# UNIT - V

## HYDRO POWER SYSTEMS (3)

Hydropower is the power obtained by utilizing the energy of water, by making it to pass through the turbines & finally generating electricity.

→ Hydro electric power station is one type of alternate method of producing power. water is used as working medium.

### Factors to be considered while selecting a site for hydroelectric power station :-

→ The following factors to be considered

① The water availability & storage

② The availability of water head

③ Distance from the load centres

④ Accessibility of the site

⑤ Type of land & cost of the site etc.

### ① The water availability & storage :-

→ The data is generally available from hydro-graphs. Requirement of Poundage & spill ways is also studied & assessed. Plant capacity depends on this analysis

→ storage of water is another important factor

because water may not be available in all seasons of the year, so with minimum expenditure maximum storage should be provided. Depends on the head, power is generated.

② Availability of water head :-

· Using stream flow recorder & geographical conditions, the water head can be estimated. water head effects the power generations considerably.

→ For a given power increase in effective head reduces the water quantity required to be stored.

③ Distance from the load center :-

→ For the power transmission to be economical, usually hydro power plants are located nearer to the load centers.

④ Accessibility of the site :-

→ The site where hydro electric plant is to be constructed should be easily accessible. while construction heavy equipments ar transported to the site.

⑤ Type of land & cost :-

→ The land must & should be observe large quantity of water. The land cost must be as low as possible, other wise it impact on total cost of the plant.

## Advantages of Hydro electric power plant :-

① The operating cost of the hydro electric power plant is low as compared to thermal plants.

② compared to thermal plant, there is no need of purchasing fuel for the hydroplants.

③ In hydro electric plants response to change of load is quick.

④ These plants use robust machines which run at low speeds at 300 to 400 rpm.

⑤ There is no problem of handling the coal & ash, contents

⑥ There is no release of smoke, so atmosphere is not pollutated,

⑦ It is also used as a base & peak load power plant.

⑧ Hydro electric energy is a continuously renewable energy.

---

## Disadvantages :-

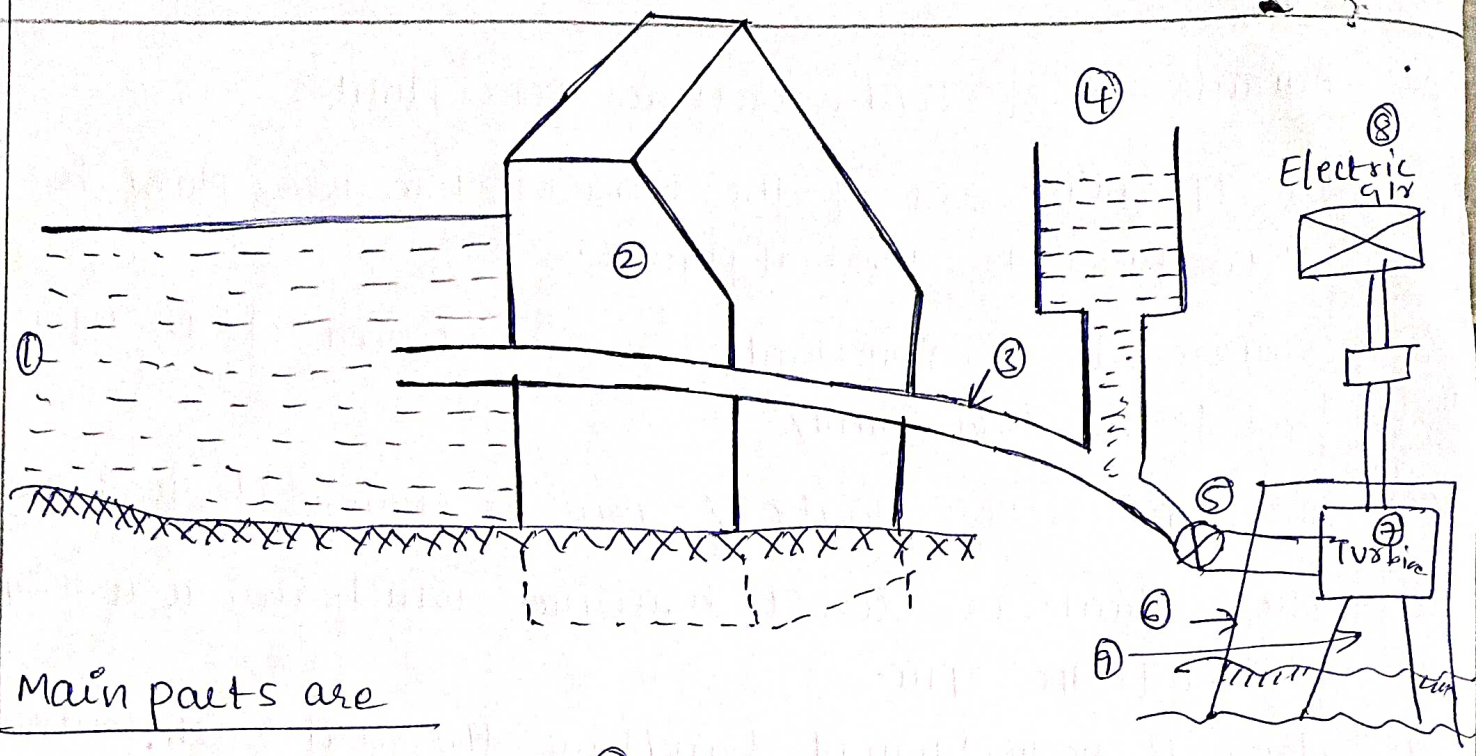
① The capital cost of the plant is more than the thermal plant.

② Power generated by the plant depends on the water quantity.

③ The time required for construction of hydro power plant is long.

④ Generally these plants are situated away from the load centres, where water facility is available so transmission cost is high.

---




Main parts are

1. Storage Reservoir
2. Dam
3. Penstock
4. Surge tank
5. Valve
6. Power house
7. Turbine
8. Electrical generator
9. Draft tube

① → **Reservior :-** It is used to store the water available from catchment area. These are two types.

i) Natural Reservoirs ii) Artificial Reservoirs

a) **Natural Reservoirs :-**

These are formed in high & huge hill rocks & mountains. water is taken through tunnels to power house.

b) **Artificial Reservoirs :-**

→ These are formed by constructing a dam across the river.

→ During flood season, water head is build up. The Dam is generally constructed to store the large quantity of water.

② **Dam:-** It is a thick reinforced, concrete wall to store large quantity of water. It has two functions.

① It builds up water head

② It works as a storage reservoir & has capacity to store water.

→ **Based on the functions:-**

① storage dams

② Diversion dams

→ **Based on the shape of dam:-**

① multiple arch dams

② Trapezoidal dams

→ **Based on the construction materials:-**

① Rocks pieces & fragments

② R.C.C. Reinforced Cement Concrete

---

III. **Penstock:-** It is a pipe used to carry the water from reservoir to the power house. It should be laid in such a way that, it follows the shortest route. It is made up of steel, R.C.C.

IV **surge tank:-** It is a reservoir fitted on the penstock near the turbine to recieve excess water when the penstock is suddenly closed by a valve or governer mechanism.

**The main functions are:-**

① Acts as a relief valve

② Reduce water hammer in penstocks

③ To maintain a smooth & continous discharge through pipe lines. ④ It is also seves as water level controller.

www.Jntufastupdates.com

control

(6) Powerhouse:- It is a building/plant in which valves, w.t, E/G, t/F & other components are housed.

(7) Turbine:- The water having high kinetic energy & potential energy is directed to flow on to the turbine blade to produce mechanical energy. two types are used

1. Impulse turbine (pelton wheel)
2. Reaction turbine (Francis & Kaplan turbine).

(8) Generator:- It is a device which is used to convert m/E → E/E → salient pole synchronous alternator

(9) Draft tube:- It is generally located at the outlet of the turbine. which is used to decrease the pressure much below the atmospheric pressure at the outlet of the turbine.

## Types of Hydroelectric power plants :-

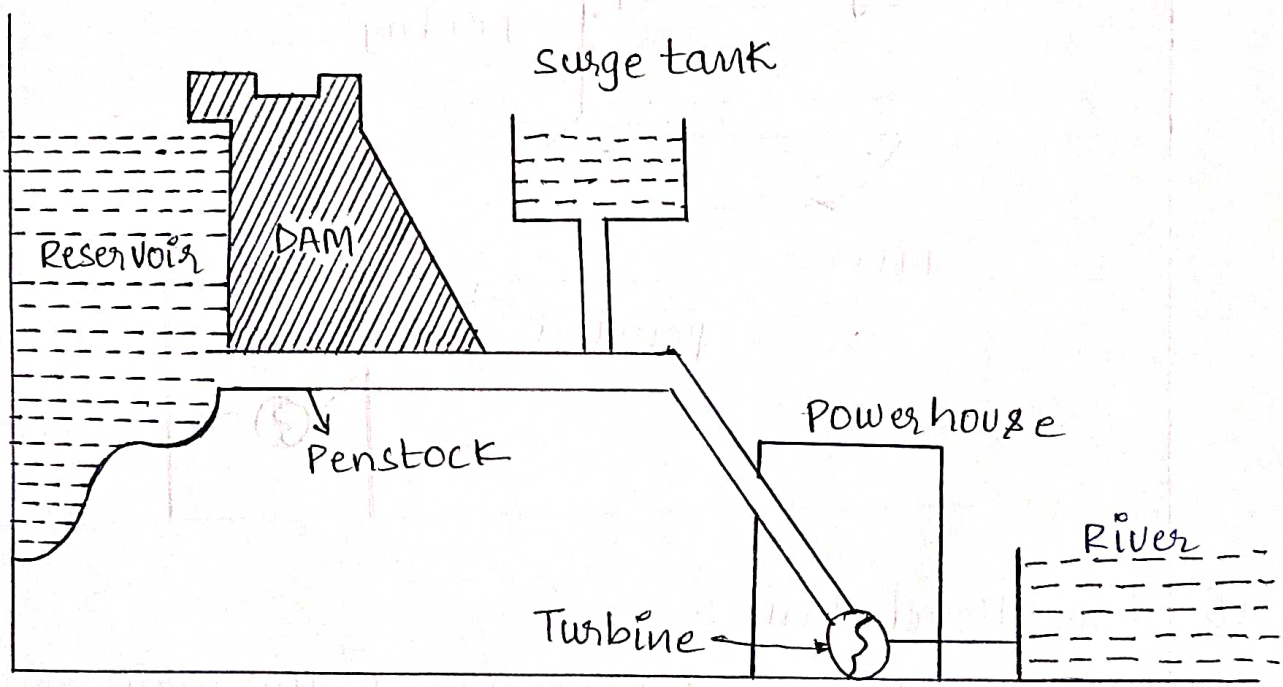
→ The Hydro electric power plants are classified as

① High head plants

② Medium head plants

③ low Head plants.

