UNIT – 5

HYDRAULIC MACHINES

Lecture-01

Turbines

Hydraulic machines which convert hydraulic energy into mechanical energy. This mechanical energy is used to run electric generator which is directly coupled to the shaft of the turbine.

Classification of turbines

1. According to the **type of energy at inlet**
    a. **Impulse turbine**: In the impulse turbine, the total head of the incoming fluid is converted in to a large velocity head at the exit of the supply nozzle. That is the entire available energy of the water is converted in to kinetic energy.
    b. **Reaction turbine**: In this type of turbines, the rotation of runner or rotor (rotating part of the turbine) is partly due to impulse action and partly due to change in pressure over the runner blades; therefore, it is called as reaction turbine.

S. No.	Impulse Turbine	Reaction Turbine
1	At the inlet, water possesses only kinetic energy	At the inlet, water possesses kinetic as well as pressure energy.
2	Unit is installed above the tailrace.	Unit is entirely submerged in water below the tailrace.
3	Flow regulation is possible without loss.	It is not possible to regulate the flow without loss.
4	e.g. Pelton Turbine	e.g. Francis & Kaplan Turbines

2. According to the **direction of flow through runner**
    a. **Tangential flow turbine**: In this type of turbines, the water strikes the runner in the direction of tangent to the wheel. Example: Pelton wheel turbine.
    b. **Radial flow turbine**: In this type of turbines, the water strikes in the radial direction. accordingly, it is further classified as,
        i. **Inward flow turbine**: The flow is inward from periphery to the centre (centripetal type). Example: Francis turbine.
        ii. **Outward flow turbine:** The flow is outward from the centre to periphery (centrifugal type). Example: Fourneyron turbine.

c. **Axial flow turbine:** The flow of water is in the direction parallel to the axis of the shaft. Example: Kaplan turbine and propeller turbine.

d. **Mixed flow turbine:** The water enters the runner in the radial direction and leaves in axial direction. Example: Modern Francis turbine.

3. According to the **head at inlet of the turbine:**
   - **a. Low head turbine:** The net head is less than 30m and also these turbines require large quantity of water. Example: Kaplan turbine.
   - **b. Medium head turbine:** The net head varies from 30m to 150m, and also these turbines require moderate quantity of water. Example: Francis turbine.
   - **c. High head turbine:** In this type of turbines, the net head varies from 150m to 2000m or even more, and these turbines require a small quantity of water. Example: Pelton wheel turbine.

4. According to the **specific speed of turbine**:
   - a. **Low specific speed turbine**: The specific speed is less than 50. (varying from 10 to 35 for single jet and up to 50 for double jet) Example: Pelton wheel turbine.
   - b. **Medium specific speed turbine**: The specific speed is varies from 50 to 250. Example: Francis turbine.
   - c. **High specific speed turbine**: The specific speed is more than 250. Example: Kaplan turbine.

Efficiency of a turbine

(i) Hydraulic efficiency

η_h = Power delivered to runner/ power supplied at inlet = R.P. / W.P.

(ii) Mechanical efficiency

η_m = power at the shaft/ power delivered to runner = S.P. / R.P.

(iii) Volumetric efficiency

η_v **=** Volume of water actually striking the runner/ volume of water supplied to the turbine

(iv) Overall efficiency

η_o **=** Power at the shaft / Power supplied at inlet = S.P. / W.P. = $\eta_h \times \eta_m$

where W.P. (in kW) = $\rho gQH/1000$

Performance of turbines

- Turbines are often required to work under varying conditions of head, speed, output and gate opening. As such, in order to predict their behaviour, it is essential to study the performance of the turbine under varying conditions.
- The head and output of the turbine may change. In this case, keeping the discharge constant, the speed is adjusted so that the efficiency remains constant.
- Keeping the head and the speed constant, the output may vary by adjusting the discharge. These are the normal operating conditions, and the curves drawn for these conditions are called operating characteristics curves.
- Keeping the head and discharge constant, the speed may vary by adjusting the load on the turbine. These conditions are possible only in the laboratories. The curves so obtained for such conditions are known as main characteristics curves.

- The head and speed may vary. This is common in turbines working under low heads.

S.No.	RGPV questions	Year	Marks
Q.1	Differentiate between impulse & reaction turbine.	Dec 2014	2
Q.2	What are the classification of turbines based on (i) flow, (ii) specific speed, (iii) head (iv) energy of striking fluid	Dec 2012	10

Unit-05/Lecture-02

Specific speed (N_s)

It is the speed of a turbine which is identical in shape, geometrical dimension, 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 used in comparing the different types of turbines as every type of turbine has different specific speed. It plays an important role for selecting the type of the turbine & predicting the performance of turbine.

Derivation of the specific speed

The overall efficiency of any turbine is given by

$$\eta_0 = \text{shaft power / water power} = \text{Power developed} / (\rho g Q H / 1000)$$

where H = head under which the turbine is working, Q = discharge through the turbine, P = power developed or shaft power.

Now from above equation,

$$P = \eta_o \times \frac{\rho g Q H}{1000}$$
$$\propto Q \times H \text{ .... (1)}$$

Now let D = dia of actual turbine, N = speed of actual turbine, u = tangential velocity of the turbine, N_s= specific speed of the turbine, V = absolute velocity of water.

