IES MASTER

Civil Engineering

Toppers Handwritten Notes

HYDRAULIC MACHINES

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- Theory
- Explanation
- Derivation
- Example
- Shortcuts
- Previous Years Question With Solution

HYDRAULIC MACHINE

Machine :-

- Assembly of Elements which have relative motion b/w them.
- Every machine has one element which is fixed. This element is known as frame of machine.

e.g. ship —structure→ Hull
Automobile → Chasis
Aircraft → Airframe

Structure	Machine
e.g. Building	e.g. Turbine
Road	Pump
Dam	Engine
	Aircraft
	ship
	Truck.

Machine Purpose :-

1. Energy Conversion Machine → Form of Energy is changed.
[e.g. - Engine i/p → Thermal o/p → mechanical]
2. Energy Transmission Machine → " " " same.
[e.g. - Gear i/p & o/p → mechanical]

Energy Conversion machine :-

Change form of energy

Thermal Machine (Temp)
- i/p → Th. o/p → Mech. e.g. → Heat Engine
- i/p → Mech. o/p → Th. e.g. → Refrigerator, AC (Reverse Heat Engine)

Electrical Machine (Voltage)
- i/p → El. o/p → Mech. e.g. → Motor
- i/p → Mech. o/p → El. Generator

Hydraulic Machine (Pressure)
- i/p → Mech. o/p → Hy. Pump
- i/p → Hy. o/p → me ch. Turbine

Design of Machine
- Turbo Machine (Blade on wheel)
- Reciprocating machine (Piston - cylinder)

- Pump
  - Reciprocating
  - Centrifugal

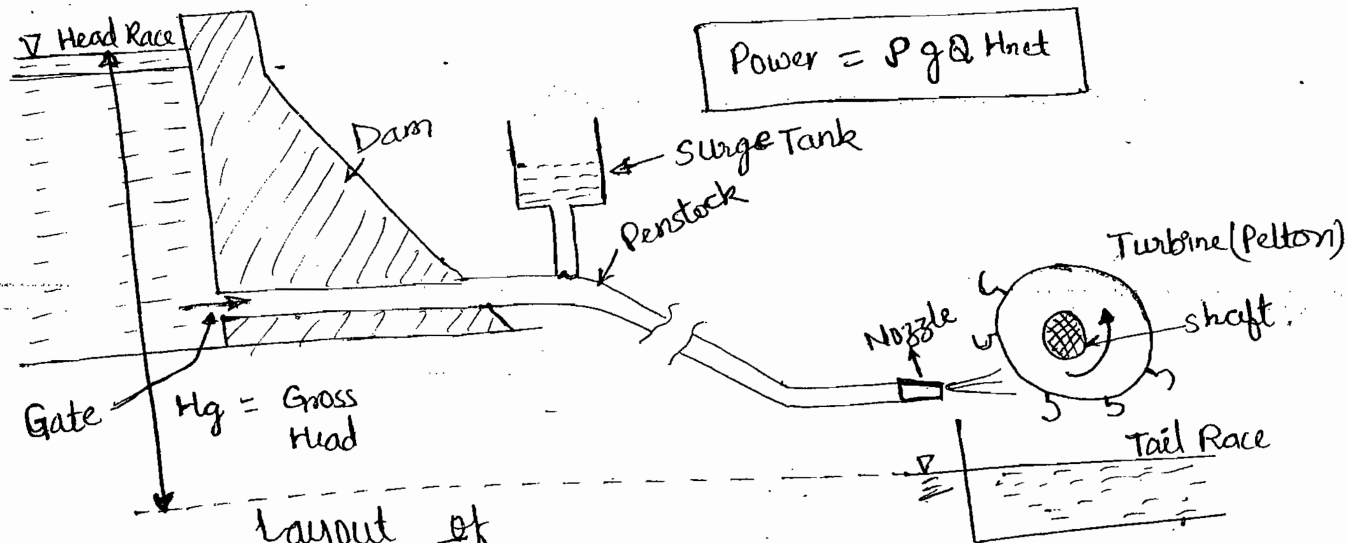
Hyd. Turbine & Hydraulic motor ...

Hydraulic Machines

Machine which converts hydraulic energy to mechanical energy or vice-versa.

