

UNIT 5

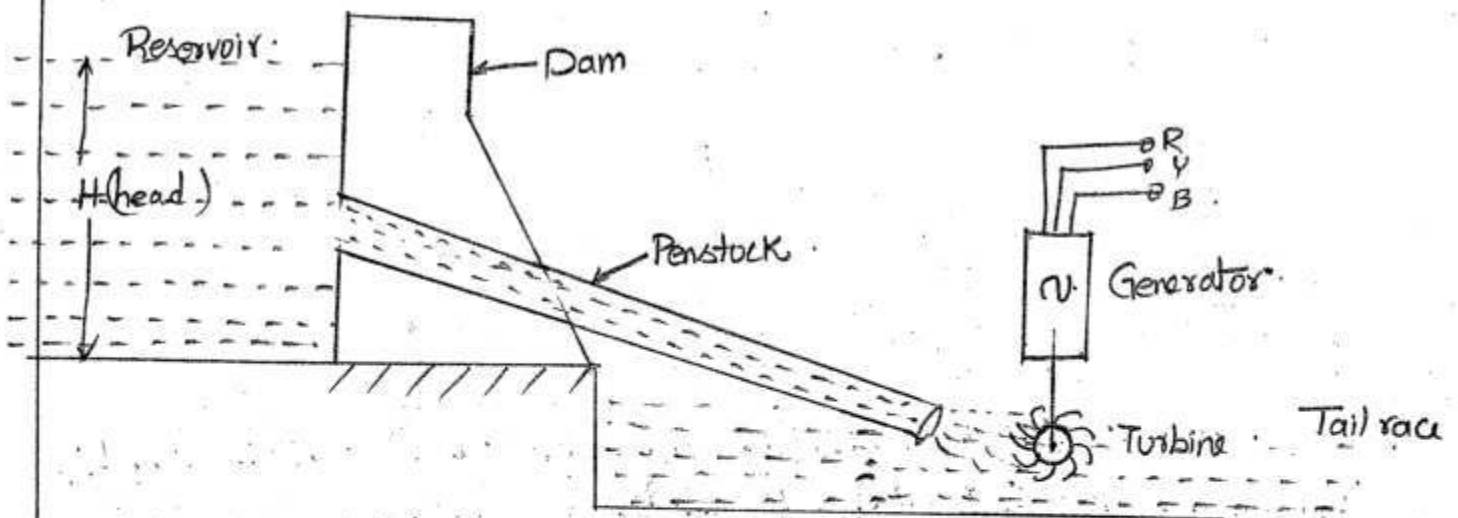
HYDRO & TIDAL POWER GENERATION

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Hydro Power plant:

The power plant that uses potential energy of water to generate electrical power is called hydro power plant.

Basic principle:



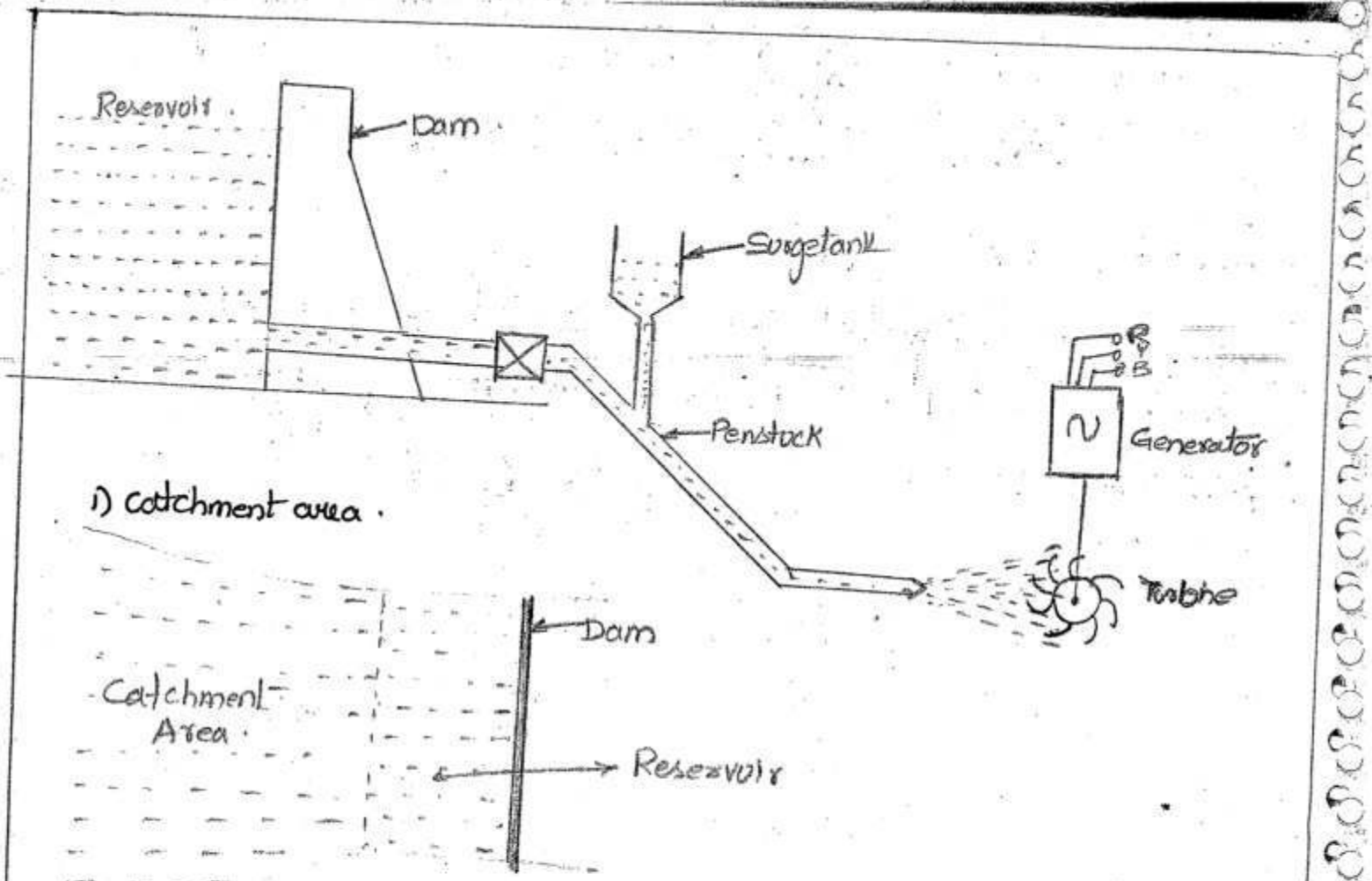
* Hydro electric power plants are generally located in hilly areas where dams can be built and large water reservoirs can be made.

* In hydro plant, water head is created by building a dam across a river (or) lake which originates due to rainfall (or) slow snow melting.

* When water is allowed through the penstock, the water turbine converts kinetic energy of water to mechanical energy at the shaft. This mechanical energy is converted into electrical energy by coupling a alternator to the turbine.

Elements of hydro-electric plant:

The main elements of hydro-electric power plant are follows



1) Catchment area.

The total area behind the dam in which water is collected and stream flow is obtained is known as Catchment area.

2) Reservoir:

It is important part of power plant, where water is collected and stored and supplied to turbine continuously.

3) Dam:

A dam is a barrier which store water and creates water head.

4) Spill way:

Due to heavy rainfall, the water level may exceed the storage capacity of the reservoir. To remove the excess water, a structure is formed at the top of reservoir. This structure is known as Spill way.

5) Surge Tank:

It is a small tank (open at top). It is provided to reduce

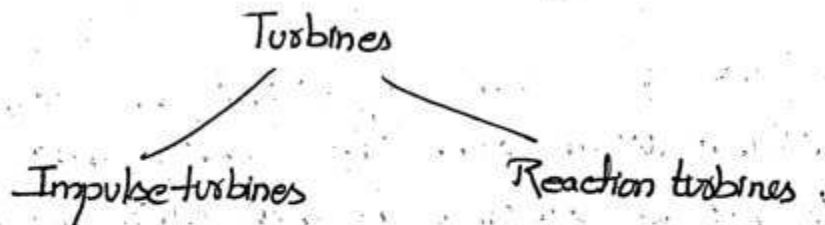
the pressure surges in the conduit. It is located near the beginning of the conduit.

6) Penstocks:

Penstocks are open @ closed conduits which carry water to the turbines. They are generally made of RCC @ Steel. The RCC penstocks are suitable for low water heads ($< 30\text{m}$). The steel penstocks are suitable for any head.

7) Water turbines:

Turbines are energy conversion devices. They convert kinetic energy of water to mechanical energy.



In Impulse turbines, water jet strikes turbine blade. Due to impulse created by water jet, the turbine rotates. ex: Pelton wheel.

Reaction turbines are completely submerged under water and work due to pressure reaction.

ex:- Francis turbine, Kaplan turbine.

Positives:

- 1) Hydro plants has long life time.
- 2) Turbine has life of 50 years with minor refurbishments.
- 3) Dam & Penstocks have life time of 100 years.
- 4) Very low cost of generation
- 5) No-pollution
- 6) Highest efficiency 90%.