## High head plants :-




→ If the head is more than 100m & more than that plants are known as high head plants. Pelton wheel is employed in such plants as a prime mover.

→ The water from the main reservior is first carried by a tunnel upto surge tank & then carried through penstock to power house. Surge tank reduces water hammer effects on the penstock.

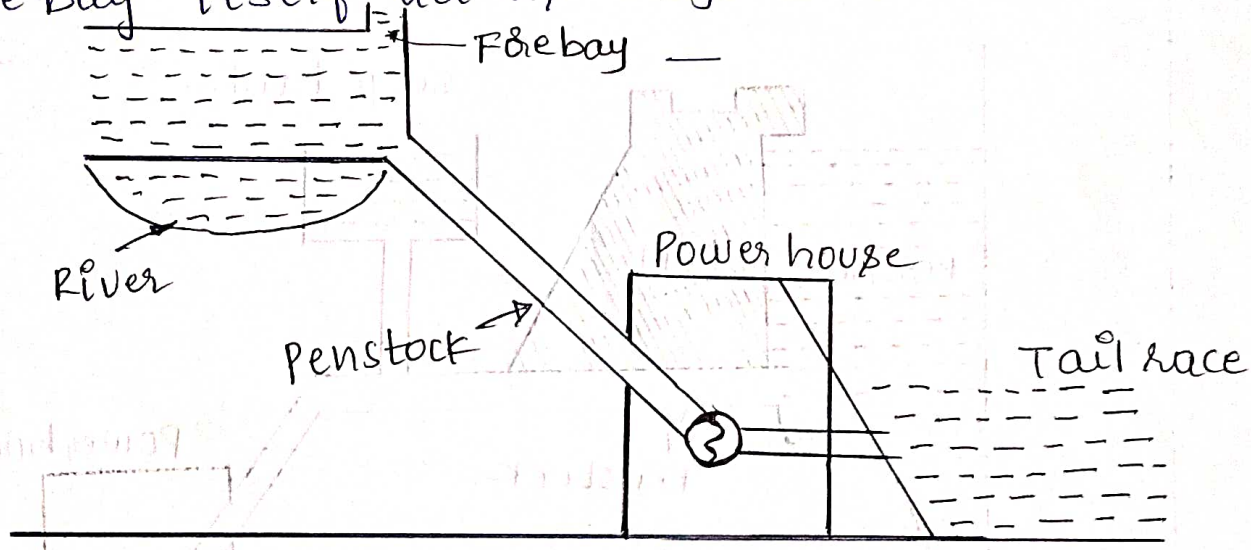
→ pelton wheel is made of cast steel, bronze or stainless steel.

## Medium Head Plant :-

→ If the head is between 30m & 100m, then the power plants are categorized as medium head power plants.

→ Francis turbines are used as prime movers in these plants. water is carried by penstocks. Forebay is provided at the begining of penstock & serves as a reservoir.

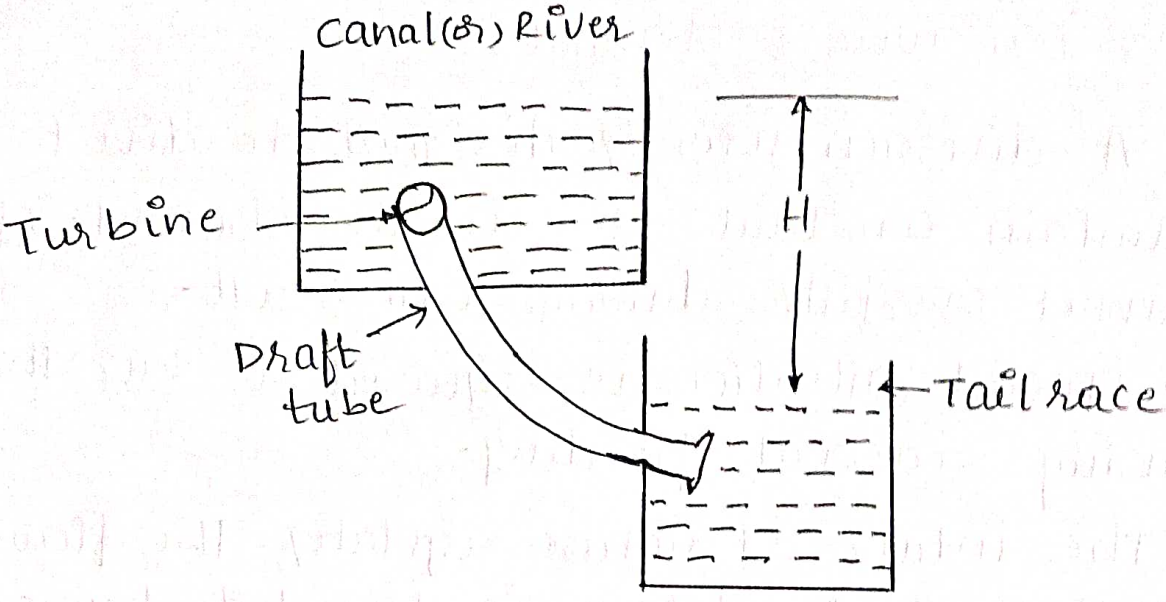
→ Forebay itself act as surge tank.




## Low Head Plant :-

In the low head power plant, the main reason for the construction of dam across the river is to create the desired head of water.

→ Generally, water is not carried to plant by penstock as the power plants are located near the dam itself, due to this reason surge tank is not required in the plant. Kaplan turbines are used for low head plants.




## (*) Micro-Hydro Power plant :-

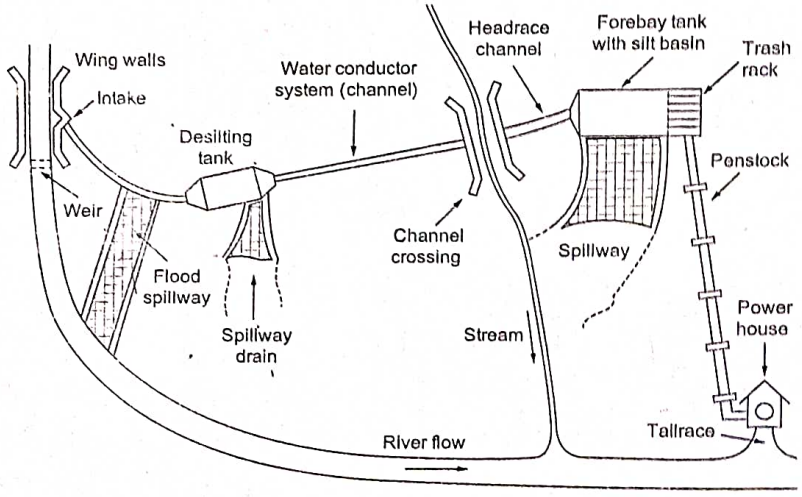



Fig. 11.1 *Typical layout of a microhydro power station*

→ The main components of the scheme are

① Diversion weir
② water-conductor system with regulating gates & spillways
③ Desilting tank with spilway
④ head race channel
⑤ forebay
⑥ Penstock ⑦ powerhouse ⑧ tail race channel.

① Diversion weir & channel :-

A diversion weir is designed to divert & maintain constant flow in the channel. If the channel overfills, damage will result.

→ special attention is required to save the channel during seasonal flooding.

→ The intake structure regulates the flow. Further control & regulation is provided by spillways.

→ The water conductor is a channel between weir & desilting tank & b/w the desilting tank to forebay.

④ Desilting tank :-

→ A desilting tank is usually provided in the initial reaches of water to trap the suspended silt load & pebbles, to minimize erosion damages to the turbine runner.

→ The depth of a silt tank may be 1.5m to 4m. The deposits of silt tank are periodically flushed out to make room for further deposition.

⑤ Forebay, Penstock & Tailrace :-

→ A forebay is a temporary storage of water, to be finally utilised for energy generation.

→ Trash racks are also provided to prevent

entry of trash, debris & ice.

→ A penstock is a water channel joining a forebay & a turbine.

→ A tailrace is a simple water channel to transport discharge from the turbine back to the river with maximum flow of 1m/sec.

## ⊛ Power house :-

### a) Speed Governor :-

→ The frequency & voltage of the generator output depends on the shaft speed.

→ voltage variations up to 7% are tolerable. Frequency variations up to 5% are permisable.

→ Governors are used to control the speed.

→ An electronic load controller is employed to increase or decrease load across the generator.

b) **Turbine :-** A suitable turbine is used to get mechanical power at the shaft from flowing stream of water.

c) **Generator :-** A generator coupled with turbines gives electrical output from mechanical input.

→ Both synchronous & induction types of ac generators are suitable for micro hydro power generation.

→ The main advantages of induction generators are cheap, rugged, reliable, require little maintenance & can withstand for 100% load.

## ⊛ Methods for the measurement of flow rate :-

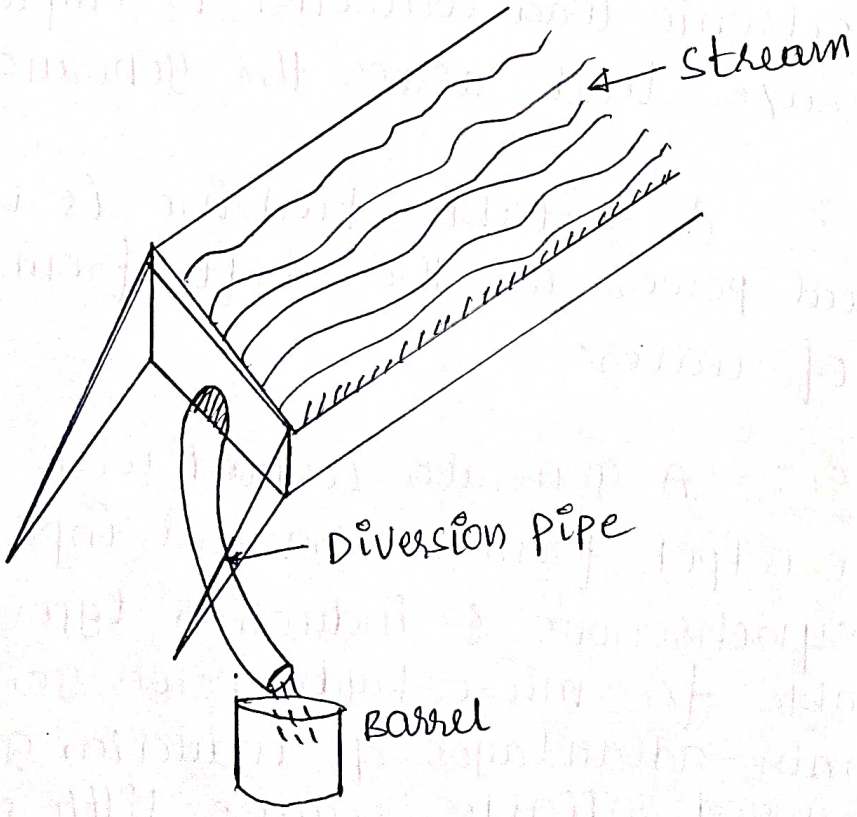
→ Based on the size & velocity of water, They are,

1. Basic method
2. Refined method-I
3. Refined method-II
4. Sophisticated method
5. Using a weir.

### ① Basic method :-

This method involves blocking of flow by means of a dam & deviating the flow into a barrel or control volume, for flow measurement.

