MULTISTAGE CENTRIFUGAL PUMPS:

When a Centrifugal pump Consists of two or more impeller, the pump is Called a multistage Centrifugal pump. The impellers may be mounted on the Same shaft or on different Shafts.

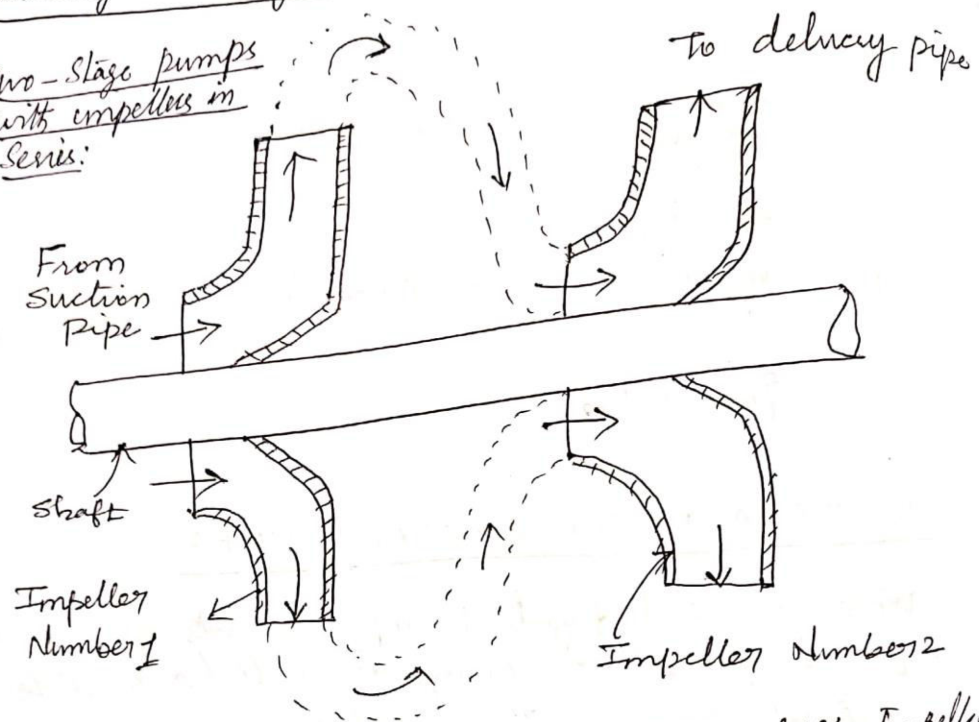
A multistage pump is having the following two important functions.

1. To Produce a high head
2. To discharge a Large quantity of liquid.

If a high head is to be developed, the impellers are Connected in Series (or on the Same shaft) while for discharging Large quantity of liquid, the impeller (or pumps) are Connected in parallel.

Multistage centrifugal pumps for High Heads:

Two-Stage pumps with impellers in Series:



Pipe Connecting outlet of 1st Impeller to inlet of 2nd impeller.

Let n = Number of identical impellers mounted on the same shaft.