Negatives:

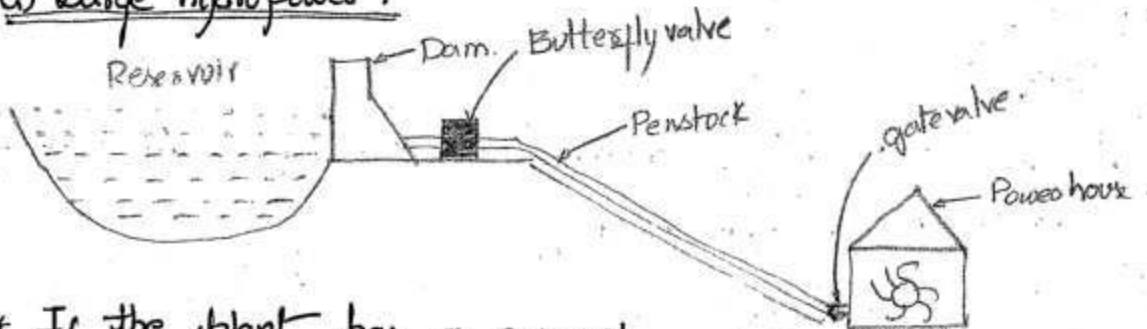
- 1) Requires large area leads to environmental impact
- 2) Has effect on fishing

- 3) People has to be displaced to new areas leads to social impact.
- 4) Requires high capital cost for installation.
- 5) Requires greater time to install (104-204)

Sizes of Hydro-electric power plant

Depending on Size and capacity, hydro-electric power plants can be classified as

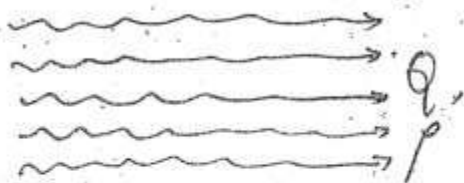
a) Large hydropower :



- * If the plant has a capacity of 30 MW and water head ranging from 100m to 1000m comes under large hydro power plants.
- * In this water flow is controlled by head gates and butterfly valves at the top of the penstocks and gate valve at the turbine.
- * Pelton wheel is a common prime mover for large hydro.

b) Medium hydro power :

Principles :-



Let Q be the discharge of fluid and ρ be the density of fluid.

$$\therefore \text{Mass of water (m)} = \rho Q$$

$$\text{Potential energy } P = m \times g \times h$$

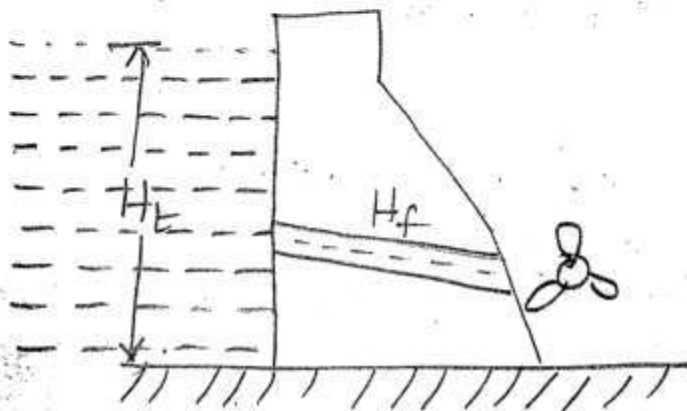
$$P = \rho Q g h$$

where $g \rightarrow$ acceleration due to gravity
 $h \rightarrow$ head (or) height

* Hence to get sufficient P , discharge should be increased but leads to turbine cost. However instead of increasing Q , increasing head leads to economical. But cost of penstock increases.

* To get sufficient P , the area requires 40cm/year rainfall.

Measurement of head H :-



Power input to the turbine does not depend upon the geometrical head available. But it depends upon the actual head available.

$H_t \rightarrow$ geometrical head

$H_f \rightarrow$ frictional losses in pipe.

$$\therefore \text{Actual head available } H_a = H_t - H_f$$

However H_f increases with pipe length. It is to be noted that $H_f \ll \frac{1}{3} H_t$. Hence hydro power stations should have steep slopes.

Measurement of flow rate Q

* flow through turbine produces power. Flow through turbine is less than the flow in the stream.

* flow of stream varies with time and season and there is lot of change in the flow during drought and flood seasons.

It is important to know the minimum amount of flow rate required for power generation without overloading the equipment. It is also important to know the maximum flow rate during flood seasons to avoid damage to installations.

* flow rate is difficult to measure than the head.

$$\therefore \text{flow rate } Q = \frac{\text{Volume passing}}{\text{Time}}$$

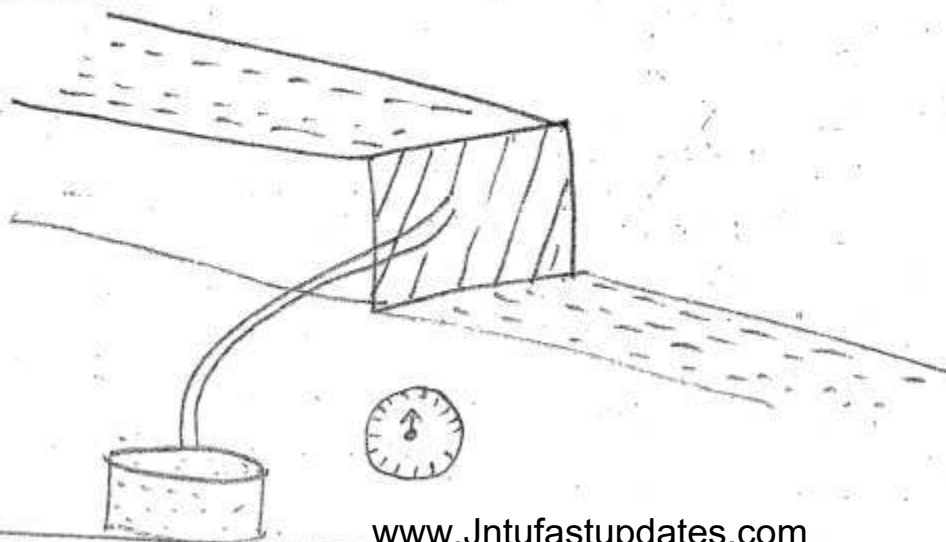
$$= \text{Mean speed } \bar{u} \times \text{Area of cross section } A$$

$$Q = \int u \cdot dA$$

Measurement of flow can be done by 3 methods.

- Basic method
- Refined method
- Sophisticate method.

i) Basic Method:

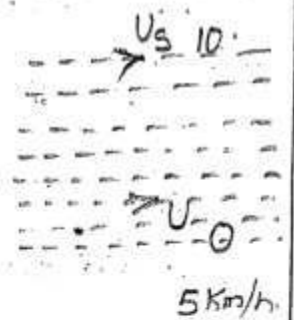
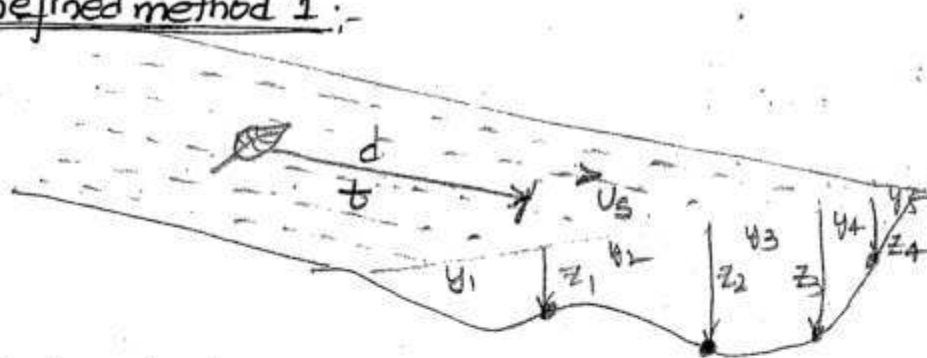


* In this flow of water is stopped either by constructing a small dam (or) by making a diversion of flow as shown in the figure.

* Now the flow is measured in the volume contained using a stop watch.

* This method has no assumptions and can be only used to measure small flows such as small water falls.

b) i) Refined method 1:-



* flow speed is zero at bottom due to viscous friction. Hence mean speed is less than the speed U_s on top surface.

for rectangular X-section, it is found that

$$U_s \approx 0.8 U_s.$$

* actual speed U_s can be measured by putting a leaf on the top surface and allowing it to travel to a certain distance along stream and calculating the time.

* cross sectional area can be measured by measuring depths at several points and integrating across stream as shown below.

$$A \approx \frac{1}{2} y_1 z_1 + \frac{1}{2} (y_2 - y_1)(z_1 + z_2) + \frac{1}{2} (y_3 - y_2)(z_2 + z_3) + \dots$$

ii) Refined method 2:-



* This method avoids accurate timing and is used for measurement of fast flows.

