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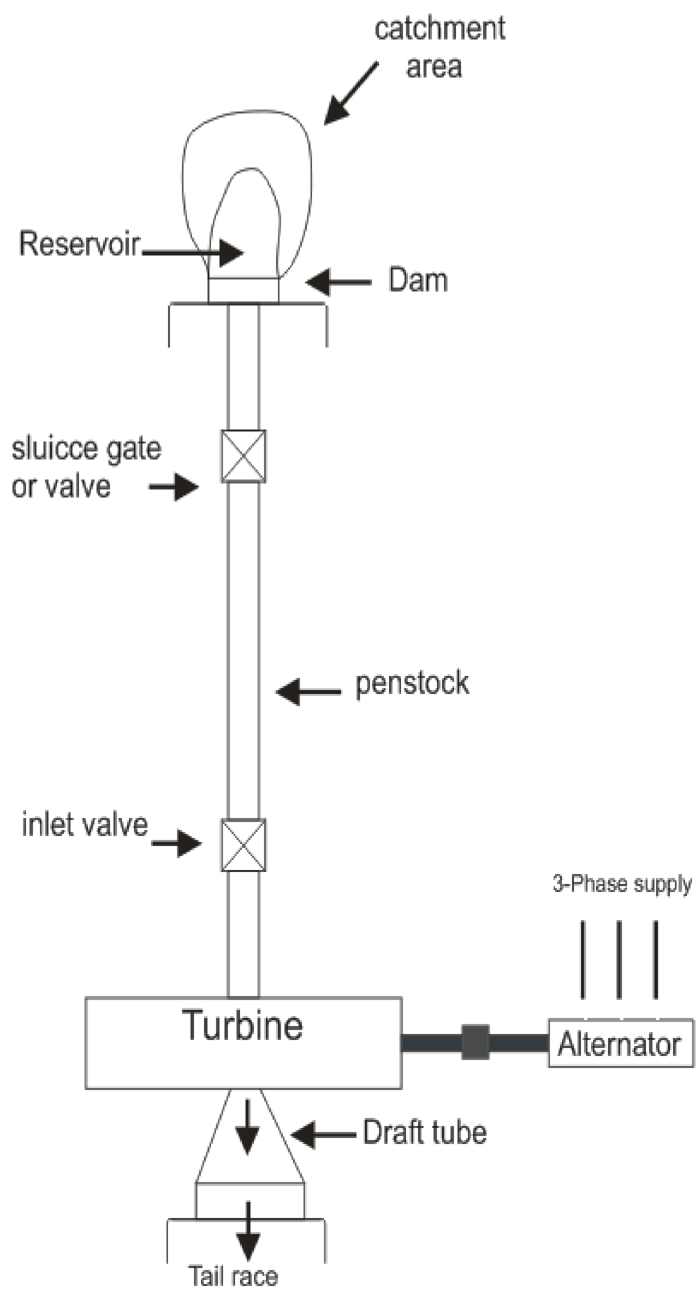
UNIT - 4

Hydraulic Turbines and Pumps

INTRODUCTION

Hydraulic turbines use the **potential and kinetic energy** of water and **converted** it into usable **mechanical energy** as efficiently as possible. The mechanical energy is used in running an electric generator which is directly coupled to the shaft of hydraulic turbine for generate the electricity & this generated power can be transmitted to long distance with the help of transmission lines & transmission towers.



CLASSIFICATION OF WATER TURBINES:-

IMPLUSE TURBINE: Are those turbines in which the available fluid energy is converted into kinetic energy by a nozzle.

REACTION TURBINE: Are those turbines in which the energy of the fluid is partly transformed into kinetic energy before it enters the runner of the turbine.

WATER TURBINE			
S.No.	**BASIS**	**IMPLUSE TURBINE**	**REACTION TURBINE**
1.	**According to water flow through runner**	**Tangential Flow** (example:- Pelton Turbine)	**a) Axial or Parallel Flow** (eg. Kaplan Turbine). **b) Mixed Flow i.e. Radial and Axial** (eg. Modern Francis Turbine). **c) Outward Radial Flow** (eg. Fourneyron Turbine) **d) Inward Radial Flow** (eg. Old Francis Turbine)
2.	**According to head**	**High Head** (above 250m) :- Pelton Turbine	**Low** (upto 30 m):- Propeller and Kaplan Turbine. **Medium Head** (60-250 m):- Modern Francis Turbine.
3.	**According to discharge**	**Small rate of flow**: - Pelton Turbine.	**Medium rate of flow**: - Modern Francis Turbine. **Very High**: - Propeller and Kaplan Turbine.
4.	**According to specific speed (in r.p.m)**	**For Pelton Turbine:-** 9-17 for a slow runner 17-25 for a normal runner 25-30for a fast runner 40for a double jet	**For Francis Turbine:-** 50–100 for a slow runner 100-150 for a normal runner 150-250 for a slow runner **For Kaplan Turbine**:- 250-850 r.p.m
5.	**According to disposition of shaft**	**Horizontal** shaft and **Vertical runner** arrangement	Either **horizontal** or **vertical** shaft