→ Thus, by analysing the volume of flow, the flow rate is determined.



(2) **Refined method-1 :-**

In this method, the equation that is used to determine the flow rate is given by,

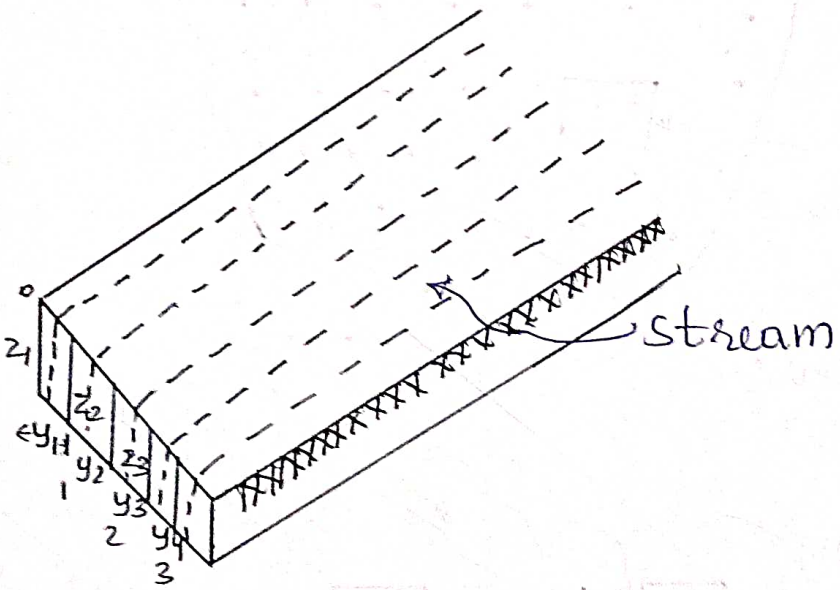
$$Q = u \times A$$

Where $u$ = Mean speed of the flow.

→ The measurement should be done at a point, where the flow is straight & uniform. The cross sectional area is measured by the following equation

$$A = \frac{1}{2} y_1 z_1 + \frac{1}{2}(y_2 - y_1)(z_1 + z_2) + \frac{1}{2}(y_3 - y_2)(z_2 + z_3) + \frac{1}{2}(y_4 - y_3) z_3 .$$

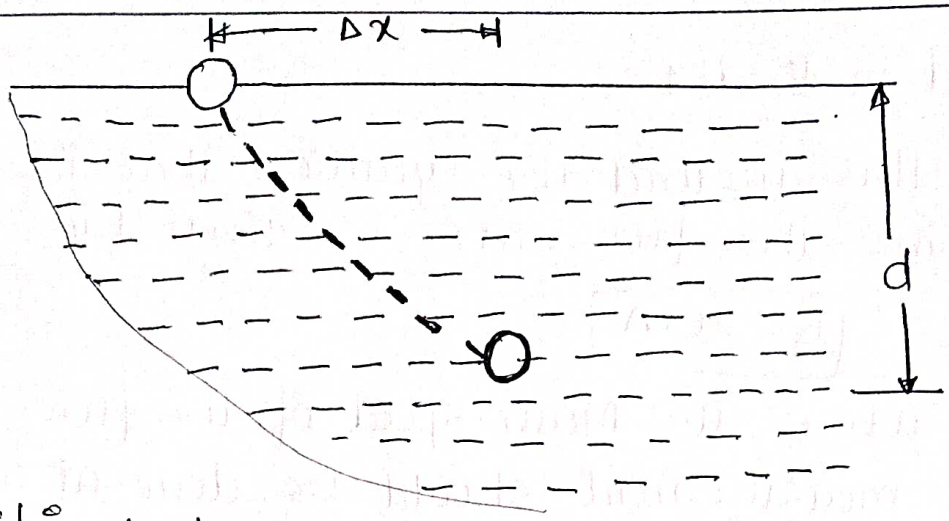
→ Where, the term 'z' is the depth of flow at different points.




(3) **Refined method-II :-**

This method is mostly suitable for fast flowing streams, In this, a float (or) a tennis ball is released from a specified depth, below the flow surface.

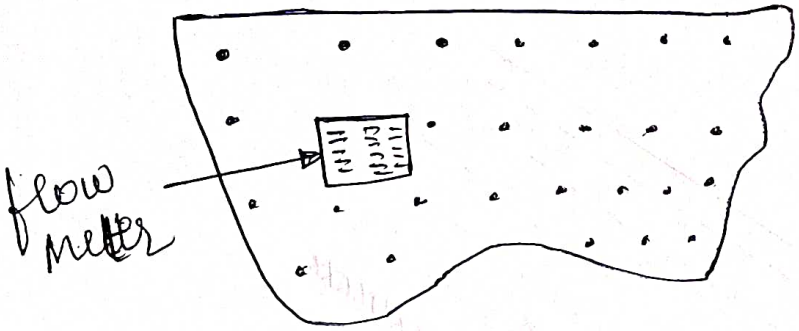
→ The speed of the flow is determined by measuring the horizontal distance travelled by the float to rise



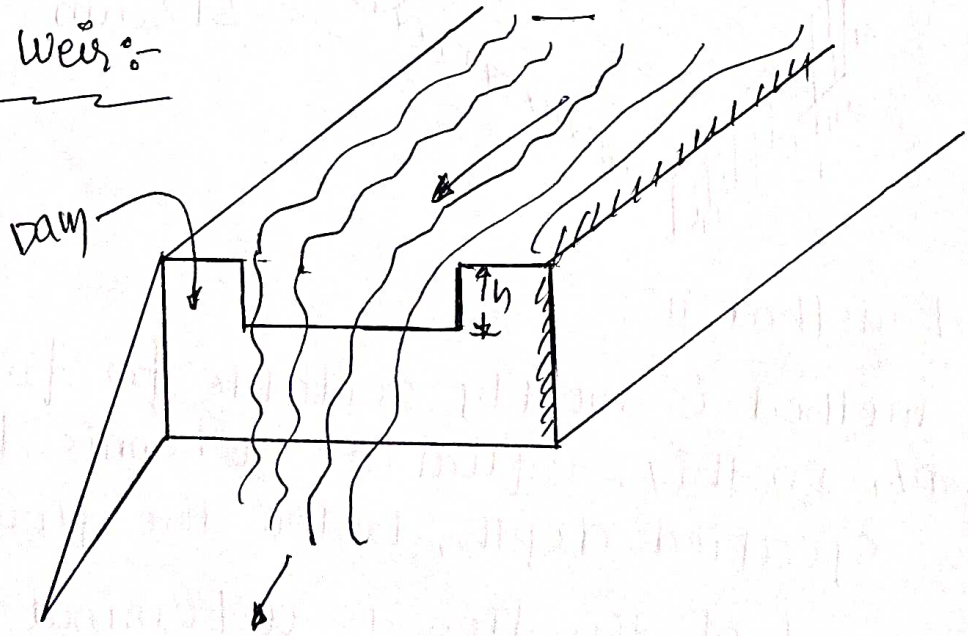

④ Sophisticated method:-

It is suitable for large streams. This method is practised by professional hydrologists.

→ Mainly the forward speed of flow is determined by means of a flowmeter.




⑤ Using a weir:-



In order to measure the flow rate of a stream throughout the year, a dam is built with a special shape calibration notch in it. The flow rate is determined by measuring the height of flow through that calibration notch.

---

(*) **Types of water turbines :-**

→ Turbines convert energy available in the form of falling water into rotating shaft power. They operate on the principle of either 'impulse' (equal pressure on each side of the runner) or 'reaction' (pressure drops across the runner).

(*) **Impulse turbines :-**

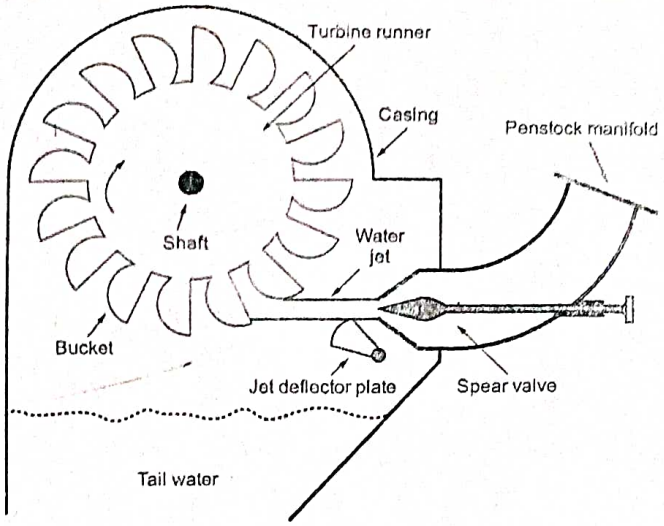
The three impulse turbines considered here are the i) pelton ii) Turgo iii) crossflow.

(1) **Pelton turbine :-**

→ The pelton turbine consists of a wheel with a series of split buckets set around its rim.

→ A high-velocity jet of water is directed tangentially at the wheel. The jet hits each bucket & is split in half, so that each half is turned & deflected back almost through 180°.

→ For optimum effeciency, the jet velocity needs to be about twice the speed of the bucket.




→ By adjusting the spear valve, in forward & backward direction the flow of water is controlled.

