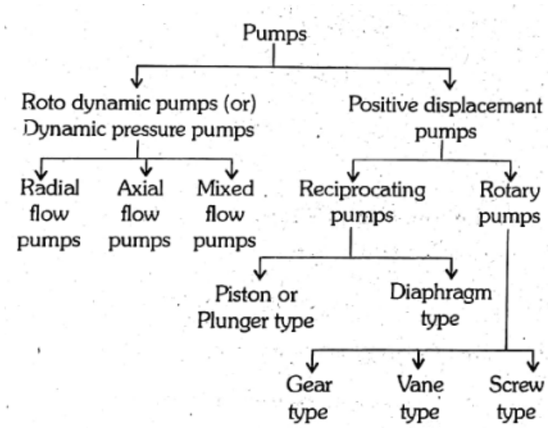
Pumps Study Materials

Pumps:

Pump is a device which is used to convert mechanical energy into hydraulic energy. Here hydraulic energy refers to potential and kinetic energy of a liquid Hydraulic pumps are the energy-absorbing machines. Since, it requires mechanical power to run.

Classification of pumps



Reciprocating pumps:

The reciprocating pump is a positive displacement pump. It operates on a principle of actual displacement or pushing of liquid by a piston or plunger that reciprocates in a closely fitting cylinder. These pumps usually have one or more cylinders which are alternatively filled with liquid to be pumped and then emptied again. In this pump, the mechanical energy is converted into hydraulic energy by sucking the liquid into a cylinder in which a piston is reciprocating and exerts the thrust on the liquid and increases its hydraulic energy. The reciprocating pumps are generally employed for light at pumping, feeding small boiler condensate return and pneumatic pressure systems.

Classification:

According to the piston being in contact with piston or plunger.

a) Single acting pump
b) Double acting pump

According to the number of cylinders provided,

a) Single cylinder pump
b) Double cylinder pump
c) Triple cylinder pump
d) Duplux double acting pump
e) Quantiplex pump

Discharge work done and power required to drive Reciprocating pump:

Case (i): Single acting pump

Let D = Diameter of the cylinder

A = Area of cross section of the cylinder or piston = $\frac{\pi}{4} D^2$

r = Radius of crank

N = Speed of the crank in rpm

L = Length of the stroke (= 2r)

hs = Height of the axis of the cylinder from water surface in sump

hd = Height of the delivery outlet above the cylinder axis.

Volume of water delivered in one revolution = Area × Length of stroke

= A × L

Number of revolution per second = $\frac{N}{60}$

Discharge / sec = Q = $\frac{ALN}{60}$

Weight of water delivered per second

W = WQ = $\frac{WALN}{60}$

Work done per second = Weight of water lifted/sec × Total height through which liquid is lifted WALN

$= W(h_s+h_d) = \frac{WALN}{60}(h_s+h_d)$

where W = Weight density of liquid.

Case (ii) Double acting pump

Discharge, $Q = \frac{2ALN}{60}$

Work done per second $= \frac{2WALN}{60}(h_s+h_d)$

Power required to drive the pump

$$P = \frac{2WALN}{60}(h_s + h_d)$$

Slip of a Reciprocating pump:

The difference between the theoretical discharge and actual discharge is called slip of the pump.

Centrifugal pumps:

Centrifugal pumps are the devices which converts mechanical energy into hydraulic energy by means of centrifugal force acting on the fluid.

Centrifugal pumps are classified as roto dynamic type of pumps in which a dynamic pressure is developed to lift liquids from a lower to a higher level. The basic working principle of centrifugal pump is that when a certain mass of liquid is made to rotate by an external force, it is thrown away from the central axis of rotation and a centrifucal pressure is developed which raises the liquid to higher level.