Difference B/W Impulse Turbine & Reaction Turbine

Sr no	Impulse turbine	Reaction turbine
1.	All the fluid energy of the fluid is convertesd into K.E by an efficient nozzle that forms a free jet.	Only a portion of the fluid energy is transformed into K.E before the fluid enters the turbine runner.
2.	The jet is unconfined & atmospheric pressure throughout the action of water on the runner, & during its subsequent flow to the tail race.	Water enters the runner with an exess pressure , & then both the velocity & pressure change as water passes through the runner
3.	Blades are only in action when they are in front of the nozzle.	Blades are in action all the time.
4.	Water may be allowed to enter a part or whole of the wheel circumfrence.	Water is admitted over the circumfrence of the wheel.
5.	The wheel does not run full & air has free access to the buckets.	Water completely fills the vane passenger throughout the operation of the turbine.
6.	Casing has no hydraulic function to perform; it only serves to prevent splashing & to guide the water to the tail race.	Pressure at inlet to the turbine is muvh higher than the pressure at outlet; unit has to be sealed from atmospheric condition &, therefore, casing is absolutely essential.
7.	Unit is installed above the tail race.	Unit is kept entirely submerged in water below rhe tail race.
8.	Flow regulation is possible without loss.	Flow regulation is always accompanied by loss.
9.	When water glides over the moving blades, its relative velocity either remains constant or reduces slightky due to fricton.	Since there is continuous drop in pressure during flow through the blade passage, the relative velocity does increase.

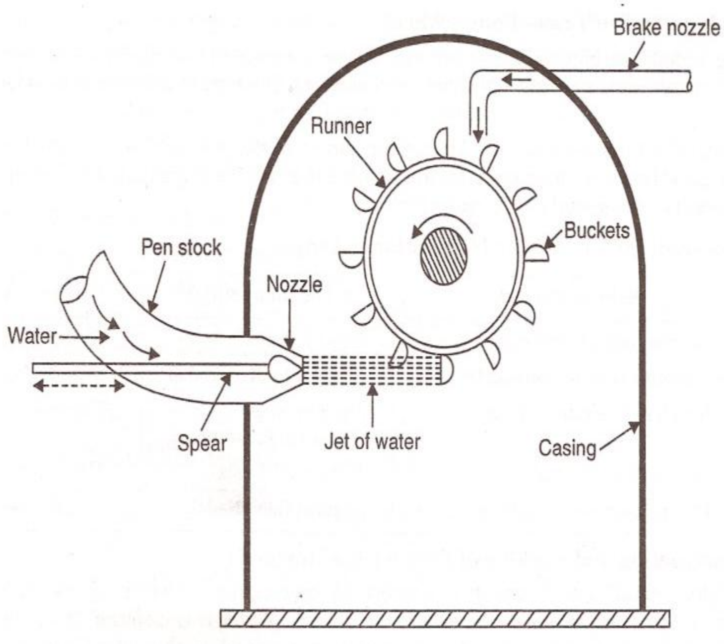
Pelton Turbine

The Pelton wheel turbine is a tangential flow impulse turbine. The water strikes the bucket along the tangent of the runner. The energy available at the turbine is only kinetic energy. This turbine is used for high head and is named after the American engineer Lester Pelton.

CONSTRUCTION DETAILS OF PELTON TURBINE

Components of the Pelton turbine:-

- **Nozzle**: - the amount of water striking the vanes (buckets) of the runner is controlled by providing a spear (flow regulating arrangement) in the nozzle.
- **Spear**: - the spear is a conical needle which is operated either by a hand wheel or automatically in an axial direction depending upon the size of the unit.
  - **Runner with bucket**: - runner of Pelton wheel consists of a circular disc on the periphery of which a number of buckets evenly spaced are fixed.
  - **Casing: -** casing is to prevent the splashing of the water and to discharge water to tail race. It is made up of cast iron or steel plate.



- **Breaking jet**: - when the nozzle is completely closed by moving the spear in the forward direction the amount of water striking the runner reduce 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 providing which directs the jet of water on the back of vanes. This jet of water is called breaking jet.
- **Governing mechanism**: - speed of turbine runner is required to be maintained constant so that electric generator coupled directly to turbine.

Working Of Pelton Turbine

The amount of water striking the vanes (buckets) of the runner is controlled by providing a spear (flow regulating arrangement) in the nozzle. Then the efficient nozzle that converts the hydraulic energy into a high speed jet, the turbine rotor is called runner. The impact jet of water is striking on the runner and runner revolves at constant with the help of governing mechanism. The runner shaft is connected with the generator; thus the electricity is produce with the help of generator.