## ⊛ Turgo turbine :-

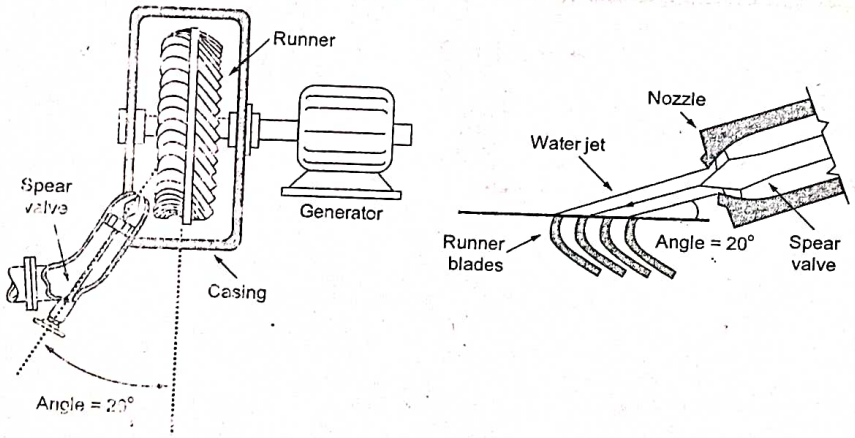



Fig. 11.3 *Turgo turbine*

→ It is similar to the pelton, but the jet is designed to strike the plane of the runner at an angle (20°) so that the water enters the runner on one side & exits on the other.

→ It has smaller diameter than pelton wheel, so runs at high speed.

→ It is more difficult to fabricate, because the buckets are complex in shape.

www.Jntufastupdates.com

(3) Crossflow turbine :- It has drum shaped runner, consisting of a two parallel discs connected together near their rims by a series of curved blades.

→ The water enters the top of the runner through the curved blades imparting most of its kinetic energy.

→ It's design suitable for a wide range of heads & power ratings.

→ Itself easily to simple fabrication techniques.

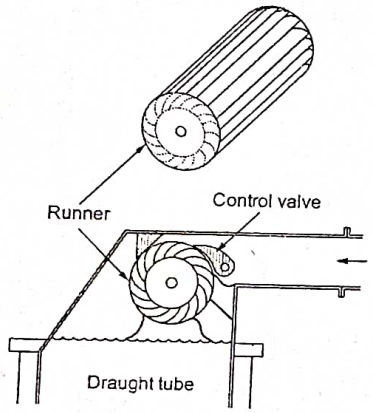



Fig. 11.4 *Crossflow turbine*

II. Reaction turbines :-

→ The two main types of reaction turbines are a) Francis turbine b) propeller (or) Kaplan turbine.

a) Francis turbine :-

→ The inlet is spiral shaped. The casing is scrolled to distribute water around the entire perimeter of the runner.

→ The guide vanes direct the water tangentially to the runner. The runner blades are profiled in a complex manner.

→ In operation, water enters around the periphery of the runner through guide vanes, passes through the runner blades before exiting axially from the centre of the runner.

→ The radial flow acts on the runner vanes, causing the runner to spin.

→ The guide vanes regulate the water flow as it enters the runner, & usually are linked to a governor system.

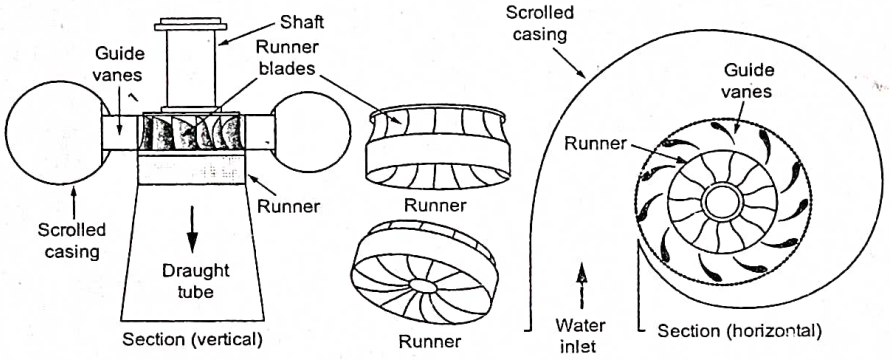



**Fig. 11.5** *Francis turbine*

b) Kaplan turbine :-

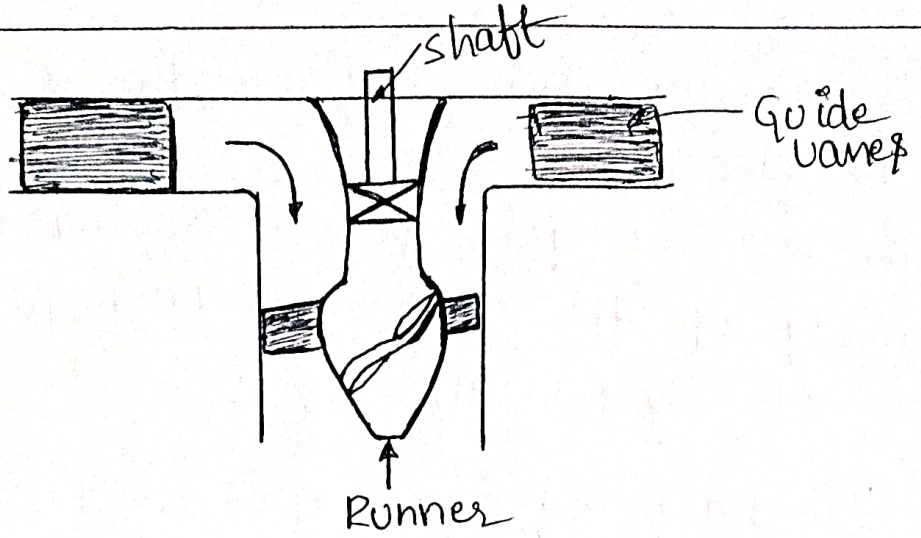
→ water flow is regulated by use of swiveling gates just upstream of the runner. This kind of propeller turbine is known as a "fixed-blade-axial flow" turbine.

→ It is used for low head hydro electric power plants.

→ The fabrication is easy & the cost is low.

→ The turbine can be installed in vertical, horizontal or inclined positions.

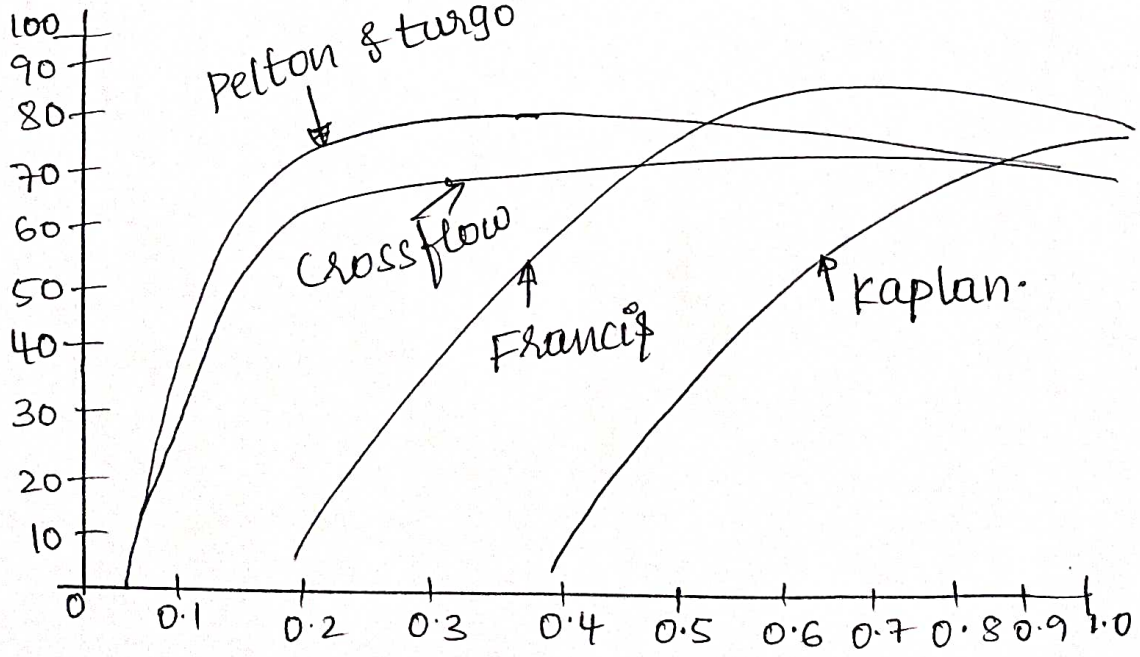
—




## ⊛ Characteristics of turbines & selection :-

| Turbine Runner | Head classification | | |
|---|---|---|---|
| | High | Medium | Low |
| Impulse | Pelton | Cross flow | Cross flow |
| Reaction | – | Francis | Kaplan |

## ⊛ Characteristics of turbine :-



① Estimate the power available from a proposed micro hydro scheme at a site having a small stream with 200 (100) litres/sec flow at a head of 35m (30). Assume density of fresh water as 995 (996) kg/m³ & overall effeciency of whole system as 50% (55)?

Sol:-

Discharge of water $Q = 200$ liters/sec $= 0.2 m^3/sec$

Head $H = 35m$

Density $\rho = 995 kg/m^3$

overall effeciency $= 50\% = 0.50$

1 litre $= 0.001 m^3$

→ Mass flow rate of water is given as

$$m = \rho Q = 995 \times 0.2 = 199 kg/sec$$

∴ Power available $P = \eta_0 mgh$

$$P = 0.50 \times 199 \times 9.81 \times 35$$

$\eta = \frac{P}{mgh}$

$P = 34.163 kW$ $P = 16.121 kW$

(11)

(*) A hydro power plant with 1050 MW $^{max}$ o/p has an effeciency of 93%. The plant load factor is 65%. It operatec at a constant head of 60m. Calculate

a) The maximum flow rate required &

b) The quantity of water to be stored behind the dam for a year's load requirement?

