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محتوى المحاضرة

UNIT 8

CENTRIFUGAL PUMPS

Introduction

A pump is a hydraulic machine which converts mechanical energy into hydraulic energy or pressure energy. A centrifugal pump is also known as a Rotodynamic pump or dynamic pressure pump. It works on the principle of centrifugal force. In this type of pump the liquid is subjected to whirling motion by the rotating impeller which is made of a number of backward curved vanes. The liquid enters this impeller at its center or the eye and gets discharged into the casing enclosing the outer edge of the impeller. The rise in the pressure head at any point/outlet of the impeller is Proportional to the square of the tangential velocity of the liquid at that point (*i.e,* $\alpha u^2/2g$). Hence at the outlet of the impeller where the radius is more the rise In pressure head will be more and the liquid will be discharged at the outlet with a high pressure head. Due to this high pressure head, the liquid can be lifted to a higher level. Generally centrifugal pumps are made of the radial flow type only. But there are also axial flow or propeller pumps which are particularly adopted for low heads.

- Advantages of centrifugal pumps:-
  1. Its initial cost is low
  2. Efficiency is high.
  3. Discharge is uniform and continuous
  4. Installation and maintenance is easy.
  5. It can run at high speeds, without the risk of separation of flow

Classification of Centrifugal Pumps

Centrifugal pumps may be classified into the following types

1. According to casing design

a) Volute pump b) diffuser or turbine pump

2. According to number of impellers

a) Single stage pump b) multistage or multi impeller pump

3. According to number of entrances to the Impeller

a) Single suction pump b) Double suction pump

4. According to disposition of shaft

a) Vertical shaft pump b) Horizontal shaft pump

5. According to liquid handled

a) Semi open impeller b) Open impeller pump

6. According to specific speed

a) Low specific speed or radial flow impeller pump Shrouded impeller

b) Medium specific speed or mixed flow impeller pump

c) High specific speed or axial flow type or propeller pump.

7. According to head (H)

a) Low head if $H<15m$

b) Medium head if $15<H<40m$

c) High head if $H>40m$

In the case of a volute pump a spiral casing is provided around the impeller. The water which leaves the vanes is directed to flow in the volute chamber circumferentially. The area of the volute chamber gradually increases in the direction flow. Thereby the velocity reduces and hence the pressure increases. As the water reaches the delivery pipe a considerable part of kinetic energy is converted into pressure energy. However, the eddies are not completely avoided , therefore some loss of energy takes place due to the continually increasing quantity of water through the volute chamber. In the case of a diffuser pump the guide wheel containing a series of guide vanes or diffuser is the additional component. The diffuser blades which provides gradually enlarging passages surround the impeller periphery. They serve to augment the process of pressure built up that is normally achieved in the volute casing. Diffuser pumps are also called turbine Multistage pumps and vertical shaft deep-well pumps fall under this category.

Centrifugal pumps can normally develop pressures upto 1000kpa (100m). If higher pressures are required there are three options.

a) Increase of impeller diameter.

b)Increase of Rpm.

c)Use of two or more impellers in series.

The pump looks clumsy in option

(a). The impeller material is heavily stressed in option

(b) The third choice is the best and is generally adopted, the impellers which are usually of the same size are mounted on the same shaft. The unit is called a multistage pump. It discharges the same quantity of fluid as a single stage pump but the head developed is high. There are centrifugal pumps upto 54 stages. However, generally not more than 10 tages are required. In the case of the double suction impeller, two impellers are set back to back. The two suction eyes together reduce the intake. The two suction eyes together reduce the intake velocity reduce the risk of cavitations. Mixed flow type double suction axial flow pumps besides are capable of developing higher heads. For convenience of operation and maintenance, horizontal shaft settings are the preferred setups for centrifugal pumps. The exceptions are deep-well turbine pumps and axial flow pumps, these have vertical shafts. Restricted space conditions usually require a vertical shaft setting. Centrifugal impellers usually have vanes fitted between the shroudes or plate.

The crown plate has the suction eye and the base plate is mounted on a sleeve which is keyed to the shaft. An impeller without the crown plate is called the non-clog or semi open impeller. In an open impeller both crown plate and the base plate are absent. Only clear liquids, can be safely pumped by a shrouded impeller pump. The semi-open impeller is useful for pumping liquids containing suspended solids, such as sewage, molasses or paper pulp. The open-vane impeller pump is employed for dredging operations in harbors and rivers. Shrouded and semi open impellers may be made of castiron Or cast steel. Open vane impellers are usually made of forged steel. If the liquid pumped are corrosive, brass, bronze or gun metal are the best materials for making the impellers.

A radial flow impeller has small specific speeds (300 to 1000) & is suitable for discharging relatively small quantities of flow against high heads. The direction of flow

at exit of the impeller is radial. The mixed flow type of impellers has a high specific speed (2500 to 5000), has large inlet diameter D and impeller width B to handle relatively
large discharges against medium heads. The axial flow type or propeller impellers have the highest speed range (5000 to 10,000). They are capable of pumping large discharges against small heads. The specific speed of radial pump will be $10<Ns<80$, Axial pump $100<Ns<450$, Mixed flow pump $80<Ns<160$.

Components of a centrifugal pump

The main components of a centrifugal pump are:

i) Impeller ii) Casing iii) Suction pipe iv) Foot valve with strainer, v) Delivery pipe
vi) Delivery valve.

Impeller is the rotating component of the pump. It is made up of a series of curved vanes. The impeller is mounted on the shaft connecting an electric motor.

Casing is an air tight chamber surrounding the impeller. The shape of the casing is designed in such a way that the kinetic energy of the impeller is gradually changed to potential energy. This is achieved by gradually increasing the area of cross section in the direction of flow.

Suction pipe It is the pipe connecting the pump to the sump, from where the liquid has to be lifted up.

Foot valve with strainer the foot valve is a non-return valve which permits the flow of the liquid from the sump towards the pump. In other words the foot valve opens only in the upward direction. The strainer is a mesh surrounding the valve, it prevents the entry of debris and silt into the pump.

Delivery pipe is a pipe connected to the pump to the overhead tank.

Delivery valve is a valve which can regulate the flow of liquid from the pump.

Priming of a centrifugal pump

Priming is the process of filling the suction pipe, casing of the pump and the delivery pipe upto the delivery valve with the liquid to be pumped. If priming is not done the pump cannot deliver the liquid due to the fact that the head generated by the Impeller will be in terms of meters of air which will be very small (because specific weight of air is very much smaller than that of water).

Priming of a centrifugal pump can be done by any one of the following methods:

i) Priming with suction/vacuum pump.

ii) Priming with a jet pump.

iii) Priming with separator.

iv) Automatic or self priming.

Heads on a centrifugal pump:

Suction head (hs): it is the vertical distance between the liquid level in the sump and the center line of the pump. It is expressed as meters.

Delivery head (hd): It is the vertical distance between the centre line of the pump and the liquid level in the overhead tank or the supply point. It is expressed in meters.

Static head (Hs): It is the vertical difference between the liquid levels In the overhead tank and the sump, when the pump is not working. It is expressed as meters.

Therefore, **HS= (hs+ hd)**

Friction head (hf): It is the sum of the head loss due to the friction in the suction and delivery pipes. The friction loss in both the pipes is calculated using the Darcy's equation, **hf=(fLV^2/2gD)**.

Total head (H): It is the sum of the static head Hs, friction head (h_f) and the velocity head in the delivery pipe ($V_d{}^2/2g$). Where, V_d=velocity in the delivery pipe.

$$\therefore H_m = \left(h_s + h_d + h_f + \frac{Vd^2}{2g} \right) ---(1)$$

Manometric head(Hm): It is the total head developed by the pump. This head is slightly less than the head generated by the impeller due to some losses in the pump.

$$\therefore H_m = H + \frac{Vs^2}{2g} - \frac{Vd^2}{2g}$$

Working of a centrifugal pump:

A centrifugal pump works on the principal that when a certain mass of fluid is rotated by an external source, it is thrown away from the central axis of rotation and a centrifugal head is impressed which enables it to rise to a higher level. Working operation of a centrifugal pump is explained in the following steps.

1) Close the delivery valve and prime the pump.

2) Start the motor connected to the pump shaft, this causes an increase in the impeller pressure.
3) Open the delivery valve gradually, so that the liquid starts flowing into the deliver pipe.
4) A partial vacuum is created at the eye of the centrifugal action, the liquid rushed from the sump to the pump due to pressure difference at the two ends of the suction pipe.
5) As the impeller continues to run, move & more liquid is made available to the pump at its eye. Therefore impeller increases the energy of the liquid and delivers it to the reservoir.
6) While stopping the pump, the delivery valve should be closed first, otherwise there may be back flow from the reservoir. It may be noted that a uniform velocity of flow is maintained in the delivery pipe. This is due to the special design of the casing. As the flow proceeds from the tongue of the casing to the delivery pipe, the area of the casing increases. There is a corresponding change in the quantity of the liquid from the impeller. Thus a uniform flow occurs in the delivery pipe.

Operation difficulties in centrifugal pumps

a) Pump fails to pump the fluid.

Cause	Remedial Measures
1) Improper priming due to leakage of foot valve or incomplete filling.	Repair or replace the foot valve, prime completely.
2) Head more than design head	Reduce the head or change the pump
3) Clogging of impeller, suction pipe or strainer	Clean the suspected part
4) Speed more than design speed	Connect another prime mover of higher speed
5) Direction of rotation of impeller is wrong	Change the direction.
6) Suction lift may be excessive	Reduce the height of pump above the sump

B) Pump does not give the required capacity

a) Leakage of air through the suction pipe or through the gland packing	Stop the leakage
b) Damage to some parts of the pump by wear & tear	Replace the damaged parts
c)Clogging of impeller passages	Clean the impeller

C) Pump has poor efficiency

a) Higher than design speed	Reduce the speed
b) Low head & higher discharge	Reduce the discharge
c) Impeller touching, the casing or improper alignment of shaft	Carryout the necessary repair.

D) Pump stops working

a) Air entry into suction pipe	Stop the pump, plug the leakage, Re prime and start
b) Suction lift is high	Reduce the suction lift.

Efficiencies of centrifugal pump

Manometric efficiency (η): it is the ratio of the manometric head to the head actually generated by the impeller

$$\eta_{mano} = \left\{\frac{Hm}{Vw_2 u2/g}\right\} = \left\{\frac{gHm}{Vw_2 u_2}\right\}$$

Mechanical efficiency(η **mech**): It is the ratio of the impeller power to the power of the motor or the prime mover.

$$\therefore \eta\ mech = \left\{\frac{\text{impeller power}}{\text{motor power}}\right\}$$

Overall efficiency(ηo): It is the ratio of the work done by the pump in lifting water against gravity and friction in the pipes to the energy supplied by the motor.

$$\therefore \eta_o = \left\{ \frac{\text{work done against gravity friction}}{\text{power of the prime mover or motor}} \right\}$$

Velocity Triangles of a Centrifugal Pump

Figure shows the inlet and outlet velocity triangles for a centrifugal pump.It may be noted

that the inlet velocity triangle is radial,(velocity of whirl is zero at inlet or $V_{W1} = 0$

Depending on the geometry of the blade at outlet it can be:

Forward:if the blade angle**<90°**,Radial if $\Phi = 90°$, c) Backward if $\Phi > 90°$

Work done by the impeller of a centrifugal pump:

Figure shows the velocity triangles at the inlet and outlet tips of a vane fixed to the impeller.

Let N=speed of the impeller in RPM

D= Diameter of the impeller at inlet

U_1 = Tangential velocity of the impeller at inlet $\pi D1N/60$

U_2= tangential velocity of the impeller at outlet $\pi D2N/60$ V_1=absolute velocity of the liquid at inlet

V_2= absolute velocity of the liquid at outlet.

Vf_1 & Vf_2 are the velocities of flow at inlet and outlet.

Vr_1 & Vr_2 Relative velocities at inlet and outlet

Vw_2 whirl velocity at outlet

α angle made by V_1 with respect to the motion of the vane

θ blade angle at inlet

ϕ = blade angle at outlet

For a series of curved vanes the force exerted can be determined using the impulse momentum equation Work=force x distance.

similarly the work done/sec/unit weight of the liquid striking the vane = $\frac{1}{g}(Vw_2u_2 - Vw_1u_1)$

But for a centrifugal pump $V\omega_1 = 0$

Work done/sec/unit weight =

Work done/sec/unit weight

And the work done/sec – (4)

Where Q=volume of liquid flowing per second = Area x velocity of

flow = Q $\pi D_2 B_2 Vf_2$ – (5)

In eq (5), B_2 is the width of the impeller at the outlet.

Performance of centrifugal pumps:

Generally a centrifugal pump is worked under its maximum efficiency conditions, however when the pump is run at conditions other than this it performs differently. In order to predict the behaviour of the pump under varying conditions of speed, discharge and head, full scale tests are usually performed. The results of these tests are plotted in the form of characteristic curves. These curves are very useful for predicting the performance of pumps under different conditions of speed, discharge and head.

Following four types of characteristic curves are usually prepared for a centrifugal pump.

a. Main characteristic.

b. Operating characteristics

c. Constant efficiency or Muschel characteristic.

d. Constant head an constant discharge curves.

Main Characteristic: the pump is operated a particular constant speed, discharge is varied by adjusting the delivery valve. Manometric head Hm and the shaft power P are measured for each discharge. The overall efficiency is then calculated. The curves are plotted between Hm & Q, P & Q, & Q. A set of similar curves are plotted by running the pump at different speeds. They will be as shown.

b. Operating characteristic: The curves are obtained by running the pump at the design speed, which is also the driving speed of the motor. The design discharge and head are obtained from the corresponding Curves, where the efficiency is maximum as shown.

c. Constant efficiency curves: The constant efficiency curves are obtained from the main characteristic curves. The line of maximum efficiency is obtained by joining the points of the maximum curvature of the constant efficiency lines. These curves are useful in determining the range of operation of a pump.

d. Constant head and constant discharge curves: If the pump has a variable speed, the plots between Q and N and that between Hm and N may be obtained by varying the speed. In the first case Hm is kept constant & in the second Q is kept contant.