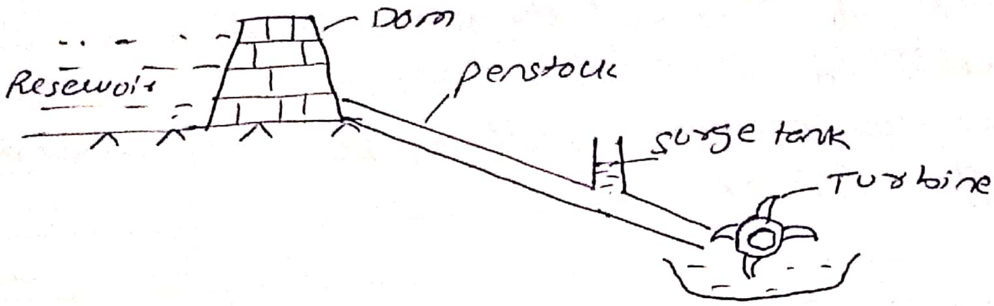
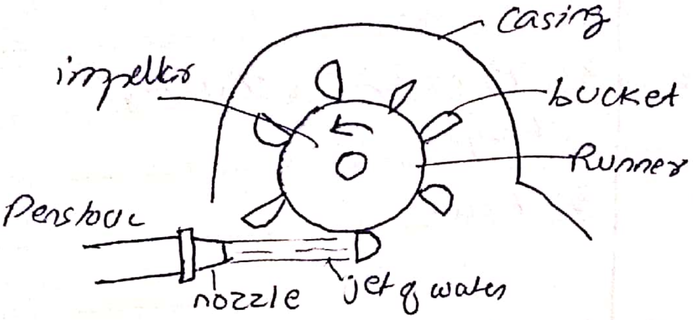
Hydraulic Turbines

Hydraulic Turbines are rotodynamic machines that converts hydraulic energy from water to electrical energy.



Principle of working: (Pelton wheel).



The fluid when enters the runner of turbine it has some kinetic energy which gets converted to pressure energy as it passes over the buckets of turbine. Pelton wheel operates at 150m-1800m head. High head low discharge reqd.

Classification:

I Acc to ~~position of water~~ type of energy at inlet.

a) Impulse turbine b) Reaction turbine.

In impulse turbine all of the available energy is converted to kinetic energy. eg: Pelton wheel

In Rxn turbine only a part is converted.

eg: Francis, Kaplan.

II Acc to dirn of flow

a) Tangential flow - pelton wheel
b) Radial flow - inward, outward (Fourneyron turbine) ~~Francis~~
c) Axial flow - eg:- Kaplan
d) mixed flow - new Francis turbine (water enters in rad dirn & leaves at centre)

III Acc to Head - High, med, low IV Sp speed - low, med, High

Principle of Reaction turbine:

A part of available energy is converted to KE and remaining part is gradually converted through runner

Impulse turbine	Reaction turbine
1) Entire available head is converted into KE	1) Only part
2) Pressure of water remains const (atm pr)	2) Pressure, velocity changes.
3) wheels must not run full	3) Full
4) To be place at the foot of the fall	4) 10m above the foot of fall
5) Possible to regulate the flow without loss	5) not possible to regulate the flow

Efficiencies of Turbine:

1) **Hydraulic eff** $\eta_h = \frac{\text{Power delivered to runner}}{\text{Power supp at inlet}} = \frac{R.P}{W.P}$

For pelton turbine, Power del to runner, $RP = \frac{W}{g}\frac{(V_{w_1} \pm V_{w_2})u}{1000}$ KW

For radial flow turbine $\eta_h = \frac{W}{g}\frac{[V_{w_1}u_1 \pm V_{w_2}u_2]}{1000}$

Power supplied at inlet of turbine (W.P) $= \frac{W \times H}{1000}$ KW

W - wt of water striking the vanes

$W = \rho g Q$

V_{w_1}, V_{w_2} - whirl velocity at inlet, outlet

U - Tangential velo of vane.

H - Net head on turbine.