Efficiencies Of Pelton Turbine

- **Mechanical efficiencies**: - It is ratio of the shaft power to the water power.
- **Hydraulic efficiencies**: - It is ratio of the power developed at the turbine runner to the power supplied by the water jet at entrance to the turbine.
- **Volumetric efficiencies**: - It is ratio of the theoretical to the actual discharge.
- **Overall efficiencies**: - It is ratio of the shaft power to the water power.

Specific Speed Of Pelton Turbine

Specific speed of a Pelton turbine is refers to the speed of a turbine which is identical in shapes, blade angles, geometrical dimensions and gate opening etc (i.e. geometrically similar turbine) which would develop unit power when working under a unit head. It is denoted by N_s.
Expression for specific speed of a turbine is:

$$N_S = \frac{N(P)^{1/2}}{(H)^{5/4}}$$

Where N: - Speed in r.p.m
P: - Power in KW
H: - Net available head

In general for Pelton Wheel Turbine: -

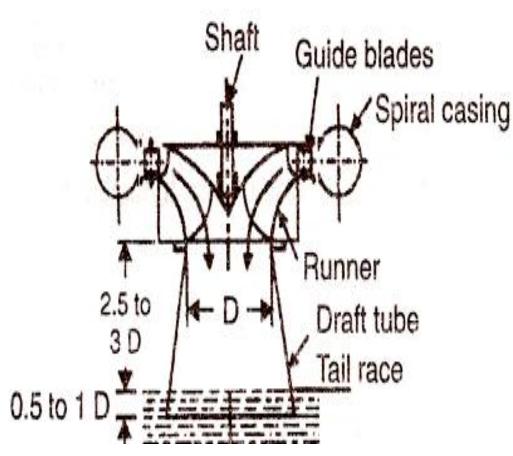
N_S	**9 – 17 for a slow runner**
	17 – 25 for a normal runner
	25 – 30 for a fast runner
	40 for a double jet

Francis Turbine

The Francis turbine is an inward mixed flow reaction turbine which was designed and developed by the American engineer James B. Francis. Francis turbine has a purely radial flow runner; the flow passing through the runner had velocity component only in a plane of the normal to the axis of the runner.

Reaction hydraulic turbines of relatively medium speed with radial flow of water in the component of turbine is runner

Diagram



Construction details of Francis turbine

Components of the Francis turbine:-

- **Pen stoke**: - It is a large sized shaped; where the water is provided to the turbine runner from the dam.
- **Scroll casing**: - Penstocks connected to and feeds water directly into an annular channel surrounding the turbine runner. The channel is spiral in its layout.
- **Guide vanes**: - A series of airfoil shaped vanes called the guide vanes are arranged inside the casing to form a number of flow passages between the casing and the runner blades. Guide vanes are fixed in position (they do not rotate with rotating runner).
- **Guide wheel and governing mechanism**: - It changes the position of guide blades to affect variation in the water flow rate in the wake of changing load conditions on the turbine. When the load changes, the governing mechanism rotates all the guide blades about their axis through the same angle so that the water flow rate to the runner.
- **Runner and runner blades**: - Runner of the Francis turbine is a rotor which has passages formed between the drat tube and scroll casing. The numbers of runner
  Blades vary b/w 16 to 24.
- **Draft tube**: - After passing through the runner, the water is discharged to the tail race through a gradually expanding tube.

Working of Francis turbine

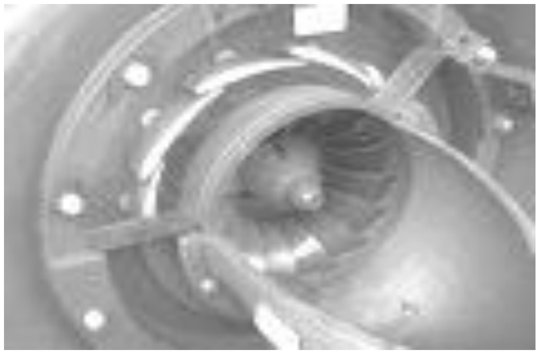
The amount of water falls on the vanes (buckets) of the runner. The turbine rotor is called runner. Runner revolves at constant with the help of governing mechanism. The runner shaft is connected with the generator; thus the electricity is produce with the help of generator. And the water is discharge from the tail race.

Theory of operation:- The Francis turbine is a reaction turbine, which means that the working fluid changes pressure as it moves through the turbine, giving up its energy. A casement is needed to contain the water flow. The turbine is located between the high pressure water source and the low pressure water exit, usually at the base of a dam.