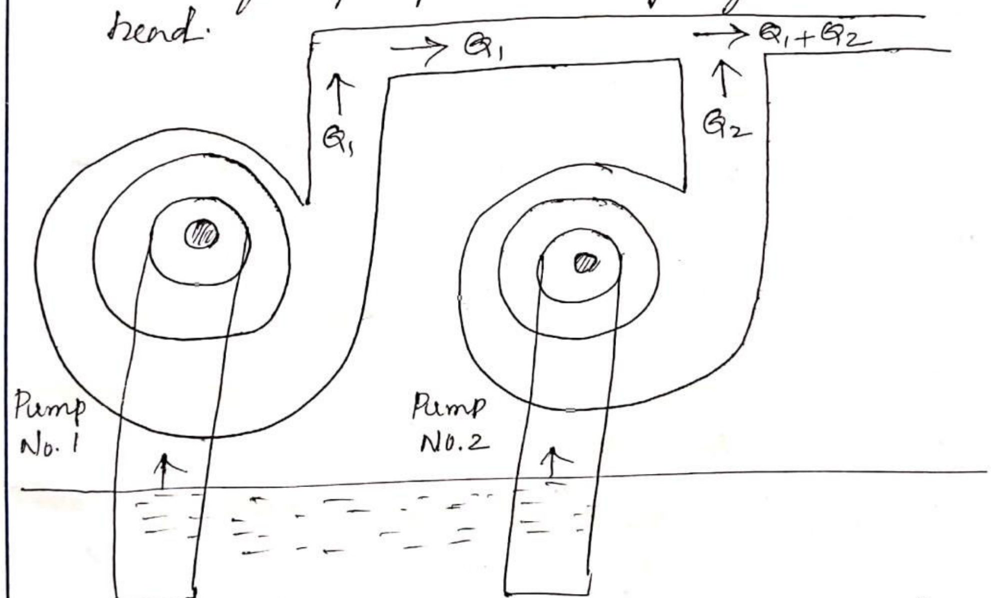
H_m = Head developed by each impeller

Then total head developed $= n \times H_m$

The discharge passing through each impeller is same.

MULTISTAGE CENTRIFUGAL PUMPS FOR HIGH DISCHARGE

- To obtain high discharge, the pumps should be connected in parallel as in fig.
- Each of the pump lifts the water from a common pump and discharges water to a common pipe to which the delivery pipes of each pump is connected.
- Each of the pump is working against the same head.



- For obtaining high discharge, the pumps should be connected in parallel.
- Each of the pumps lifts the water from a common common pump and discharges to a common pipe to which the delivery pipes of each pump is connected. Each pump is working against the same head.

n = Number of identical pumps arranged in parallel
Q = discharge from one pump
Total Discharge $= n \times Q$

Specific Speed of a Centrifugal pump (N_s)

The Specific Speed of a Centrifugal pump is defined as the Speed of a geometrically Similar pump which would deliver one Cubic metre of liquid per Second against a head of one metre. It is denoted by N_s

Expression:

$$Q = \text{Area} \times \text{Velocity of flow}$$

$$= \pi D \times B \times V_f \quad \text{or} \quad Q \propto D \times B \times V_f \quad \text{—— (1)}$$

where D = Diameter of the impeller of the pump
B = Width of the impeller

W.K.T $B \propto D$

From Eqn i we have $Q \propto D^2 \times V_f$ —— (2)

We also know that tangential velocity is given by

$$u = \frac{\pi D N}{60} \propto DN \quad \text{—— (3)}$$

Now the tangential velocity (u) and velocity of flow (V_f) are related to the manometric head (H_m) as

$$u \propto V_f \propto \sqrt{H_m} \quad \text{—— (4)}$$

Substituting the Value of u in equation (3i) we get

$$\sqrt{H_m} \propto DN \quad \text{or} \quad D \propto \frac{\sqrt{H_m}}{N}$$

Substituting the Values of D in equation (2)

$$Q \propto \frac{H_m}{N^2} \times V_f$$

$$Q \propto \frac{H_m}{N^2} \times \sqrt{H_m} \quad \left[\because \text{From equation (4)} \; V_f \propto \sqrt{H_m}\right]$$

$$\propto \frac{H_m^{3/2}}{N^2}$$

$$\boxed{Q \propto K \frac{H_m^{3/2}}{N^2}} \qquad \text{———— (5)}$$

where K is a Constant of Proportionality

If $H_m = 1\,m$ and $Q = 1\,m^3/s$ N is N_s

Substituting these values in equation (5) we get

$$1 = \frac{K\,1^{3/2}}{N_s^2} = \frac{K}{N_s^2}$$

$$K = N_s^2$$

$\therefore$ Substituting the value of K in equation ~~5~~ we get

$$Q = N_s^2 \frac{H_m^{3/2}}{N^2}$$

$$N_s^2 = \frac{N^2 Q}{H_m^{3/2}}$$

$$\boxed{N_s = \frac{N\sqrt{Q}}{H_m^{3/4}}}$$

MODEL TESTING OF CENTRIFUGAL PUMPS:

Before manufacturing the Large sized pumps, their models which are in complete similarity with the actual pumps called Prototype are made.