Now, u ∝ V, and V ∝ $H^{1/2}$. Hence

$$u \propto H^{1/2}$$

But u = π D N / 60 , or

$$u \propto DN$$

Hence

$$\sqrt{H} \propto DN$$

or

$$D = \frac{\sqrt{H}}{N}$$

Now

$$Q \propto D^2 \times \sqrt{H}$$
$$\propto \frac{H}{N^2} \sqrt{H}$$
$$\propto \frac{H^{3/2}}{N^2}$$

Hence eq (1) becomes

$$P \propto \frac{H^{5/2}}{N^2}$$

Or

$$P = K \frac{H^{5/2}}{N^2}$$

where K = constant of proportionality.

If P = 1, H = 1, then the speed N = specific speed N_s. putting this in above equation, we get

$$K = N_s^2$$

Hence

$$P = N_s^2 \frac{H^{5/2}}{N^2}$$

Or

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

In above eqn, if P is taken in metric horse power, the specific speed is obtained in MKS units. But if P is taken in kilowatts, the specific speed is obtained in SI units.

Unit Quantities

In order to predict the behaviour of a turbine working under varying conditions of head, speed, and power, recourse has been made to the concept of unit. The unit quantities give the speed, discharge and power for a particular turbine under a head of 1m assuming the same efficiency. The following are the three important unit quantities.

1. Unit speed
2. Unit power
3. Unit discharge

1. **Unit speed (N_u)**: The speed of the turbine, working under unit head (say 1m) is known as unit speed of the turbine.
   If H=1; then **$N = N_u\sqrt{H}$**
   Where,
   H = head of water under which the turbine is working;
   N= speed of turbine under a head, H; u= tangential velocity;
   N_u = speed of the turbine under a unit head.
2. **Unit Power (P_u):** The power developed by a turbine, working under a unit head (say 1m) is known as unit power of the turbine.
   If H=1, then, $P_u = P/H^{3/2}$
3. **Unit discharge (Q_u)**: The discharge of the turbine working under a unit head (say 1m) is known as unit discharge.
   If H = 1, then $Q_u = Q/\sqrt{H}$
   If a turbine is working under different heads, the behaviour of the turbine can be easily known from the unit quantities.

Use of unit quantities: If a turbine is working under different heads the behaviour of the turbine can be easily known from the values of the quantities i.e. from the values of unit speed, unit discharge & unit power.

Let H_1, H_2 be the heads under which a turbine works, then

$$N_u = \frac{N_1}{\sqrt{H_1}} = \frac{N_2}{\sqrt{H_2}}$$

Hence if the speed of a turbine under a head is known, then by using above equation, the speed of the same turbine under a different head can be obtained easily.

Runaway speed of a turbine (www.scribd.com)

- The runaway speed of a hydraulic turbine is the speed at which the turbine coupled to the generator runs at the maximum possible speed due to loss of load.
- The runaway speed of the turbine is determined by the turbine designer and is influenced by the maximum discharge of water from the penstock, the combined inertia of the turbine runner and the generator and the flywheel. This factor can vary from 1.5 up to 3 times the nominal speed of the turbine and is determined by the turbine designer considering all the load parameters.

S.No.	RGPV questions	Year	Marks
Q.1	What are unit quantities? Define the unit quantities of turbine. Why they are important?	June 2015	2
Q.2	Define specific speed & runaway speed of a hydraulic turbine.	June 2015	2
Q.3	Derive an expression for specific speed of a hydraulic turbine.	June 2009	10

Unit-05/Lecture-03

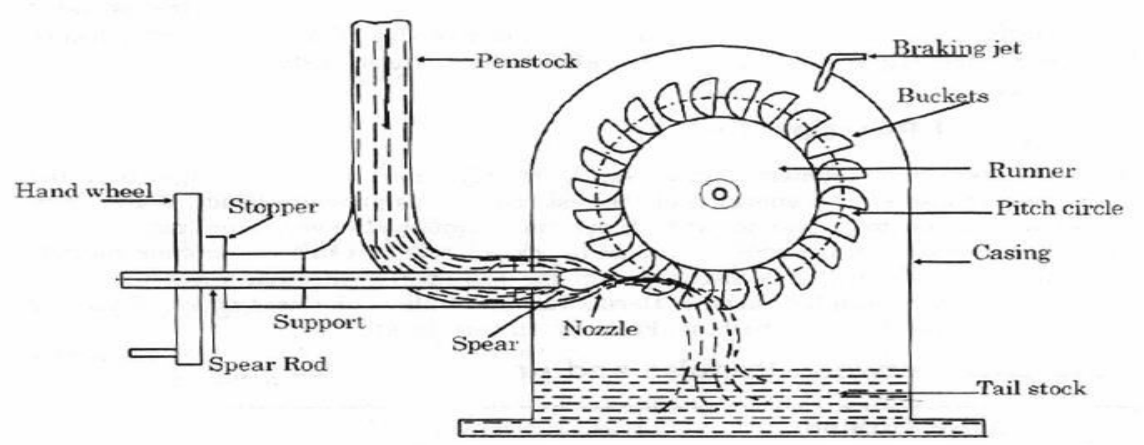
Pelton Turbine:

Pelton Wheel or Pelton Turbine is a Tangential Flow Impulse Turbine. This Turbine is used for High Heads. The water strikes the bucket along the tangent of the tangent of the runner. The energy available at the inlet of the turbine is only Kinetic Energy. The pressure at the inlet and outlet is atmospheric pressure. The nozzle increases the kinetic energy of the water flowing through the penstock. At the outlet of the nozzle, the water comes out in the form of a jet and strikes the buckets (vanes) of the runner. Pelton Wheel Turbine is used for High Heads. Pelton Wheel Turbine has a Specific Speed less than 30(S.I) for single jet and between 30 and 60 (S.I) for multi-jet.
The main parts of pelton turbine are:

1. **Penstock:**
   It is a large sized conduit which conveys water from high level reservoir to the turbine. For the regulation of water flow from the reservoir to the turbine, the penstock is provided with control valves.