The inlet is spiral shaped. Guide vanes direct the water tangentially to the runner. This radial flow acts on the runner vanes, causing the runner to spin. The guide vanes (or wicket gate) may be adjustable to allow efficient turbine operation for a range of water flow conditions.

As the water moves through the runner its spinning radius decreases, further acting on the runner. Imagine swinging a ball on a string around in a circle. If the string is pulled short, the ball spins faster. This property, in addition to the water's pressure, helps inward flow turbines harness water energy.

Francis Turbine and generator



Guide vanes at minimum flow setting (cut-away view)

Guide vanes at full flow setting (cut-away view)

At the exit, water acts on cup shaped runner features, leaving with no swirl and very little kinetic or potential energy. The turbine's exit tube is specially shaped to help decelerate the water flow and recover kinetic energy.

Application

Francis Inlet Scroll, Grand Coulee Dam.Large Francis turbines are individually designed for each site to operate at the highest possible efficiency, typically over 90%. They are best suited for sites with high flows and low to medium head. Francis Turbines are very expensive to design, manufacture and install, but operate for decades.

In addition to electrical production, they may also be used for pumped storage; where a reservoir is filled by the turbine (acting as a pump) during low power demand, and then reversed and used to generate power during peak demand.

Francis turbines may be designed for a wide range of heads and flows. This, along with their high efficiency, has made them the most widely used turbine in the world.

Specific speed of Francis turbine

Specific speed of a Francis turbine is refers to the speed of a turbine which is identical in shapes, blade angles, geometrical dimensions and gate opening etc (i.e. geometrically similar turbine) which would develop unit power when working under a unit head. It is denoted by N_s. Expression for specific speed of a turbine is:-

$$N_S = \frac{N\,(P)^{1/2}}{(H)^{5/4}}$$

Where N: - Speed in r.p.m
P: - Power in KW
H: - Net available head

For Francis Turbine: - $\mathbf{N_S}$ = 50 – 100 for a slow runner
= 100 – 150 for a normal runner
= 150 - 250 for a fast runner

Work done and efficiencies of Francis turbine:-

Work done (W):- $\rho Q\,(V_{u1}\,u_1 + V_{u2}\,u_2)$

Where: V_{u1}, V_{u2}:- velocity of whirl at inlet and outlet respectively
u_1, u_2:- peripheral velocity at inlet and outlet respectively

Hydraulic efficiencies (η):- $\eta_h = \dfrac{V_{u1}\,u_1}{gH}$

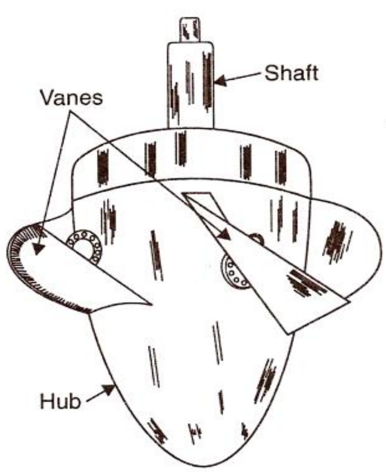
Where N: - Speed in r.p.m
P: - Power in KW
H: - Net available head

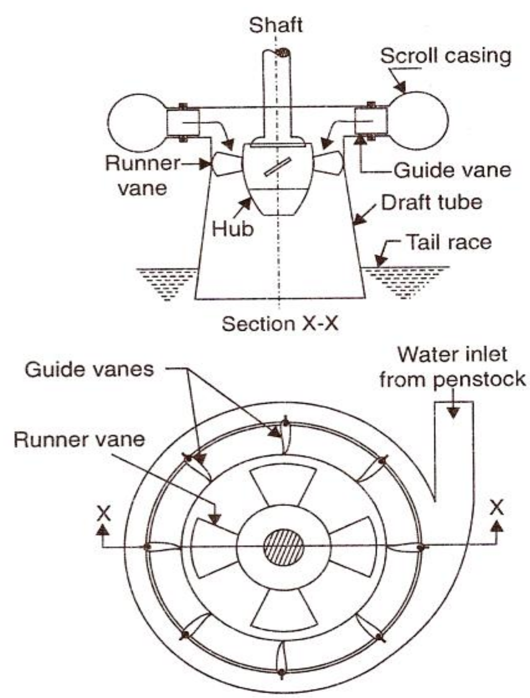
Kaplan Turbine

Kaplan-type hydraulic turbine in which the positions of the runner blades and the wicket gates are adjustable for load change with sustained efficiency, it is a purely axial flow turbine with a vertical shaft disposition. Which was designed and developed by the Australian engineer Viktor Kaplan? Kaplan turbine has adjustable runner blades with less number of blades (i.e. 3 to 8 blades). Kaplan turbines are now widely used throughout the world in high-flow, low-head power production.