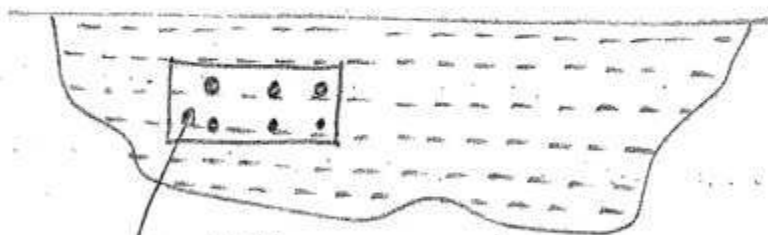
* In this a tennis ball is released from a known depth. The distance travelled

* The time required by the float to raise to the surface of stream is independent of horizontal distance travelled.

* The horizontal distance travelled (Δx) gives the speed of the stream.

c) Sophisticated method:

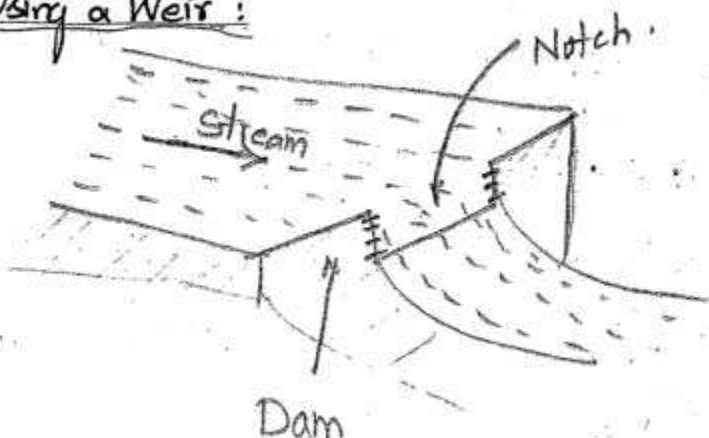
* This method is accurate method and used by professional hydrologists.



* In this forward speed v is measured at different points extending along the stream using a flow meter.

The integral of the summation gives speed of the stream.

d) Using a Weir:

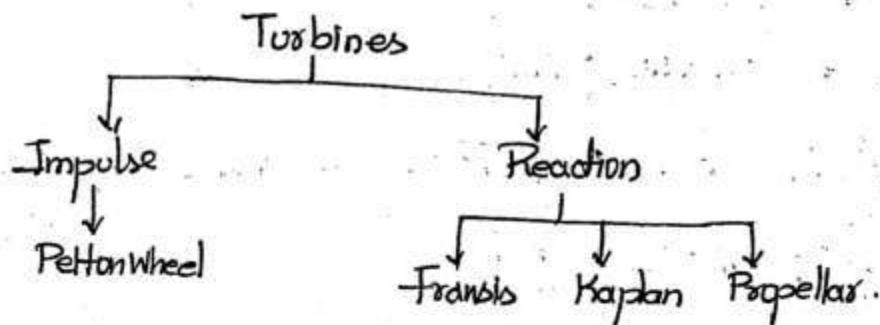


* If flow is to be measured for the same stream through out the year, this method is most suitable.

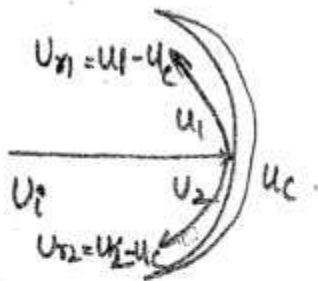
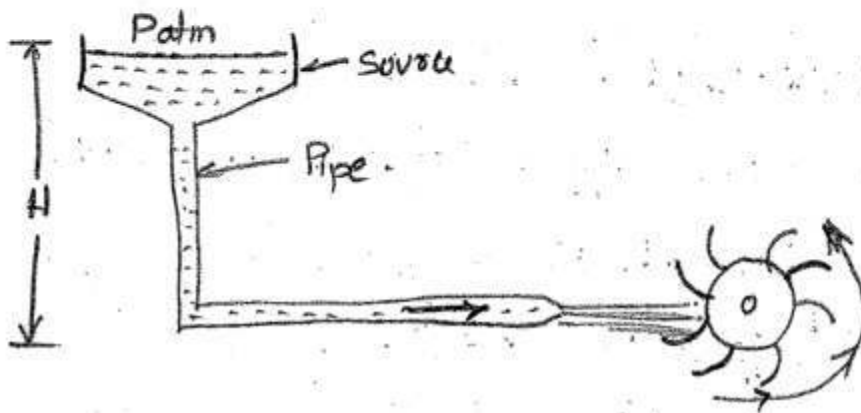
* In this special dam is built across the stream with ~~precise~~ ^{structure} -boxed notch. Such dam is called weirs.

* The height of the flow through this notch gives the flow rate.

Types of turbines:-



1) Impulse Turbine:



* The potential energy of water is converted into kinetic energy of one (or) more jet's. This jet's strikes the turbine blades mounted on the perimeter of steel wheel.

* When jet's strikes the blades deflection of fluid causes.

This deflection causes change in momentum of the fluid.

* Jet's exerts force on blades and blades exerts force on jet. The tangential force applied to the wheel causes it to rotate.

Let $\rho \rightarrow$ density of fluid.

$Q \rightarrow$ flow rate

$u_i \rightarrow$ input jet speed

$u_c \rightarrow$ cup-speed

$u_i - u_c \rightarrow$ relative jet speed

The change in momentum, force experienced by the cup F is

$$F = 2\rho Q_i (u_i - u_c) \rightarrow (1)$$

The power P_i transferred to cup is

$$P_i = F \times u_c$$

$$P_i = 2\rho Q_i (u_i - u_c) \cdot u_c \rightarrow (2)$$

To get maximum power, diff (2) w.r.t. u_c and equate to zero

$$\frac{dP_i}{du_c} = 0 \Rightarrow u_i u_c - 2u_c^2 = 0$$

$$\Rightarrow \frac{u_c}{u_i} = 0.5 \rightarrow (3)$$

Sub (3) in (2), we get

$$P_i = 2\rho Q_i (u_i - 0.5u_i) \cdot 0.5u_i$$

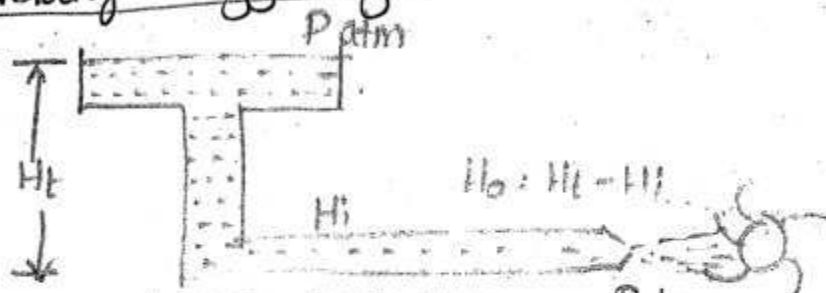
$$= 2\rho Q_i (0.5u_i^2 - 0.25u_i^2)$$

$$= 2\rho Q_i (0.25u_i^2)$$

$$\Rightarrow P_i = 0.5\rho Q_i u_i^2$$

$$P_i = \frac{1}{2}\rho Q_i u_i^2$$

Jet velocity & Nozzle size:



* Atmospheric pressure at both top and at nozzle is same. Therefore with Bernoulli's equation, neglecting friction, we can write

$$u_i^2 = 2gH_a \rightarrow (1)$$

where H_a = available water head

* If there are n nozzles, let a be the area of cross section, the total flow can be given as

$$Q_t = n \times a \times u_i = nQ \rightarrow (2)$$

* Let η_{nm} be the efficiency for converting kinetic energy of jets to mechanical energy. The mechanical power output P_m of the turbine with n nozzles,

$$P_m = \eta_{nm} P_i = \eta_{nm} \frac{1}{2} \rho Q_i u_i^2$$

$$= \eta_{nm} \frac{1}{2} \rho (a u_i) \cdot u_i^2 \cdot n$$

$$P_m = \frac{1}{2} \eta_m n a \rho (2gH_a)^{3/2}$$

Angular velocity & turbine size:



Let $R \rightarrow$ Radius of turbine

$\omega \rightarrow$ Angular velocity of turbine.

$$\text{Power } P = F \times R \times \omega \rightarrow (1)$$

Larger the wheel area, smaller the angular speed ω .

Since $u_c = R\omega$ and $u_c = 0.5 u_i$

$$\therefore R = \frac{0.5 (2gH_a)^{1/2}}{\omega} \rightarrow (2)$$

The nozzles are circular in cross section, of jet's of area a and radius r ,

So $a = \pi r^2$.

$$r^2 = \frac{P_m}{\eta_m n \pi (g H_a)^{3/2} \sqrt{2}} \rightarrow (3)$$

Combining (2) & (3)

$$\frac{r}{R} = 0.68 (\eta_m n)^{-1/2} \angle$$

where $\angle = \frac{P_m^{1/2} \omega}{\rho^{1/2} (g H_a)^{5/4}}$.