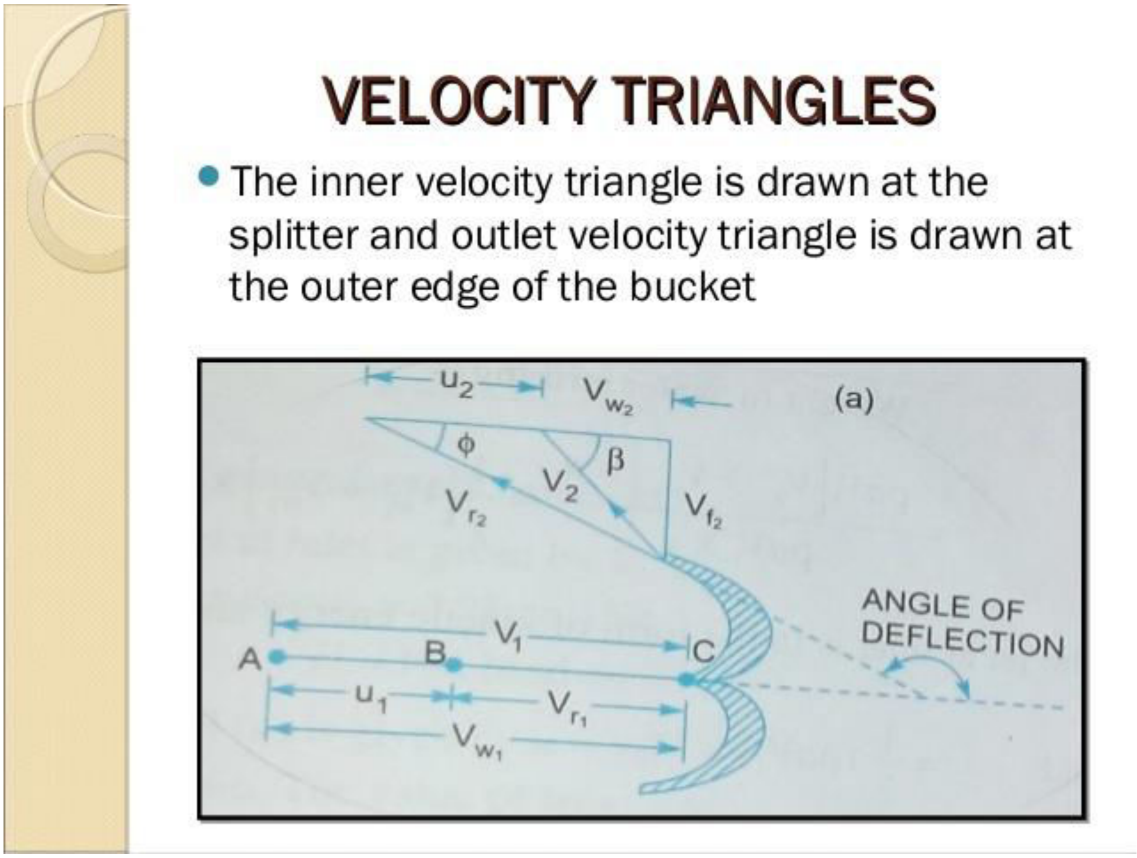
2. **Nozzle and flow regulating arrangement(spear):**
   The amount of water striking the buckets is controlled by providing a spear in the nozzle. The spear is a conical needle operated in the axial direction depending up on the size of the unit. When the spear is pushed forward, the amount of water striking the runner is reduced and when the spear is pushed back, the amount of water striking the runner increases.

3. **Runner with Buckets:**
   Runner consists of a circular disc on the periphery of which a number of buckets evenly spaced are fixed. The space of the buckets is of a double hemispherical cup or bowl. Each bucket is divided into two symmetrical parts by dividing wall which is known as Splitter. The Splitter divides the jet into two equal parts. The buckets are shaped in such a way that the jet gets deflected through 160° or 170°. The buckets are made of cast iron, cast steel bronze or stainless steel depending upon the head at the inlet of the turbine.



4. **Casing:**
   It is made of cast iron or fabricated steel plates. Its function is to prevent the splashing of water and to discharge water to tail race. It also acts as safeguard against accidents.

5. **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 vanes. This jet of water is called Breaking Jet.



VELOCITY TRIANGLES

- The inner velocity triangle is drawn at the splitter and outlet velocity triangle is drawn at the outer edge of the bucket

Unit-05/Lecture-04

Characteristic curves of a turbine

These are curves which are characteristic of a particular turbine which helps in studying the performance of the turbine under various conditions. These curves pertaining to any turbine are supplied by its manufacturers based on actual tests.

The data that must be obtained in testing a turbine are the following:

1. The speed of the turbine N
2. The discharge
3. The net head H
4. The power developed P
5. The overall efficiency
6. Gate opening (this refers to the percentage of the inlet passages provided for water to enter the turbine).

