

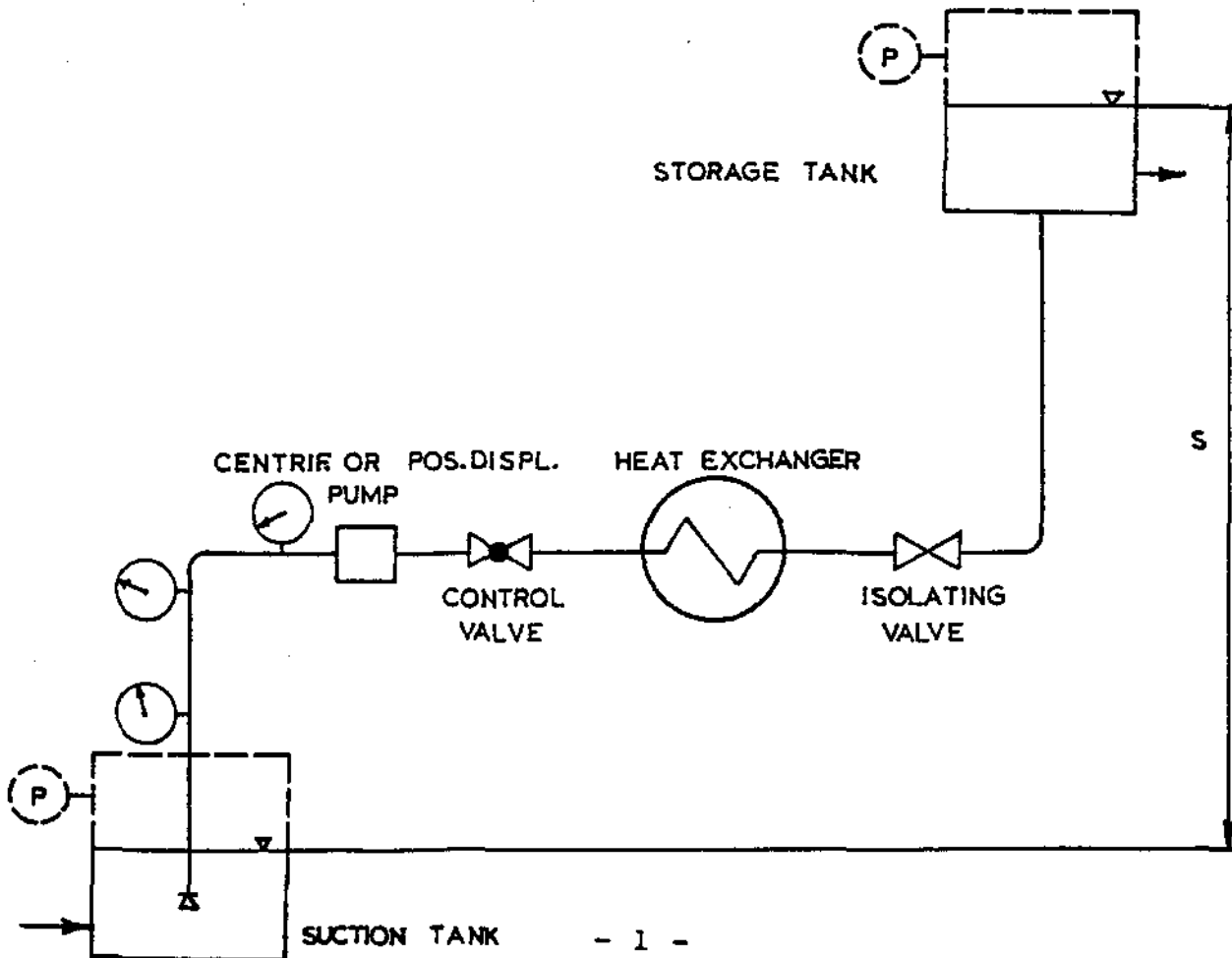
## Mechanical Equipment - Course 430.1

## CENTRIFUGAL PUMPS

In both nuclear and heavy water plants the process depends on the transport and pressurization of fluids which are either incompressible liquids or compressible vapours and gases.

Liquids are handled by devices called pumps. Depending on the basic principle of operation, the pumps can be divided into either kinetic or positive displacement. In each of these basic groups there is a number of different designs. Although we use a number of designs of positive displacement pumps, in the case of kinetic principle, our choice is practically limited to one design only which is the centrifugal pump.

At this point a question arises: What is the difference(s) between a centrifugal and a positive displacement pump? The best way to answer it, is to show and discuss the performance of the pump in a typical system in Figure 1.



The pump works with so-called suction lift, because its centerline is above the suction tank. If it was below, we would talk about the suction head. The pump delivers the liquid through a control valve, a heat exchanger and an isolating valve into a storage tank where it is ready to be used further in the process.

To perform this function, the pump has to overcome several resistances:

1. It has to work against gravitation to lift the liquid through the vertical distance S.
2. It has to overcome friction resistance to the flow of all system components, including piping.
3. Finally if suction and storage tanks are not both open to the atmosphere or under the same pressure in general, the pump has to work against the pressure difference.

The sum of all these work components is called a total head and for a pump to overcome this head it must develop high enough pressure. Obviously, if any of the resistances change, eg, the storage tank is put higher, control valve is closed more, the run of piping changed or a pressure or level in the suction tank drops, the total head will change accordingly.

Having understood how a system is applying a load on a pump, the differences between centrifugal and positive displacement pumps can be listed:

1. Change in Total Head - Change in Capacity.
2. Regulation of Flow.
3. Operation Against the Discharge Valve Closed.
4. Priming.
5. Capacities.
6. Pressures - Total Heads.
7. Handled Liquids.
8. Maintenance.

1. Change in Total Head - Change in Capacity

The basic difference between a centrifugal and a positive displacement pump is how they react to a change of the total head.

- (a) A centrifugal pump is sensitive to changes of the total head and the change of the total head will result in a change of the delivered flow called 'capacity'. In the majority of cases the increase

of the total head will cause the capacity to drop. If the total head drops, the capacity will increase.