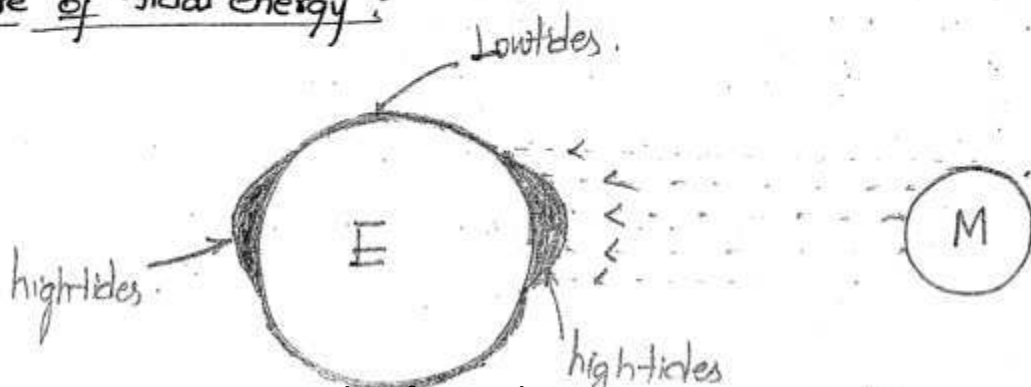
Tidal energy:-

Periodic rise & fall of sea water due to gravitational force of sun and moon over earth and oceans are called Tides.

This tides contains large amount of potential energy.

- * The highest level of tidal water is called high tides (or) flood tides.
- * The lowest level of tidal water's is called low tides (or) ebb tides.
- * The level difference between high & low tides is called tidal range.
- * The large scale up & down's of sea water represents large and unlimited source of energy. This vast tidal energy can be converted into electricity.

Origin & Nature of tidal energy:-

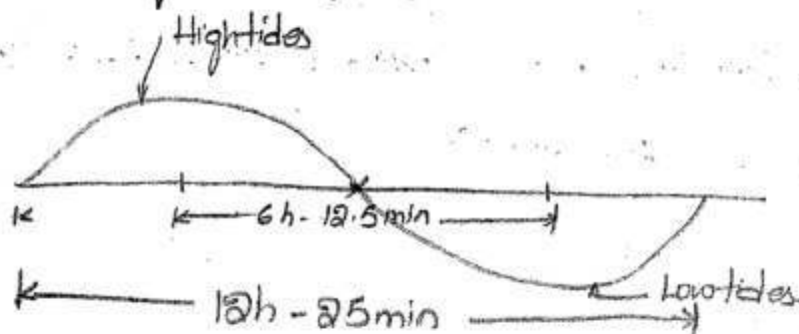


Sea tides are caused due to gravitational attraction of moon and sun over solid earth.

* Since moon is closer to earth as compared to sun, the major source of tides are caused due to moon's gravitational field over earth (70% of tide producing forces).

* When moon comes closer to earth, hence earth is subjected to more gravitational field. The water is pulled in the direction of moon facing the earth. At the same time solid earth is pulled back from water on the opposite side. To balance the water level, the water level on the far side of earth also experience a rise in sea level. Hence earth rotates with a period of 1 day with this two bulges. As earth rotates, the position of point also changes with respect to moon and hence tides also changes.

* Since earth rotates in westward direction, the ocean waves lasts a period of 12h-25min.



* However sun's gravitational effect is low as compared to moon and comprises only 2.2 times less than that of moon and has a tidal period of 12h.

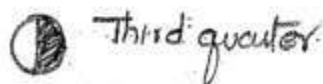
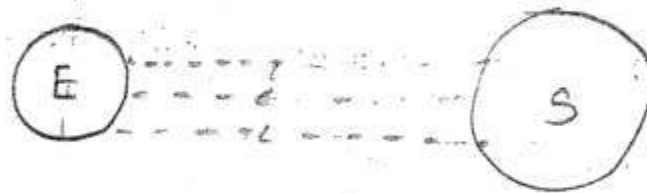
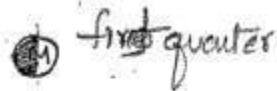
* Due to difference in tidal periods, solar tides moves in and out of phase with lunar tides.



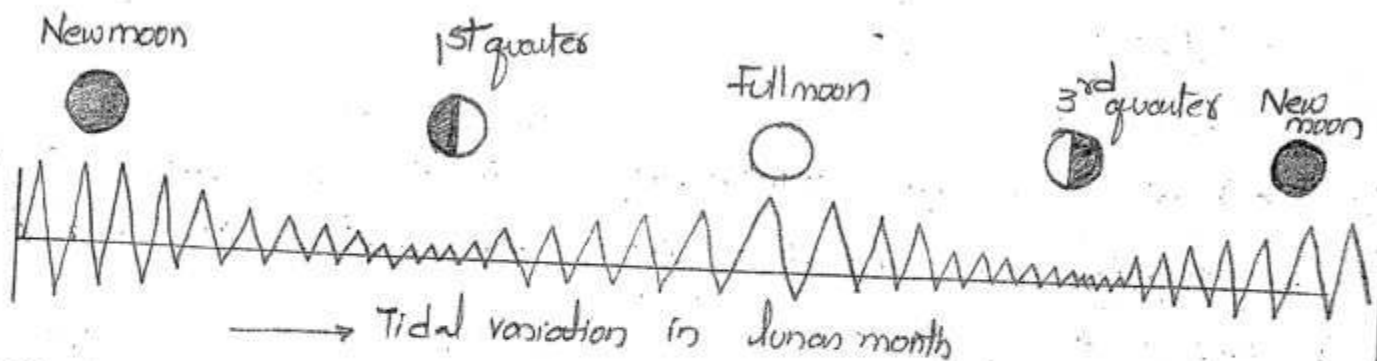
* When sun and moon are in phase with earth, oceans produce Spring tides. These tides are highest.

Spring tides are produced twice a month on new moon and full moon.

* When sun and moon are quadrature with each other, the gravitational force on earth are cancelled by each other and produce neap tides.



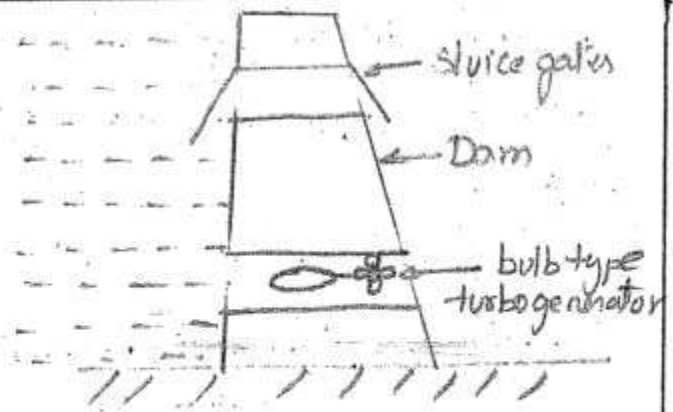
Neap tides are also produced twice in a month on half moons (first & third quarter).



Requirement of Tidal power plant

Tidal power plant consists of

- 1) Dam (or) Dyke
- 2) Sluice ways
- 3) Bulb-type turbo generator.



1) Dam (or) Dyke:

A barrier constructed to hold and store water.

2) Sluice ways:-

Rapid controlled gates for fast filling and emptying the basin.

3) Turbo-generator:-

Steel shell containing alternator and special Kaplan turbine with variable pitch blades.

Tidal power range:

Let the catchment Area = A

The water stored has a potential energy:

The potential energy stored at an incremental height dh over the head h is

$$dw = dm \cdot g \cdot h \rightarrow (1)$$

$$\text{where } dm = \rho \cdot A \cdot dh \rightarrow (2)$$

Sub (2) in (1)

$$dw = \rho \cdot A \cdot dh \cdot g \cdot h \rightarrow (3)$$

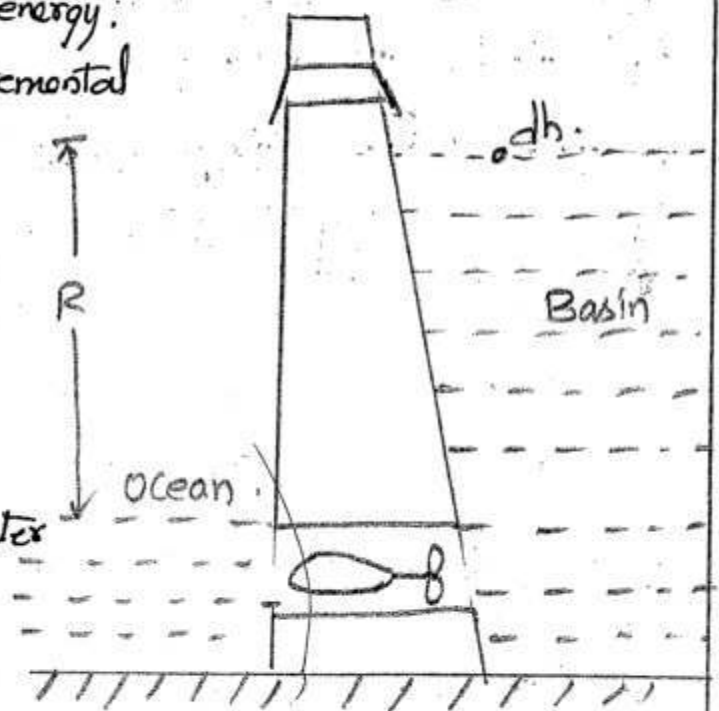
Total potential energy stored in water

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

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

$$= \frac{\rho A g}{2} \cdot h^2 \Big|_0^R$$

$$\therefore W = \frac{\rho A g R^2}{2} \rightarrow (4)$$



The time difference b/w high & low tides is 6h 12.5min. which is equal to (22350s). The power should be utilized within this period.