Victor Kaplan obtained his first patent for an adjustable blade propeller turbine in 1912. But the development of a commercially successful machine would take another decade. Kaplan struggled with cavitations problems, and in 1922 abandoned his research for health reasons.

DIAGRAM





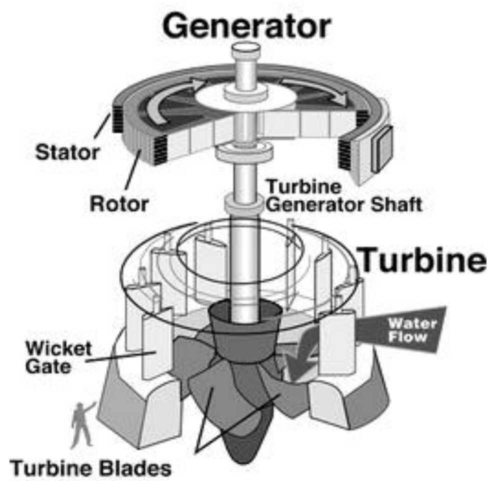
Construction details of Kaplan turbine

Components of the Kaplan turbine:-

- **Scroll casing**: - It is the cashing in which we pass the water to the runner in the turbine.
- **Guide vanes:** - It is the blade in which guides the water and control the water passage (i.e. how much the water flow goes in the turbine).
- **Draft tube**: - After passing through the runner, the water is discharged to the tail race through a gradually expanding tube.
- **Runner**: - It is an important part of the turbine which is connected to the shaft of the generator and consist movable vanes and hub (boss).
- **Hub (Boss):-** It is the part of the runner in which blades are mounted.

Working of Kaplan turbine

The Kaplan turbine is an inward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy. The design combines radial and axial features.



The inlet is a scroll-shaped tube that wraps around the turbine's wicket gate. Water is directed tangentially, through the wicket gate, and spirals on to a propeller shaped runner, causing it to spin.

The outlet is a specially shaped draft tube that helps decelerate the water and recover kinetic energy.

The turbine does not need to be at the lowest point of water flow, as long as the draft tube remains full of water. A higher turbine location, however, increases the suction that is imparted on the turbine blades by the draft tube. The resulting pressure drop may lead to capitation. Variable geometry of the wicket gate and turbine blades allows efficient operation for a range of flow conditions. Kaplan turbine efficiencies are typically over 90%, but may be lower in very low head applications.

Applications

Kaplan turbines are widely used throughout the world for electrical power production. They cover the lowest head hydro sites and are especially suited for high flow conditions. Inexpensive micro turbines are manufactured for individual power production with as little as two feet of head.

Large Kaplan turbines are individually designed for each site to operate at the highest possible efficiency, typically over 90%. They are very expensive to design, manufacture and install, but operate for decades.

Work done and efficiencies of Kaplan turbine:-

The W.D of Kaplan turbine will be :

Work done (W):- $\rho Q (V_{u1} u_1 + V_{u2} u_2)$

Where V_{u1}, V_{u2}:- velocity of whirl at inlet and outlet respectively

u_1, u_2:- peripheral velocity at inlet and outlet respectively

ρ: - density of water

Q: - discharge

Hydraulic efficiencies (η):- $\eta_h = \frac{V_{u1} u_1}{gH}$

Where N: - Speed in r.p.m

P: - Power in KW

H: - Net available head

Discharge (Q):-

$$Q = \frac{\pi (D_o^2 - D_b^2) K_f (2gH)^{1/2}}{4}$$

Where D_o: - outer diameter of runner

D_b: - diameter of hub

K_f: - flow ratio

H: - head of the turbine

Specific speed of Kaplan turbine:-

Specific speed of a Kaplan turbine is refers to the speed of a turbine which is identical in shapes, blade angles, geometrical dimensions and gate opening etc (i.e. geometrically similar turbine) which would develop unit power when working under a unit head. It is denoted by N_s.