Sol:- Given data:-

Maximum output = 1050 MW

Effeciency = 93% = 0.93 $\quad \eta = \frac{o/p}{I/p}$

Load factor = 65% = 0.65

Head H = 60m.

a) Power input available = $\frac{o/p}{\eta} = \frac{1050 \times 10^6}{0.93} = 1129.032$ MW

→ Maximum flow rate is possible

~~Power available = power output~~

Power available = power input

$mgH = 1129.032$

$\rho Q g H = 1129.032$

$QgH \times 10^{-3} = 1129.032 \Rightarrow Q = \frac{1129.032}{9.81 \times 60}$

$\therefore Q = 1918.166 \ m^3/sec$

b) Discharge $Q_{avg}$ = Load factor * Q

$Q_{avg} = 0.65 \times 1918.166$

$Q_{avg} = 1246.808 \ m^3/sec$

→ Total quantity of water to be stored ⇒

$$Q = 1246.808 \times 24 \times 365 \times 60 \times 60$$

$$\boxed{Q = 39.319 \text{ km}^3}$$

② A high-head turbine develops 50mw at a head of 450m at effeciency of 90%. The entrance diameter of pipe line is 1.2m. calculate

a) Quantity of water flowing per second

b) Value of K

Sol:- Given data:-

Power output = 50MW

Height of head = 450m

effeciency = 90%.

Diameter = 1.2m

$mgh$

$\rho g h = P_{in}$

=>

$$\eta = \frac{P_{out}}{P_{in}} \Rightarrow Q = \frac{P_{out}}{g \times h \times \eta}$$

$$Q = \frac{50 \times 10^3}{9.81 \times 450 \times 0.90}$$

$$\boxed{Q = 12.585 \text{ m}^3/\text{sec}}$$

ii) Value of K:-

$$A = \frac{Q}{\sqrt{2gHK}} \Rightarrow \frac{\pi}{4}(D^2) = \frac{12.585}{\sqrt{2 \times 9.81 \times 450 \times K}}$$

$$\boxed{K = 0.014}$$

# * TIDAL ENERGY. *

## Tidal Energy :-

The term tide refers to the rise & fall of water level. Tides are produced by the gravitational forces between the sun & moon.

→ The tides contains large amount of potential energy.

→ The highest level of tidal water is known as flood tide or high tide.

→ The lowest level is known as low tide or ebb.

* The level difference between the high & low tide is known as "tidal range"

* The tidal range varies greatly with location.

→ only sites with large tidal ranges (about 5m & more) are considered suitable for power generation.

## Phenomenon & Nature of tidal energy :-

→ Tides are produced by the gravitational attraction of the moon & the sun acting upon the rotating earth.

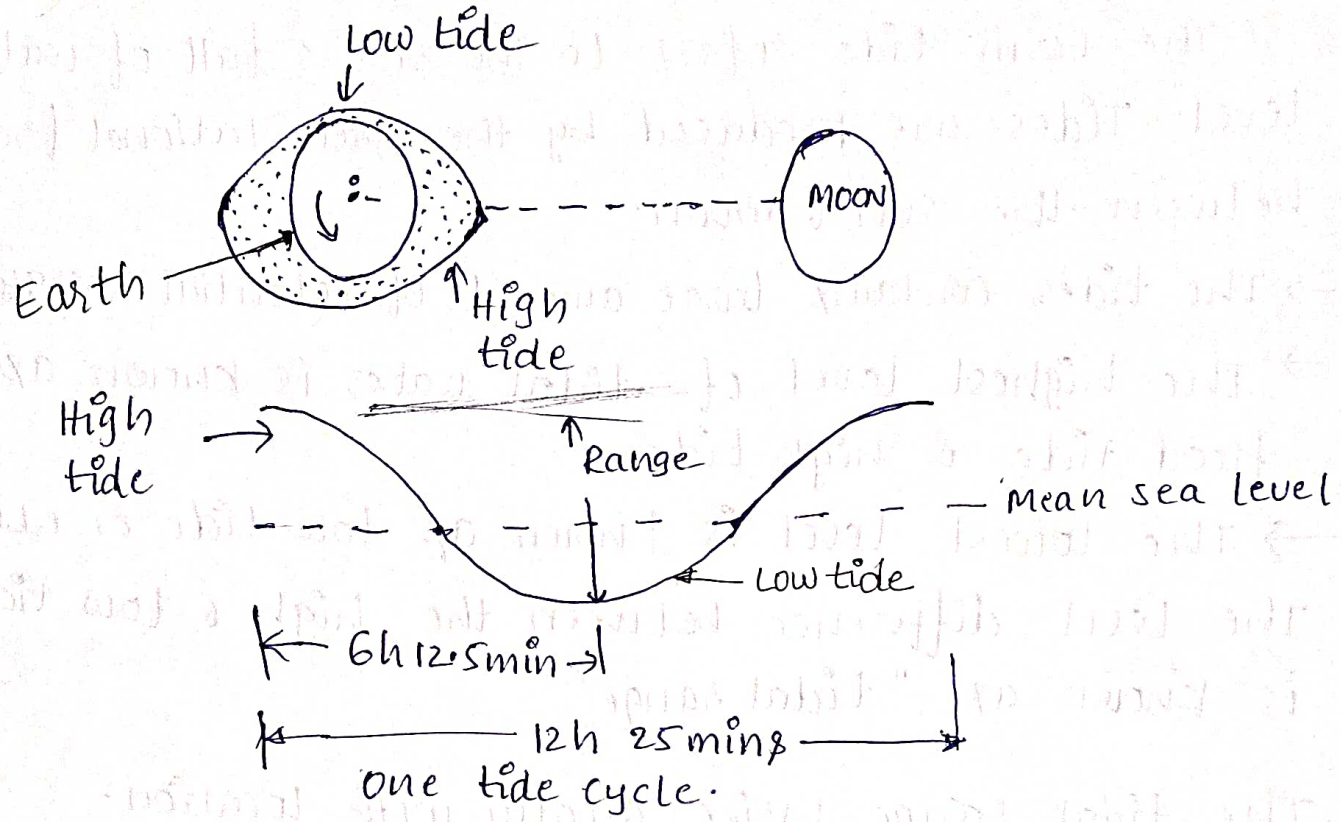
→ The moon exerts a large gravitational force (about 70% of tide producing force) on the earth.

→ 30% of force is due to sun.

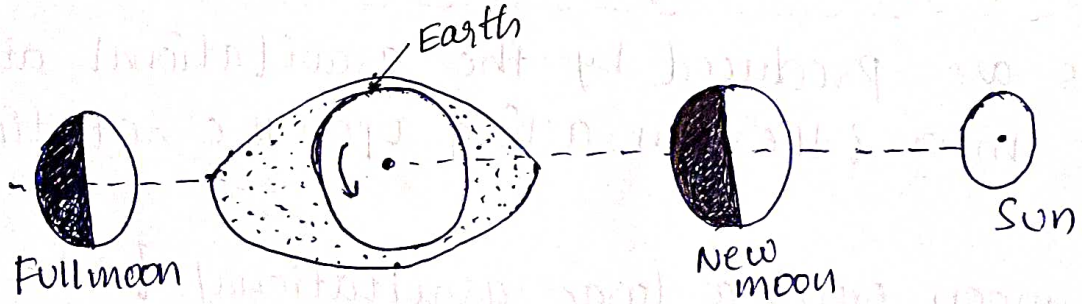
→ Surface water is pulled away from the earth on the side facing the moon, & at the same time the solid earth is pulled away from the water on the opposite side.

www.Jntufastupdates.com

→ Thus the tides are produced.

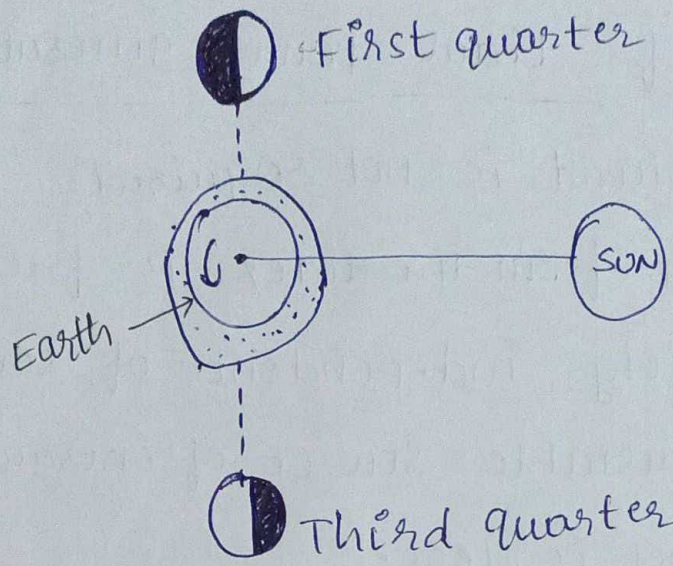



→ When the sun, earth & moon are aligned in conjunction, producing tides of maximum range.
→ These tides are called <u>spring tides</u>.

