Fatigue failure

Fatigue failures in pumps – part 3

In this final part of a short series of articles on fatigue failures in pumps, Rafael Ocampo uses real examples to illustrate how inattention to detail during maintenance and failure to recognize stress concentrations can lead to this common type of mechanical breakdown. A final summing up of the causes of fatigue failures and steps to reduce their occurrence is also presented.

Following on from the second part in the series, this third article continues the discussion of case studies as real examples of the influence of stress raisers on the fatigue failure of pumps and their motors.

Pump shaft failure

The first case study considers the fatigue fracture of a pump shaft at the coupling end. The relevant factor in this case is that the degree of misalignment was found to be larger than the small value allowed by the coupling type.

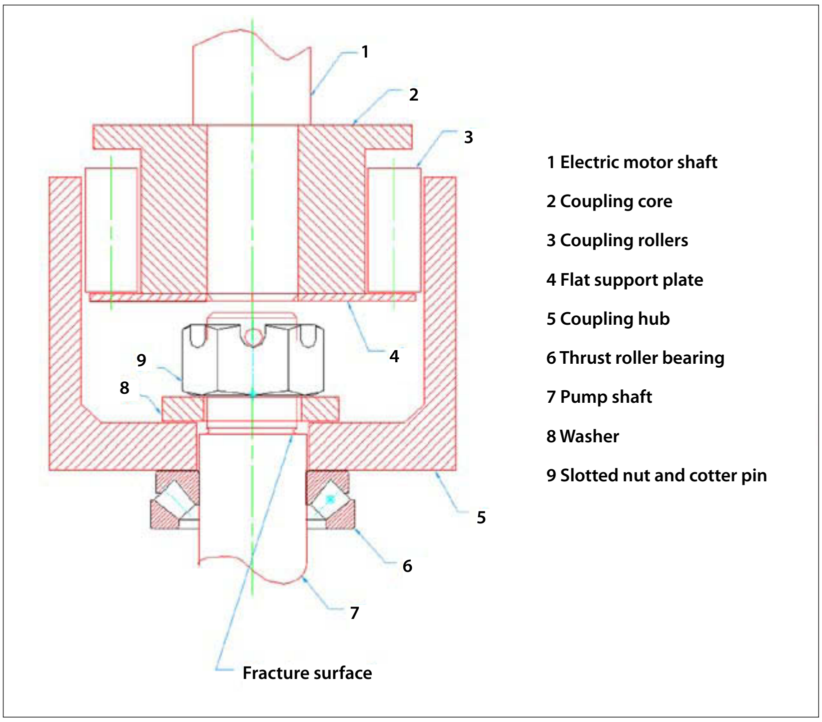

Figure 1. Sketch of the shaft ends with coupling and thrust bearing.

This case occurred in a vertical condensate extraction pump using an old design of over-running clutch coupling. The coupling hub is locked by a nut on the pump shaft end and the coupling core is fitted on the electric motor shaft. A set of cylindrical rollers is installed in a cage between the core and the hub, transmitting the torque only in the correct rotation direction. In this particular design of pump, the axial hydraulic thrust and the weight of the pump rotor are supported by a thrust bearing located immediately below the coupling and the inner ring of the bearing is locked in position by the coupling hub and the nut (Figure 1). Because of the length of the rollers, this coupling allows very little angular misalignment between pump and motor shafts.

As in every fatigue failure, the breakdown occurred suddenly and nothing could be done to prevent the damage to the internal parts of the pump. The fracture was located in a change of section in the shaft under the coupling hub (Figures 1 and 2), and the appearance of the fracture surface suggested the presence

Figure 2. Location of fatigue fracture in a change of section on the pump shaft.

Figure 3. Appearance of pump shaft fatigue fracture surface.

Figure 4. Damage to first-stage casing, wear ring and bottom bush.

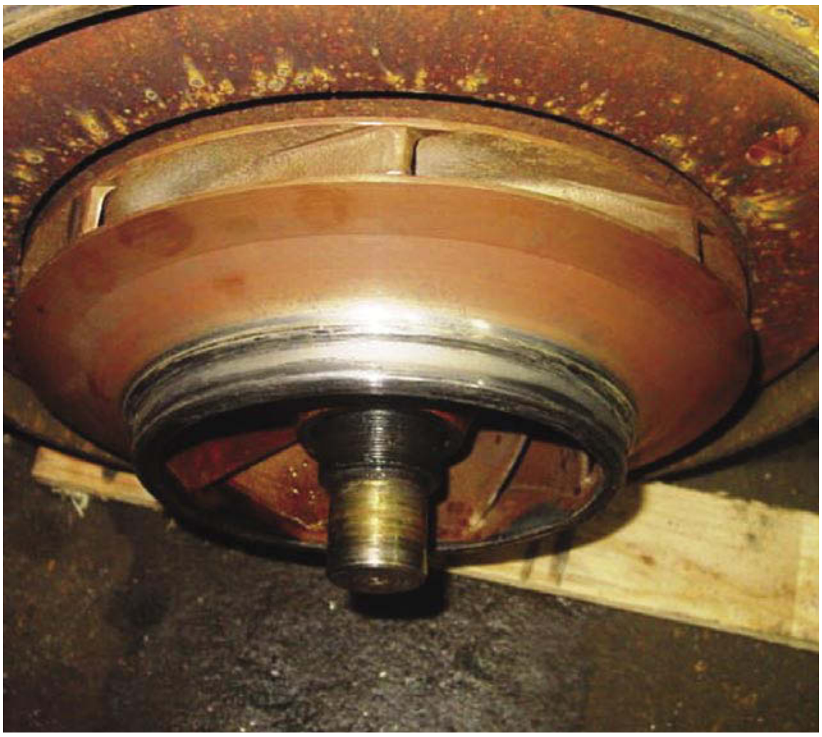

Figure 5. Damage to first-stage impeller front shroud and wear ring.

of symmetric bending stress in rotation acting over a low stress concentration factor at a moderate cyclic load (Figure 3).