The characteristic curves obtained are the following:

a) Constant head curves or main characteristic curves
b) Constant speed curves or operating characteristic curves
c) Constant efficiency curves or Muschel curves

Constant head curves

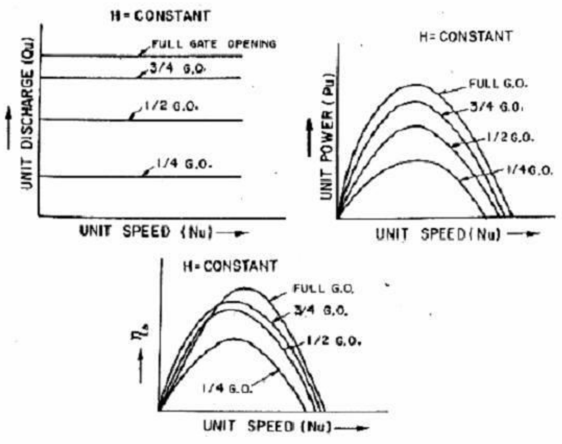
Maintaining a constant head, the speed of the turbine is varied by admitting different rates of flow by adjusting the percentage of gate opening. The power P developed is measured mechanically. From each test the unit power P_u, the unit speed N_u, the unit discharge Q_u and the overall efficiency η_o is determined. The characteristic curves drawn are unit discharge vs unit speed, unit power vs unit speed & overall efficiency vs unit speed.

Constant speed curves

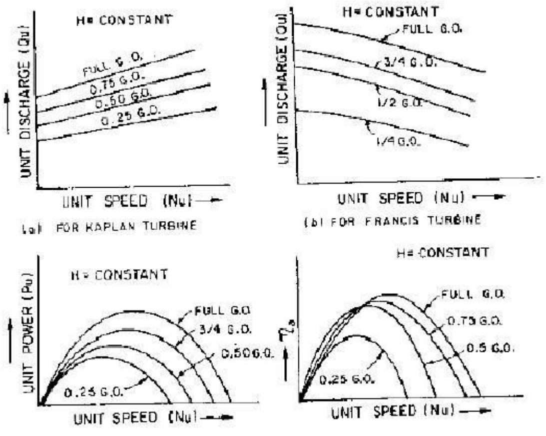
In this case tests are conducted at a constant speed varying the head H and suitably adjusting the discharge Q. The power developed P is measured mechanically. The overall efficiency is aimed at its maximum value. The curves drawn are P vs Q, η_0 vs Q, η_0 vs P_u $\eta_{0\,max}$ vs % Full load.

Constant efficiency curves

These curves are plotted from data which can be obtained from the constant head and constant speed curves. The object of obtaining this curve is to determine the zone of constant efficiency so that we can always run the turbine with maximum efficiency. This curve also gives a good idea about the performance of the turbine at various efficiencies.

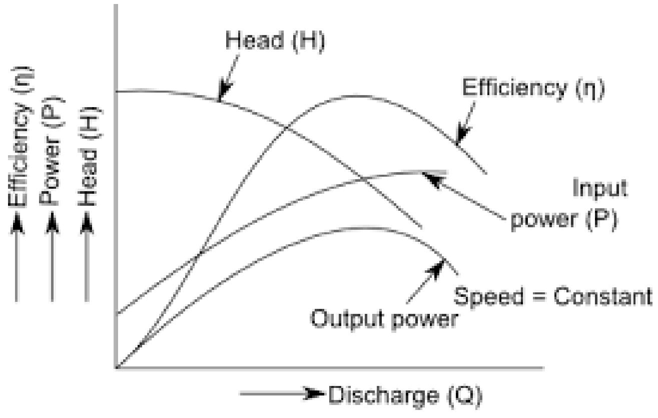


. Main characteristic curves for a Pelton wheel.