- Hydraulic Machine
  - i/p – Hydraulic, o/p – Mech. → **Turbine/ motors**
    - Turbo machine (Turbines) — eg. Pelton, Francis, Kaplan
    - Reciprocating machine
  - i/p – Mechanical, o/p – Hydraulic → **Pumps**
    - Turbo machine — eg. Centrifugal Pumps
    - Reciprocating machine — eg. Reciprocating Pump

HYDROELECTRIC POWER PLANT



Power = $\rho g Q H_{net}$

Layout of Hydroelectric Powerplant

$H_{net} = H_{gross} - \text{Losses} = H_g - h_f$

Components:-
1. Dam
2. Gate
3. Penstock
4. Nozzle
5. Turbine
6. Surge-Tank / ForeBay

Classification of Hydropowerplant

A.) Based on Head:-

1. High head → ~~300~~ 100 m & above → social & environmental cost (Flooding) (stability)
   (Pelton)
2. Med^m Head → 30 m to ~~100 m~~ 300 m
   (Francis)
3. Low Head → Below 30 m
   (Kaplan & propeller)

Turbines

B.) Based on function:-

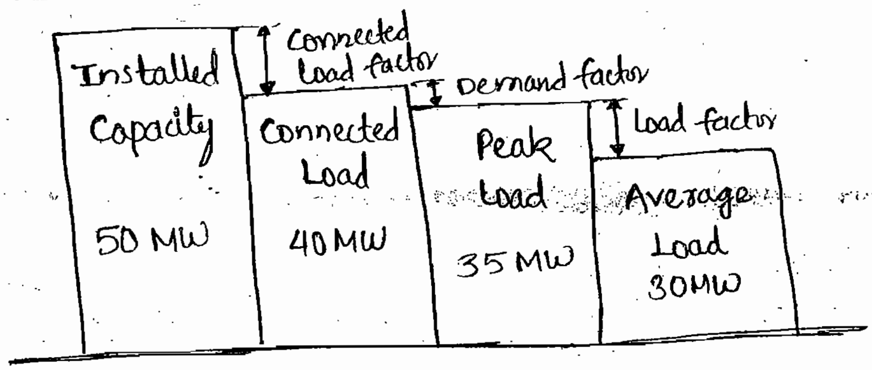
1. Runoff River (Pondage Plant) → is one which does not store any water. It uses the water as it flows. Some Runoff River plant has limited storage called Pondage. This is provided with barrage / wier to meet fluctuation with flows.
2. Storage plant (Impounding)
   (Base Load Plants)
3. Pumped storage plant
   ↓
   (Energy storage)

2. Storage plant → Base load plants → Heavy capital cost, Special cost, enviornmental cost

C.] Based on load :-

1. Base load Powerplant → supply cont. constt power
2. Peak Load " → supplies power during peak-time
   (Quick start - quick stop)

Factors related with Hydro Powerplant



$\text{Load factor} = \dfrac{\text{Avg. Load}}{\text{Peak Load}}$

$\text{Demand factor} = \dfrac{\text{Peak load}}{\text{Connected load}}$

$\text{Connected load factor} = \dfrac{\text{Connected load}}{\text{Installed capacity}}$

$\text{Capacity factor} = \dfrac{\text{Avg. load}}{\text{Installed capacity}}$

$\text{Utilisation factor} = \dfrac{\text{Peak load}}{\text{Installed Capacity}}$

Ex. 1: Hydel Plant, Load varies from 10,000 kW (min) to 35,000 kW (max). Two turbo-generators of 22,000 kW are installed in Plant. Find i.) load factor ii.) Utilisation factor

$$\text{Load factor} = \frac{\frac{(10{,}000 + 35{,}000)}{2}}{35{,}000} = 64.3\%$$

$$\text{Utilisation factor} = \frac{35{,}000}{2 \times 22{,}000} = 79.5\%$$

Pondage factor = $\frac{\text{Total inflow of water}}{\text{Total no. of days in a weak}}$