The load causing the failure is assumed to be the bending stress caused by the actual angular misalignment being larger than that allowed by the over-running clutch coupling. The original motor support frame had been replaced and it is possible that a slight dimensional difference caused misalignment. Maintenance engineers ought to have recognized the additional care required by this type of coupling during alignment and demanded more accurate work from the maintenance operators and the use of more precise tools for the job. The change of section on the shaft behind the thread is the fully loaded stress raiser nearest to the load application point, the rest of the pump shaft being very smooth.

After the failure of the shaft, the coupling hub and the thrust bearing inner ring are free and the whole pump rotor is also free to move downwards, while still rotating at high speed, until it collides with the pump first-stage casing and bottom bush. Damage to the first-stage casing, first-stage casing wear ring and bottom bush are shown in Figure 4, while Figure 5 shows the damage to the first-stage impeller front shroud and wear ring.

Motor shaft fracture

The second case study examines the fatigue fracture of an electric motor shaft. Again, the problem was found to stem from the actual misalignment being larger than that allowed by the coupling type.

This case also occurred on a vertical condensate extraction pump using an old design of over-running clutch coupling. The pump involved was in fact a 'twin' to that discussed in the previous case study. This time the fracture was located not on the pump shaft but on the motor shaft immediately behind the coupling core (Figure 6). As in the previous case study, the appearance of the fracture surface suggested the presence of symmetric bending stress in rotation acting over a low stress concentration factor at a moderate cyclical load (Figure 7).

As with the twin pump, it is inferred that the load causing the failure arises from the actual angular misalignment exceeding that allowed by the over-running clutch coupling. As was the case with the first pump, the motor support frame had been replaced. The stress concentration factor this time is the corner of the keyway, where the crack clearly starts (Figure 6).

The damage in this case was limited to the motor shaft. No damage was sustained by the pump because the pump rotor remained in its working position supported by the thrust bearing.

Helpful hints

The frequent occurrence of fatigue failures in industry is a clear indication of how difficult it can be to design an apparently simple spare part successfully, and how easy it can be to produce an incorrect design that will fail in service without any obvious warning signs.

A few theoretical hints will help to deal with fatigue failures in everyday life.

- Fatigue failures of parts, even those made from plastic materials, do not usually involve any external manifestation of plastic deformation and the breakage occurs suddenly, without previous indication that a failure is going to occur.
- Under rotating bending loads, the fracture generally occurs on a surface that is perpendicular to the rotation axis, regardless of whether the load is high or low. The appearance of the fracture surface in different cases will present features that can give an indication of the type and magnitude of the load and also about the presence of a stress raiser.
- The reduction of fatigue strength in corrosive media is very considerable, so the careful selection of the material is of the highest importance as well as preventing crevices and other factors favouring corrosion.
- The form of machine elements is of special importance. Abrupt changes of form should be avoided; stress concentration points of any type on the surface should be reduced to the minimum; forces should be directed away from the stress concentration points, introducing additional smaller concentration points functioning as stress relieving points for larger stress raisers.
- Many decisions taken while designing, manufacturing or repairing pump parts could lead to fatigue failures if the possible introduction of stress raisers is not very carefully checked and avoided. Although it is not always carried out, a very careful final inspection of parts manufactured on site will reveal harmful details.

Figure 6. Fracture location on the motor shaft immediately behind the coupling core.

Practical experiences such as those discussed in the case studies presented in this paper also yield helpful indications for dealing with fatigue.

- Fatigue failures can occur under cyclic stresses in rotating pump parts, in rotating pump parts without apparent cyclic load and even in stationary pump parts without apparent cyclic load. Small and apparently unimportant pump parts are also subjected to this type of failure.
- Manufacturing spare parts on site can present a serious risk of producing parts prone to fatigue failure if the basic fatigue theory is unknown or neglected.
- Repair jobs and spare parts manufactured on site should be carefully inspected by skilled engineers in order to detect and remove stress raisers inadvertently introduced by inexperienced personnel.
- Repair and/or maintenance malpractices can introduce weak points in different pump parts leading to later fatigue failures. Maintenance personnel should take into account the care required by different types of equipment, especially when replacing important parts. Misalignment should be recognized as a source of harmful stresses on pump and motor rotating parts, and the type of coupling installed and its particular features taken into account.

Figure 7. The fatigue fracture surface of the motor shaft.

Final word

When repairing a pump or any other machine, the aim is to return it as close as possible to its original design condition. However, if you do not know that condition exactly and you do not have the required knowledge regarding machine design, you can hardly carry out a reliable and durable repair job.

Through many years of industrial experience, the author has witnessed countless cases proving that lack of knowledge and techniques concerning the design of machine elements on the part of field engineers frequently leads to malpractices in repair and maintenance that are sources of fatigue failures. The same is true for lack of design knowledge applied to manufacturing spare parts. Only the knowledge and application of basic fatigue theory, the accumulation of practical experience and the thorough inspection of every component of the equipment will help to reduce the prevalence of this type of failure in industry. ■

Contact

Rafael Ocampo

Tel: +53 43 519915

E-mail: rocampod@gmail.com