Classification of centrifugal pumps:

1. Shape and type of casing
a) Volute or spiral casing
b) Vortex or whirlpool casing
c) Volute casing with guide blades
2. Working head
a) Low head (upto 15m)
b) Medium head (15m to 40m)
c) High head (over 40m)
3. Number of stages:
a) Single stage
b) Multistage
4. Liquid handled
a) closed impeller pump
b) semi-closed impeller pump
c) open impeller pump
5. Specified speed
a) Low specific speed pumps
b) Medium specific speed pumps
c) High specific speed pumps
6. Number of entrances to the impeller
a) Single suction pr single entry pump
b) Double suction or double entry pump

Workdone by the Impeller of a centrifugal pump:

Let

D_1 = Diameter of the impeller at inlet.

u_1 = tangential velocity of the impeller at inlet = $\frac{\pi D_1 N}{60}$

v_1 = Absolute velocity of water at inlet

v_{w1}= Velocity of whirl at inlet

v_{r1} = Relative velocity of liquid at inlet

v_{f1} = Velocity of flow at inlet

α = Angle made by v_1 at inlet with the direction of motion of vane

θ = Angle made by v_{ri} at inlet with the direction of motion of vane.

Wor'kdone $= \frac{w}{g}(V_{w_1} \pm V_{w_2}u_2)$

where w = weight of the liquid per second that passes through the impeller = pgQ

θ = Volume of liquid $= \pi D_1 B_1 \times V_{f_1}$

$= \pi D_2 B_2 \times 2$

where B_1 and B_2 are the width of the impeller at inlet and outlet respectively.

Since α=90° and V_{w_1} =0

Workdone by the impeller on water per second

$= \frac{W}{g}(V_{w_2}u_2)$

Head and Efficiencies of a pump

i) Suction head (hs):

It is the vertical height of the centre line of the pump shaft above the liquid surface in the sump from which the liquid is being raised.

Delivery head (h_d):

It is the vertical height of the liquid surface in the tank/ reservoir to which the liquid is delivered above the centre line at the pump shade.

Static head (H_{stat}):

The sum of suction and delivery head is known as static head.

H_{start} = hs + hd

Manometric head (Hm):

It is the head against which a centrifugal pump has to work. It is given by the following expressions.

H_m = Head imparted by the impeller to liquid loss of head in the pump

$$H_m = \frac{V_{w_2}u_2}{g} - (h_{Li} + h_{Lc})$$

where h_{Li} ⇒ Loss of head in the impeller

h_{Lc} ⇒ Loss of head in the casing

$H_m = \frac{V_{w_2}u_2}{g}$ → if there is no loss in the

b) $H_m = H_{stat}$+ Losses in pipes+$\frac{V_d^2}{2g}$

$$H_m = h_s + h_d + h_{is} + h_{id} + \frac{V_d^2}{2g}$$

where

h_{fs} ⇒frictional loss in the suction pipe

h_{fd} ⇒ frictional loss in the delivery pipe v_d ⇒ velocity of liquid in the delivery pipe

c) H_m = Total head at outlet of the pump - Total head at the inlet of the pump

$$= \left(\frac{p_2}{w} + \frac{v_2^2}{2g} + z_2\right) - \left(\frac{p_1}{w} + \frac{v_1^2}{2g} + z_1\right)$$

where

$\frac{p_1}{w}$ ⇒ Pressure head at inlet of the pump = h_s

$\frac{v_1^2}{2g}$ ⇒ Velocity head at inlet of the pump

Z_1 = Vertical height of the pump inlet from the datum line

$\frac{p_2}{w} + \frac{v_2^2}{2g}$ and Z_2 are corresponding values of pressure head, velocity head and datum head at outlet of the pump.

Efficiencies of a pump:

i) Manometric efficiency (η_{mano}):

$$\eta_{mano} = \frac{\text{Manometric head}}{\text{Head imparted by impeller}}$$

$$= \frac{H_m}{\left(\frac{V_{w_2}u_2}{g}\right)} = \frac{gH_m}{V_{w_2}u_2}$$

$$\eta_{mano} = \frac{\text{Power actually delivered by the pump}}{\text{Power imparted by the impeller}}$$

or

$$\eta_{mano} = \frac{\text{Output of the pump}}{\text{Power imparted by the impeller}}$$

Volumetric efficiency (η_n):

It is defined as the ratio of quantity of liquid discharged per second from the pump to the quantity passing per second through the impeller.