Avg. density of sea water = 1025 Kg/m^3 .

$$P_{\text{avg}} = \frac{1025 \times 9.8 \times A \times R^2}{2 \times 22,350} \quad \text{where } P = \frac{W}{T}$$

$$\therefore P_{\text{avg}} = 0.225 \times A \times R^2 \text{ watt's.}$$

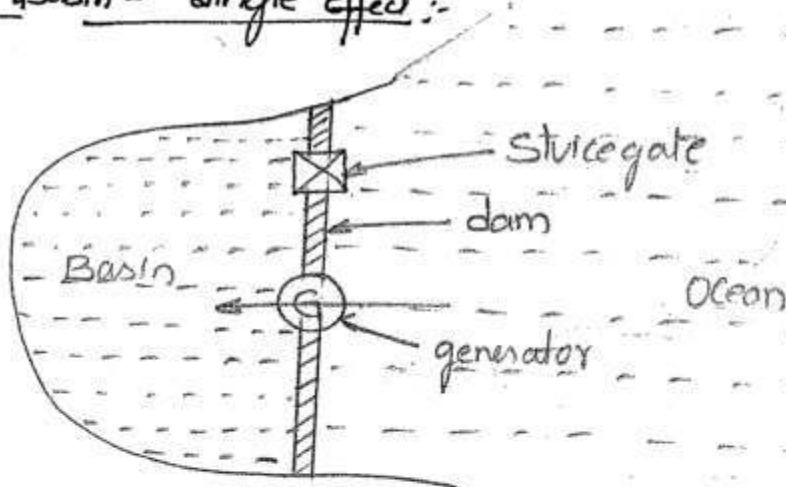
The tidal power developed is proportional to area of basin and square of the range.

Tidal energy Conversion Schemes :-

Tidal energy conversion schemes are :-

- 1) Single basin - Single effect
- 2) Single basin - Double effect
- 3) Two basin - linked basin
- 4) Two basin - Paired basin
- 5) Tidal flow basins.

1) Single basin - Single effect :-



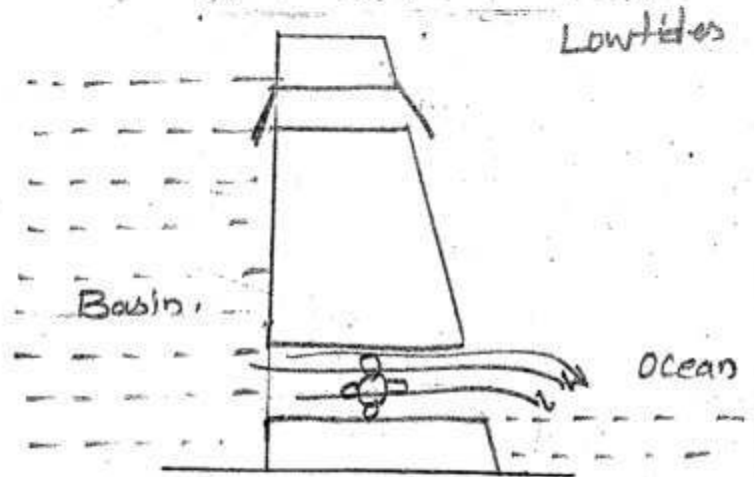
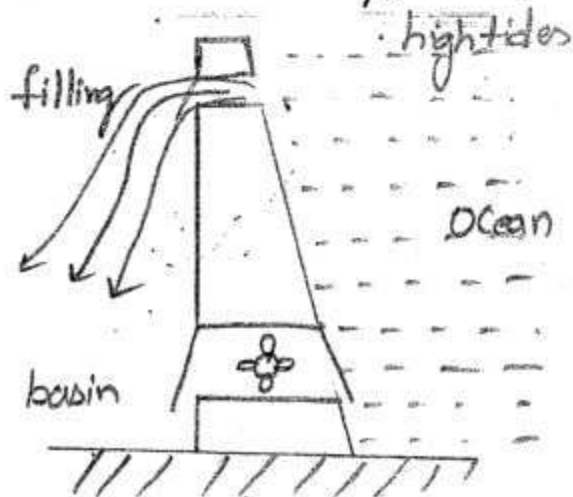
* This scheme consists of only one basin. In this power is generated either during filling the basin or emptying the basin.

* In this scheme there are two types of possible operation.

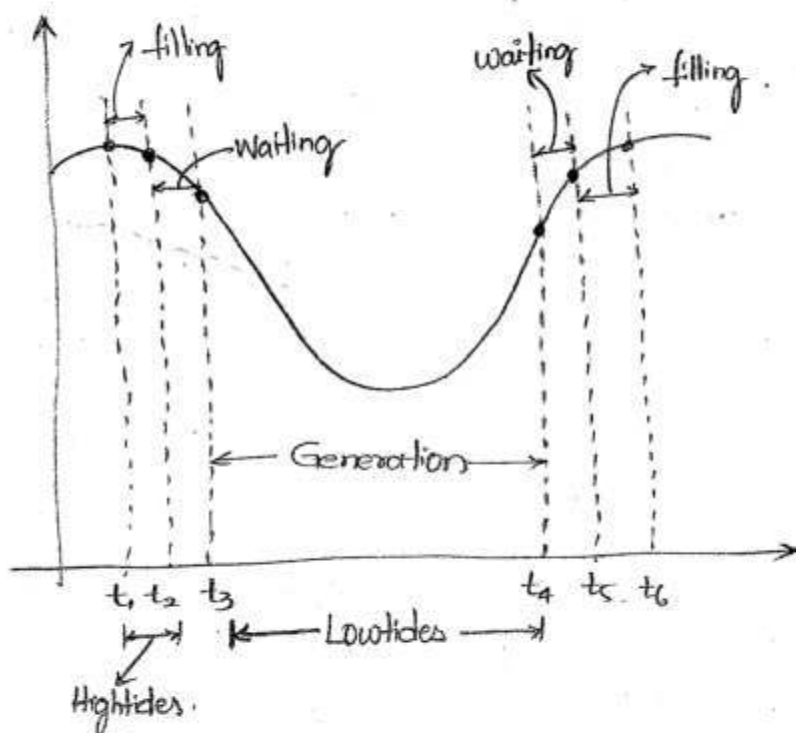
- a) Ebb generation cycle
- b) Flood generation cycle

a) Ebb generation:-

In this basin is filled during high tides in the oceans by opening the sluice gates. The water is stored and held until it creates a sufficient head.



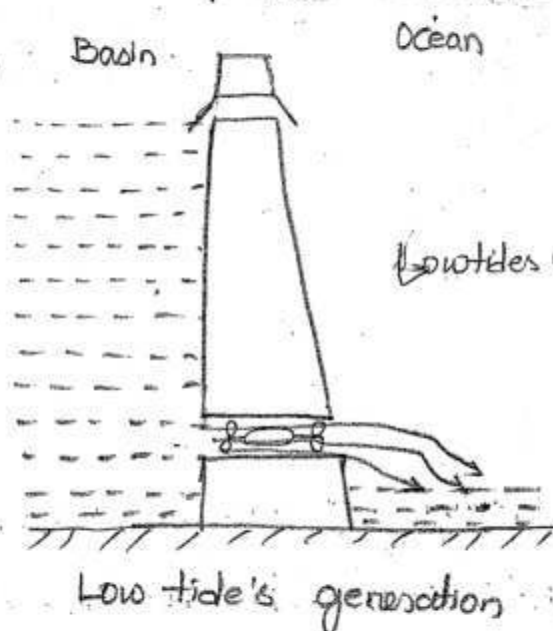
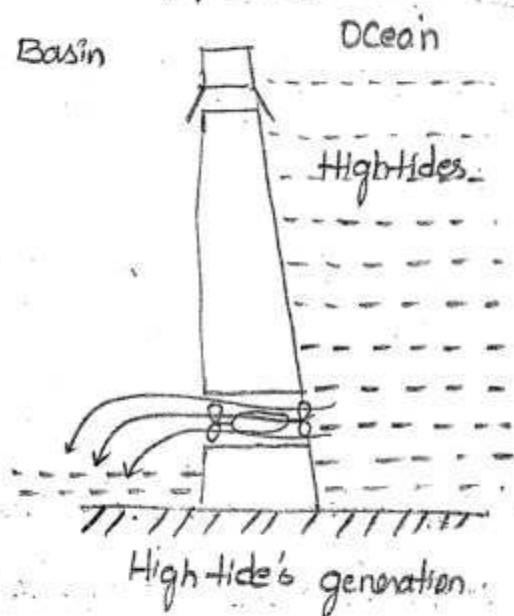
During low tides in oceans, the Ocean water will fall and create sufficient tidal range. Now the water stored is passed through the turbine for generating power.