$\therefore \frac{W \times H}{1000} = \frac{\rho g Q H}{1000}$

$\rho = 1000\ kg/m^3 \Rightarrow gQH$ for water

2) **Mechanical eff** $= \frac{\text{Power at the shaft of turbine}}{\text{Power del by water to runner}} = \frac{S.P}{R.P}$

3) **Volumetric eff**:

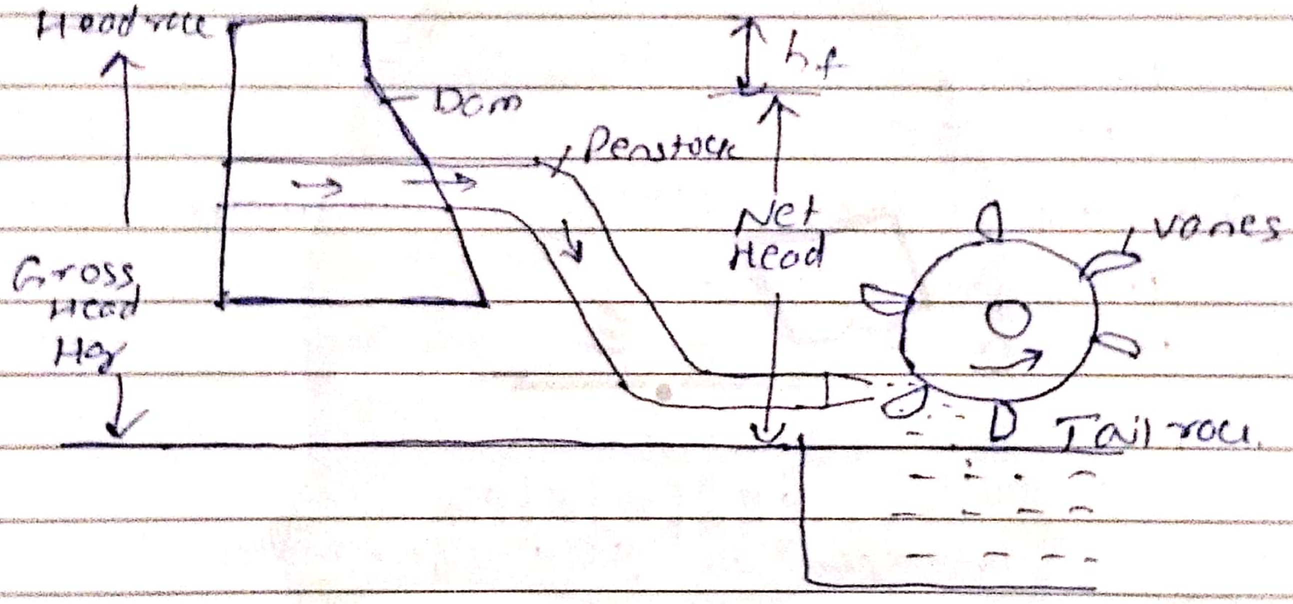
$\eta_v = \frac{\text{vol of water actually striking runner}}{\text{vol of water supp to turbine}}$

4) **Overall eff**: $\eta_o = \frac{\text{Power at the shaft}}{\text{Water power}} = \frac{S.P}{W.P}$

Gross Head: The difference b/w head race level and tail race level when no water is flowing is called Gross head H_g.

Net head: It is defined as head available at inlet of turbine. ~~when no water is flowing.~~
There exist head loss due to friction h_f b/w water ~~&~~ penstock & turbine.

$\therefore$ Net head $H = H_g - h_f$



Gross head $H_g = \frac{4fLV^2}{2gd}$

V - velo. of flow
L - length of penstock
D - dia of penstock

FLUID MACHINES (UNIT-3)

classification of Fluid machines

① Based on Principle of operation:

a) Positive displacement m/c
b) Turbomachines

Positive disp m/c :- The machines whose functioning depends essentially on change of volume of certain amount of fluid within the machine.

Turbomachines: These are machines whose functioning depends basically on principle of fluid dynamics.

When turbomachines absorb power they become a pump.
When they produce power → Turbine.

② Based on direction of fluid flow

a) Radial flow b) Axial flow c) Tangential d) mixed

③ Based on direction of energy conversion

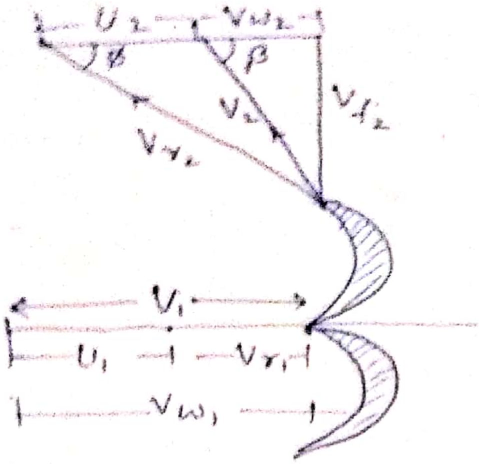
a) Impulse b) Reaction

Efficiency of pelton wheel:

ϕ - vane angle at outlet

Net Head $H = H_g - h_f$

$$h_f = \frac{4fLV^2}{2gD}$$



Velo of jet at inlet $V_1 = \sqrt{2gH}$

$$u = u_1 = u_2 = \frac{\pi D N}{60}$$

$$V_{r_1} = V_1 - u_1$$
$$= V_1 - u$$
$$V_{w_1} = V_1$$

$V_{r_2} = V_{r_1}$ and $V_{w_2} = V_{r_2}\cos\phi - u_2$

Force exerted by jet of water $F_x = \rho a V_1 [V_{w_1} + V_{w_2}]$

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

$$\text{Power} = \frac{\rho a V_1 [V_{w_1} + V_{w_2}] u}{1000}$$

$$\text{w.d per unit wt} = \frac{\rho a V_1 [V_{w_1} + V_{w_2}] u}{\rho a V_1 \times g} = \frac{1}{g}[V_{w_1} + V_{w_2}] u$$

$$\text{Energy supp at inlet} = K.E = \frac{1}{2} m v^2 = \frac{1}{2}(\rho a V_1) V_1^2$$

$$\text{Hydraulic eff} = \frac{w.d}{\text{Energy i/p}} = \frac{\rho a V_1 [V_{w_1} + V_{w_2}] u}{\frac{1}{2}(\rho a V_1) V_1^2}$$

Subs the values of V_{w_1}, V_{w_2}

$$\eta_h = \frac{2u}{V_1^2}[V_1 + V_{r_2}\cos\phi - u]$$

$$= \frac{2u}{V_1}[V_1 + V_{r_1}\cos\phi - u]$$

$$= \frac{2u}{V_1}[V_1 + (V_1 - u)\cos\phi - u]$$

$$\eta_h = \frac{2(V_1 - u)(1+\cos\phi)u}{V_1^2}$$

For max eff $\frac{d}{du}(\eta_h) = 0$

$$\Rightarrow \frac{1+\cos\phi}{V_1^2}\left[\frac{d}{du}\{2(V_1-u)u\}\right]$$

$$+ 2(V_1-u)u \frac{d}{du}\left\{\frac{1+\cos\phi}{V_1^2}\right\} = 0$$

$$\frac{1+\cos\phi}{V_1^2}\left[2V_1 - 4u\right] = 0$$

$$2V_1 - 4u = 0$$

$$V_1 = 2u$$

$$u = V_1/2$$

Scanned with CamScanner

Specific Speed (N_s)

It is the speed of turbine identical in shape, geometrical dimensions, ~~blade~~

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

P - Power in kW

H - Head in m

N - speed in rpm

Specific speed is used to compare different turbines.

Unit speed : It is defined as speed of a turbine working under unit head

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

Unit discharge : Discharge of turbine working under unit head

$$Q_u = \frac{Q}{\sqrt{H}}$$

Unit power Power developed by turbine working under unit head.

$$P_u = \frac{P}{H^{3/2}}$$

Speed ratio $= u_1 / \sqrt{2gH}$

Flow ratio $= \frac{V_{f1}}{\sqrt{2gH}}$

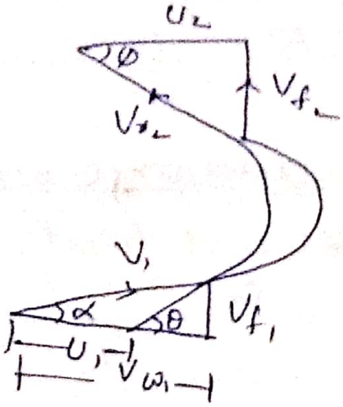
(6) A Kaplan turbine working under a head of 20m develops 11772 kW Shaft Power. The outer dia of runner is 3.5m and hub diameter is 1.75m. The guide blade angle at the extreme edge of runner is 35°. The hydraulic & overall efficiencies of turbine are 88% and 84% resp. If velocity of whirl is zero at outlet. Determine

i) Runner vane angles at inlet & outlet at extreme edge of runner ii) Speed of turbine.

Soln $H = 20m$, $S.P = 11772$ kW

$D_o = 3.5m$, $D_h = 1.75m$ $\alpha = 35°$

$\eta_h = 88\%$ $\eta_o = 84\%$ $V_{w_2} = 0$



$\eta_o = \frac{S.P}{W.P}$

$W.P = \frac{\rho g Q H}{1000}$

$\eta_o = 84\%$, $SP = 11772$

$0.84 = \frac{11772}{\rho g QH/1000}$

$Q = \frac{11772 \times 1000}{0.84 \times 1000 \times 9.81 \times 20} = 71.428\ m^3/s$

