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Operating

Making centrifugal pumps more reliable

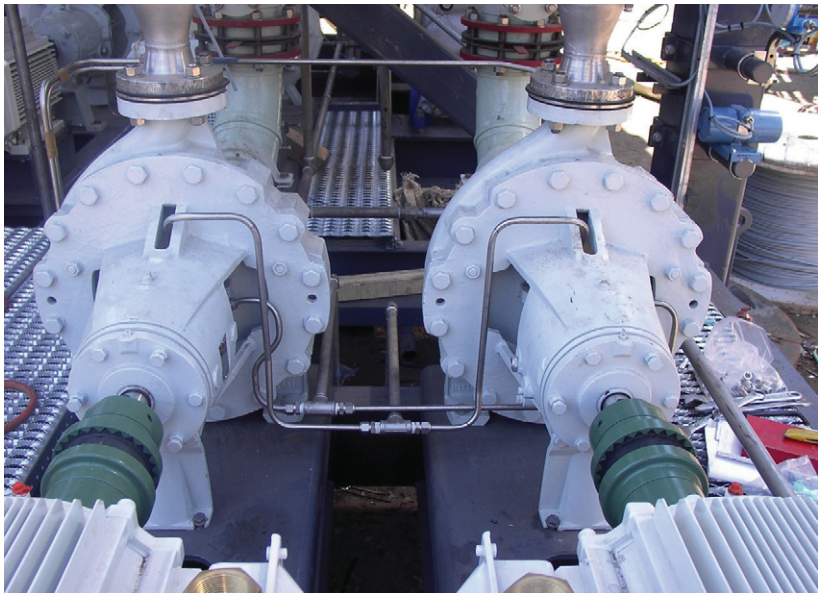
Decisions and actions taken during the specifying, commissioning, operation and maintenance of centrifugal pumps can all affect reliability, an increasingly important issue with the growing emphasis on efficiency and cost reduction. Trinath Sahoo of Indian Oil Corp provides the details.

One of the oldest machines known to mankind, the pump is widely used in industry. Nowadays the techniques for specifying, commissioning, operating and maintaining centrifugal pumps have gained greater importance as inefficient plants will be phased out for competitive reasons. Pump reliability management in the process industries can be divided into three phases:

1) Pump selection and pre-erection reliability assurance
2) Preparation for start-up
3) Post start-up reliability assurance.

Pump selection

Satisfactory performance and long periods between failures or overhauls can generally be achieved as long as centrifugal pumps are operating at near-design conditions. It should be noted, however, that 'design' refers not only to pressure, flows, temperatures and other process parameters, but also to flange forces and moments, coupling forces and moments, bearing lubrication and similar mechanical considerations. Conservatively designed pumps will only tolerate a certain amount of off-design operation either process or mechanically induced before performance levels start to suffer. So pumps should be selected for operation near their best efficiency point (BEP).



Pumps that are correctly installed remain in alignment for longer periods, develop fewer casing and flange leaks and vibrate less.

Centrifugal pumps with a high suction specific speed (S) can often be expected to give satisfactory operation over only a narrow range. Recirculation occurs in high-head pumps, using a large impeller inlet eye area in an effort to achieve low NPSHR (net positive suction head required). Pumps with low NPSHR have suction specific speeds in the range of 12 000. If the normal flow deviates from BEP flow, internal recirculation will occur and it will render pump operation hydraulically unstable. Turbulent flow causes impeller erosion and significant fluctuations in mechanical seal action, bearing loading and shaft deflection. The life expectancy of centrifugal pump components is influenced by pump suction specific speed, throughput percentage (Q actual/Q at BEP), NPSH margin (NPSHA – NPSHR), head rise per stage and casing design. User demands for high efficiency, lower cost and low NPSHR pumps have driven suction specific speed into the range above 12 000, where relatively small deviations from BEP flow cause internal recirculation phenomena. Ideally, pumps should be selected with a suction specific speed of around 8500.

Stuffing box design

Many pumping systems require that the mechanical seal environment be kept at a moderate temperature. This is some-

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The load and stress imposed from a connecting piping system can greatly affect the reliability of equipment.

times achieved by external flush injection. Another option for achieving a moderate seal environment is stuffing box cooling. In many pumps the stuffing box cavity is remote from the seal faces that need to be cooled. A superior design from the point of view of effective cooling should be used.

Typically, radial clearance between the seal outside diameter and stuffing box bore ranges from 1.5 mm to 0.75 mm. Design compromises are responsible for: inadequate heat removal from seals; the vulnerability of seals to damage from abrasives; the lack of standardization and interchangeability of parts; and excessive seal face deflection due to the smaller cross section of parts.