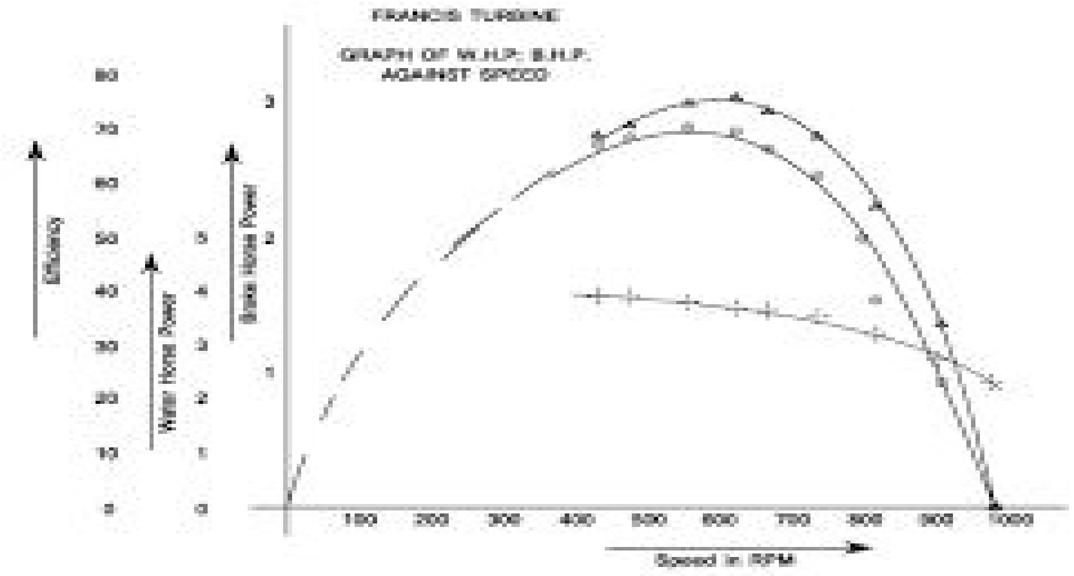

(a) FOR KAPLAN TURBINE

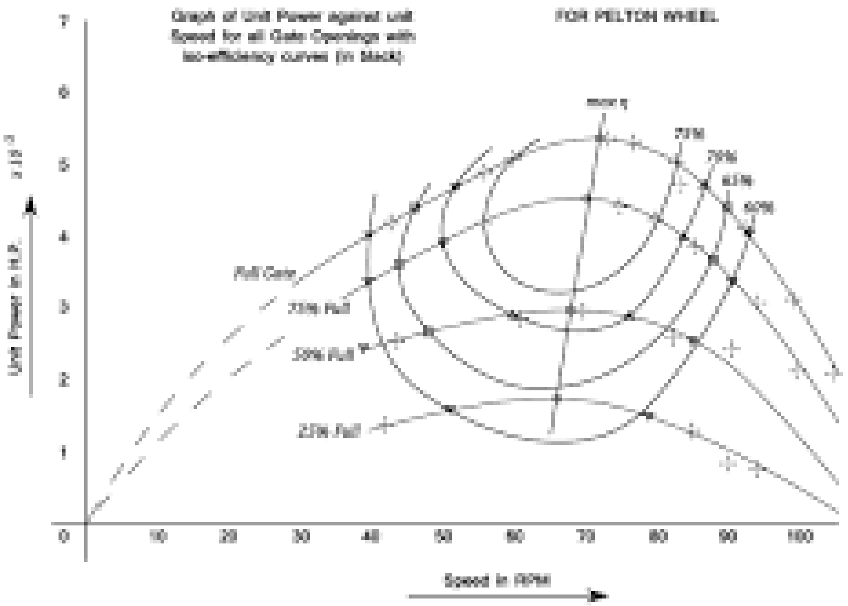
(b) FOR FRANCIS TURBINE

Main characteristic curves for reaction turbine.



Operating characteristic surves of a pump.





Comparison of turbine and pump by CC

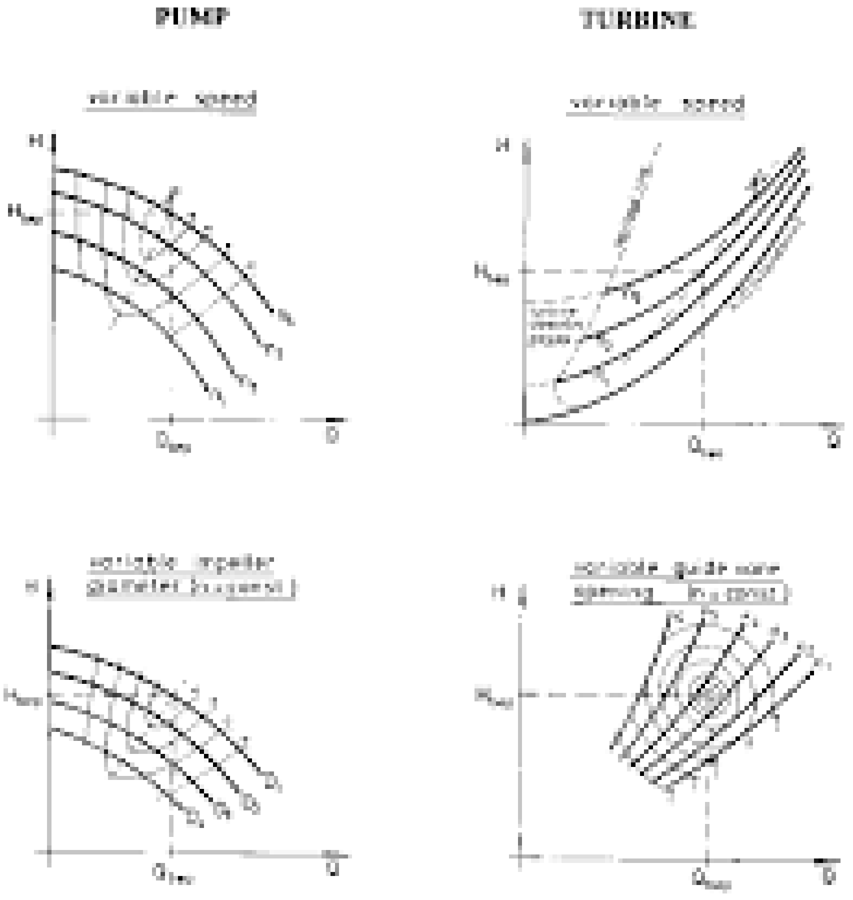


FIGURE 8. 16 :
Hill Charts

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	What are the characteristic curves of a turbine? How are they obtained & what is their utility?	Dec 2015	7

Unit-05/Lecture-05

Reaction Turbines

Reaction turbine means that the water at the inlet possesses kinetic energy as well as pressure energy. As water flows through the runner, a part of pressure energy goes on changing into kinetic energy.

In Reaction turbine major portion of the pressure loss takes place in the rotating wheel. Fluid entering the rotor around its entire circumference is in action. So its rotor needs to be so large as compared to the impulse turbine of same power.

In reaction turbine, water enters the wheel under pressure and flow over vanes. As the water, flowing over the vanes, is under pressure, therefore wheel of the turbine runs full and may be submerged. The pressure head of water, while flowing over the vanes, is converted into velocity head and is finally reduced to the atmospheric pressure, before leaving the wheel.