Tests are conducted on the models and performance of the Prototype are Predicted. The Complete Similarity between the model and actual pump (Prototype) will exit if the following conditions are satisfied.

1. Specific speed of model = Specific speed of prototype

$$(N_s)_m = (N_s)_p$$

(or)

$$\left(\frac{N\sqrt{Q}}{H_m^{3/4}}\right) = \left(\frac{N\sqrt{Q}}{H_m}\right)_p \quad \text{——— (1)}$$

2. Tangentially velocity (u) is given by

$$u = \frac{\pi D N}{60} \quad \text{also} \quad u \propto \sqrt{H_m}$$

$$\sqrt{H_m} \propto DN$$

$$\frac{\sqrt{H_m}}{DN} = \text{Constant} \quad \text{——— (1-A)}$$

$$\left(\frac{\sqrt{H_m}}{DN}\right)_m = \left(\frac{\sqrt{H_m}}{DN}\right)_p \quad \text{——— (2)}$$

3. From equation of Art (2) ∴s previous expression gives when $V_f \propto u \propto DN$

$$Q \propto D^2 \times V_f$$

$$\propto D^2 \times D \times N$$

$$\propto D^3 \times N$$

$$\frac{Q}{D^3 N} = \text{Constant} \quad \text{(or)} \quad \left(\frac{Q}{D^3 N}\right)_m = \left(\frac{Q}{D^3 N}\right) \quad \text{(3)}$$

4 Power of the pump

$$P = \frac{\rho \times g \times Q \times H_m}{75}$$

$$P \propto Q \times H_m$$

$$\propto D^3 N H_m \quad (\because Q \propto D^3 N)$$

$$\propto D^3 N \times D^2 N^2 \quad (\because \sqrt{H_m} \propto DN)$$

$$\propto D^5 N^3$$

$$\frac{P}{D^5 N^3} = \text{Constant} \quad (\text{or}) \quad \left(\frac{P}{D^5 N^3}\right)_m = \left(\frac{P}{D^5 N^3}\right)_p \quad \text{—④}$$

Priming of a Centrifugal pump:

Def: "operation in which the suction pipe, casing of the pump and a portion of the delivery pipe upto the delivery valve is completely filled up from outside source with the liquid to be raised by the pump before starting the pump."

Thus the air from these parts of the pump is removed and these parts are filled with the liquid to be pumped.

The work done by the impeller per unit weight of liquid per sec is known as the head generated by the pump.

Head generated by the pump $= \frac{1}{2} V_{w_2} u_2$ metre.

This equation is independent of the density of the liquid. This means that when pump is running in air, the head generated is in terms of metre of air

If the pump is primed with water, the head generated is same metre of water. But as the density of air is very low, the generated head of air in terms of equivalent metre of water head is negligible and hence the water may be sucked from the pump.

To avoid this difficulty Priming is necessary.

CAVITATION:

Def: Phenomenon of formation of vapour bubbles of a flowing liquid in a region where the Pressure of the liquid falls below its vapour Pressure and the sudden collapsing of these vapour bubbles in a region of higher Pressure.

When the vapour bubbles collapse, a very high Pressure is created. The metallic surfaces, above which these vapour bubbles collapse, is subjected to these high Pressure, which cause pitting action on the Surface

Thus Cavities are formed on the metallic surface and also considerable noise and vibrations are produced.

Precautions:

(i) The Pressure of the flowing liquid in any part of the hydraulic system should not be allowed to fall below its vapour Pressure.

(ii) The Special materials or coatings such as aluminium-bronze and stainless steel, which are cavitation resistant material should be used.

Effect of Cavitation:

(i) The metallic surfaces are damaged and cavities are formed on the surfaces.

(ii) Due to sudden collapse of vapour bubble, considerable noise and vibrations are produced.

(iii) η of a turbine decreases due to cavitation due to pitting action, the surface of the turbine blades becomes rough and the force exerted by water on the turbine blades decreases. Hence, the work done by water or output horse power becomes less and thus efficiency decreases.