$Q = \pi/4 (D_o^2 - D_b^2) V_{f_1}$ for Kaplan Turbine

$71.428 = \frac{\pi}{4} (3.5^2 - 1.75^2) V_{f_1}$

$= 7.216 V_{f_1}$

$V_{f_1} = 9.9$ m/s

$\tan\alpha = \frac{V_{f_1}}{V_{w_1}} = \tan 35°$. $V_{w_1} = \frac{9.9}{\tan 35°} = 14.14$ m/s

Centrifugal pump

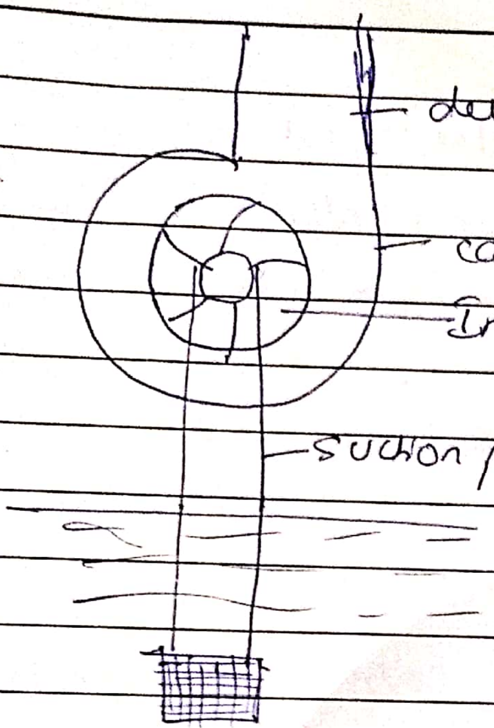
The hydraulic machine that converts mechanical energy to hydraulic energy is called pump.

In centrifugal pump mechanical energy is converted to pressure energy by means of centrifugal force.

The parts of centrifugal pump are

1. Impeller 2. Casing 3. Suction pipe 4. Delivery pipe.

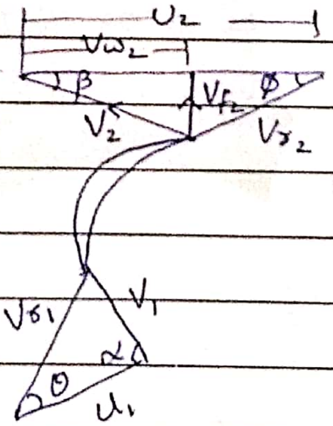
1. Impeller: The rotating part of centrifugal pump is called impeller.
2. Casing: It is an air tight passage surrounding the impeller. In this kinetic energy of water is converted into pressure energy.
3. Suction pipe: A pipe whose one end is connected to inlet of pipe & other end dips into water is known as suction pipe.
4. Delivery pipe: A pipe whose one end is connected to outlet of pump & other end delivers the water



work done by centrifugal pump

In centrifugal pump the water enters radially at inlet i.e V_1 makes 90° w.r.t direction of motion of impeller at inlet.

$\alpha = 90^\circ$ $V_{w_1} = 0$



N - speed of impeller

D_1 - dia of impeller at inlet

U_1 - tangential velo of impeller at inlet.

Similarly D_2, U_2

A centrifugal pump work reverse of radial inward flow reaction turbine.

w.d by water per unit wt $= \frac{1}{g}[V_{w_1}u_1 - V_{w_2}U_2]$

for centrifugal pump w.d $= -\frac{1}{g}[V_{w_1}U_1 - V_{w_2}U_2]$

$V_{w_1} = 0 \Rightarrow$

$$wd = \frac{V_{w_2} U_2}{g}$$

Work done by ~~water on~~ impellar on water per sec

$$= \frac{W V_{w_2} U_2}{g}$$

W - wt of water

$W = \rho g Q$

$Q = \pi D_1 B_1 V_{f_1} = \pi D_2 B_2 V_{f_2}$

D - dia, B - width, V_f - flow velocity.

Suction Head (h_s)

It is the vertical height of centre line of centrifugal pump above the water surface in the tank

It is also called ~~stock~~ suction lift.

Delivery head (h_d):

It is vertical distance from centre line of pump and water surface of tank to which water is to be delivered.

Static head (H_s)

$$H_s = h_s + h_d$$

Efficiency

1. manometric eff

$$\eta_{man} = \frac{\text{Manometric head}}{\text{Head imparted by impellar to water}}$$

$$= \frac{H_m}{\frac{V_{w_2} U_2}{g}} = \frac{g H_m}{V_{w_2} U_2}$$

It is ratio of power given to water to the power available at impeller.

manometric head $H_m = \frac{V_{w_2} U_2}{g}$ - loss of head