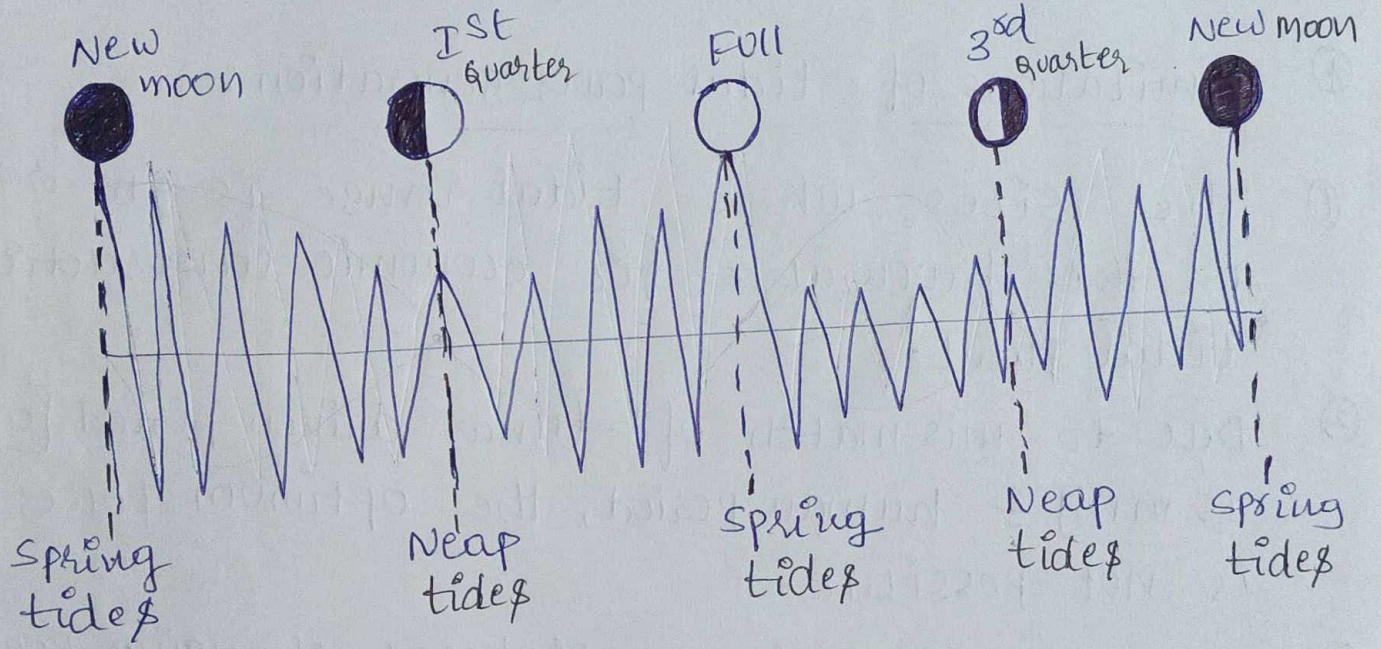



Spring tides

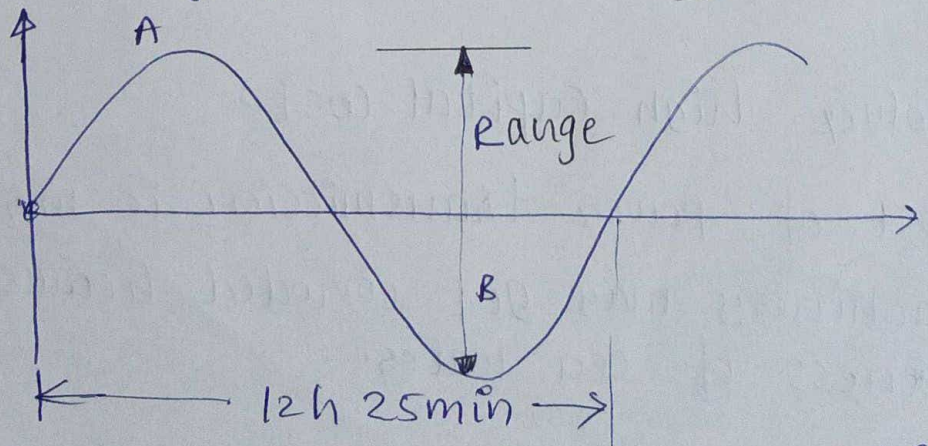
→ When sun-earth & moon-earth directions are perpendicular producing tides of minimum range.
→ These are called neap tides.




Neap tides.




→ Two low tides & two high tides occur during one lunar day (24 hours 50 mins).




→ The time duration between the high tide & low tide is 6h 12.5min

www.Jntufastupdates.com

## (*) Advantages of tidal power generation :-

1. large area of land is not required.
2. Power generation from the tides is free from pollution.
3. It is completely independent of rain.
4. It is in exhaustable source of energy
5. Maintenance cost is less.
6. It is a reliable source of energy.

## (*) Limitations of tidal power generation :-

(1) The sites where tidal range is 5m or more is the favourable for economic construction of tidal plant.

(2) Due to mismatch of lunar driven period [of 12 hours 25 min] & human period, the optimum power generation is not possible.

(3) Changing tidal range, produces changing power.

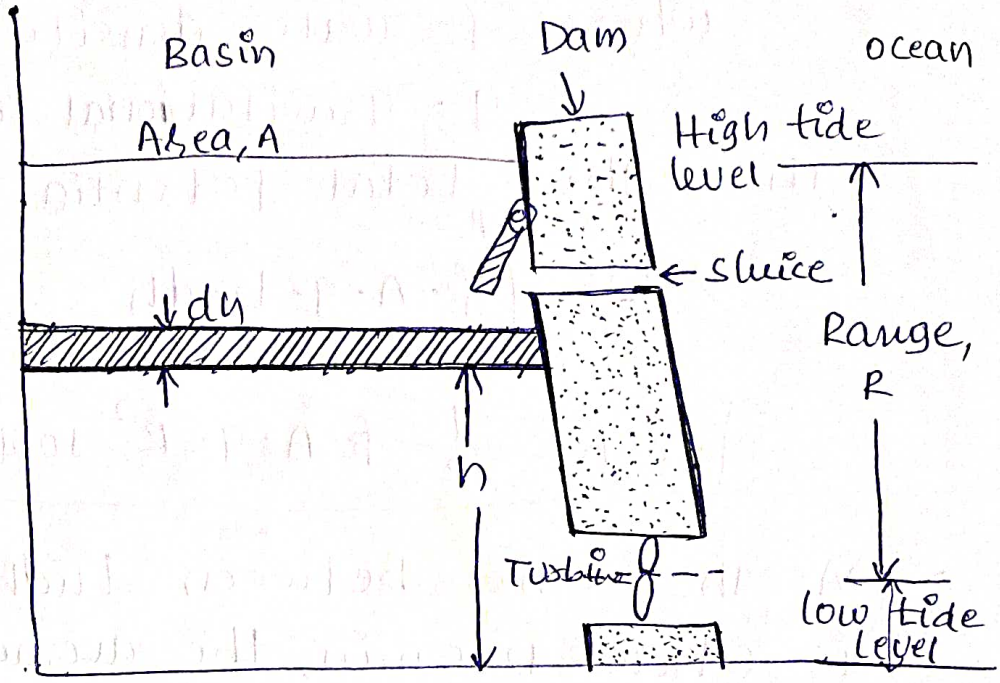
(4) The turbines are required to operate at variable head.

(5) It involves high capital cost.

(6) The cost of power transmission is more

(7) The machinery may get corroded because of the corrosiveness of sea water.

## Principle of operation of a tidal power generation :-




→ Tidal energy is a renewable energy. Tidal energy is converted into mechanical energy by hydro turbines. The hydro turbines drive the electrical generator rotors.

→ During high tide, the level of water increases with reference to low tide. The potential energy is higher during high tide.

→ The dam (barrage) is built across the tidal path. water flows from ocean to the basin during the high-tide.

→ Consider a basin area A, h is the head due to incremental head dh, the change in potential energy is

$$\boxed{dw = dm \cdot g \cdot h}$$

But $dm = \rho \cdot A \cdot dh$

where $\rho$ = water density

$g$ = gravitational constant.

→ Thus the total potential energy is

$$W = \int_0^R \rho \cdot A \cdot g \cdot h \cdot dh$$

$$\therefore W = \frac{1}{2} \rho \cdot A \cdot g \cdot R^2 \text{ Joules.}$$

→ As the time between high tide & low tides is 6 hours 12.5 min, the average power produced is

$$P_{avg} = \frac{1025 \times 9.81 \times A \times R^2}{2 \times 22,350}$$

$\rho = 1025 \text{ kg/m}^3$

$g = 9.81$

$$P_{avg} = 0.225 \times A \times R^2 \text{ watts.}$$

Thus the tidal power is directly proportional to 1) area of basin 2) square of range.

(*) In practical the power generation is less than the theoretical $P_{avg}$ due to frictional losses of the fluid, turbine & generator conversion effeciencies.

→ The turbine has to be stopped when the head reaches a minimum value of 'R' which the operation is uneconomical.

$$\therefore W = \int_R^R \rho \cdot A \cdot g \cdot h \, dh \cdot \text{ Joules.}$$

(*) ~~under consideration~~

$$W = \frac{1}{2} \rho A \cdot g (R^2 - s^2)$$

$$P_{avg} = 0.225 \times A \times (R^2 - s^2) \text{ watts.}$$

(*) Ocean tidal energy conversion schemes :-

→ The main tidal energy schemes are

① single basin :- sigle effect
② sigle basin :- Double effect
③ two basin : linked basin
④ two basin : paired basin.

(*) Single basin :- single effect :-

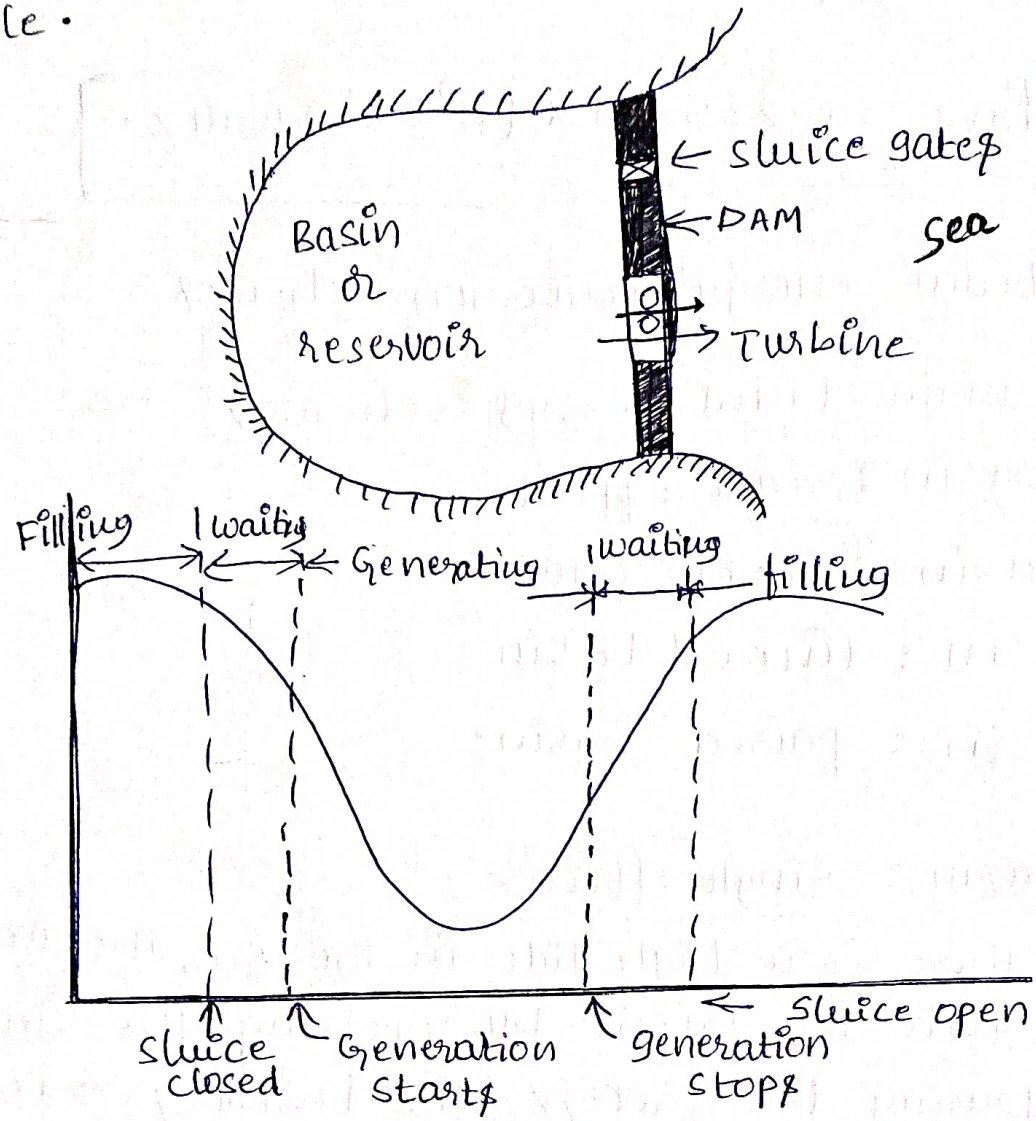
→ when there is a high tide in the sea, the water is allowed into the basin by opening the sluice gates. During this process, the turbines sets are closed. The water flows into the basin till it attains the maximum tide level.

→ when the other ebb begins the sluice gates are closed

→ Then, the water from the basin flows through the turbine, so the power is produced.

→ The turbines are operated only when there is a difference b/w heads of basin water & sea water.

Then the gates are opened again & the turbines are closed. This process of operation is repeated as a cycle.




## ⊛ single basin :- Double effect :-

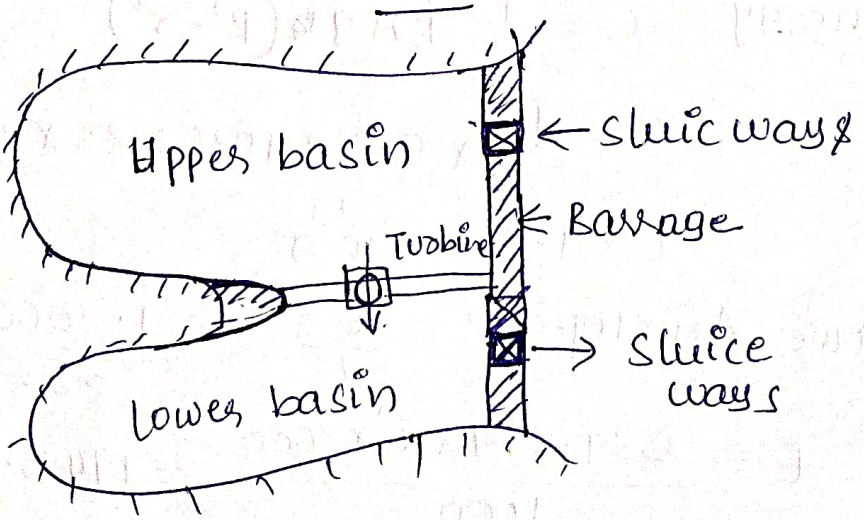
In this system, both ebb & flood tides are producing the power generation. When the sea is at high tide & reservoir is at low tide level, the filling of basin takes place, while the sea is at low tide level, basin is at high tide level, the emptying is takes place.

→ Therefore, both the directions of water flow helps in driving the turbines to generate power.

Two-way (reversible) hydraulic turbines are used.
→ Pumping may also be used to increase the output.

III Two basin :- linked basin scheme :-

→ In order to maintain continuity of power supply, linked & paired basin schemes are used.
→ The linked basin consists of two basins, one is for high tide & is for low tide.
(upper basin) (lower basin)
→ The turbines are placed between the two basins.
→ When there is a high tide, the sluice gates of upper basin are open, to allow the sea water into it. During this the lower basin gates are closed.
→ Upper basin is filled, & lower basin is empty difference of head is created, then turbines are operated.



Paired-basin

III. Two basin :- It consists two single basin schemes. one scheme generates on flood & the other on the ebb cycle. The output is not quite & continous. so it is not preferred.

---

① A tidal power plant of single basin type has a basin area of $25 \times 10^6 m^2$. The tide has a range of 10m. The turbine however, stops operating when the head on it falls below 2m. Calculate the energy generated in one filling process, in Kwh if the turbine generator effeciency is 75% (Density of sea water = 1025 $kg/m^3$)

Sol:- Given that:-

Basin area $A = 25 \times 10^6 m^2$

$R = 10m$;

head falls $r = 2m$

$\eta = 75\% = 0.75$

Density of water $\rho = 1025 kg/m^3$

→ Energy $E = \frac{1}{2} \rho A g h (R^2 - r^2)$

$E = \frac{1}{2} \times 9.81 \times 1025 \times 25 \times 10^6 (10^2 - 2^2)$

$E = 1.2066 \times 10^{13} J$

→ Power developed $= \frac{E}{t} = \frac{1.2066 \times 10^{13}}{22350}$

$E = \frac{539.879 \times 10^6 \times 3600}{1000} = 1943.564 \times 10^6 Kwh$

---

∴ Energy generated in one filling process ⑥

$= \eta \times E = 0.75 \times 1943.564 \times 10^6$

$E = 1457.673 \times 10^6$ Kwh

② A single basin type tidal power plant has a basin area of 2 $km^2$. The tide has an average range of 13m. Power is generated only during the ebb cycle. The turbine stops operating when the head falls below 3m. Calculate the average power generated by the plant in single emptying process of basin. If the turbine generator effeciency is 0.7. Estimate the average annual energy generation of the plant?

Sol:

Area $A = 2 km^2 = 2 \times 10^3 m^2$

$R = 13m$

$r = 3m$

Turbine generator effeciency $\eta = 0.7$

$\rho = 1025 kg/m^3$

→ The average power generated is

$P_{avg} = 0.225 * A * (R^2 - r^2)$

$P_{avg} = 0.225 * 2 \times 10^3 \times (13^2 - 3^2)$

$\therefore P_{avg} = 72 MW$

→ The average power generated $P = P_{avg} * \eta$

$P_{out} = 72 * 0.7$

$P_{out} = 50.4 MW$

→ Energy available

$$E = \frac{1}{2} \rho A g (R^2 - x^2)$$

$$E = \frac{1}{2} * 1025 * 2 \times 10^3 * 9.81 (13^2 - 3^2)$$

$$\boxed{E = 160840 \text{ MJ}}$$

→ Number of Ebb cycles in a year

$$n = \frac{365 * 24}{\text{Time period for 1 ebb cycle}}$$

$$n = \frac{365 * 24}{12\text{hr } 25\text{ min}} = 706$$

$$\eta = \frac{E}{n * E}$$

→ Annual energy of the plant

$$E_{out} = \eta * E_{in} * n$$

$$E_{out} = 0.7 * 160840 \times 10^6 \times 706$$

$$\boxed{E_{out} = 2.208 \times 10^8 \text{ kwh}}$$

→ The Gujarat government is all set to develop India's first tidal energy plant.

→ The capacity of the plant is 50MW.

(*) Environmental Impacts :-

→ Tidal energy doesnot result in emission of gases.

→ Changing tidal flows by damming a bay, however, result in negative impacts on aquatic & shore line ecosystem.

→ The barriage destroys the places that are home to many birds, fish & other animals.

# WAVE ENERGY

→ Waves are caused by the transfer of energy from surface winds to the sea. The rate of energy transfer depends upon the wind speed & the distance over which it interacts with water.

→ The fluctuating mechanical energy obtained is modified/smoothed out to drive a generator. Wave power is usually expressed in kilowatts per meter.

## Advantages of wave energy :-

① It is a renewable energy & lasts for long life.

② The waves are steady state after the power is generated.

③ The equipments do not require huge land area for establishment.

④ It is used for protecting coasts from erosion & destruction that is caused due to large waves.

⑤ Power generation from waves is free from environmental pollution.

## Disadvantages :-

① The construction is complicated & is depends on other sources.

② It can be used only on particular area

③ The equipments should be designed such that they can withstand large wave impact on them.

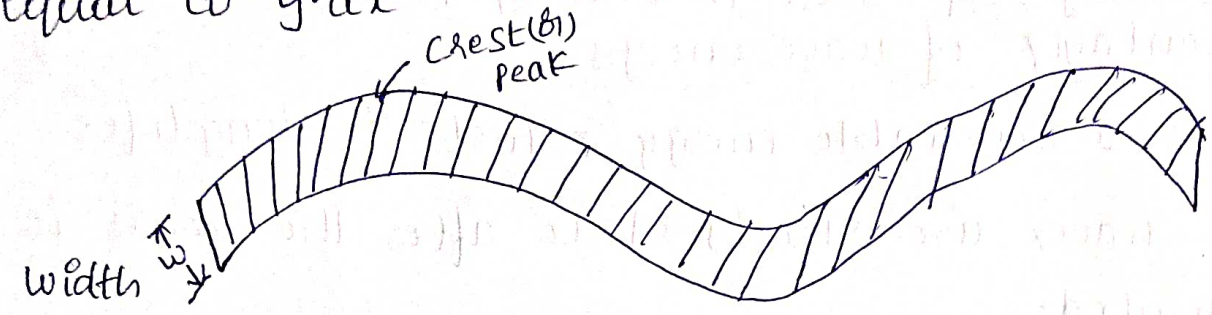
④ The initial cost, maintenance, repair costs of the plant is very high

## Derivation for Kinetic Energy Expression :

### Potential energy :-

→ The potential energy of wave is obtained as the water rises up to wave crest above mean sea level.

→ Consider, the water element of length 'dx' & width 'w', then the area of cross section of the element is equal to $y \cdot dx$.




$\therefore$ Area of element $= y \cdot dx$ —— ①

Mass = Density × Volume

$m$ = mass of water element

= Volume × density

$$\boxed{m = (ydx \times w) \times \rho} \quad \text{—— ②}$$

work done = mgh

$h = \frac{y}{2}$

$\therefore$ work done $= ydx \times w \times \rho \times \left(\frac{y}{2}\right) \times g$

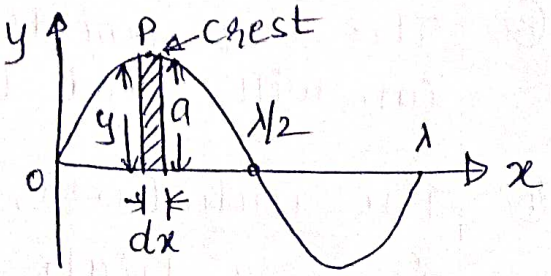
$\therefore$ Potential energy $= \frac{1}{2} g \rho y^2 w dx$. —— ③

where $g$ = gravitational constant

$y$ = height above mean level

$w$ = width of wave.

→ A wave consists of crests (high) & throughs (low) during the Propagation.



→ By using mathematical analysis the value of 'y' is obtained.

→ A point 'P' on surface of wave with element of thickness 'dx' is considered.

