictional loss. Assuming an overall efficiency of 87%, determine how much single jet unit running at 300 rpm will be required.

Solution:

Specific speed

Net head = Head available − loss in head

$$\text{friction Loss} = \frac{fLV_p^2}{2gD}$$

$$Q = V_p \times A_p \times \text{number of pipes}$$

$$Q = 20 \, m^3/s \quad (\text{given}).$$

$$\Rightarrow \quad V_p = \frac{20}{\left(\frac{\pi}{4} \times 2^2\right) \times 2} = 3.182 \, m/s$$

$$V_p = 3.183 \, m/s$$

$$L = 2000 \, m, \quad f = 0.029$$

$$h_f = \frac{0.029 \times 2000 \times 3.183^2}{2 \times 9.81 \times 2}$$

$$\boxed{h_f = 14.98 \, m}$$

$$\text{Total loss of head} = \left(1 - \frac{1}{4}\right) \times 14.98$$

$$= \frac{5}{4} \times 14.98$$

$$= 18.72 \, m$$

$$\therefore \text{Net head} = 550 - 18.72$$

$$= 531.28 \, m$$

$$\therefore \text{Power}, P = \eta Q \rho g H$$

$$P = 0.87 \times 20 \times 1000 \times 9.81 \times 531.28$$

$$\boxed{P = 90.6863 \times 10^3 \, W}$$

$$\text{specific speed}, \; N_s = \frac{300}{60} \cdot \frac{\sqrt{90.686 \times 10^3}}{531.28^{5/4}}$$

$$\boxed{N_s = 18.667}$$

Suitability of single jet unit

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

$$= 0.98\sqrt{2\times 9.81\times 531.28}$$

Velocity of jet, $V_j = 100.05\ \text{m/s}$

Discharge, $Q = A\cdot V_j$

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

$$d = \left(\frac{4Q}{\pi V_j}\right)^{1/2}$$

$$d = \left(\frac{4\times 20}{\pi\times 100.05}\right)^{1/2}$$

$d = 0.5\ \text{m}$ (high)

Also, $\frac{\pi DN}{60} = 0.46\times 100.05$

$D = 2.93\ \text{m}$

Jet speed ratio $= \frac{2.95}{0.5}$

$= 6$ (low)

If three jets are suggested,

then $d = 0.29\ \text{m}$

Jet speed ratio $= 10$ (Suitable).

$$\therefore\ N_s = \frac{300}{60}\frac{\sqrt{90.6863\times 10^6/3}}{531.28^{5/4}}$$

$N_s = 10.77$

Hence a three jet unit can be suggested.