Main Components of a reaction turbine

A reaction turbine has the following main components.

1. Spiral casing
2. Guide mechanism
3. Turbine runner
4. Draft tube

1. Spiral casing

The casing of reaction turbine is designed in such a way that it’s cross sectional area goes on reducing uniformly around the circumference. The cross sectional area is maximum at the entrance and minimum at the tip. Due to this, the casing will be of spiral shape. That is why it is called spiral casing or scroll casing. The water from a pipeline is distributed around the guide ring in a casing.

The material of the casing depends upon the head of water. If head is upto 30 meter then concrete should be used. If head is upto 100 meter then welded rolled steel plate should be used. If it is more than 100 meter then cast steel should be used for casing.

2. Guide mechanism

This is the arrangement of blades and vanes which will guide the water to move towards runner. The guide vanes are fixed between the two rings in the form of a wheel. This wheel is fixed in the spiral casing.

Functions of guide vanes

- Guide vanes allow the water to enter the runner without shock. Guide vanes keep relative velocity at inlet of the runner, tangential to the vane angle and thus results in entering of water without shock.
- They allow the water to flow over them without forming eddies.
- They allow the required quantity of water to enter the turbine. This is done by adjusting the vanes.

All the guide vanes can rotate about their respective pivots. Pivots are connected to the guided ring or regulating ring. This ring is connected to the regulating shaft by means of two regulating rods. Guide vanes may be closed or opened by rotating the regulating shaft, thus allowing required quantity of water to flow. The regulating shaft is operated by a governor whose function is to govern the turbine. Governor function is to keep the speed constant at varying loads.

Guide vanes are generally made of cast steel.

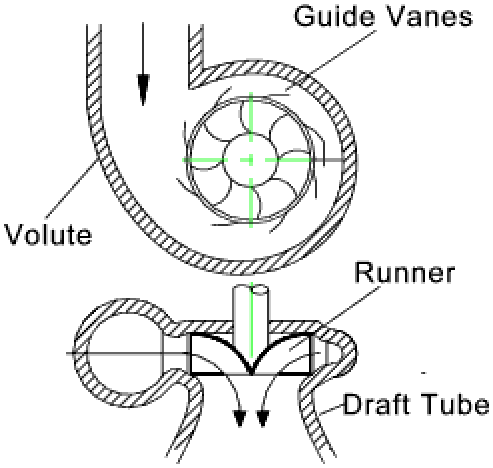
3. Turbine Runner

- The rotating wheel of the reaction turbine is known as runner. Runner consists of many curved plates welded with circular discs. For small diameter they are casted as single units.
- The runner is keyed to a shaft, which may be vertical or horizontal. If the shaft is vertical, it is called a vertical turbine. Similarly if shaft is horizontal, it is called as horizontal turbine.
- The surface of the runner is made very smooth to minimize frictional losses. The runner may be cast in one piece or may be made of separate steel plates and welded together.
- For low heads, the runner may be made of cast iron. But for high heads, the runner is made of steel or alloys. When the water is impure, special alloys are used.

4. Draft tube

The water, after passing through the runner, flows down through a tube called draft tube.

- It increases the head of water equal to the height of the runner outlet above the tail race.
- It increases efficiency of the turbine.



S.NO	RGPV QUESTIONS	Year	Marks
Q.1	What are reaction turbines? What are their important component parts & what are their functions?	Dec 2011	10

UNIT 5/LECTURE 6

Draft Tube:

It is a pipe of gradually increasing area which connects the outlet of the runner to the tailrace. In a Reaction turbine such as a Francis turbine or Kaplan turbine, a diffuser **tube** is installed at the exit of the runner, known as **Draft Tube**. It has following functions:

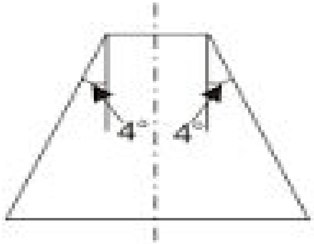
- It is used for discharging water from the exit of the turbine to the tailrace.
- It permits a negative head to be established at the outlet of the runner & thereby increase the net head on the turbine.
- It converts a large portion of KE rejected at the outlet of the turbine into useful pressure energy.

Types of draft tube:

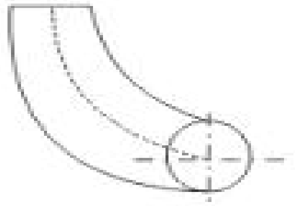
1. **Conical diffuser or straight divergent tube**-This type of draft tube consists of a conical diffuser with half angle generally less than equal to 10° to prevent flow separation. It is usually employed for low specific speed, vertical shaft Francis turbine. Efficiency of this type of draft tube is 90%.

2. **Simple elbow type draft Tube**-It consists of an extended elbow type tube. Generally, used when turbine has to be placed close to the tail-race. It helps to cut down the cost of excavation and the exit diameter should be as large as possible to recover kinetic energy at the outlet of runner. Efficiency of this kind of draft tube is less almost 60%.

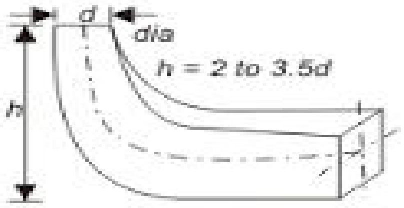
3. **Elbow with varying cross section**-It is similar to the Bent Draft tube except the bent part is of varying cross section with rectangular outlet.the horizontal portion of draft tube is generally inclined upwards to prevent entry of air from the exit end.