Expression for specific speed of a turbine is:-

$$N_S = \frac{N (P)^{1/2}}{(H)^{5/4}}$$

Where N: - Speed in r.p.m

P: - Power in KW

1H: - Net available head

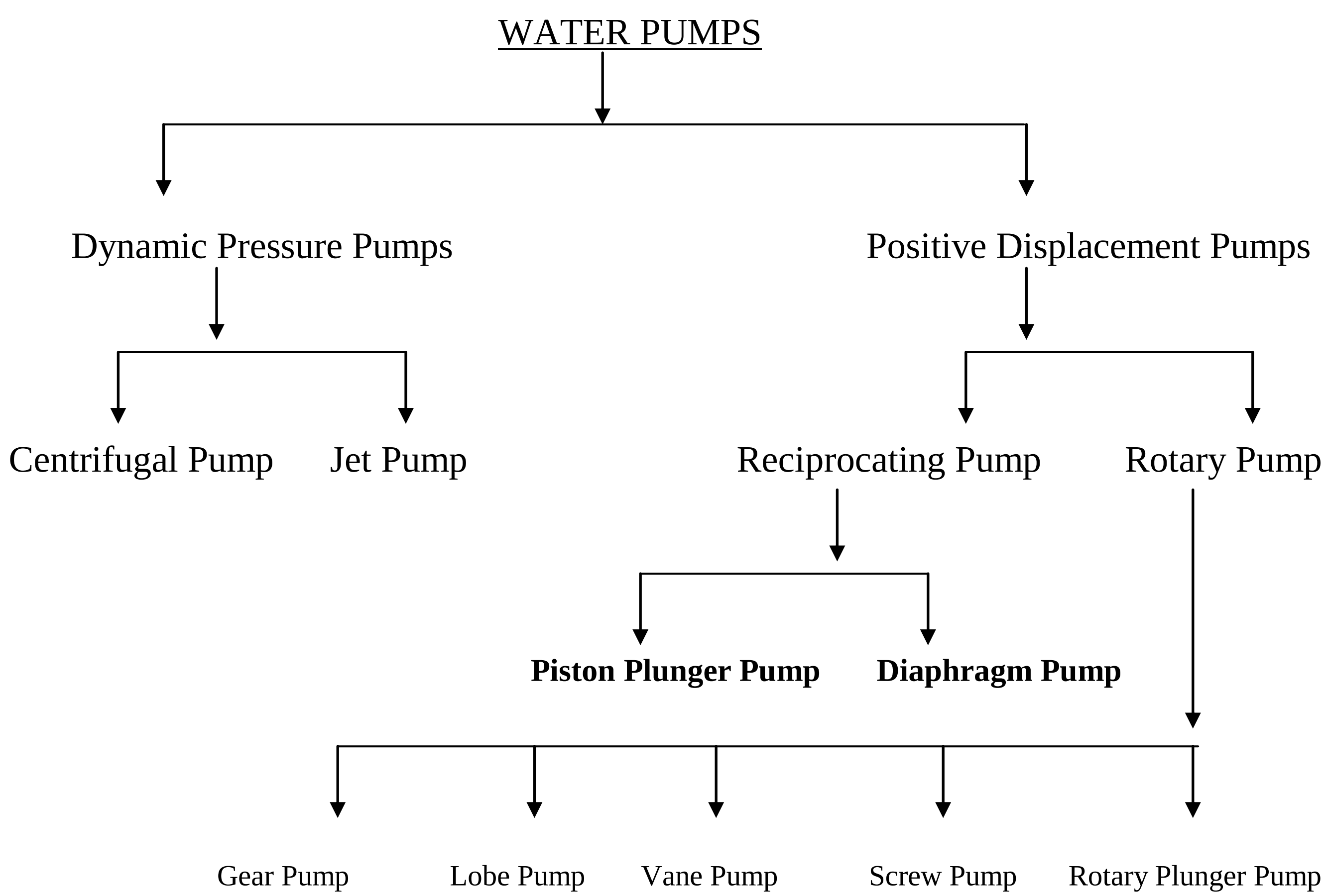
For **Kaplan Turbine**: - $N_S = 250 - 850$

Water Pumps

There are many types of hydraulic machinery. The most popular ones used in civil engineering are called turbo machines (i.e. a rotating element through which the fluid passes). The rotor is called runner in a turbine and impeller in a water pump.

Turbo machines are classified as axial-flow, radial-flow and mixed-flow machines depending on the predominant direction of the fluid motion relative to the rotor's axis as the fluid passed the blades.

Classification Of Water Pumps



Descriptions : there are two types of water pump which are:

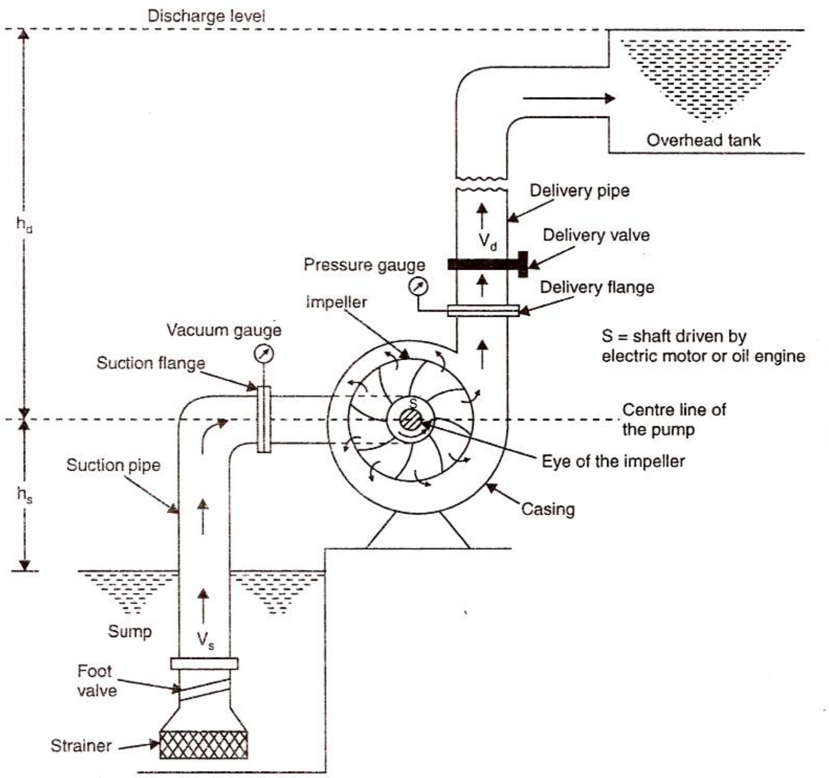
- Centrifugal Pump
- Reciprocating Pump

Centrifugal Pump

Centrifugal pumps are the most widely used of all the turbo machine (or rotodynamic) pumps. This type of pumps uses the centrifugal force created by an impeller which spins at high speed inside the pump casing.

Principle: Its principle work on Centrifugal force.

Diagram



Contruction Details Of A Centrifugal Pump

Centrifugal pump is classified as the following:-

1. Stationary components
2. Rotating components

1. Stationary components of the centrifugal pump are the following :-

a) **Casing**: - It is an air tight passage surrounding the impeller. It is designed in such a way that the kinetic energy of the water discharged at the outlet of the impeller is converted into pressure energy before the water leaves the casing and enters the delivery pipe.

Types of casing:-

- **Volute casing**: - It is spiral type of casing in which area of flow increase gradually. The increase in area of flow decreases the velocity of flow and increases the pressure of water.
- **Vortex casing**: - if a circular chamber is introduced between casing and the impeller, the casing is known as vortex casing.
- **Casing with guide blades**: - the impeller is surrounded by a series of guide blades mounted on a ring know as diffuser.

b) **Suction pipe**: - a pipe whose one ends is connected to the inlet of the pump and other end dip into water in a sump.

c) **Delivery pipe**: - a pipe whose one end is connected to the outlet of the pump and other end is involved in delivering the water at a required height.

2. Rotating component of the centrifugal pump is Impeller.

Impeller: - It is the main rotating part that provides the centrifugal acceleration to the fluid.

Classification of impeller:-

a) **Based on direction of flow** :-

- **Axial-flow**: - the fluid maintains significant axial-flow direction components from the inlet to outlet of the rotor.
- **Radial-flow**: - the flow across the blades involves a substantial radial-flow component at the rotor inlet, outlet and both.
- **Mixed-flow**: - there may be significant axial and radial flow velocity components for the flow through the rotor row.

b) **Based on suction type** :-

- **Single suction**: - liquid inlet on one side.
- **Double suction**: - liquid inlet to the impeller symmetrically from both sides.

c) Based on mechanical construction :-

- **Closed**: - shrouds or sidewall enclosing the vanes.
- **Open**: - no shrouds or wall to enclose the vanes.
- **Semi-open or vortex type**.

<u>Working Of Centrifugal Pump</u>

Water is drawn into the pump from the source of supply through a short length of pipe (suction pipe). Impeller rotates; it spins the liquid sitting in the cavities between the vanes outwards and provides centrifugal acceleration with the kinetic energy. This kinetic energy of a liquid coming out an impeller is harnessed by creating a resistance to flow. The first resistance is created by the pump volute (casing) that catches the liquid and shows it down. In the discharge nozzle, the liquid further decelerates and its velocity is converted to pressure according to BERNOULLI’S PRINCIPAL.

Specific speed: - speed of an imaginary pump geometrically similar in every respect to the actual pump and capable of delivering unit quantity against a unit head. It is denoted by N_S:-

$$N_S = \frac{N (Q)^{1/2}}{(H)^{3/4}}$$

Where: N: - pump speed in r.p.m

Q: - discharge in m^3/sec

H: - head per stage in mete

Tabulated form of specific speed in a centrifugal pump:

Pump	Speed	Specific speed (in r.p.m)
Radial flow	Slow Medium High	10-30 30-35 50-80
Mixed flow		80-160
Axial flow		100-450

Efficiencies of centrifugal pumps:-

1. **Mechanical efficiencies**: - It is ratio of the impeller power to the shaft power.
2. **Hydraulic efficiencies**: - It is ratio of the manometric head to the Euler head.
3. **Volumetric efficiencies**:- It is ratio of the actual to the theoretical discharge.
4. **Overall efficiencies**: - It is ratio of the water power to the shaft power.