So, when purchasing new pumps, an enlarged seal chamber should be specified. The key to lowering operating temperatures is to surround the seal faces with an open throat (the restricted annular space at the impeller end of the seal chamber) in a seal chamber that is self-venting at start-up.

The major goals of the design should be:

1) To provide a seal chamber that allows seal faces to run cooler and with better lubrication.
2) To avoid seal faces operating in a restricted bore.
3) An open throat is preferred, to promote self-venting of the seal chamber.

Nozzle forces

When piping is bolted to the flange of a pump case, external forces due to the pipe's weight, thermal expansion and the weight of the process fluid begin to act on the pump. These forces can distort the casing, causing internal misalignment, rubbing between the casing, the impeller and the shaft, and even shaft seizure. They can produce moments around the pump that could result in a misalignment between pump and driver shaft, which can in turn lead to premature failure of the coupling, bearings or mechanical seals. Therefore limits must be established for these nozzle forces and moments. For piping designers, these limits are the maximum values that a piping configuration may impose on a pump.

Seal selection

Seal and seal environmental-system selection for pumps is very complex. Cartridge seal units offer major maintenance advantages. They are designed for rapid installation and removal from the pump shaft. If the stuffing box is large enough, cartridge configurations of both bellow- and spring-type seals can be used. Cartridge seals can be replaced easily with less risk of assembly error and assembly damage than with a conventional mechanical seal. When selecting the seal face material, consider that heat generated at the seal face must be rapidly conducted away to avoid fluid vaporization. High thermal conductivity and hardness make silicon carbide the preferred seal face material.

Storage

After the pump is correctly designed and ordered, the vendor will dispatch it for storage at the owner's premises until installation is scheduled.

Wrap all stored pumps with waterproof tarpaulins. Be certain that the tarpaulin passes completely under the pump and over both ends. Protect the bearings and shaft coupling from dust and dirt.

Factors influencing construction material choice

The choice of construction materials affects pump life span. Five important factors guide this choice.

Pressure

The maximum pressure value experienced by components must be taken into account, not merely the total dynamic head (TDH) imparted by the pump. Pump specifiers must also take account of transient effects and shock.

Temperature

High temperatures not only reduce the strength of metals and non-metals but also speed up corrosion. Very low temperatures increase the danger from impact.

Corrosion

Direct and predictable effects of acids and alkalis, and also the danger from galvanic corrosion should be considered.

Erosion

Wear results from impingement on surfaces from waterborne particles that cut away material.

Stress

The mechanical and hydraulic loads on the components impact the choice of materials.

Pump location

Correct pump location is important from both the operating and maintenance stand points. To ensure good flow conditions, locate the pump as close as possible to its liquid supply. Where enough space is available, have the pump inlet below the level of the supply liquid. Allow enough space around the pump for inspection and maintenance. Always try to have sufficient head room above the pump for use of an overhead crane or chain hoist capable of lifting the heaviest part of the pump. Locate the pump in a clean, dry area. Avoid places where dirt, dust or moisture may be excessive.

Foundation

A pump foundation located on soil must be carefully designed so that the load of the pump and its driver does not exceed the bearing capacity of the soil. Almost

all pumps are mounted on a concrete foundation because this material is low cost and strong. Secure the correct number of suitably sized anchor bolts. Grout the machine after it has been wedged, shimmed and aligned.

Pump installation

One of the biggest factors in successful operation and maintenance of all classes and types of pumps is correct installation. Pumps that are correctly installed remain in alignment for longer periods, develop fewer casing and flange leaks, and vibrate less.

Piping connection

The load and stress imposed by a connecting piping system can greatly affect the reliability of equipment. These loads, either from expansion of a pipe or from other sources, can cause shaft misalignment as well as casing deformation, interfering with the internal moving parts. Therefore it is important to design the piping system to impose as little stress as possible on the equipment. The key points for pump piping are given in the box below.

Key points for the design of pump piping systems

- There should be at least ten diameters of pipe between the pump suction and the first elbow. This is especially critical in double-ended pump designs, as the turbulent inlet flow can cause shaft thrusting and subsequent bearing problems.
- Ensure eccentric reducers are not installed upside down at the pump suction. The top of the reducer should be straight into the suction flange.
- If bends are necessary use a long-radius elbow whenever possible.
- If an expansion joint is recommended then a pipe anchor should be installed between it and the pump.
- It is good to increase the size of the suction and discharge pipes at the pump nozzle in order to decrease the head loss from pipe friction.
- Suction piping should be at least one size larger than the suction flange.
- A horizontal suction line should have a gradual slope to the pump suction.