(a) Straight type

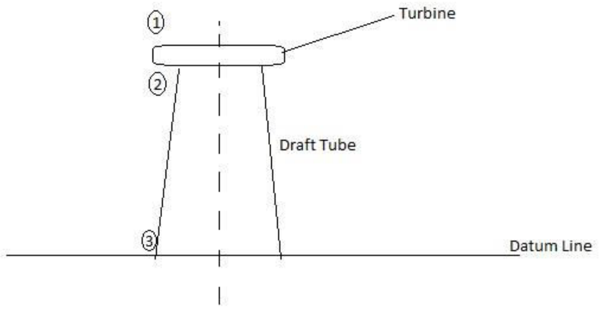


(b) Simple elbow type



(c) Elbow type with varying cross-section

Draft tube theory:



Cavitation occurs when the local absolute pressure falls below the saturated vapor pressure of the water for the water temperature. The height of draft tube is an important parameter for avoiding cavitation.
Applying Bernoulli's equation between outlet of the runner and discharge point of the draft tube

Neglecting any head loss in draft tube)

$$z_2 + \frac{p_2}{\rho g} + \frac{V_2^2}{2\,g} = z_3 + \frac{p_3}{\rho g} + \frac{V_3^2}{2\,g},$$

z_2 = z (Height of draft tube)

z_3 = height of tail race which is referenced as datum line (=0)

p_2 = pressure at the outlet of the runner

p_3 = gauge pressure

$$\frac{p_2}{\rho g} = -\left[z + \frac{V_2^2 - V_3^2}{2\,g}\right]$$

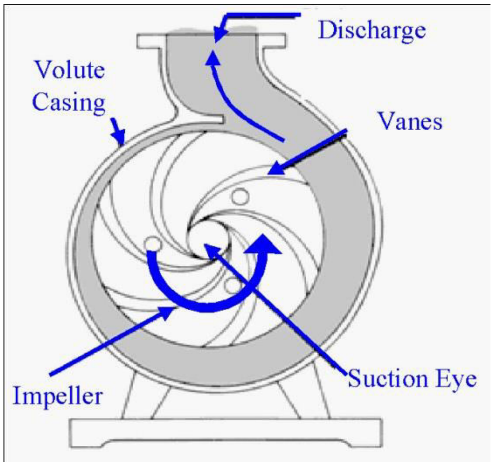
Since draft tube is a diffuser V_3 is always less than V_2 which implies p_2 is always negative thus height of the draft tube is an important parameter to avoid cavitation.

S.NO	RGPV QUESTION	YEAR	MARKS
Q.1	What is a draft tube? Why is it used?	Dec 2014	2
Q.2	What is a draft tube? Explain its different types.	Dec 2013	4

UNIT 1/LECTURE 7

Centrifugal Pump

It is a pump having vanes that rotate in a casing and whirl the fluid around so that it acquires sufficient momentum to discharge from the extremities into a volute casing which surrounds the impeller and in which the fluid is conducted to the discharge pipe.



Main parts of centrifugal pump

1. **Impeller:**

   The rotating part of the pump, consisting of a series of backward curved vanes & is mounted on a shaft which is connected to the shaft of an electric motor.

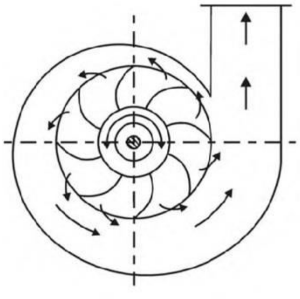
2. **Casing:**

   Similar to the casing of reaction turbine, it is an airtight passage surrounding the impeller & is designed in such a way that the KE of the water discharged at the outlet of the impeller is converted into pressure energy before the water leaves the casing & enters the delivery pipe. Types of casing are:

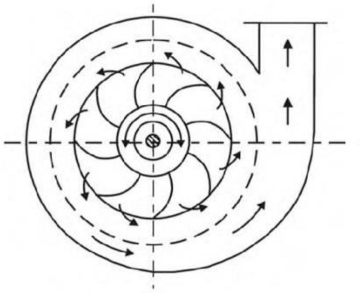
   i. **Volute casing:** the casing that receives the fluid being pumped by the impeller, slowing down the fluid's rate of flow. A volute is a curved funnel that increases in area as it approaches the discharge port. The volute converts kinetic energy into pressure by reducing speed while increasing pressure, helping to balance the hydraulic pressure on the shaft of the pump.

   ii. **Vortex casing:** If a circular chamber is introduced between the casing & the impeller, it is called vortex casing. By introducing circular chamber, the loss of energy due to the formation of eddies is reduced to a considerable extent. Thus the efficiency of the pump is more than the efficiency when only volute casing is provided.

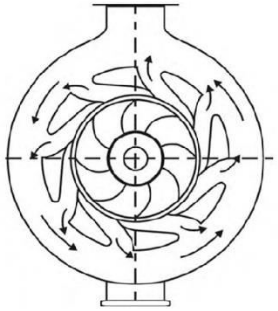
   iii. **Casing with guide blades:** In this, impeller is surrounded by a series of guide blades mounted on a ring which is called diffuser. The guide vanes are designed in such a way that the water from the impeller enters the guide vanes without shock. Also the area of the guide vanes increases, thus reducing the velocity of flow through guide vanes & consequently increasing the pressure of water.