→ The value of 'y' is given as

$$y = a \sin\left[\frac{2\pi x}{\lambda} - \frac{2\pi\theta}{T}\right]$$

where $(x, y)$ are the coordinates of point

$a$ = Amplitude of wave

$\lambda$ = wave length

$\theta$ = Time in seconds

$T$ = wave period.

→ substituting the value of 'y' in equation ③ & integrating,

$$P.E = \frac{1}{2} \rho g \int_0^{\lambda} a^2 \sin^2 [Mx - Nt]\, dx$$

where $M = \frac{2\pi}{\lambda}$, $N = \frac{2\pi}{T}$

$$P.E = \frac{g \rho w a^2}{2} \left[\frac{1}{2} x - \frac{1}{4M} \sin 2Mx\right]_0^{\lambda}$$

$$P.E = \frac{1}{4} g \rho w a^2 \lambda \quad \text{—④}$$

Potential energy per unit Area a,

$$\frac{P.E}{A} = \frac{1}{4} g \rho a^2 \quad \text{—⑤}$$

⑥ Kinetic energy is expressed as

$$K.E = \frac{1}{4} \rho g w a^2 \lambda$$

$$K.E = \frac{1}{4} \rho g a^2 A \quad \text{—⑥}$$

Kinetic energy density is given by

$$\frac{K.E}{A} = \frac{1}{4} g \rho a^2 \quad \text{—⑦}$$

→ Total energy of ocean wave,

$$= P.E + K.E$$

$$= \frac{1}{4} \rho g a^2 \lambda^2 w + \frac{1}{4} \rho g a^2 \lambda w \quad \text{—⑧}$$

$$\text{Energy density} = \frac{E}{A} = \frac{1}{2} g \rho a^2$$

$$\text{Power} = \frac{\text{Energy}}{\text{Time}}$$

$$\boxed{P = \frac{1}{2} \rho g w \lambda a^2 F \text{ (watts)}}$$

## ⑧ Wave Energy Technologies :-

→ A wave device may be placed in the ocean in various possible situations & locations. The fluctuating mechanical energy obtained is modified/smoothed out to drive a generator.

⑧ The capturing wave, devices are classified as. (Power)

① Heaving float type

② Pitching type

③ Heaving & pitching float type

④ oscillating water column type

⑤ surge devices.

I. Heaving float type :- A float (buoy) placed on the surface of water heaves up & down with waves due to the rise & fall of the water level.

→ The resulting vertical motion is used to operate the piston of an air pump through linkage. The pump may be anchored to the sea bed. Several float operated air pumps are used to store energy in a compressed storag

→ The compressed air is used to generate electricity through an air turbine coupled to a generator.

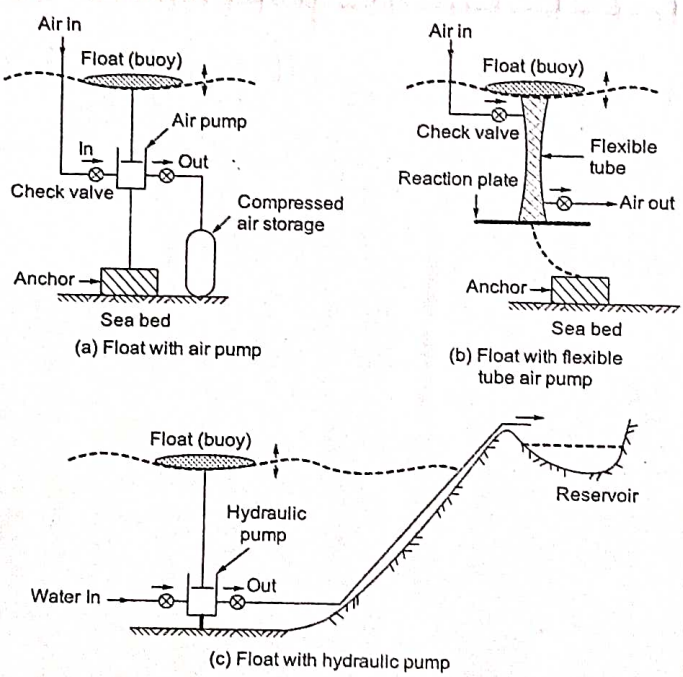



Fig. 10.11 *Heaving-float type devices*

→ In fig (c), a hydraulic pump is operated by the motion of a buoy to raise water to an onshore reservior & passed through a turbo-generator to generate electricity.

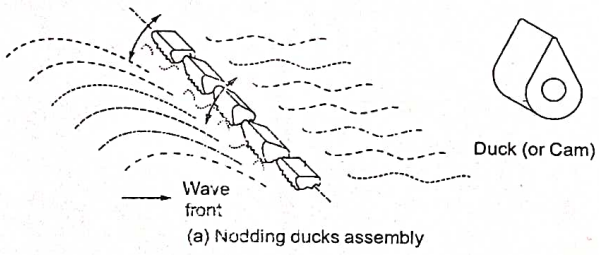
II Pitching type :- In pitching type devices, the waves strike horizontally on a floating piece or flap causing it to deflect.

→ several cam-shaped floating pieces knowing as nodding ducks; are hinged to a common flexible linkage & spin to form a nodding duck assembly.

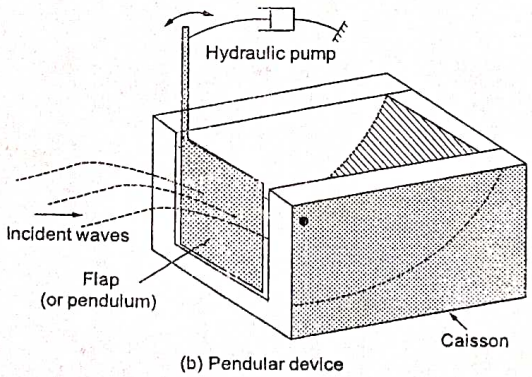
→ A wave entering from the left turns the beak of the duck in the direction of motion.

→ It then oscillates about its axis. The ratchet & wheel mechanism converts the motion of the ducks to a common shaft.

→ power collected by an individual duck is thus pooled to drive the generator through linkages & gears.



(a) Nodding ducks assembly



(b) Pendular device

**Fig. 10.12** *Pitching-type devices*

In fig b, a pendulum flap is hinged over the opening of a terminating rectangular box. The action of the waves causes it to swing back & forth.

→ This motion is then used to power a hydraulic pump & generator.

---

### III. Heaving & Pitching - Float type :-

A system consisting of a three pontoons, which move relative to each other in the wave.

→ A damper plate is attached to a central pontoon, which ensures that it stays still as the force & aft pontoon move relative to the central pontoon by pitching about the hinges.

→ Energy is extracted by hydraulic pumps attached to hinges. Electricity can be generated via a hydraulic turbine & generator.

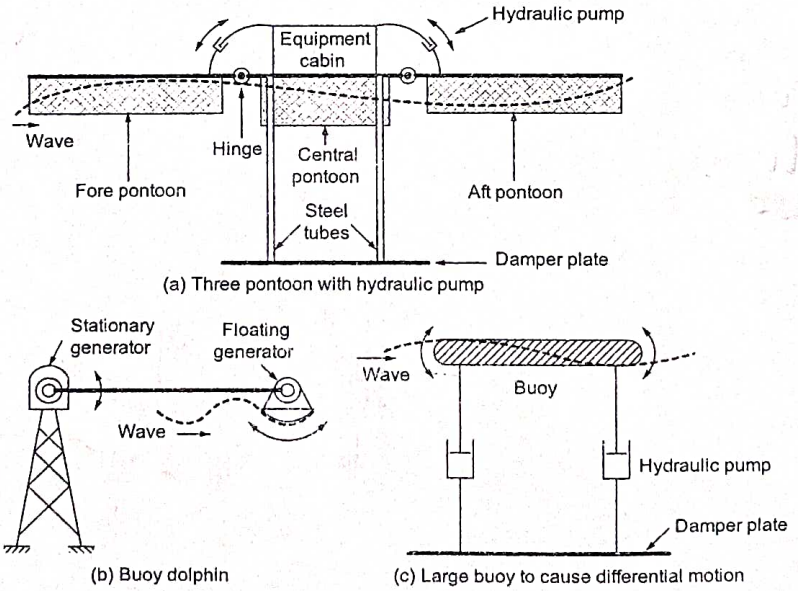



**Fig. 10.13** *Heaving and pitching float-type devices*

fig b → A specially shaped float known as Dolphin rides the

wave & rolls as well as heaves as the wave passes.

→ The two motions are converted to unidirectional motion by a ratchet-wheel arrangement & used to operate floating & stationary generators s.p.

→ fig c, a large float is used to produce differential motion between two extreme sides of float. The motion can be used to operate a hydraulic pump.

—

IV. Oscillating water-column type :-

→ This device comprises a partly submerged concrete & steel structure, which has an opening to the sea below the water line, thereby enclosing a column of air above a column of water.

→ The wave causes the water column to rise & fall, The wave compresses & depressurises the air column.

→ The air is allowed to flow through a turbine, which drives the generator.

→

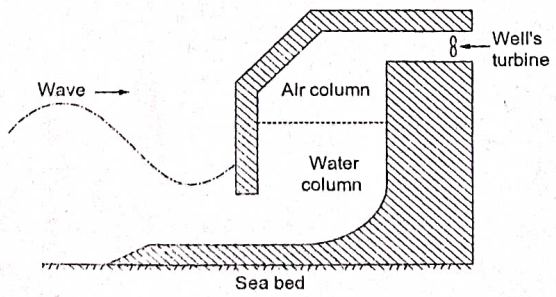



Fig. 10.14 *Oscillating water column device*

V. Surge Devices :- When a moving wave is constricted, a surge is produced raising its amplitude. Such a device is known as tapered channel device.

→ The waves enter from the wide end of the channel & as they propagate towards narrower region.

→ The water forcely pushes into the reservior, which provides a stable water supply to a low head turbine.

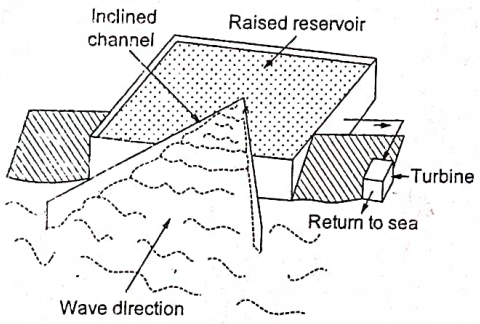



Fig. 10.15 *Tapered Channel Device*