Pump systems can be kept up to the mark with regularly scheduled maintenance procedures. This would include checking bearing temperature, filling with clean lubricant, checking shaft packing and seals, and wear ring clearance.

Pipe cleanliness

Pumps have close-clearance running parts that must be protected from the abrasive particles often found in a new piping system. Rust particles lodged in the running clearance of a pump will seize, requiring expensive repair. To reduce the possibility of larger abrasive particles from reaching the pump, install a strainer.

Alignment

Bring the pump to its operating temperature by admitting liquid to the casing. Check the alignment. Check the driver and pump rotation. The pump should turn in the direction of the arrow in the casing.

Misalignment may cause:

1) Possible overload of the pump bearing
2) Axial movement of the rotating mechanical seal back and forth; the more the seal moves, the more the opportunity for the lapped faces to open
3) Contact between stationary and rotating components, if misalignment is severe enough
4) Wear ring contact
5) Contact between the impeller and the volute or back plate.

Clearance

A good wear ring with a proper clearance improves pump reliability. Correct impeller to volute or back-plate clearance should also be maintained. Pump efficiency decreases with time because of wear. A well-designed pump usually comes with a diametral clearance of 0.2–0.4%. However, as long as it remains below 0.6–0.8% its effect on efficiency remains negligible. When the clearance starts to increase beyond these values efficiency starts to drop drastically. For equal operating conditions, the rate of wear depends primarily on the design and material of the wear ring. Generally, for noncorrosive liquids, the resistance to wear increases with the hardness of the sealing surface material.

Pump warm-up

With pumps handling hot water or other hot liquids, the casing, rotor and other parts must be brought to a temperature within 50°F (ca. 30°C) of that of the liquid before the unit is started. This prevents unequal expansion, with the possibility of contact between moving and stationary parts.

Post start-up reliability management falls into two categories, namely operation and maintenance.

Flow range

As a centrifugal pump is run over its range of possible flows, the design conditions are no longer matched and various hydraulic events occur.

Impeller inlet choking

The area between the vanes is no longer large enough for the flow, causing the NPSHR characteristic to steepen sharply. Inlet

choking varies with suction specific speed (S), being typically 130% of BEP for a low S impeller and falling to 105% of BEP as S increases.

Discharge recirculation

Below the discharge recirculation capacity, secondary flows exist at the impeller discharge. These can cause discharge vane erosion, impeller shroud fracture and fluctuating axial thrust. The onset ranges from 70% of BEP to beyond BEP in certain cases.

Suction recirculation

At the suction recirculation capacity a reverse flow is established in the outer region of the impeller eye. If the reverse flow is intense enough it can cause flow surging vibration, cavitation-like noise and impeller vane erosion. The onset of suction recirculation is closely related to suction specific speed and ranges from 50% of BEP in low S designs to beyond BEP for high S designs.

Rotor loads

Depending upon both the hydraulic and mechanical design, rotor loads, either static or dynamic, can reach a point where the resultant rotor deflection is high enough to cause rapid clearance and seal wear, and premature shaft and bearing failure. Flow limits based on rotor loads range from none to around 50% of BEP.

Correct pump location is important from both the operating and maintenance standpoints.

Temperature rise

In a centrifugal pump, most of the difference between the input and output energy is accounted for by heat loss to the pumped liquid. As flow decreases, the resultant temperature rise can be sufficient to pose the risk of flashing within the pump.

Seal reliability

Seals fail for two reasons: the lapped faces open up, or one of the seal components becomes damaged. When a seal face opens, it allows solids to penetrate between the lapped surfaces. The solids embed themselves into the softer carbon/graphite face causing it to act like a grinding wheel. This grinding action will cause severe wear in the hard face. It should be noted that seal

Typical routine maintenance schedule

Monthly schedule

Use a thermometer to check the temperature of each bearing in the pump. In general the temperature of any bearing should not exceed 160°F (ca. 70°C).

Quarterly

Every three months, drain the oil from sleeve-type bearings. Wash out the oil wells and bearing interior parts with clean kerosene. Repair or replace any oil rings. Refill the bearing with the correct amount of lubricant.

Semiannually

Check the shaft packing by observing the leakage from it. If leakage from the stuffing box is excessive or the packing is badly worn replace all the packing. If a mechanical seal is used repair or replace it. Check the shaft sleeve for wear. If the shaft sleeve is badly scored or worn replace it. Check for shaft runout.