Reciprocating pumps

Reciprocating pump operates on the principle of pushing of liquid by a piston that executes a reciprocating motion in a closed fitting cylinder.

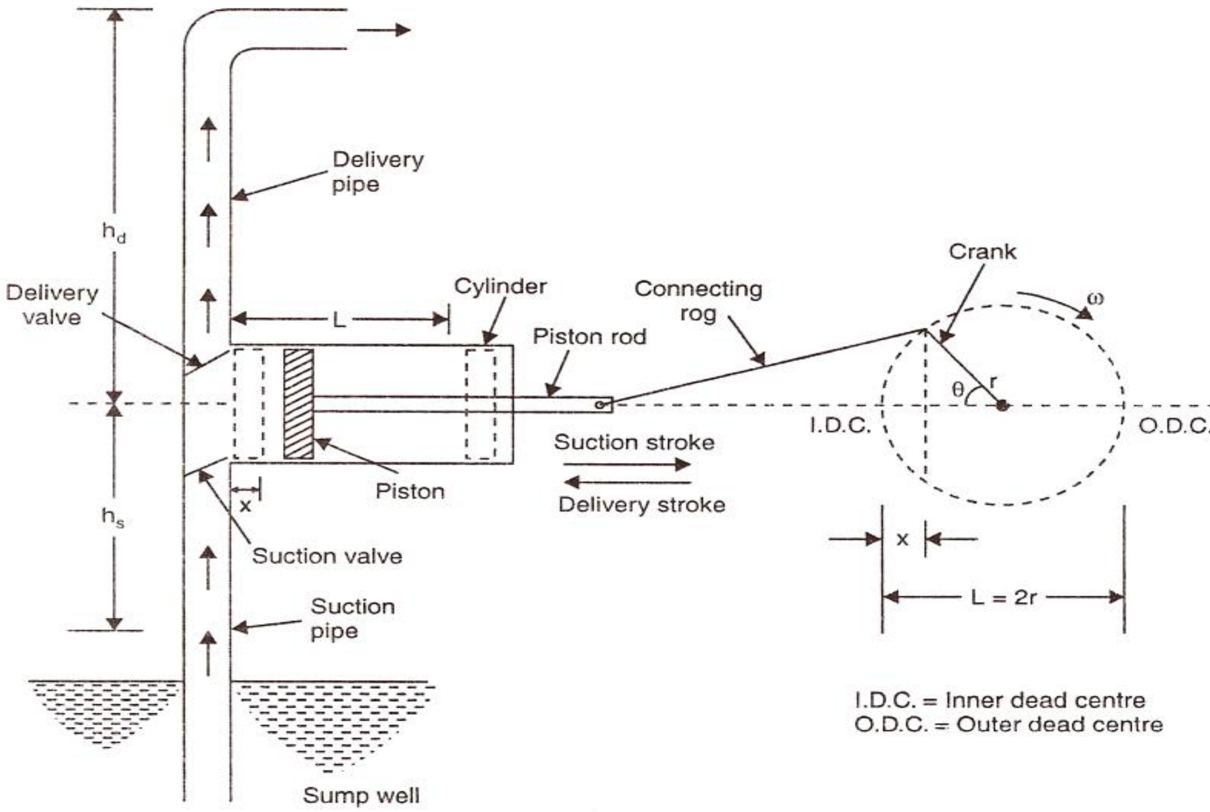
Contruction Details Of A Reciprocatin Pump

Components of reciprocating pumps:-

a) **Piston or plunger**: - a piston or plunger that reciprocates in a closely fitted cylinder.
b) **Crank and Connecting rod**: - crank and connecting rod mechanism operated by a power source. Power source gives rotary motion to crank. With the help of connecting rod we translate reciprocating motion to piston in the cylinder.
c) **Suction pipe**: - one end of suction pipe remains dip in the liquid and other end attached to the inlet of the cylinder.
d) **Delivery pipe**: - one end of delivery pipe attached with delivery part and other end at discharge point.

e) **Suction and Delivery value**: - suction and delivery values are provided at the suction end and delivery end respectively. These values are non-return values.

Diagram:



Working Of Reciprocating Pump

Operation of reciprocating motion is done by the power source (i.e. electric motor or i.c engine, etc). Power source gives rotary motion to crank; with the help of connecting rod we translate reciprocating motion to piston in the cylinder (i.e. intermediate link between connecting rod and piston). When crank moves from inner dead centre to outer dead centre vacuum will create in the cylinder. When piston moves outer dead centre to inner dead centre and piston force the water at outlet or delivery value

Expression for discharge of the pump:-

$$Q = \frac{A\,L\,N}{60}$$

Where: - Q: - discharge in m^3/sec
A: - cross-section of piston or cylinder in m^2
L: - length of stroke in meter
N: - speed of crank in r.p.m