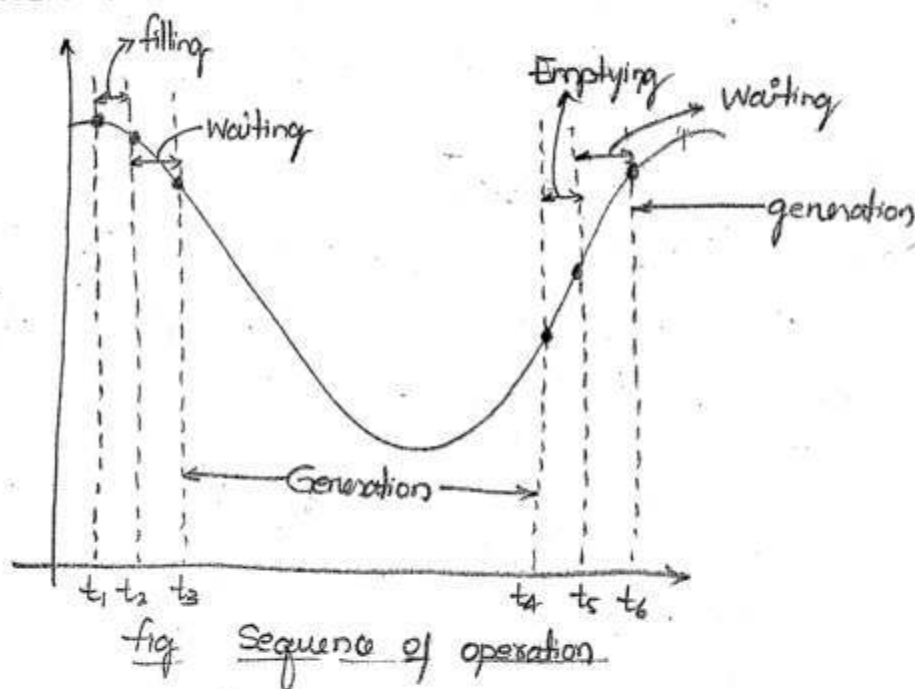
* The operation can also be achieved in Flood cycle also. However the turbine is operated during high tides in oceans.

2) Single basin double effect scheme:

In this scheme, the power can be generated both in ebb tides and flood tides. For this purpose we have to use reversible hydraulic turbines.

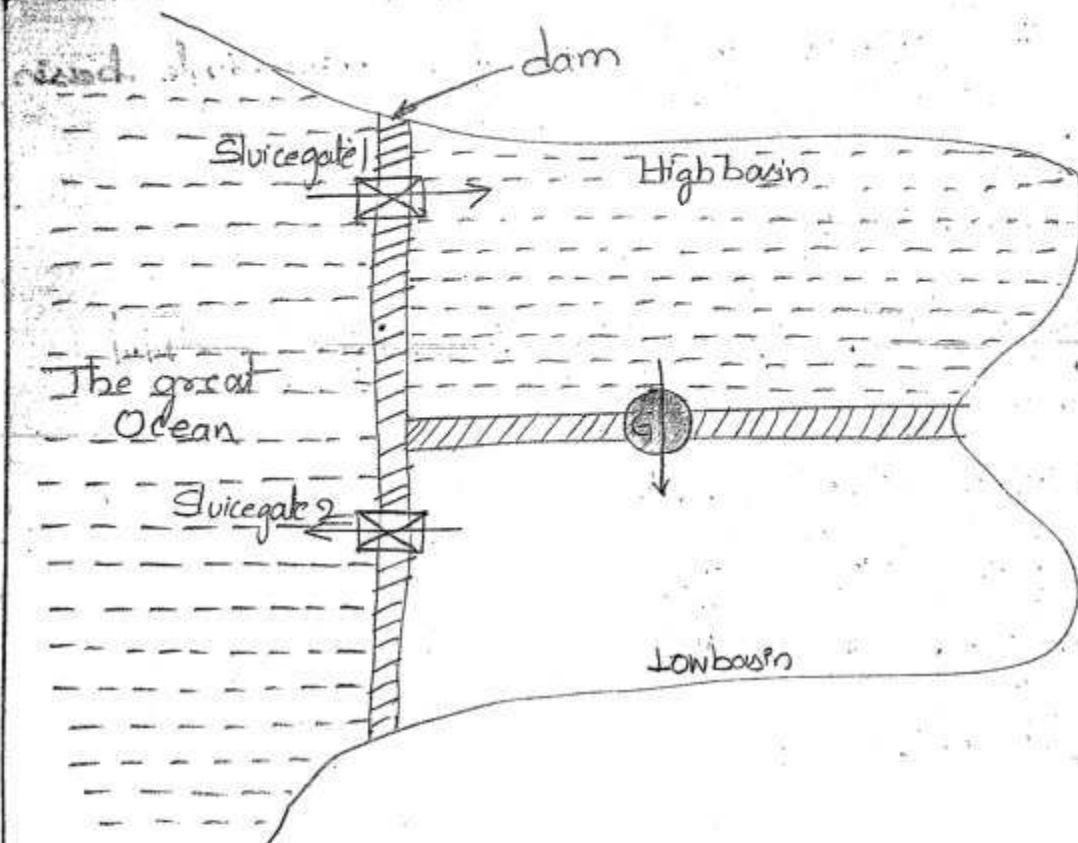


* The operation can be clearly understood by the above figures.



3) Two basin-linked basin:

To have continuity of power supply we have to use two basin linked basin scheme.



* This scheme consists of two basins, one filled during high tides other basin is emptied during low tides thus creating a permanent head between two basins.

* During high tides Sluice gate 1 is opened and starts filling high basin. When water is sufficiently filled gate 1 is closed and waited for generation.

* During low tides Sluice gate 2 is opened and starts emptying low basin hence creating a sufficient head between water stored in high basin and low basin.

* The generator valve in the barrier dam is opened for generation. When water from high pool rushes through generator turbine, electric power is produced.

A) Two basin - Paired basin: * (for diagram Refer last page) *

This scheme uses two single basin schemes. One scheme generates power during high tides and other scheme generates power during ebb tides. The output of scheme is not continuous.

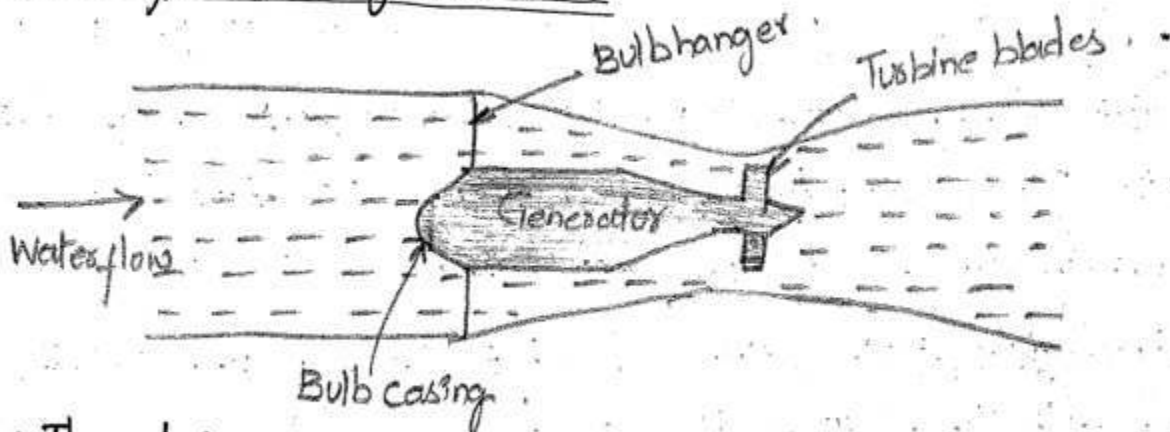
But the scheme is generally more economical than single basin schemes.