DATE - 23/11

HYDRAULIC TURBINES

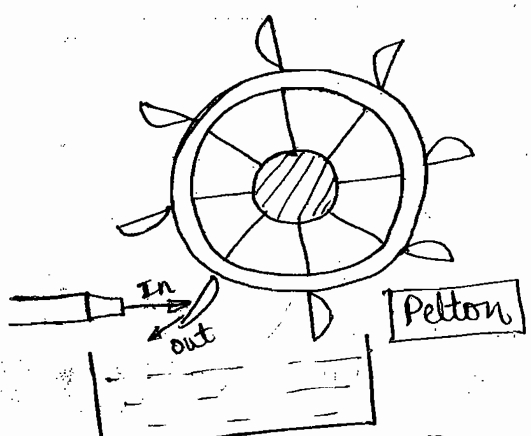
- Hydraulic turbine is a hydraulic machine which converts hydraulic energy into mechanical energy.

Types of Turbines :-

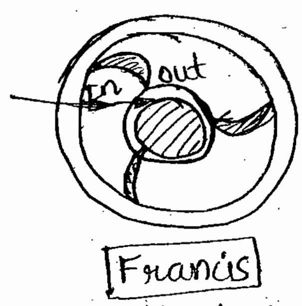
A.) Type of energy at inlet
B.) Direction of flow through ~~~~ runner
C.) Head at inlet
D.) Specific speed of Turbine

B.) Dir^n of flow through Runner

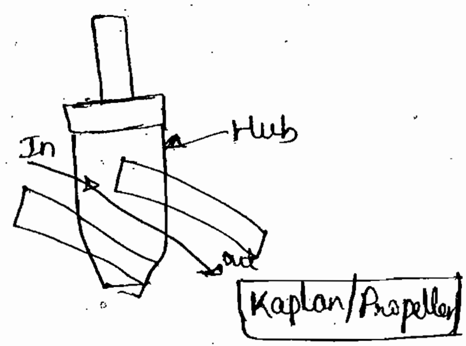
1. Tangential flow (Pelton)
2. Radial " (old Francis)
3. Axial " (Kaplan/ Propeller)
4. Mixed " (Moder Francis) → mix of Radial & axial



Tangential flow



Radial flow



Axial flow

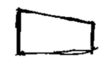
Pelton → Impulse Turbine
$[P_2 = P_1]$
{1 - Entry

Francis/Kaplan → Impulse - rea^n Turbine
$P_2 < P_1$

Based on types of Force :-

1. Impulse Turbine → Impulse force. (it is produce due to change in moment)
   ↳ Flow area constt
2. Reaction turbin → Reaction force.
   ↳ Flow area converging
   Rea^n force is produced due to drop in pressure.
3. Impulse - Reaction Turbine → Both impulse & rea^n are there.

$$\text{Degree of Rea}^n = \frac{\text{Rea}^n \text{ Force}}{\text{Impulse force} + \text{Rea}^n \text{ force}}$$

- Nozzle is used before Turbine. [velocity ↑ Pressure ↓]  nozzle
- Diffuser is mainly used after Pump. [velocity ↓ Pressure ↑]  Diffuser

A/c to Head :-

1. High Head → >100 m
2. Med^m Head → 30 m to 300 m
3. Low Head → < 30 m

A/c to specific speed :-

Sp. speed is used for selection of Turbine.

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

N → rpm
P → KW
H → m

- Sp. speed is the speed at which Turbin will produce 1 KW power (unit) under 1 m (unit) head.

Ns	Type of Turbine
upto 30	Pelton Turbine with single jet
30 - 50	Pelton Turbine with multiple jet
50 - 250	Francis
> 250	Kaplan / Propeller

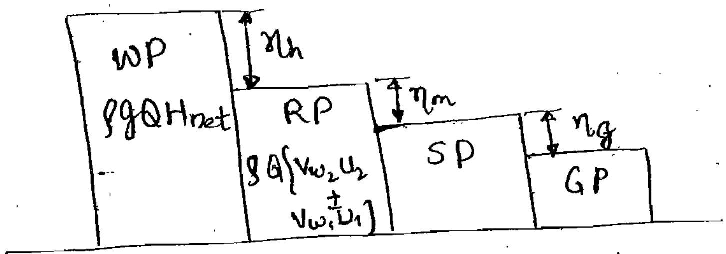
Kaplan → Adjustable blade
Propeller → Blade is fixed to hub

10. A turbine develops 9000 kW when running at speed of 140 rpm under head of 30 m. Which turbine should be selected for this application.

$$N_s = \frac{N\sqrt{P}}{H^{5/4}} = \frac{140\sqrt{9000}}{(30)^{5/4}} = 189.16$$

Francis Turbine can be selected.

Efficiency of Turbine



WP = Water Power (power available at inlet of reservoir)

RP = Runner Power = $\rho Q [V_{w_2}U_2 \pm V_{w_2}U_1]$
(Power produced by wheel)

SP = Shaft Power (power available at shaft)

GP = Generator Power

Hydraulic efficiency $= \eta_h = \frac{RP}{WP}$

Mechanical efficiency $= \eta_m = \frac{SP}{RP}$

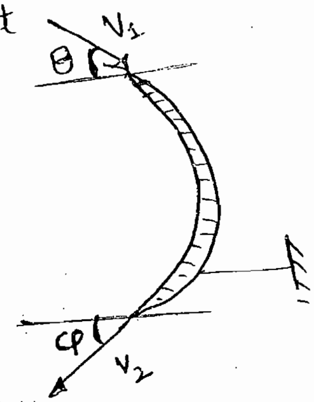
Generator efficiency $= \eta_g = \frac{GP}{SP}$

$$\eta_{plant} = \frac{GP}{WP} = \eta_h \cdot \eta_m \cdot \eta_g \cdot \eta_v$$

$$\eta_{Turbine} = \frac{SP}{WP} = \eta_h \cdot \eta_m$$

Volumetric efficiency $= \frac{Q \text{ hitting Runner}}{Q \text{ supplied to Runner}} = \eta_v$

Forces on fixed Blade (Curved) due to water flow



All angles are taken from tangential dirⁿ.

$\theta \rightarrow$ Blade angle at inlet

$\varphi =$ " " " outlet/exit "

$$\text{Force on water} = \frac{\text{Final momentum of water} - \text{Initial momentum of water}}{\text{time}}$$

$$\text{Force on Blade} = \frac{\text{Initial momentum} - \text{Final momentum}}{\text{time}}$$

$$F_t = \frac{m\vec{V}_{1t} - m\vec{V}_{2t}}{t} = \frac{m}{t}\left[\vec{V}_{1t} - \vec{V}_{2t}\right]$$

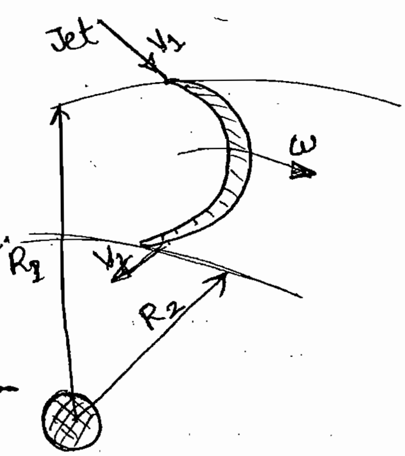
$$F_t = \dot{m}\left(V_{1t} - V_{2t}\right) \qquad \boxed{\dot{m} = \rho Q}$$

$$F_t = \rho Q\left[V_1\cos\theta - (-V_2\cos\varphi)\right]$$

$$\boxed{F_t = \rho Q\left[V_1\cos\theta + V_2\cos\varphi\right]}$$

Force on moving Blade / Torque & power calculation

Wheel along with Blade is moving with ω angular velocity.



Tangential velocity of Blade at entry.

$$u_1 = \omega R_1 = \frac{\pi D_1 N}{60}$$

$$u_2 = \omega R_2 = \frac{\pi D_2 N}{60}$$

$$\omega = \frac{2\pi N}{60}$$

Velocity hitting the Runner

$$\therefore \vec{V_r} = \vec{V} - \vec{u}$$

V_r = Relative velocity of water

V = Abs. velocity " "

u = Blade velocity

$$\Rightarrow \left[\vec{V} = \vec{V_r} + \vec{u}\right]$$

At inlet: $\vec{V_1} = \vec{V}_{r_1} + \vec{u_1}$

At exit: $\vec{V_2} = \vec{V}_{r_2} + \vec{u_2}$