Mechanical Efficiency (η_{mech}):

$$\eta_{mech} = \frac{\text{Power at the impeller}}{\text{Power at the shaft}}$$

$$\eta_{mech} = \frac{\frac{W}{g}\left(\frac{V_{w_2}u_2}{1000}\right)}{\text{Shaft power in kW}}$$

Output efficiency (h_0):

$$\eta_0 = \frac{\text{Power output of the pump}}{\text{Power input to the pump}}$$

$$= \frac{WQH_m}{P}$$

$$\eta_0 = \eta_{mano} \times \eta_v \times \eta_{mech}$$

Impeller Blade Profiles:

Backward curved vanes:

The blade angle ϕ <90°

Radial vane:

ϕ= 90°

Forward curved vanes:

$\phi > 90°$

Specific speed for a pump (N_s):

The specific speed of a centrifugal pump is defined as the speed of a geometrically similar pump which will deliver unit quantity (i.e. 1 litre of liquid per second) against a unit head (i.e. 1 meter)

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

The above equation gives the specific speed in terms of discharge and manometric head. Sometimes another definition of the specific speed may be used which is based on unit power.

$N_s = \frac{N\sqrt{p}}{H_m^{5/4}}$

Centrifugal pumps with the corresponding ranges of specific speeds.

S.No.	Types of impeller	Specific Speed, N_s
1.	Slow speed radial flow	10 - 30
2.	Medium speed	30 – 50
3.	High speed radial	50 – 80
4.	Mixed flow	80 – 160
5.	Axial flow	160 – 500

Design Aspects of a centrifugal pump:

I) Speed ratio (K_u):

It is the ratio of peripheral speed at outlet (u_2) to the theoretical velocity of jet corresponding to manometric head H_m.

$$K_u = \frac{u_2}{\sqrt{2gH_m}}$$

K_u varies from 0.95 to 1.25

ii) Flow ratio (K_f):

It is the ratio of the velocity of flow at exit (V_{f2}) to the theoretical velocity of the jet corresponding to manometric head (H_m).

$$K_f = \frac{u_{f2}}{\sqrt{2gH_m}}$$

Value of K_f varies from 0.1 to 0.25

Outlet diameter of impeller (D_2):

$$D_2 = \frac{84.6K_u\sqrt{H_m}}{\pi N}$$

Inlet diameter of impeller (D_1):

$D_1 = 0.5\ D_2$

Least diameter of impeller:

$$D_2 = \frac{97.68\sqrt{H_m}}{N}$$

Diameter of suction pipe (D_s):

$$D_s = \sqrt{\frac{4Q}{\pi V_s}}$$

Diameter of delivery pipe $D_d : \sqrt{\frac{4Q}{\pi V_d}}$

Pumps in series:

A number of impeller are mounted on the same shaft in series to obtain a high head. If n identical impellers are mounted on the same shaft in series, then the total head developed will be

$H_{total} = n \times H_n$

The discharge passing through each impeller is same. Pipes in series are employed for delivering a relatively small quantity of liquid against very high head.

Pumps in parallel:

A number of pumps are connected in parallel for obtaining high discharge. Here the impellers are mounted on separate shafts. Each unit works separately and the discharge from various impellers are collected in common delivery pipe.

If Q is the discharge capacity for one impeller and there is ~ identical impellers arranged in parallel then totai discharge will be $Q_{total} = n \times Q$
when a large quantity of liquid is required to be pumped against a relatively small head, then pump in parallel arrangement is used.

Pump characteristics:

i) Main characteristics curves (H, p, η, VSQ)
ii) Operating characteristic curves (H, p, η VSQ)
iii) Constant efficiency or Muschel curves (H VS Q)
iv) Constant head and constant discharge curves (Q VS N, H=const ; H VS N, Q = const)

Cavitations in Hydraulic Machines:

Hydraulic machines subjected to cavitations are reaction turbines and centrifugal pumps.
Cavitation is defined as the 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. The collapsing pressure of bubbles may be as high as 100 atmospheres and this may cause a local mechanical failure of the solid surface. The ultimate effect may be the breakdown of the machine itself due to severe pitting and erosion of blade surfaces in the region of cavitation. The cavitation in a pump can be noted by a sudden drop in efficiency, head and more power requirement.

Harmful effects of cavitation are:

- Pitting and erosion of surface due to continuous hammering action of the collapsing bubbles.
- Sudden drop in head, efficiency and the power delivered to the fluid.
- Noise and vibrations produced by the collapse of vapour bubbles.

Priming of a centrifugal pump:

The operation of filling liquid (which is to be pumped) in the suction pipe, casing of the pump and a portion of the delivery pipe upto delivery valve before starting the pump is called priming of a centrifugal pump.