Turbines for Tidal power:

There are 3 types of turbines used for tidal power generation

- 1) Bulb type turbo generators
- 2) Tube type " "
- 3) Rim type " "

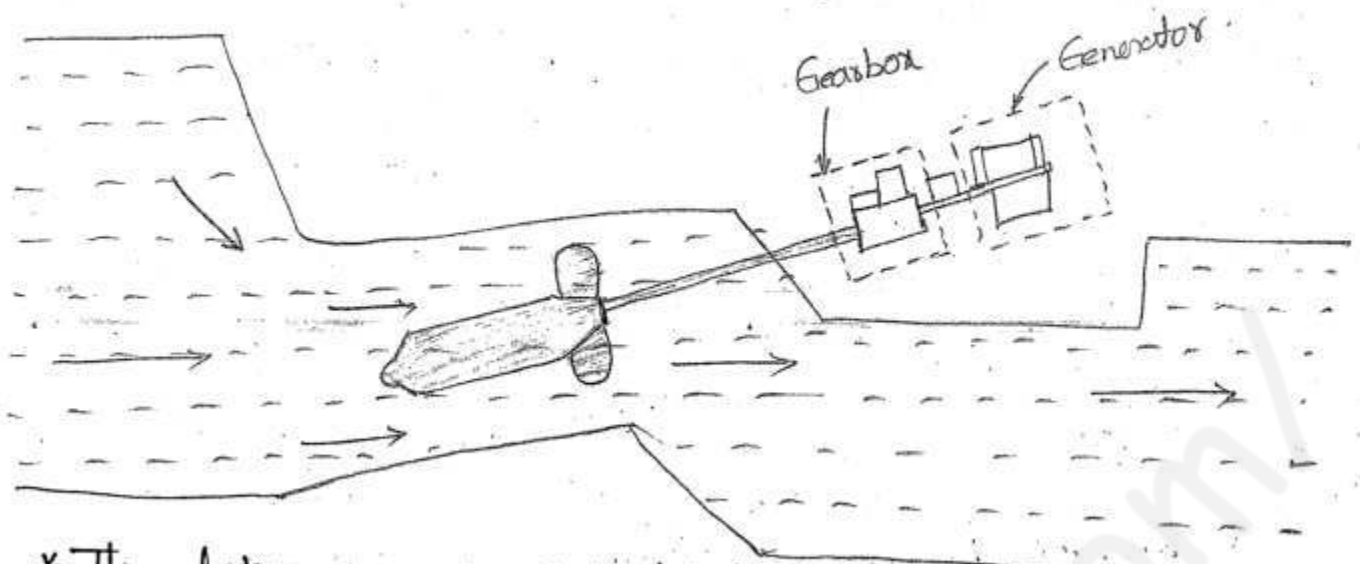
1) Bulb type turbo generators :-



- * The turbine can either be Kaplan (or) propeller type turbine.
- * The generator is coupled to turbine either through direct shaft (or) through gear mechanism.
- * Always the generator is located at the upstream side where as the turbine is located at the downstream side as shown.
- * Water flows in the axial direction along the bulb and turbine blades.

2) Tube type turbo generators.

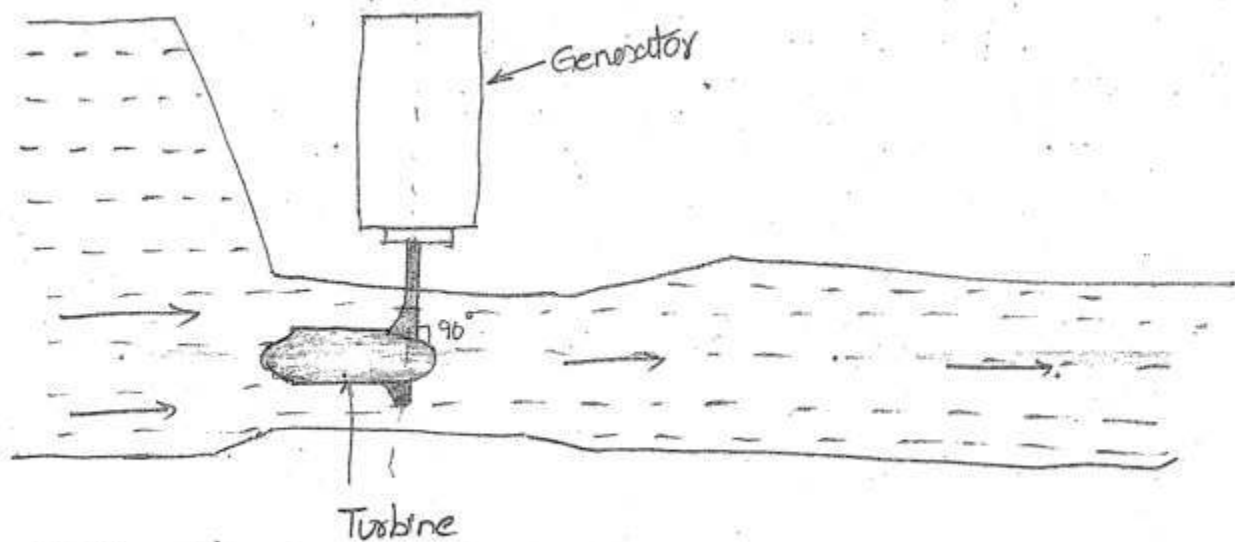
- * In this turbine is housed inside the closed conduit but the generator is mounted outside in a pit as shown below.



- * The turbine is connected to the generator using a inclined shaft at 45° as shown.
- * The water flows in the axial direction through the turbine blades. The blades can be adjusted. That means for large power generation, blade length is to be increased and decreased vice versa. Hence it can meet the amount of power needed as required.
- * This allows the turbine to run more efficiently, generating only the amount of power needed.
- * Furthermore, this design gives some room to gearbox which allows more efficient operation of generator.
- * However, it presents some vibration problems of the long shaft and it cannot be reversed to operated on flood tide (i.e.) used to pump storage.

3) Francis type turbines:

- * Turbine's generator is separate from the turbine itself.
- * Generator is mounted on the bearing and is right angle (90°) to the turbine blade.



* Generator is connected through shaft that moves with the turbine.

* This kind of turbine is preferred for its greater theoretical efficiency and greater inertia (to satisfy stability criteria).

* However it can be operated only on ebb tide (low tide) and cannot be used to pump storage to the basin due to their more delicate nature.

Wave energy:

Waves are caused due to indirect solar energy.

Solar energy $\Rightarrow$ Wind energy $\Rightarrow$ Ocean waves.

* However wave energy is most active and most concentrated than solar energy. Hence wave energy from oceans can produce great power densities than solar devices.

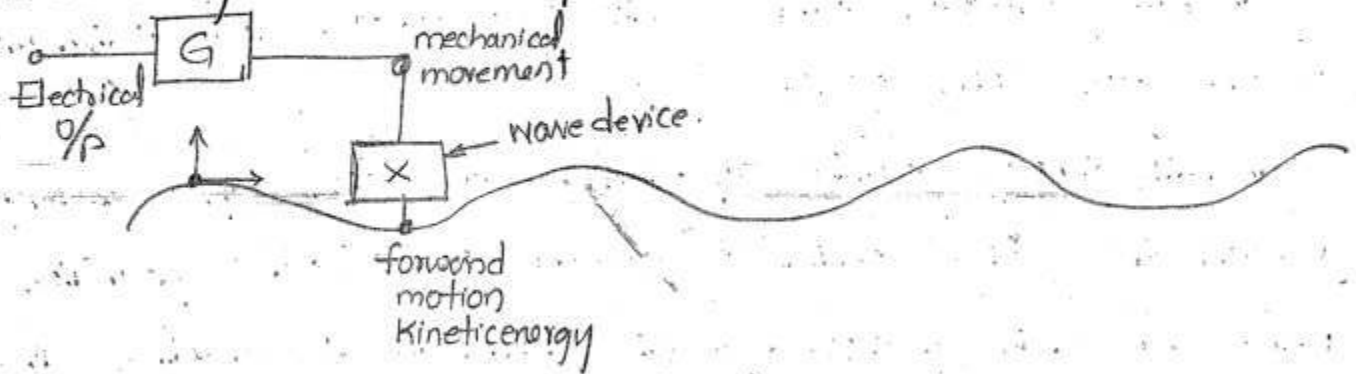
Wave energy conversion devices:

Principle:

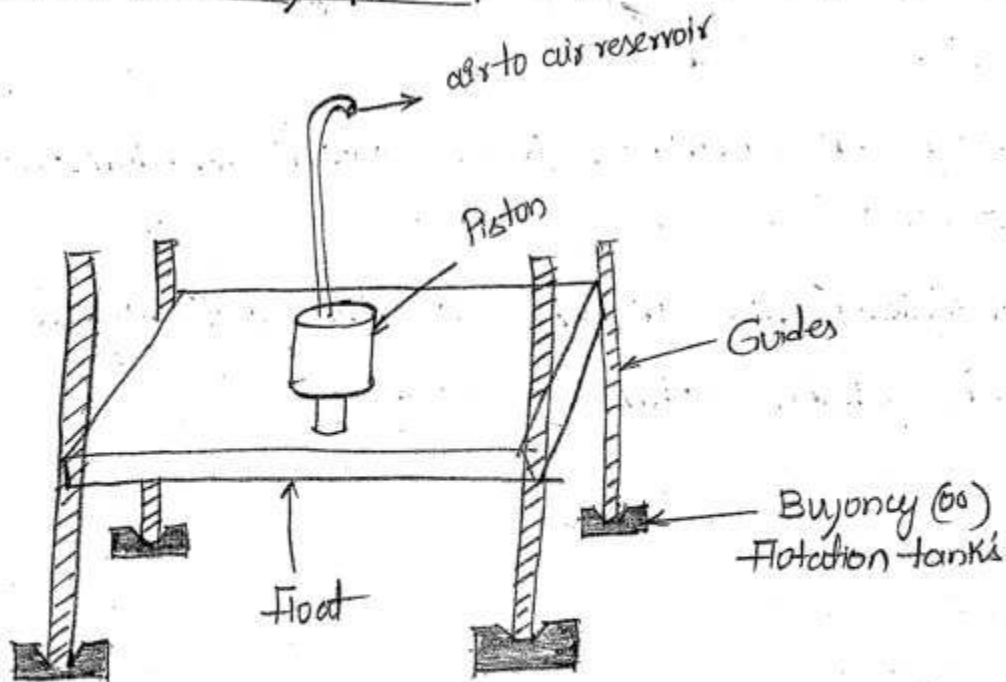
* Ocean poses forward motion kinetic energy, which is very strong.