- (b) This is not true for positive displacement pumps. They are the pumps which deliver a constant quantity of liquid per stroke or revolution regardless of the total head changes. Although it is not exactly true because with the increased discharge pressure the leakage along the shaft, along pistons, plungers and other moving components will go up, within practical limits this leakage is small compared with the discharge flow.

## 2. Regulation of Flow

The basic difference just explained will have implications as far as the system of regulation is concerned.

- (a) Centrifugal pumps are sensitive to changes of the total head which can be easily accomplished by closing (= throttling) or opening (= dethrottling) of a regulating valve. Therefore the regulation of the flow in a system with a centrifugal pump is accomplished by having a regulating valve in the system, usually close to the discharge of the pump.
- (b) This type of regulation would not work on positive displacement pumps because they are not sensitive to system head changes. The methods used on these pumps are either the change of speed of a driving motor or a change of the length of the stroke.

## 3. Operation Against the Discharge Valve Closed

Usually for isolation purposes the discharge from a pump is furnished with an isolating valve. During a shutdown, the discharge valve was closed. The pump was then started and the discharge valve was left closed. What happened?

- (a) The impeller of a centrifugal pump started rotating but because the discharge is blocked, the liquid is churned within the pump. The discharge pressure increased slightly but no immediate damage occurred. If the mistake is not corrected, all energy from the motor is spent in churning the liquid and the temperature in the pump starts increasing. If nothing is done this temperature might increase so high that the problems like

seizing, burning of seals, bearing damage will happen. The time when serious problems develop depends very much on the design and size of the pump and can vary from 30 seconds to 30 minutes.

As a matter of fact, some centrifugal pumps are deliberately started with discharge valve closed because starting power and torque requirements are cut down. As soon as the set reaches the operational speed the valve is opened.

- (b) Positive displacement pumps deliver constant quantity per stroke or revolution. Even when the discharge valve is closed, the pump is trying to deliver its standard capacity and because it handles incompressible medium the discharge pressure increases rapidly to a point when the weakest point in the system would yield. It may be a pressure gauge, gasket, seal, lid, rotating parts, pipe, depending on a set-up. The conclusion is, an immediate damage to the pump or to the system follows. To prevent the damage, any system with a positive displacement pump should be equipped with a relief valve. This valve should be put between the pump and the first obstacle which usually is the valve itself.

#### 4. Priming

Priming means filling the pump itself and the suction piping with handled liquid. If a suction tank is above the centerline of a pump, gravity will do the priming. But if the suction tank is below the pump as in Figure 1, then prior to or during a startup, the pump must prime itself if it is selfpriming or there must be some other means provided to prime it.

- (a) Centrifugal pumps are not selfpriming and must be primed before a startup. Manufacturers sometimes offer "selfpriming centrifugal pumps" but on close inspection we always find some auxiliary equipment making the pump selfpriming. The most common design is a priming chamber which always holds a certain amount of water to prime the pump. A vast majority of pumps appearing in our plants work with suction head and priming is done automatically by gravity.
- (b) Positive displacement pumps if in good shape are generally selfpriming. The manufacturer usually specifies a suction lift limit up to which a pump will prime itself.

5. Capacities

- (a) Centrifugal pumps are available in a wide range of capacities, the largest ones being condenser cooling water pumps with the capacity of  $13 \text{ m}^3/\text{s}$  (~170,000 IGPM). No positive displacement pumps is available for such capacities.
- (b) Positive displacement pumps are available for relatively small capacities, approximately up to  $0.15 \text{ m}^3/\text{s}$  (~2,000 IGPM).

6. Pressures - Total Heads

- (a) A single stage centrifugal pump can develop only a limited pressure. For higher pressures, stages are compounded. But even then there is a practical limit to the size of a pump. In our plants we find 20 stage heat transport pressurizing pumps developing 10 MPa(g) (~1470 psig).
- (b) Positive displacement pumps in general, plunger pumps in particular, are available for pressures up to 100 MPa (15,000 psi) and even higher.

7. Handled Liquids

- (a) Centrifugal pumps can be designed to literally handle anything which has a slight tendency to flow. Slurries, paper stock, mixtures of abrasives, molasses are examples.
- (b) Positive displacement pumps due to tight tolerances used in their design are vulnerable to abrasives and thick plugging liquids.

8. Maintenance

Because of a limited metal-to-metal contact and the overall simplicity of design, centrifugal pumps require less maintenance than positive displacement pumps.

To summarize, centrifugal pumps lend themselves better to most of the requirements in our plants and that is why the vast majority of pumps in our plants are of this type. But there are some systems where it is not possible to use them. In hydraulic systems where positive delivery of a relatively small quantity of liquid is required at high pressure, in chemical injection systems where accurate metering is required, and as a standby in pressurizing systems, we find positive displacement pumps.

CENTRIFUGAL PUMPS

Centrifugal pumps come in a large variety of designs. There are several basic features according to which they can be classified:

1. Mount.
2. Staging.
3. Casing.
4. Impeller
5. Flow.
6. Energy Conversion.

1. Mount

Centrifugal pumps can be:

- (a) horizontally mounted, Figure 2.
- (b) vertically mounted, Figure 3.

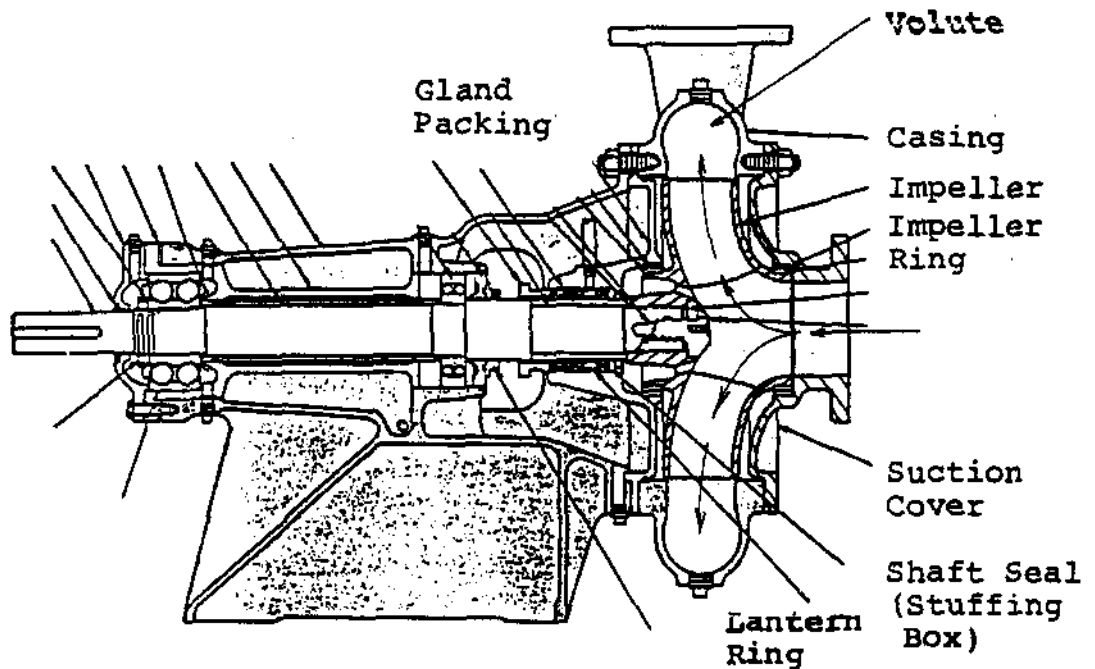


Figure 2

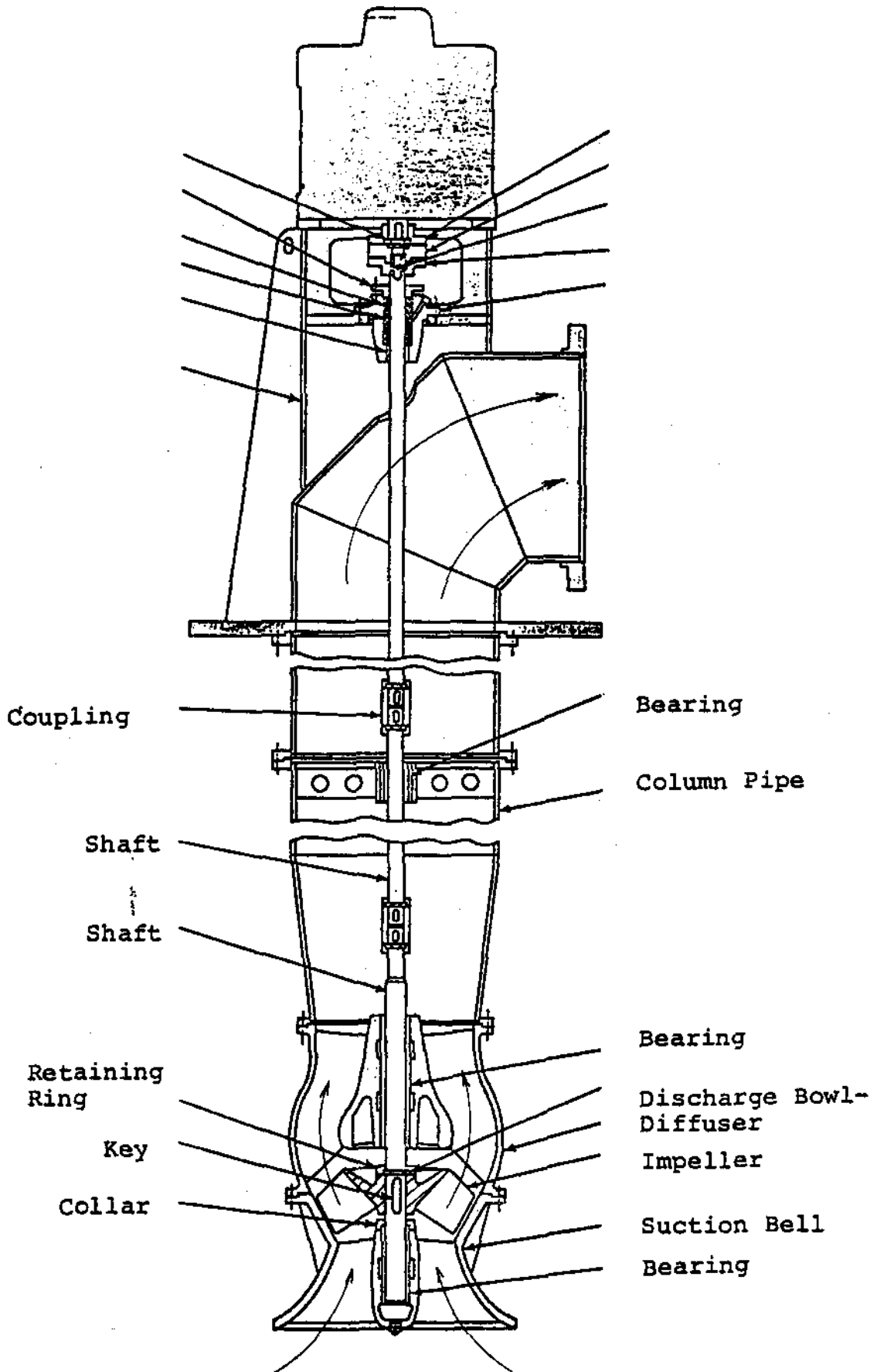


Figure 3

2. Staging

Centrifugal pumps are:

- (a) single stage, Figures 2, 3.
- (b) multi stage (two or more stages), Figure 4.

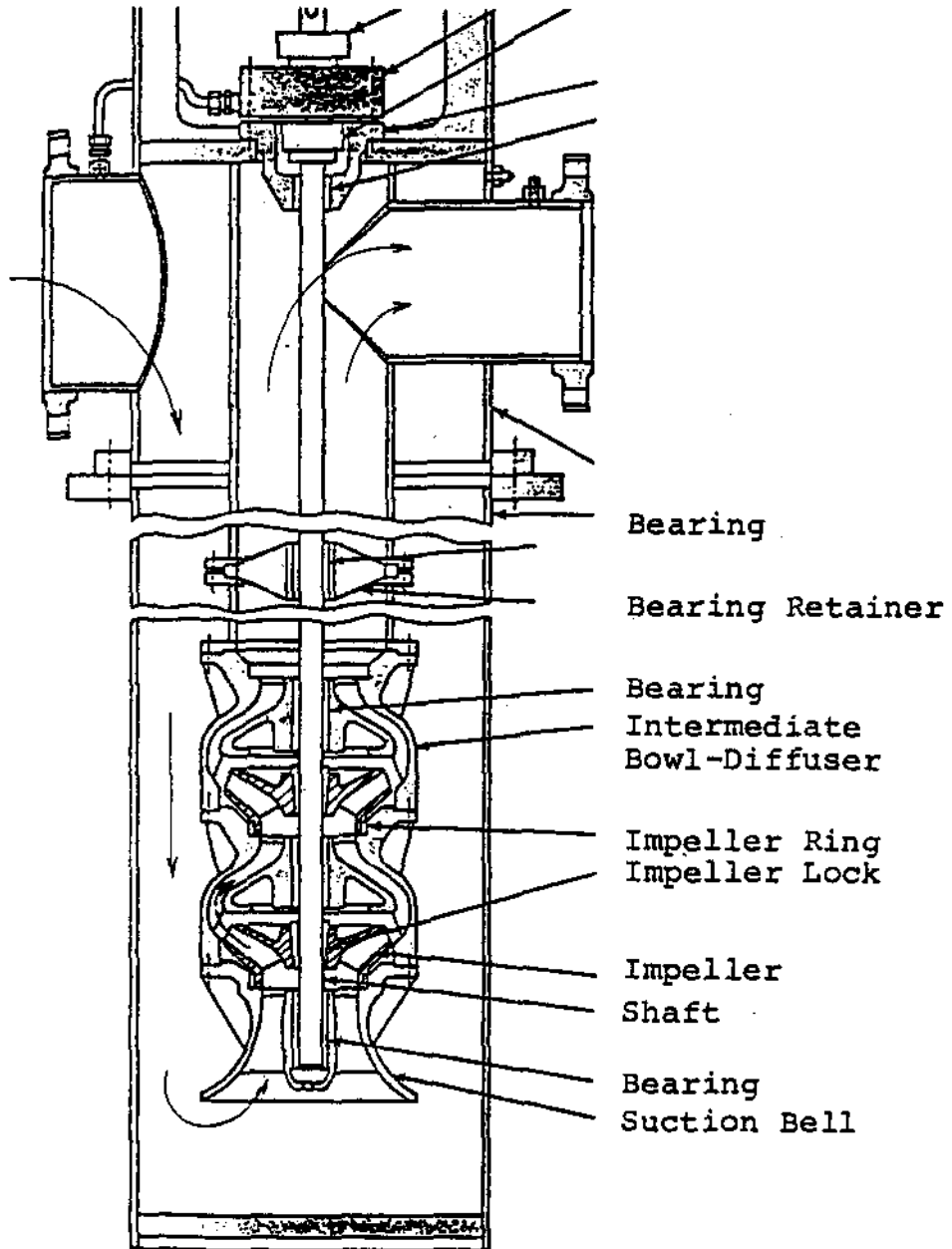


Figure 4



3. Casing

Types of casings found on centrifugal pumps are:

- (a) Radially split casing, Figure 2. The plane of split is perpendicular to the shaft.
- (b) Axially split casing, Figure 5. The plane of split runs through the axis of the shaft.
- (c) Barrel type of casing, which is actually two casings, the internal axially or radially split and the external barrel. A simplified schematic of this type of casing is in Figure 6. It is used on high pressure, multi stage pumps.

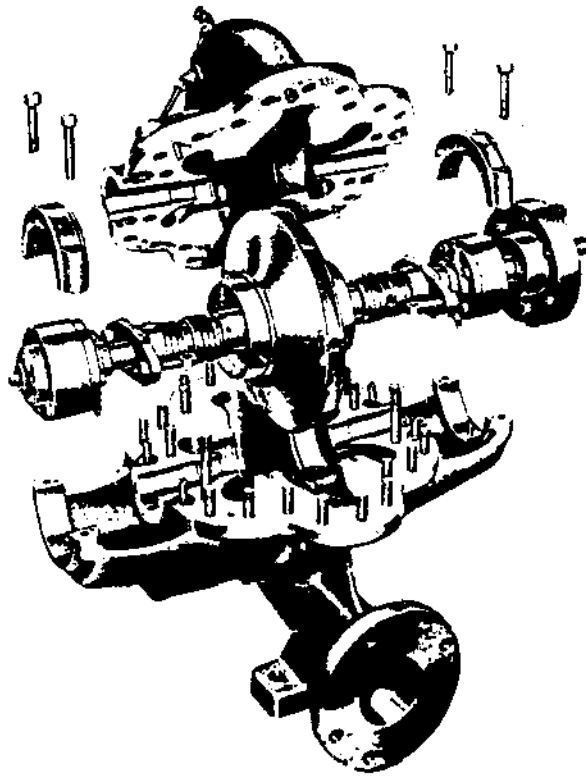


Figure 5

4. Impeller

According to the design, impellers can be:

- (a) Fully Shrouded Impeller - Blades are sandwiched between two discs. They can develop higher pressures than other types of impellers. An example is in Figure 7 (a).

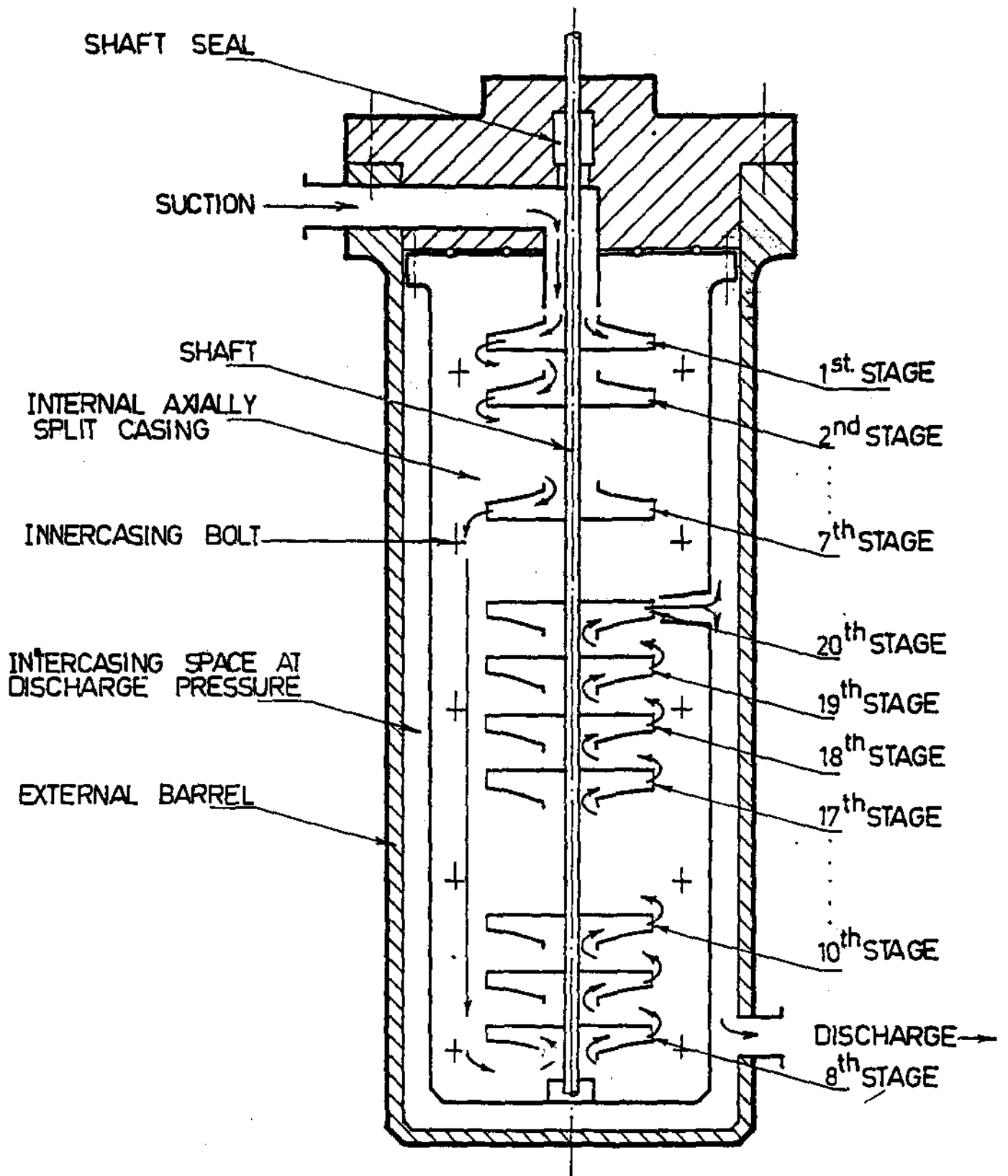
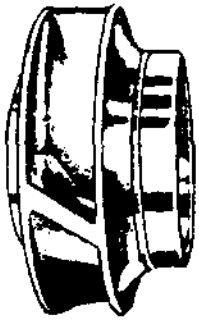


Figure 6

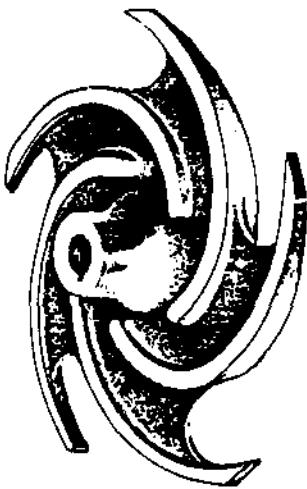
- (b) Semi-Shrouded Impellers - One disc is missing; blades are attached to one disc. They are cheaper, not able to develop as high pressures as fully shrouded impellers and are less efficient due to leakage along blades back to suction. An example is in Figure 7 (b).
- (c) Open Impellers, Figure 7 (c), have blades attached to the hub with very little or no shroud at all. A special type of this kind is a propeller used on vertical pumps. It is shown in Figure 7 (d).



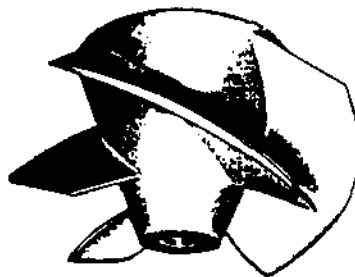
(a)



(b)



(c)



(d)

Figure 7

5. Flow

Depending on the flow through the impeller, centrifugal pumps are classified as:

- (a) Radial Flow Pumps - flow enters the impeller axially and leaves radially as in Figure 8 (a).
- (b) Mixed Flow Pumps - flow enters axially and leaves at some angle between radial and axial as in Figure 8 (b).
- (c) Axial Flow Pumps - flow enters axially and leaves axially as in Figure 8 (c).

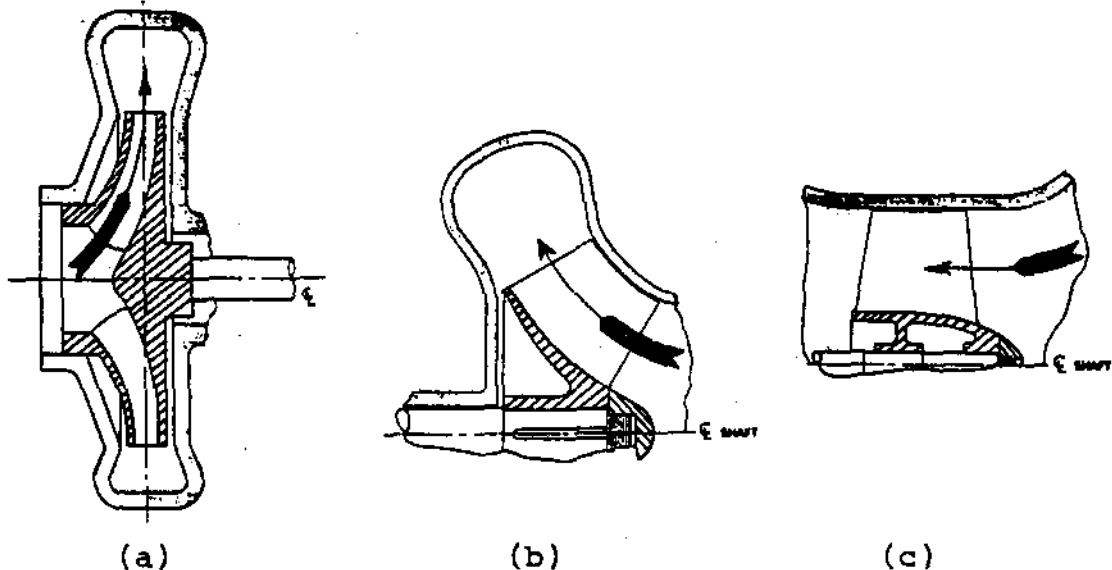


Figure 8

6. Energy Conversion

Centrifugal pumps are not pressurizing the liquid directly like positive displacement pumps. The mechanism creating a pressure head is as follows: liquid entering the impeller is flung into the volute with increased velocity (Figure 9). In other words the impeller imparts kinetic energy to the liquid. The liquid enters the volute, the cross section of which is increasing towards the discharge. This results in a decrease of velocity of the liquid and decrease of its kinetic energy. Because energy cannot be destroyed but only converted into another type of energy, decrease in

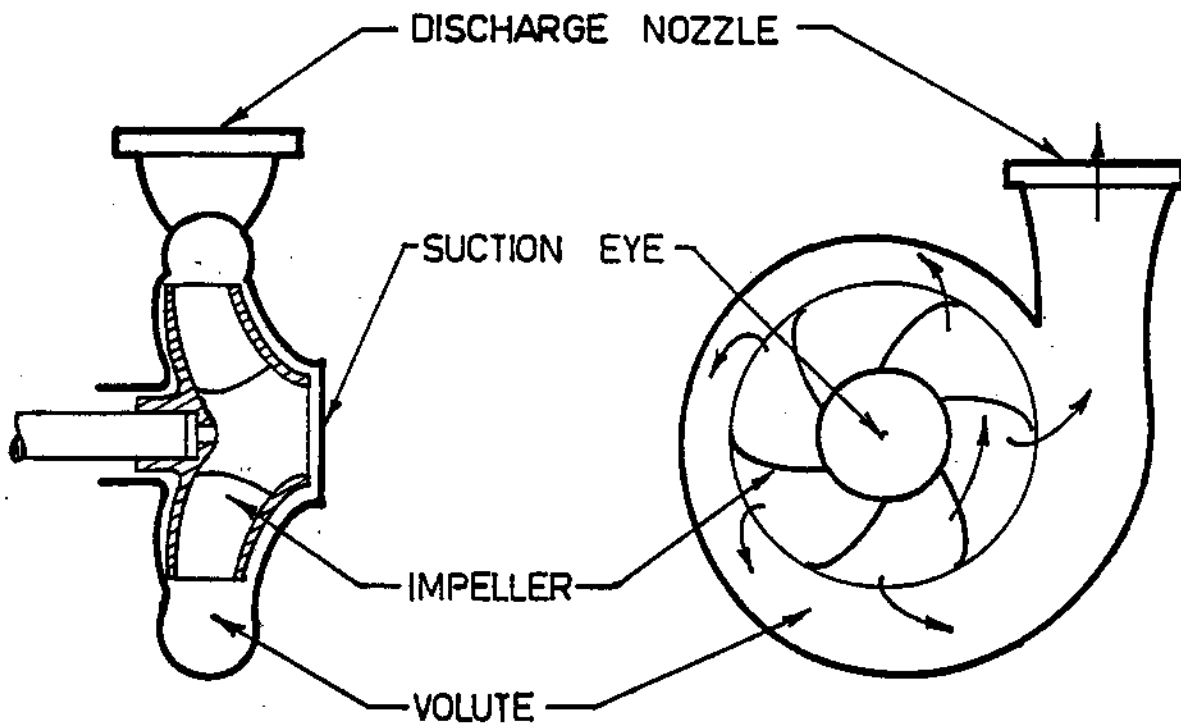


Figure 9

kinetic energy must result in the increase of some other type of energy. Total energy of flowing liquid in a pipe consists of several components. There is gravitational energy due to elevation of liquid above the ground, kinetic energy due to motion, pressure energy and heat energy. The elevation difference between the suction and discharge is very small and consequently the change in potential energy is insignificant. Also a change in temperature of in- and out-coming liquid is small, maximum 1°C, suggesting that the increase in heat energy due to internal friction is relatively small. So by the process of elimination the conclusion is that the change in kinetic energy results mainly in the change of pressure energy because it is the last remaining energy liquid can possess. If kinetic energy decreases, pressure energy must increase. Efficiency of a pump indicates how much of the supplied energy is converted into pressure energy and how much was wasted in friction which appears as heat in the liquid.

To summarize, the liquid is accelerated at first, then slowed down, the result is that the kinetic energy input at first is converted mainly into the pressure energy. This conversion by decelerating can be accomplished:

- (a) in a volute, which is the scroll in a casing surrounding the impeller (Figure 9);
- (b) in a diffuser, a stationary piece, adjacent to the impeller exit, which has multiple passages of increasing cross sectional area for converting velocity to pressure. Figure 10 shows the arrangement of a diffuser for a horizontal pump. Often this type is called a diffuser vane ring.

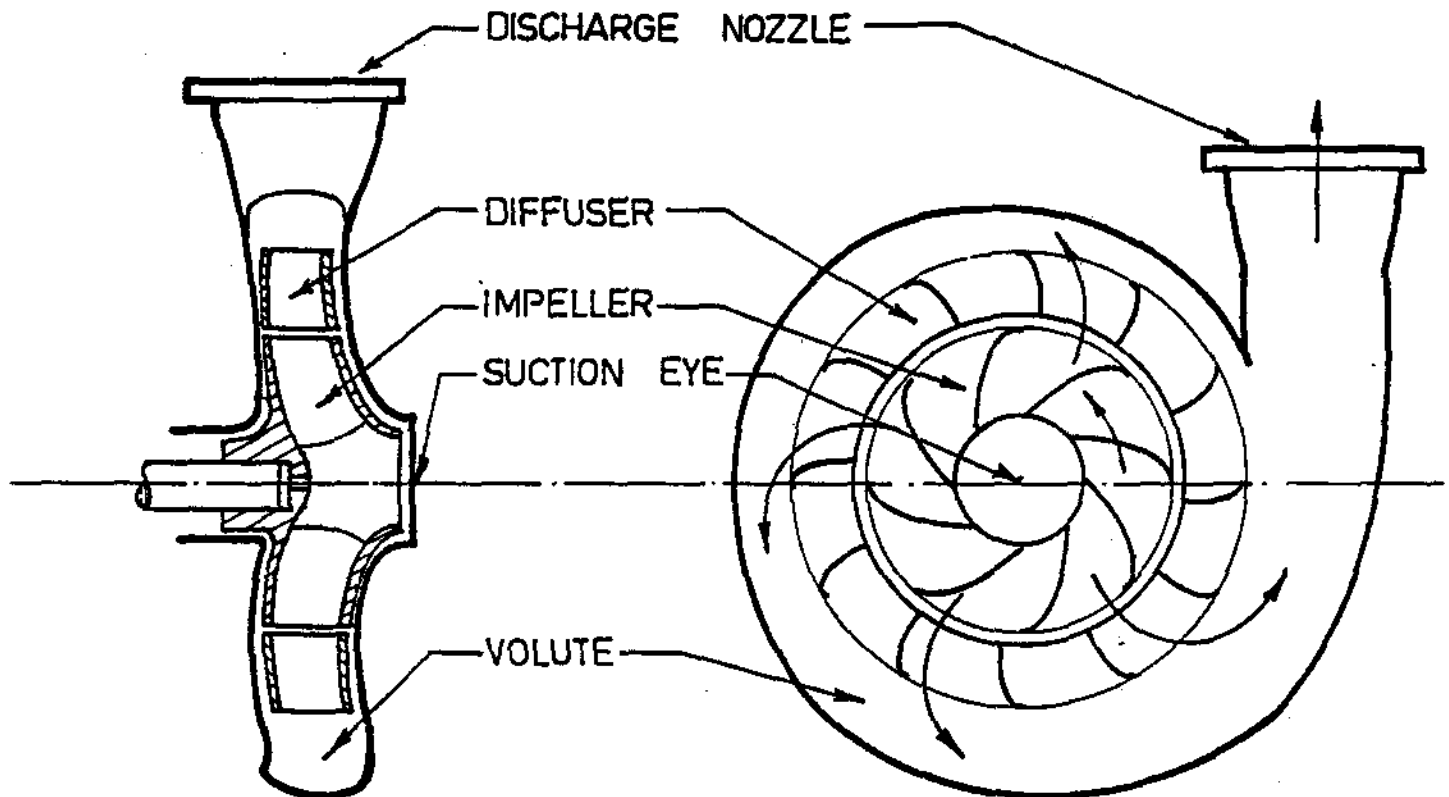


Figure 10

Another example of a diffuser on a vertical pumps is in Figure 3.

Diffusers are not common on horizontal units but are frequently found on vertical pumps.

### OPERATION OF CENTRIFUGAL PUMPS

Before a centrifugal pump is started it is advisable to check a few things. All bolts on flanges and base are tight, covers and guards in place, shaft spinning freely, pump is primed. If after the startup the pump is not delivering at all or delivers less than expected, there are several operational problems to be suspected:

1. The pump is rotating in the wrong direction as a result of a mistake in the electrical hook-up.
2. The impeller is mounted the wrong way around. This is nearly impossible with single suction impellers, but a double suction impeller which is symmetrical can be reversed by mistake.

The described situations are shown in Figure 11.

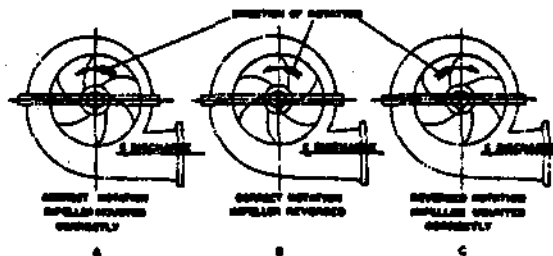


Figure 11

Experience shows that a vast majority of operational problems of centrifugal pumps originate in suction. They can be caused by:

#### 1. Airlocking

If a pump is working with a suction lift or takes suction from a vessel which is at a pressure way below the atmospheric pressure, suction piping and inlet to the pump might be under vacuum. In that case, any leakage due to poor piping joint or sealing arrangement will not be to the outside, but the ingress of air into the system will occur. Bubbles of air will also enter the system if there is not a sufficient submergence of the suction pipe or if bubbles of air are trapped by liquid falling into the suction tank are not separated before the liquid enters the suction pipe.

A centrifugal pump can handle a certain amount of air or, generally speaking, gas entrained in the liquid. But if the limit is exceeded, flow is interrupted and the pump is airlocked. If a pump works in other than air atmosphere, we talk about gaslocking.

## 2. Cavitation

In a system shown in Figure 1, the pressure at the surface of the liquid in an open tank will be the atmospheric pressure. As the liquid enters the suction piping it loses its pressure due to the friction losses and due to the lift. So the pressure progressively decreases and is the minimum as the liquid enters the impeller where the process of pressure buildup starts. The boiling point of any liquid depends on pressure and generally speaking it decreases with the decreasing pressure. If, during the passage through the suction piping, the pressure of liquid drops so much that it is equal or lower than boiling (= saturation) pressure corresponding to the temperature of the liquid, boiling will start. Small bubbles of steam, or generally vapour, will enter the impeller where the pressure is building up and again becomes higher than the saturation pressure of the liquid at the particular temperature. Vapour in the bubbles exposed to this higher pressure will condense leaving voids behind because the specific volume of liquid to vapour can be as high as 1 : 30,000. Surrounding liquid will immediately rush to fill these voids. This results in high speeds and resulting impacts. If a bubble and later a void happened to be at the metal surface of the impeller or casing, the intruding liquid will hammer the surface. Millions of these impacts result in pitting and damage to pump parts. The whole process, starting with pressure drop and bubble formation up to the implosion and impact is called 'cavitation'.

Although the cavitation is most common in centrifugal pumps serving water systems it is stressed here that cavitation can occur in any component handling any liquid if the basic conditions exist, ie, drop in pressure under the saturation level and subsequent recovery of pressure above this level. Examples are cavitating piston pumps, valves, elbows, boat propellers and others.

It should be mentioned that components can be operating years under mild cavitation without a detrimental effect to their basic function. If it is not possible to get rid of cavitation by the change of design, material choice can make the lifetime of the component acceptable. As an example, alloy steels have better resistance to cavitation than mild carbon steels.



3. Vapourlocking

If the pressure in the suction piping drops grossly below the saturation pressure, vigorous boiling will take place and large bubbles of vapour will be generated. Similarly as in gaslocking, the vapour will fill the pump and interrupt the flow. If it happens unnoticed vapour and liquid will be churned within the pump, temperature will increase and the damage to the pump will follow.

Methods used to alleviate problems of cavitation and vapourlocking are explained at higher levels of this course where deeper background knowledge of operation characteristics of centrifugal pumps is available to a trainee.

ASSIGNMENT

1. Explain the terms used in pump operation:
  - (a) suction lift.
  - (b) suction head.
  - (c) total head.
  
2. A pump is to be selected to provide cooling lake water for a number of station systems above water level. A large flow (25 000 GPM) at low pressure is required.
  - (a) What type of pump would you choose? Why?
  - (b) Is priming a problem? If so, suggest a solution.
  
3. How is the flow regulated in a system with:
  - (a) centrifugal pump?
  - (b) positive displacement pump?
  
4. A centrifugal pump delivers a large flow of cooling lake water (200 000 GPM) at low pressure. Suggest a pump design with respect to:
  - (a) type of impeller.
  - (b) direction of flow through impeller.
  - (c) number of stages.
  
5. A throttle valve on the discharge side of a centrifugal pump is defective and closes. If the pump is still operational:
  - (a) are there any immediate problems? Long term problems?
  
6. A pump under suction lift conditions is vibrating badly. A check with the control room indicates that motor current has dropped as well as discharge pressure which is unsteady.
  - (a) Suggest a problem.
  - (b) What are the possible long term effects?
  - (c) Can you suggest a possible solution, if a pressurized tank is on suction.

7. Draw a simple sideview schematic of a centrifugal pump with appropriate labels which has:
  - (a) fully shrouded impeller.
  - (b) one stage.
  - (c) radial flow through impeller.
  - (d) radial split casing.
  - (e) volute.
  
8. Explain the difference between airlocking and vapour locking.
  
9. Classify the pump shown in Figure 1 according to the six basic features.

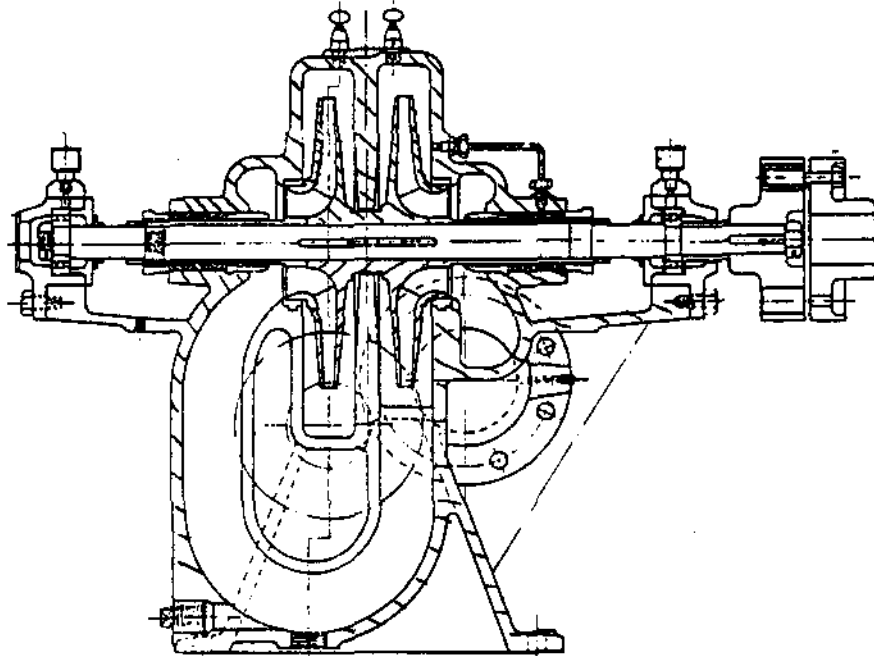


Figure 1

K. Mika