Volute Casing



Vortex Casing



Diffuser Ring Casing

3. **Suction pipe, foot valve & strainer**

   Suction pipe connects the centre of the impeller to the sump from which liquid is to be lifted. It is airtight & provided with a strainer at its lower end so as to prevent the entry of solid particles & other foreign materials etc into the pump. The foot valve is a one way valve located above the strainer into the suction pipe. It serves to fill the pump with liquid before it is started & prevents back flow when the pump is stopped.

4. **Delivery Pipe**

   A pipe whose one end is connected to the outlet of the pump & other end delivers the water at a required height is known as delivery pipe.

Working of a centrifugal pump

The pump is initially primed wherein the suction pipe, casing & portion of the delivery pipe upto the delivery valve are completely filled with the liquid to be pumped. Rapid motion imparted to the impeller then builds up centrifugal force which throws the liquid towards the impeller periphery. This causes pressure gradient in the suction pipe i.e. a partial vacuum exists at the impeller eye (centre of the impeller) while the liquid in the sump is at atmospheric pressure. Consequently liquid from the sump is sucked in the impeller eye. When the liquid passes through the impeller, it receives energy & that results in the growth of both pressure & velocity. The casing collects the liquid from the impeller & guides it to the delivery pipe. Since the casing increases in cross sectional area towards the delivery, kinetic head represented by the high discharge velocity is partially transferred into pressure head before the liquid leaves the pump. The process is continuous as long as motion is given to the impeller & there is supply of liquid to draw upon.

Priming of pump:

Most centrifugal pumps are not self-priming. In other words, the pump casing must be filled with liquid before the pump is started, or the pump will not be able to function. If the pump casing becomes filled with vapours or gases, the pump impeller becomes gas-bound and incapable of pumping. To ensure that a centrifugal pump remains primed and does not become gas-bound, most centrifugal pumps are located below the level of the source from which the pump is to take its suction. The same effect can be gained by supplying liquid to the pump suction under pressure supplied by another pump placed in the suction line.

S.NO	RGPV QUESTION	YEAR	MARKS
Q.1	Explain briefly with neat sketches any two of the following- (i) Volute casing (ii) Vortex casing (iii) Casing with guide blades	Dec 2013	7

UNIT 1/ LECTURE 8

Efficiencies of centrifugal pump

1. Manometric efficiency (η_{max}): ratio of manometric head to the head imparted by the impeller to the water is called manometric efficiency.

   The power at the impeller of the pump is more than the power given to the water at outlet of the pump. The ratio of the power given to water at outlet of the pump to the power available at the impeller is called manometric efficiency.
2. Mechanical efficiency (η_m): the power at the shaft is more than the power available at the impeller of the pump. The ratio of the power available at the impeller to the power at the shaft is known as mechanical efficiency.
3. Overall Efficiency (η_o): it is the ratio of output power of the pump to input power of the pump.

Definitions of head:

1. Suction lift (h_s): the vertical distance between the top surface of liquid in the sump & the centre of the pump impeller.
2. Discharge lift (h_d): the vertical distance between the centre of the pump impeller & the top surface of liquid in the discharge tank.
3. Total static or vertical lift: sum of suction & delivery lifts
4. Suction head (H_s): It is the vertical height of the centre line of the centrifugal pump above the water surface in the suction tank or pump from which water is to be lifted.

   $H_s = h_i + h_{fs} + h_s + (V_s^2/2g)$

Where h_i = loss of head at inlet to suction pipe, h_{fs} = loss of head due to friction and V_s = flow velocity in suction pipe (s denotes for suction pipe) The head ($h_i + h_{fs} + h_s$) is measured by a vacuum gauge installed near the suction flange quite adjacent to pump.

5. Delivery head (H_d): It is the vertical distance between the centre line of the pump & the water surface in the tank to which water is delivered.

$H_d = h_{fd} + h_d + (V_d^2/2g)$

h_{fd} = head loss due to friction & V_d = flow velocity in discharge pipe (d denotes for discharge/delivery pipe).

6. Total external head (H): head against which the pump has to work. It is given by

$H = H_s + H_d - (V_s^2/2g)$

Where $H_s + H_d$ is also called static head.

7. Manometric head: difference between the total energy of fluid at inlet to and at exit from the pump. It is given by following expressions:

a. H_m = total head at outlet – total head at inlet

$=\left\{\frac{P_o}{\rho g} + \frac{V_o^2}{2g} + Z_o\right\} - \left\{\frac{P_i}{\rho g} + \frac{V_i^2}{2g} + Z_i\right\}$

b. H_m = static head + head losses (friction & minor) in the suction & delivery pipe + velocity head at delivery pipe

$= H_s + H_d + h_{fd} + h_{fs} + \frac{V_o^2}{2g}$

8. Net positive suction head: NPSH = (absolute pressure at inlet to pump) – (vapour pressure of liquid being pumped) + (velocity head in suction pipe)

$\text{NPSH} = \frac{P_i}{\rho g} - \frac{P_v}{\rho g} + \frac{V_i^2}{2g}$

NPSH represents suction head at the impeller eye, which further represents the head required to make the liquid flow from the suction pipe to the pump impeller. For smooth & cavitation free operation of the pump, NPSH should have a value such that the flowing liquid does not boil under reduced pressure.

9. Shut off head: It is the highest point to which the pump will lift the liquid.

S.NO	RGPV QUESTION	YEAR	MARKS
Q.1	Define manometric, mechanical & overall efficiency of a centrifugal pump.	Dec 2014	3