Cavitation in centrifugal pumps: In centrifugal pumps the cavitation may occur at the inlet of the impeller of the pump, or at the suction side of the pumps, where the pressure is considerably reduced. Hence if the pressure at the suction side of the pump drops below the vapour pressure of the liquid then the cavitation may occur.

The cavitation in a pump can be noted by a sudden drop in efficiency and head. In order to determine whether cavitation will occur in any portion of the suction side of the pump, the critical value of Thoma's cavitation factor (σ) is calculated.

Thoma's cavitation factor for centrifugal pumps:

$$\sigma = \frac{H_b - H_s - h_{LS}}{H} = \frac{(H_{atm} - H_v) - H_s - H_{LS}}{H}$$

H_{atm} → Atmospheric pressure head in m of water or absolute pressure head at the liquid surface in pump.

H_v → Vapour pressure head in m of water

H_s → Suction pressure head in m of water

h_{Ls} → Head lost due to friction in suction pipe

H → Head developed by the pump.

Maximum Suction Lift (or SUCTION HEIGHT)

$$H_a = H_v + \frac{V_s^2}{2g} + h_s + h_{fs}$$

$$h_s \rightarrow H_a - H_v - \frac{V_s^2}{2g} - h_{fs}$$

where $H_a = \frac{P_a}{\rho g}$ = Atmospheric pressure head in metre

$H_v = \frac{P_v}{\rho g}$ = vapour pressure head ~~m~~etre

V_s = Velocity of liquid through suction pipe

h_s = Height of inlet of pump from datum line

h_{fs} = Loss of head in the foot valve, strainer and suction pipe.

NET POSITIVE SUCTION HEAD (NPSH)

NPSH = Absolute pressure head at inlet of the pump
− vapour pressure head (absolute units).
+ velocity head.

$$= (H_a - h_s - h_{fs}) - H_v$$

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Cavitation in Centrifugal pump

Thoma's Cavitation factor is used to indicate whether Cavitation will occur in pumps.

Thoma's Cavitation factor for pumps as

$$\sigma = \frac{(H_{atm} - H_v) - H_s - h_{fs}}{H}$$

$$\sigma = \frac{NPSH}{H_m}$$

If the value of σ is Less than the Critical value σ_c then Cavitation will occur in the pumps. The value of σ_c depends upon the specific ~~head~~ Speed of the pump

$$N_s = \frac{N\sqrt{Q}}{H_m^{3/4}}$$

The following empirical relation is used to determine the value of σ_c

$$\sigma_c = 0.103 \left(\frac{N_s}{1000}\right)^{\frac{4}{3}}$$

$$= 0.103 \frac{N_s^{4/3}}{(10^3)^{4/3}} = \frac{0.103 N_s^{4/3}}{10^4}$$

$$\boxed{\sigma_c = 1.03 \times 10^{-3} N_s^{4/3}}$$

From inlet velocity triangle $\tan\theta = \frac{V_{f_1}}{u_1} = \frac{V_{f_1}}{12.56}$

$V_{f_1} = 12.56 \tan\theta$

$= 12.56 \times \tan 20^\circ$

$= 4.57$ m/s

$$\boxed{V_{f_2} = V_{f_1} = 4.57 \text{ m/s.}}$$

From outlet velocity triangle $\tan\phi = \frac{V_{f_2}}{u_2 - V_{w_2}} = \frac{4.57}{25.13 - V_{w_2}}$

$25.13 - V_{w_2} = \frac{4.57}{\tan\phi} = \frac{4.57}{\tan 30^\circ} = 7.915$

$V_{w_2} = 25.13 - 7.915$

$$\boxed{V_{w_2} = 17.215 \text{ m/s}}$$

The work done by impeller per kg of water per second is given by $\frac{1}{g} V_{w_2} V_2$ $(V_{w_1} = 0)$

$= \frac{1}{2} V_{w_2} u_2$

$= \frac{17.215 \times 25.13}{9.81}$

$$\boxed{W_{\text{impeller}} = 44.1 \text{ Nm/N.}}$$