Annually

Check the wear ring clearance. The clearance should not be more than three thousandths of an inch per inch of wear ring diameter. Replace worn wear rings. When the wear ring clearance is increased a loss in capacity and head ensues.

face opening accounts for the majority of mechanical seal failures.

The seal faces may open up for the following reasons:

1) The dynamic elastomer is not free to slide or move on the rotating shaft or the sleeve. This may happen if the shaft is oversized, the shaft finish is too rough, or product is crystallizing.
2) The product is viscous.
3) The shaft is being displaced causing the seal to hit something as it rotates or causing the rotating face to run off the stationary face. This may happen if the pump is operating away from its BEP; the shaft is bent; the rotor is unbalanced; pipe strain is twisting the pump stuffing box; or because of cavitation.
4) Product is vaporizing between the seal faces causing the faces to blow apart.
5) Environmental control has failed.

Controlling stuffing box temperature

Many fluids are adversely affected by a change in their temperature and, when such a reaction takes place, seal failure is almost sure to follow. One of the seal components can be destroyed (the elastomer, the seal faces or the metal parts), or coated hard faces can crack. Hydrocarbon can solidify between the seal faces and even pull out pieces of carbon. The carbon/graphite faces can lose their lubricating ability at cryogenic temperatures and chip on the outside diameter due to slip stick. Elastomers can become compression set and crack at elevated temperatures, while cold temperatures can cause elastomers to harden. The liquid can crystallize, restricting seal movement and opening the faces, or it may vaporize between the faces causing them to open.

By keeping the stuffing box temperature within specified limits, you can prevent all the above from happening.

Controlling stuffing box pressure

Controlling stuffing box pressure is one way of controlling the temperature and is extremely important in many seal applications. We can raise the pressure in the stuffing box to prevent fluid from vaporizing in the stuffing box or across the seal faces. If the product vaporizes across the seal faces, it can open the faces and possibly do some damage as they rapidly open and close. In many cases solids will also be left between the faces as the fluid vaporizes.

Bearing reliability

When we install a bearing into a piece of rotating equipment the general rule is to have the interference fit on the race that is rotating and therefore carrying the load. All centrifugal pumps and motors have the bearings installed with the inner race an interference fit and rotating with the shaft. The outer race remains stationary or in a fixed position.

Bearings fail for two reasons: either through contamination of the bearing oil by water, another liquid or solid particles; or because of high heat, which is often caused by overload or too much lubrication. As little as 0.002% water in the bearing oil will reduce bearing life by 48%.

Several methods are used by pump companies to keep the water or other contaminant liquid out of the bearing housing. A flinger ring is used by many companies to deflect packing or seal leakage away from the bearing. Solids enter the lubricant from several sources. The metal seal cage – the part that separates the balls that are held between the bearing races – may wear, or abrasive particles may leach out of the bearing housing castings. Solids can be introduced into the system during assembly or airborne particles may penetrate the bearing seals.

When the pump is operating at its BEP, the only load the bearing has to carry is the weight of the rotating assembly, the stress caused by the interference fit on the shaft, and any bearing preload specified by the manufacture.

The bearing can become overloaded for the following reasons: wrong interference fit between bearing and shaft; misalignment between pump and driver; bent shaft; unbalanced rotating equipment; operating the pump off its BEP; cavitation; axial thrust; or vibration.

This overloading will cause the lubricant to decrease in viscosity, generating more heat as it loses its ability to support the load. The lubricant forms a varnish residue and then coke at the elevated temperature. This coking will destroy the ability of the grease or oil to lubricate the bearings.

Before any pump is started, its bearings must be carefully inspected, cleaned and lubricated. With oil-lubricated sleeve bearings, remove the cap, linings, thrust shoes and drain plug. Flush out the housing, oil piping and sump tank with kerosene. Flush the entire system with lubricating oil and allow it to drain. New and improved bearing seals and shields are available to exclude all contamination.

Maintenance after start-up

Post start-up maintenance falls into two categories: routine preventive maintenance, and overhaul or repair.

Routine maintenance (see box) is performed primarily to rectify the effects of normal wear in the pump. Overhaul or repair operations are carried out to rectify the results of excessive wear, damage caused by solids in the liquid or erosion. ■

Contact

Trinath Sahoo, maintenance manager
3/51 Mathura Refinery Nagar
Indian Oil Corp Ltd
Mathura
Uttar Pradesh
281006 India
Tel: +91 565 2417572
E-mail: sahoot@iocl.co.in
www.iocl.com