* The wave devices absorb this forward motion kinetic

energy in the waves and transforms it into mechanical movement of the internal parts in the conversion device.



Wave energy Conversion by float's



- Wave motion is basically horizontal motion where as water movement is vertical
- The floats which we are using here absorbs the vertical energy of water
- This scheme consists of floats which moves up and down along with sea water with in the relative stationary guides.
- This reciprocating motion of floats is first converted in to mechanical energy later is converted in to electrical energy.

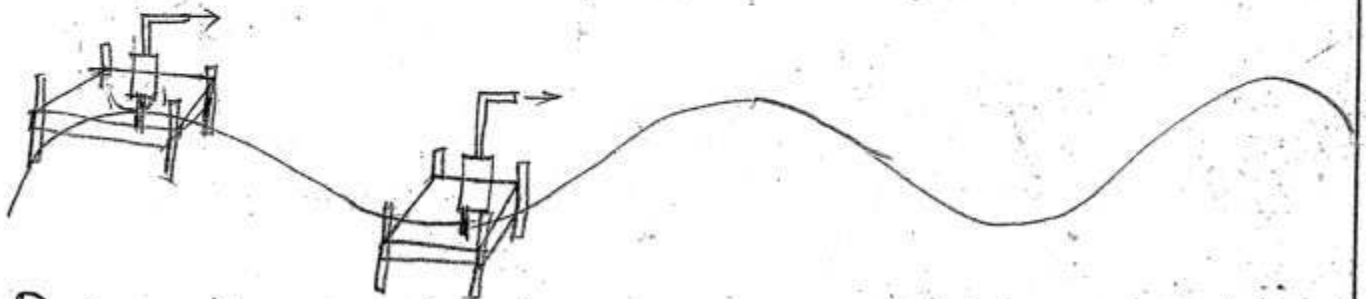
Working:

* This Conversion device consists of a square float which moves up and down with waves.

* This square float is supported by 4 vertical guides as shown. Beneath the guides consists of 4 large under water flotation tanks. The main purpose of this tanks is to stabilize the platform against the horizontal and vertical displacement of sea water.

* Hence the platform is a robust and immovable to the sea waves.

* A piston is attached to the float which reciprocates into the piston with sea water.



* During trough of the sea wave, the square float lowers and hence the piston is drawn downwards. During this time the piston sucks the air through inlet valve.

* During crest of the sea wave, the float raises and push the piston into the cylinder. This causes air to pump into the air reservoir's beneath through outlet valve. Later the air stored in the reservoir is sent into air turbines for power generation.

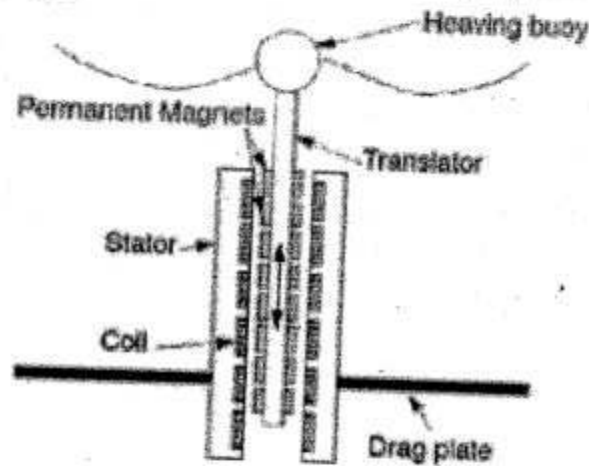
Hence the flotation tanks beneath serve two purposes.

→ buoyancy floating

→ Air storage

Linear Generators:

Linear electrical machines are used as an alternative drive system in transportation and conveyor systems, where they replace pneumatic/hydraulic systems or rotating electric machines driving a spindle. Generally speaking linear machines are unwound rotating machines, either asynchronous or synchronous machines. In Figure the principle layout of a permanent magnet synchronous linear generator is depicted. In the example the coils are placed on the stator and the magnets on the translator, mounting vice versa is also possible.



Almost all linear electrical machines are connected to the grid by means of a frequency converter (FC). In this configuration the behavior is pretty similar to a rotating electrical machine grid connected by an FC. A PTO (Power Take Off) systems comprising a linear electrical machine and an FC(Frequency converter)

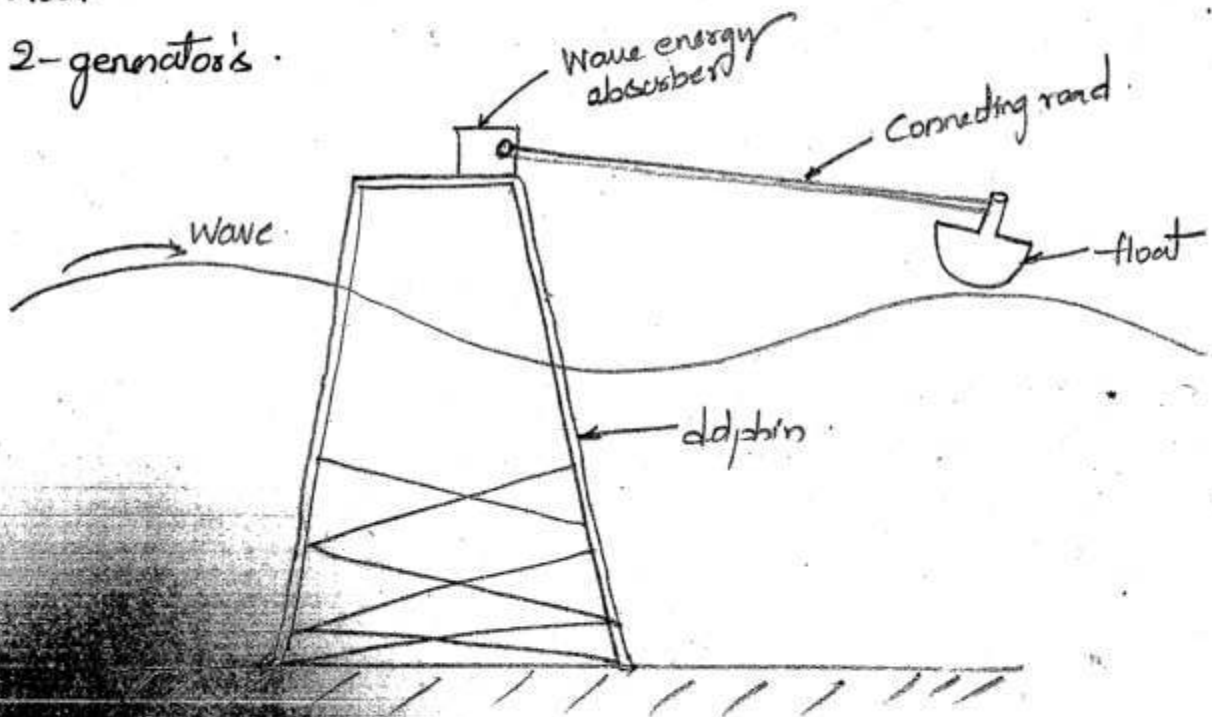
- Firstly the system shows excellent control behavior and extremely short response times in the range of some milliseconds. The overall efficiency of the system – electrical machine and FC – is comparably high. At full-load efficiencies well above 80% up to 95% can be expected. Also at part-load especially the permanent magnet synchronous machine shows a high efficiency.
- Further positive aspect is the overload capacity. Electrical machines typically have an overload capacity in the range of 700% and the thermal time constant in the range of some 10 minutes is definitely sufficient for the short power peaks of a WEC. Looking at the FC reduced overload capacities (up to 200%) and thermal time constants (in the range of some seconds some minutes) will be found.
- One major drawback of linear electrical machines is surely the relatively low distribution of the technology, resulting in the need of a tailored machine. With the tailored machine come high investment cost and additional development risks, etc. Another issue often discussed are the fluctuating prices for the magnets, which could result in a rapid increase of overall costs.

* The power generated is transmitted to land using water cables.

Dolphin type wave power machine:

This scheme consists of the following main components.

- 1) Dolphin
- 2) Float
- 3) 2-generators.



The float used here has two motions.

a) Rolling motion about its own fulcrum with connecting rod.

b) Vertical movement and downward and upward movement about the connecting rod.

+ Both the movements of the float is simultaneous.

* This movement of the float is amplified and is converted into continuous motion which drives the two generators.

Other power Machines :- (Extra)

There are no. of varieties of Wave power devices: