



Process engineering

Pumps, turbines and compressors

Centrifugal pumps (5)

Any pump will be subject to wear during operation. It is very important to be able to determine the cause of wear and to assess the potential consequences. One of the ways in which wear becomes noticeable is by an increase in clearance in the wearing rings and the bearings.

In most cases, clear limits can be set on the acceptable clearance of the wearing rings. For bearings this is more difficult due to the large variety of types and specifications.

Among other effects, wear leads to a lower capacity and reduced efficiency of the pump. Wear in possible combination with factors such as vibrations, imperfect alignment and assembly errors, can lead to serious faults. When the wear becomes extensive, the balance may be impaired and bearings will be subjected to increased load.

It is therefore important to have a good understanding of the factors and guidelines that enable a centrifugal pump to operate at maximum efficiency and to keep wear to a minimum. For the same reason it is important to be aware of possible causes of failures in this type of pump.

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- 1 Wearing rings and their function
- 2 Pump overhaul
- 3 Operation of centrifugal pumps
- 4 Potential failures with centrifugal pumps



Lesson

1. Wearing rings and their function

-clearances

- rings

- wear-resistant material

Between the impeller and the pump casing there are narrow clearances. This prevents excessive liquid from flowing back along the impeller from the discharge side to the suction side of the pump. If the liquid is contaminated, wear may occur in this narrow passage, leading to a widening of the gap between the impeller and the pump casing as well as to increased leakage loss. In most cases, the manufacturer has made a provision for rings at these positions. These rings can be replaced when the clearance has become too wide due to wear. In view of their function these are called wearing rings. They are often made of wear-resistant material to prevent the need for frequent replacement.

- balance chamber

Figure 1 schematically illustrates the position of the wearing rings in the case of a pump with a non-balanced impeller. Figure 2 shows their position in the case where the impeller is balanced. In the first case, only the suction side of the pump has to be sealed off from the discharge side of the pump. In the second case, a seal is also required between the discharge side and the balance chamber. The suction pressure also prevails in the balance chamber due to openings in the impeller.

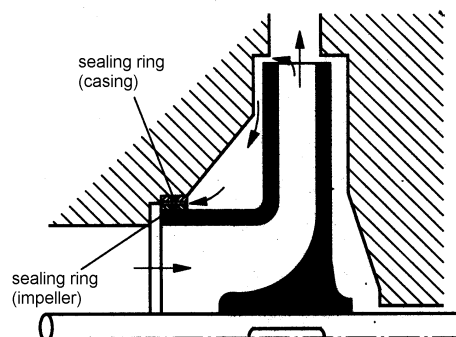


Figure 1
Centrifugal pump with two wearing rings. One of the rings is shrunk into the pump casing while the other ring is shrunk onto the impeller

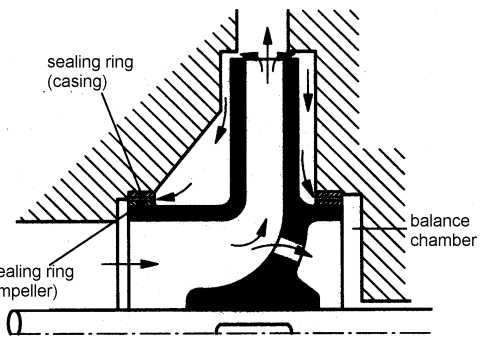


Figure 2
Centrifugal pump with overhanging impeller and two pairs of wearing rings

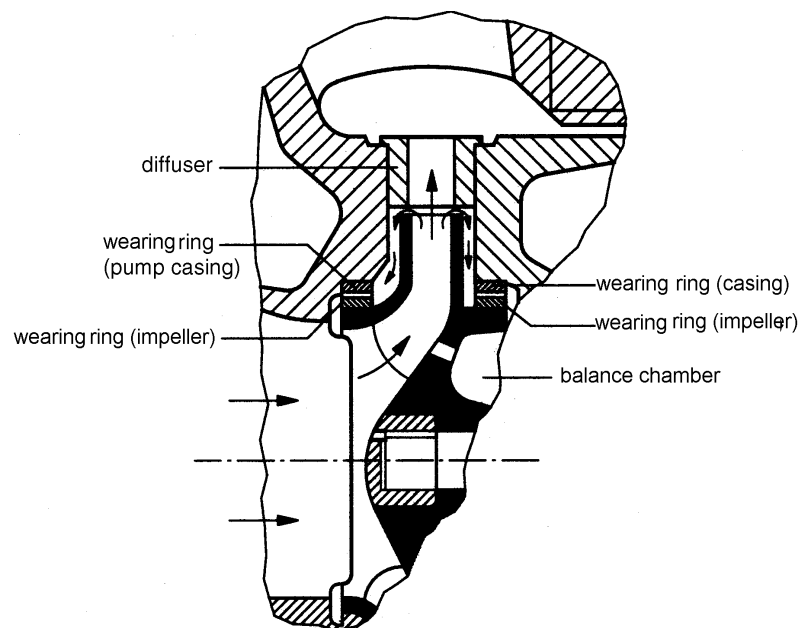
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- overhanging impeller

Figure 3 shows the position of the wearing rings in a pump with an overhanging balanced impeller that is provided with a diffuser.

- contravanes

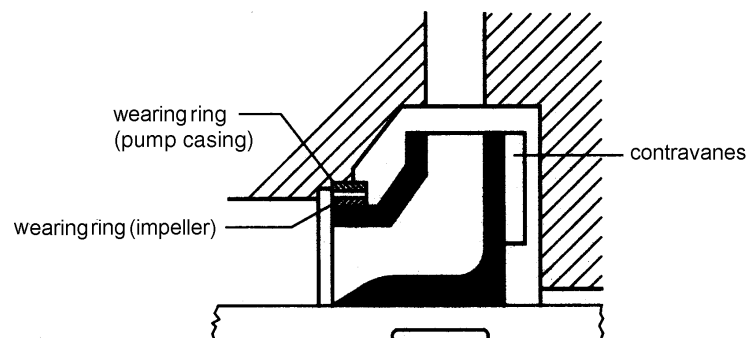
Some pumps are equipped with impellers having contravanes on the back. Due to the centrifugal action on the liquid the pressure at the back of the impeller is lower than the discharge pressure but higher than the suction pressure. The contravanes provide a partial balancing of the impeller. Pumps of this type have sealing rings only on the inlet side, as shown in figure 4.



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Figure 3

Centrifugal pump with overhanging impeller and two sets of wearing rings. The pump is equipped with a diffuser ring



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Figure 4

Impeller partly balanced by means of contravanes

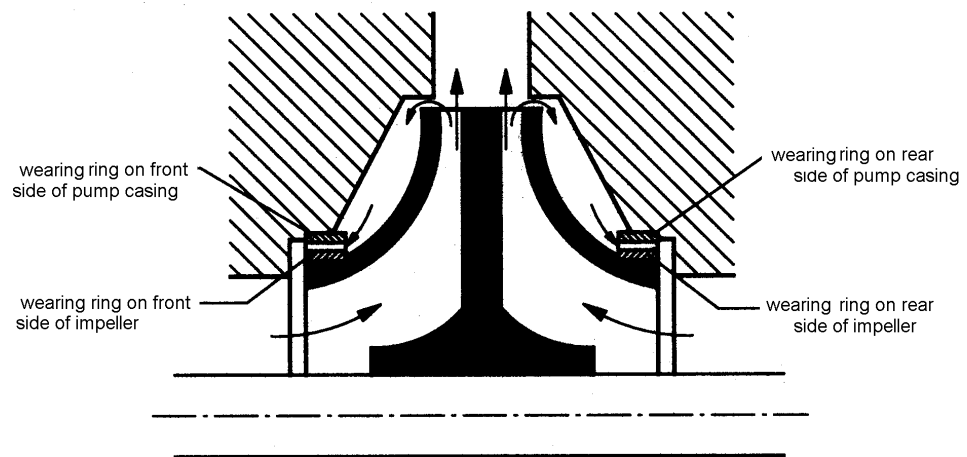
In pumps with a double-suction design, the pump casing and the impeller are both provided with wearing rings on the front and rear sides. Figure 5 shows a schematic illustration of a design of this kind.

This design is often used in order to eliminate axial thrust on the impeller. The axial forces on both sides of the impeller are balanced out. As a result, this type of impeller is perfectly balanced.

- balance out

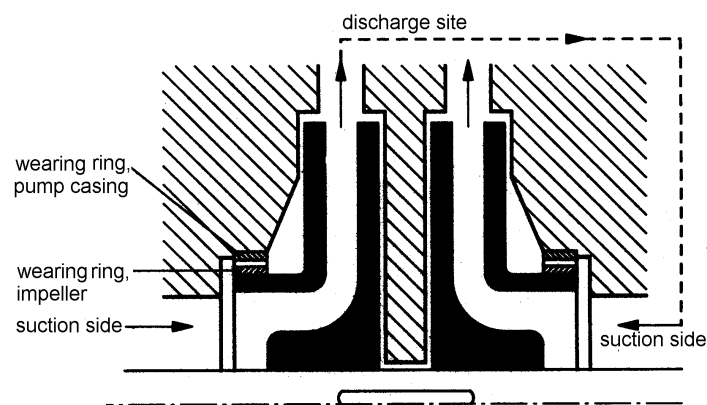
- back-to-back

A similar design is used in pumps with multiple impellers on a single shaft. The impellers are placed back-to-back, which results in an almost perfect balancing out of the axial thrust on the impellers. Figure 6 illustrates this design for a two-stage pump. The discharge side of one impeller is connected to the suction side of the other.



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Figure 5
Schematic illustration of double-suction impeller. This design ensures perfect balancing of the impeller



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Figure 6
Schematic illustration of a balanced two-stage pump. Again the two sets of wearing rings can be seen

The pump casing and the impellers on the suction side of such pumps are provided with wearing rings.

- clearance
- leakage loss

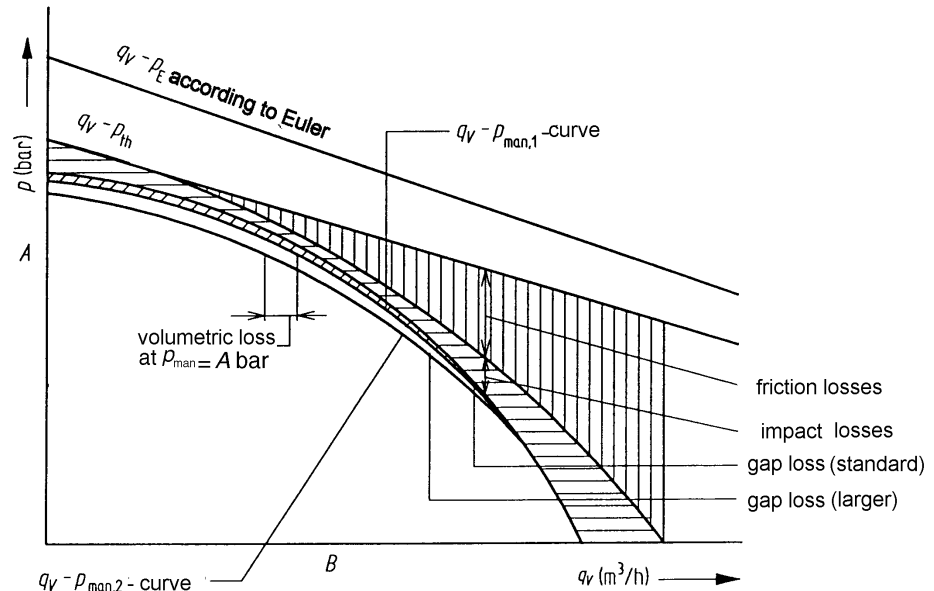
In addition to the actual differential pressure, the clearance between the wearing rings is the main factor determining the leakage loss of the pump. The graph in Figure 7 shows the effect of increasing clearance on the effectiveness of the pump.

In this figure the horizontal distance between the curves $q_V-p_{\text{man.1}}$ and $q_V-p_{\text{man.2}}$ corresponds to the increased volumetric loss caused by the increased clearance. It can be seen that the pump capacity is reduced.

The power P_{shaft} supplied to the pump remains unchanged and as a consequence the efficiency of the pump is reduced. Therefore, optimum pump efficiency with respect to leakage losses is achieved with a minimum clearance between the wearing rings.



Obviously, manufacturers aim for maximum pump efficiency by minimising the clearance between the wearing rings. Furthermore, the pumps are tested using water at ambient temperature.



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Figure 7

q_v - p_{man} curve, showing standard and excessive gap (leakage) losses. Increases with increasing p_{man}

Question 1

Which clearance largely determines the leakage loss?

- operating conditions

Operating conditions in practice will be different depending on the type of liquid to be pumped and its temperature. Moreover, when a pump is in operation there are several factors that must be given careful attention when determining wearing ring clearance:

- bending of the impeller shaft when rotating;
- differences in expansion between impeller and casing;
- vibrations and the radial displacement of the impeller shaft caused by them;
- possible distortion of the pump casing at elevated temperature, tension exerted on the pump casing by the pipes;
- dirt present in the liquid to be pumped.

If insufficient attention is paid to these factors, then this may lead to damage or seizing of the pump. This may happen if the clearance is too narrow. If one makes the clearance too wide this may lead to larger leakage losses and corresponding efficiency loss.

- efficiency loss



2. Pump overhaul

- condition of vital parts

When overhauling a pump, the Engineering Department inspects the condition of the vital parts. The dimensions of these parts and the associated clearances may change as a result of wear.

The most important points are:

- Checking the shaft for straightness.
- Checking the shaft diameter and the bearing casing diameter for good bearing.
- Checking the wearing rings, both on the impeller and in the pump casing, for wear and the condition of the sleeve and intermediate bushing.
- Checks during the assembly of the rotating part.
- Balancing of a rotating part.
- Installation of the rotating part in the bearing seat or seats.
- Installing the sliding ring seal.
- Alignment.
- Lubrication.

3. Operation of centrifugal pumps

3.1 Start-up of centrifugal pumps

- filling necessary

A centrifugal pump can only perform its function if it is completely filled with liquid. Filling is absolutely vital, unless the pump is of a special design that makes it self-priming.

Starting up of a centrifugal pump proceeds as follows:

- line up the suction pipe;
- check, vent and slowly turn over the pump;
- line up the discharge pipe (leave discharge valve closed);
- start the pump; when it is running at operating speed and delivers pressure, open the discharge valve;
- check and adjust the pump.

The start-up as described above assumes that the pump has been in normal operation throughout. If it has been overhauled, there are additional points to be addressed.

- lining up

By lining up we mean preparing a pipe section for pumping a product. This includes a number of activities, such as:

- opening and closing of valves in such way that only the relevant section is used;
- removing any undesired products, flushing and cleaning substances from this section;
- if required preparing specific facilities according to the instructions, such as heating or cooling, quenching and the like;
- venting at high points.



For proper operation of the system these instructions should be followed carefully.

When preparing the pump for operation it should be checked for:

- Direction of rotation, which in most cases is indicated on the pump. Particularly for pumps driven by electric motors there is a possibility that the motor will rotate in the wrong direction. When checking the rotation, make sure that the pump is uncoupled from its drive.
- Lubrication. It should be ensured that the pump is, or will be, lubricated with the correct lubricant.

Question 2

Which steps would you take when there is doubt whether the correct lubricant has been used?

- venting

The next action is venting. This should be carried out with care. If the pressure is too high when the pump is filled, the seals on the shaft, and the sliding ring seals in particular, risk becoming damaged.

- slowly turning over

The pump can be slowly turned over by hand if it is not too large. When the discharge valve is closed, the pump can be started and brought up to speed and pressure. Then the discharge valve can be opened slowly.

Question 3

What is the standard procedure for checking the direction of rotation of the electric motor?

3.2 Control of centrifugal pumps

- never use suction valve

In contrast to plunger pumps, the capacity and pressure of centrifugal pumps can be controlled by adjusting the discharge valve. Never try to control the capacity by means of the suction valve. However, it is possible to control the capacity by:

- changing the motor speed (in a few cases only);
- spill back control. Some of the liquid flow is returned to the suction pipe. This has the drawback that the temperature of the recycled liquid, and therefore the temperature of the pump, will increase. A higher vapour pressure may cause the pump to stall. While flowing through the pump, the liquid absorbs energy and heats up. Returning the liquid flow to the pump inlet therefore leads to a temperature increase.

Never use the suction valve to control the pump; this creates a high risk of cavitation in the pump.

Question 4

Why is it that throttling the suction valve may lead to cavitation in the pump?

Finally the pump should be checked with respect to the temperature of the seals and bearings and, if possible, the power required by the pump. Power can be read from an ammeter, for example.

*Question 5**What other value do we need to compute the power absorbed?*

3.3 Stopping a centrifugal pump

In principle, a centrifugal pump is stopped in the reverse order of the start-up procedure.

Generally speaking, the stopping procedure is as follows:

- close the discharge valve;
- switch off the pump.

The time between closing the discharge valve and the actual switching off of the pump should not be too long.

Remember that in this situation all of the energy absorbed by the pump will be converted into heat. With contemporary pumps, the quantity of liquid in the pump is very small and therefore the temperature will very rapidly increase. This may lead to serious damage of the pump;

- when the pump has stopped running the suction valve should be closed. This will prevent liquid from flowing out of the pump.

4. Potential failures with centrifugal pumps

- signs of failure

There are many ways in which the operation of a centrifugal pump may be disrupted. We shall discuss only the most common signs of failure.

4.1 Insufficient capacity due to low suction pressure

Low suction pressure may result from:

- clogged filter

- suction valve not fully open;
- suction filter partly or completely clogged, or installed filter is too fine;
- suction pipe partly or completely blocked.

In these situations, the pipe resistance increases, leading to a different pipe characteristic and a different operating point for the pump, resulting in a lower capacity. In addition, there will be a negative effect on the $NPSH_A$, which could lead to cavitation.

In addition to the possibilities mentioned above, the $NPSH_A$ may also be negatively affected by:

- too low a level in the suction vessel;
- too high a vapour pressure of the liquid, without being compensated by a higher pressure in the suction vessel;
- too high liquid density;
- too high liquid viscosity as a result of a decrease in temperature. On the other hand, this does have a positive effect on the vapour pressure.



4.2 Damage to bearings

Bearings may be damaged by:

- incorrect lubrication or contaminated oil;
- incorrect installation of the bearing;
- excess load on the bearing.

Incorrect lubrication or contaminated oil

If a bearing is not correctly lubricated or the lubrication oil is contaminated, damage to the bearing is not uncommon. If a bearing is not *properly* lubricated it will be destroyed.

Incorrect lubrication can mean both too much or too little lubricant.

Oil "as delivered" is only rarely contaminated. The oil can being used for lubrication should be completely clean. Water is not desirable as a lubricant in most cases and care should therefore be taken to prevent water from penetrating the bearings. It is extremely important to check that the correct lubricant is used, in the correct quantity. It should also be ensured that the lubricant is free of all dirt or foreign substances.

Incorrect installation of the bearing

There are many factors that can lead to incorrect installation of a bearing:

- the fit of the bearing on the shaft and in the bearing casing;
- unusual forces during assembly;
- incorrect restraining of the bearings;
- fixing the bearings too tightly.

The fit onto the shaft and in the housing is very important, for sleeve bearings as well as for ball and roller bearings. Relevant data can be found in the instruction set belonging to the pump, for instance.

- do not use sections of pipe

To avoid unusual forces during assembly it must be ensured that the correct method of installation is followed. This means that large hammers or sections of pipe should not be used.

Incorrect restraining may result from a bushing that does not fit, is skewed, or is pushing against a skewed surface. This will distort the bearing, causing it to overheat. Additional lubrication will then be of little help. Distortion of a bearing can also occur when bushings that are too long or too short are used. Restraining is mainly of importance in the case of ball bearings and roller bearings.

Distortion can also occur when a bearing is fitted too tightly. Clearances may then become too small and excessive forces will arise; the bearing overheats or seizes. Manufacturers provide instructions for the correct way to restrain bearings as well.

**- boosting****Overload on bearings**

Under standard operating conditions an overload on the bearings rarely occurs. Overload may result, however, when a pump is made to run under conditions substantially exceeding the original design conditions. For instance, a pump which may have been designed for a discharge head of 4 bar is required to operate at a head of 10 bar (boosting). The impeller will no longer be balanced. Axial forces will develop for which the pump was not designed, causing an overload on the bearing.

Question 6

For which type of bearing is the correct way of restraining particularly important?

4.3 Vibrations**- frequency
- amplitude**

A vibration is a periodic motion in a certain direction. In most cases this motion cannot be seen by the eye but it can sometimes be felt and often be heard. Two parameters are important when discussing pumps: the frequency (i.e. the number of oscillations per second) and the amplitude (the magnitude of the displacement). By using the proper instrumentation it is possible to measure these quantities.

The frequency will depend on the type and size of the pump and on the operating conditions. In considering possible action these have to be taken into account.

Vibrations can have various causes. Some of these are:

- imbalance of the drive, the coupling or the impeller;
- incorrect alignment;
- play in the bearings;
- uneven wear of wearing rings;
- cavitation.

Imbalance of the drive, the coupling or the impeller

Imbalance of rotating parts can almost always be avoided by careful balancing. Poor balancing at first causes slight vibrations. These will lead to wear of the bearings and these, in turn, will cause more serious vibrations. In the end, the entire machine will become badly damaged. Wear and dirt often disturb the balance of the impeller. The vibrations depend on the speed of rotation and can be located by measurements.

Incorrect alignment**- type of coupling**

If the pump and the drive mechanism are not correctly aligned, vibrations will result that depend on the type of coupling and the speed of rotation.

The alignment may also be changed by large variations in the temperature of the pump, the drive or the base. The alignment should be adjusted at the operating temperature, if possible. In doing so, one should also take into consideration the forces on the pump casing which are caused by the pipes.



Tolerance in the bearings or "not mechanically tight"

Whenever there is tolerance in the bearings, an imbalance will result. This imbalance will cause the tolerance to increase rapidly. Again, the intensity of the vibrations will depend on the speed of rotation.

- uneven

Uneven wear of wearing rings

Unevenly worn wearing rings will lead to local variations in the pressure acting on the impeller. These variations will upset the axial balance and cause vibrations.

- cavitation

Cavitation

Cavitation may be a cause of vibrations. Cavitation means the formation of vapour bubbles when the pressure on the entry side of the impeller becomes lower than the vapour pressure of the liquid. When these vapour bubbles are transported to a place where the pressure is higher than the vapour pressure, they will collapse (implode). Because the vapour bubbles are unevenly distributed inside the impeller, the impeller balance will be disturbed. The implosions of the bubbles against the vanes and the walls produce uncontrolled forces which further upset the impeller balance.

- implosion

- pitting

Implosion against the vanes and the walls has another undesirable effect as well: they cause pitting of the material. Pitting, which means that metal is removed, is another cause of imbalance.



4.4 Failures and their possible causes

Table 1 gives an overview of common failures and possible associated causes.

	Pump does not supply liquid flow	Pump supplies insufficient liquid flowrate	Pump supplies insufficient discharge pressure	Pump shuts-down after start-up	Suction pressure decreases following normal operation of the pump	Pump requires deviating power
Pump and suction pipeline are not completely filled	×					
Stuck non-return valve in the discharge line	×	×				
Blockage in suction line (dirty filter)	×	×		×	×	
Foreign object or dirt in impeller	×	×	×			
Blocked filters	×	×				
Gas or air released from the liquid	×	×	×	×		
Pump and suctionline not properly vented	×	×	×	×		
Leakage in the suction line	×	×	×	×	×	
Air leaks in through sealing		×	×	×	×	
Level in the suction vessel is too low, leading to vapour formation	×	×		×	×	
Suction height too great, leading to vapour formation	×	×				
Wrong direction of rotation		×				×
Speed too low	×	×	×			
Wearing rings are worn		×	×			×
Impeller is damaged		×	×			
The shaft is bent						×
Stuffing fitted incorrectly						×
Bearings insufficiently lubricated						×
Speed too high						×
Back-pressure from discharge system is too high	×					×
Temperature of the liquid is too high	×					
Density and/or viscosity of the liquid is too high						×
The system pressure at the discharge is lower than calculated, which causes a too high liquid flowrate						×



Summary

Leakage losses are determined mainly by the wearing rings. When these wearing rings wear out, the pump capacity will be drastically reduced. In order to limit wear of the rings, all parts of the pump should have the correct dimensions at the time of assembly, within a narrow tolerance range.

Balancing is also of great importance. Tolerances in the bearings result from overloading or deviations from the required accuracy. Tolerances in the bearings cause accelerated wear of rotating parts.

Overhaul of a pump involves inspecting the condition of all vital components. Important points to check during assembly are listed in the lesson.

The start-up procedure of a centrifugal pump is as follows:

- check the direction of rotation (only required after an overhaul);
- fill pump with liquid;
- open suction valve and close discharge valve;
- start the drive;
- slowly open discharge valve.

The capacity of a centrifugal pump can be varied by:

- changing the speed of rotation;
- using a spill back.

The procedure for stopping a centrifugal pump is basically the reverse of the start-up procedure.

In most cases it is possible to trace centrifugal pump failures to certain specific causes.

The most common disturbances are:

- capacity too low due to low suction pressure;
- damaged bearings;
- vibrations.

Vibration of the pump is an important sign of malfunctioning. It means that somewhere there is a defect. If the vibration results from cavitation, corrective action must be taken with respect to liquid transport. If the cause lies in a mechanical defect, this should be eliminated.



Test

Exercises

Do not send in your answers for correction

1. Which kind of liquid practically excludes the use of metal?
2. Name some materials that are resistant to the corrosive properties of certain liquids. What drawback do these have in practical applications?
3. How can excessive temperatures of the liquid in the pump be avoided when using control by spill back?
4. For relatively large capacity pumps the manufacturer will carry out a number of tests before delivering the pump. In these tests water is often used at ambient temperature.
Explain why.
5. Which factors should be carefully checked when determining the dimensions of the wearing rings?
6. Which parts should be checked during the assembly of a centrifugal pump?

Answers to the questions in the lesson

1. The clearance between the stationary pump casing and the rotating impeller determines the (internal) volumetric leakage losses. Moreover, the differential pressure obviously is a determining factor as well.

When there is any doubt about the quality of the lubricant present in the pump, it is advisable to replace it with a product which is guaranteed to have the correct properties for the system.

2. Checking the direction of rotation of the electric motor must always be carried out after the pump has been uncoupled from the motor. (For pumps that are vertically mounted this is not always possible. In such cases it is necessary to check the direction of rotation of the shaft.)
The reason is that certain types of seals will be damaged if the pump is rotated in the wrong direction.
3. Throttling the suction valve will increase the system resistance in the suction section. This will cause a drop in the pressure in the suction section of the pump. If this pressure falls below the vapour pressure corresponding to the temperature of the liquid, vapour bubbles will form. Further down the pump these bubbles cannot exist and they will collapse. The implosion causes very large point forces which can do serious damage to the material.



4. To determine the power consumption one also needs to know the value of the voltage at the terminals.
5. Correctly restraining roller bearings or ball bearings is very important for the proper functioning of these bearings and, therefore, of the pump.

Answers to the exercises

1. Metal pumps are not suitable for pumping corrosive liquids. Unacceptable corrosion of the metal would occur. However, metals can be used if they are completely isolated from the liquids to be pumped.
2. For this purpose glass, porcelain, silicon, cast iron and also lead may be considered. These materials are often not strong enough. Resistant metals do exist, but most of these are expensive and difficult to use as construction materials.
3. In such a case the spill back flow should be returned to the suction vessel instead of the suction of the pump.
4. Use of a liquid at ambient temperature ensures that the clearances between the wearing rings will become neither larger nor smaller. If the clearances do not increase, leakage losses will be kept to a minimum. Such conditions mean better pump performance. If the temperature of the liquid increases, one will have to wait and allow sufficient time for the pump (that is, both the casing and the impeller) to reach that same temperature. This ensures that the measurement produces a reliable reference value and can be repeated at a later point in time.
5. When determining the dimensions of wearing rings in centrifugal pumps, the following points should be taken into account:
 - the possibility of impeller shaft distortion during operation;
 - differences in expansion with temperature changes;
 - vibrations, resulting in changes in the amount of radial clearances;
 - the possibility of distortion of the casing in the event of (relatively large) temperature variations;
 - distortion of the pump caused by stress in pipes;
 - possible contamination in the pump. (For example, the clearance should exceed the mesh size of a suction filter, if present.)



6. When assembling a centrifugal pump, the following points require special attention:
- straightness of the shaft;
 - shaft and bearing diameters;
 - extent of wear of important components (rings);
 - the way in which the rotating part is assembled;
 - balancing of the rotating part;
 - installation of the rotating part in the bearings;
 - fitting of sliding ring seals;
 - correct alignment of the unit;
 - lubrication (which lubricant to use).

Problems and assignments

Answer and send in for correction

1. List four materials that can be used for the interior of an acid pump casing.
2. What is meant by 'aligning' a pump?
3. Briefly describe the standard start-up procedure of a centrifugal pump.
4. List three ways of changing the capacity of a centrifugal pump.
5. A pump delivers insufficient pressure and capacity, whereas power consumption is relatively high. What are the possible causes of the problem?
6. What check should one carry out if the suction pressure drops after correct operation?
7. At which points in a centrifugal pump will wear affect the leakage loss?