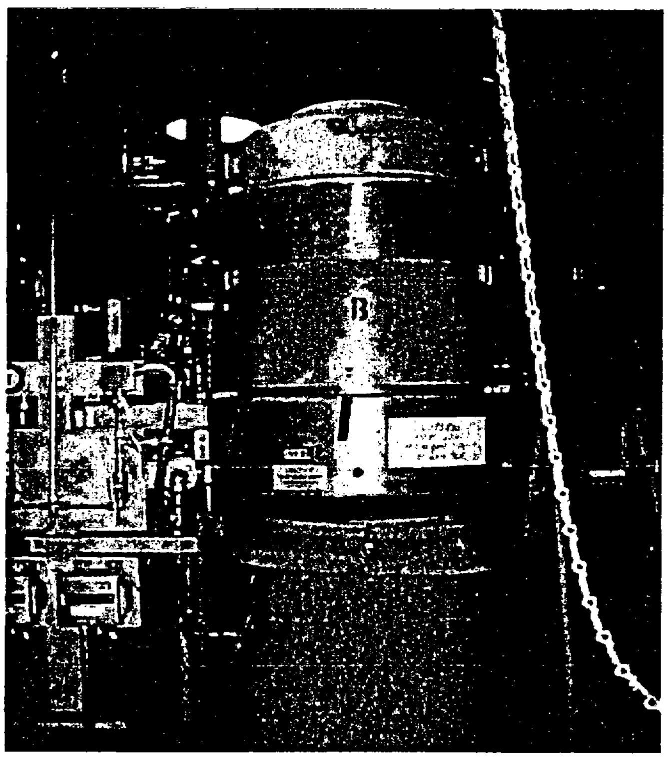
R4-2 A18

Comments Concerning Loss of Gland Water to the Service Water Pumps at Cooper Nuclear Station



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Premise

It is postulated that a valve supplying gland water to a service water pump is closed, and the service water pump is deprived of gland water. How would this affect the service water pump?

Background Information

The service water pumps at Cooper Nuclear Station are Byron-Jackson, mixed flow, single stage, vertical, irrigation type pumps. They operate at 1180 rpm, have a rating of 8000 gpm, and are driven by a 300 hp electric motor.

Loss of gland water does not directly affect the motor-driver.

Loss of gland water does not directly affect the lower bronze bearing at the impeller. It is immersed in the river and will self lubricate sufficiently to be unaffected by the loss of gland water.

Loss of water does not directly affect the impeller and wear ring. They are immersed in the river.

Loss of gland water primarily affects the rubber, Cutless bushings that are spaced along the length of the shaft.

There are ten Cutless bushings, more or less evenly spaced from the bottom to the top of the pump shaft and one bronze bushing located at the bottom.

The rubber bushings have an inside diameter of 2.193 to 2.199 inches, and are 7.5 inches long. There are ten flutes cut into the rubber to allow passage of water. The shaft that fits through the bushing is nominally 2.1875 inches in diameter.

The bushing material that contacts the pump shaft is nitrile rubber, or buna-N. The maximum service temperature for nitrile is 250 degrees F. Nitrile rubber is often used for rotary shaft seals and o-rings. The tensile strength at room temperature is about 2000 psi.

The rubber bushings in the service water pump do not carry significant bearing loads. Their purpose is to minimize lateral movement of the pump shaft, since it is relatively long. As is noted in *Kent's Mechanical Engineers' Handbook,* 12th Edition, "Design and Production" Volume, page 12-46:

> *Rubber is used to line bearings where only water is available as lubricant and where bearing pressure is light. It is useful in guide bearing bushings for vertical revolving shafts, and in stern tube bearings in ships.*

Because the pump shaft is relatively long, about 45 feet, any centerline or mass distribution eccentricities in the pump shaft will cause the shaft to vibrate or wobble when it rotates. If the Cutless bushings were not present, lateral motion would be greatest at the center of the shaft, and least at the two ends.

By placing a bushing at the center of the shaft, the maximum lateral motion at that point is reduced to the clearance dimension. This effectively divides the pump shaft then into two shafts with smaller wobbles at their midpoints, or at the ¼ and ¾ points along the shaft. With eleven Cutless bushings, the pump shaft is effectively eleven short shafts that wobble slightly at their midpoints. Due to the stiffness of the shaft between bushings, the maximum lateral motion of the pump shaft is essentially the clearance between the shaft and the bushings.

The pumps originally were equipped with bronze bushings. However, this was changed to rubber Cutless type bushings. It was thought that the rubber would tolerate river sand better than the bronze. Since rubber is softer than bronze and more resilient, occasional contact with the rubber surface does not scratch or gall the 410 hardened stainless steel pump shaft. The rubber also provides better vibration damping.

Typically, when gland water is supplied to a service water pump, water flows downward through the bushings. It flows through the fluted slots in the bushing, and it flows through the clearance between the shaft and the bushing I.D.

A typical gland water flow rate is 5 to 10 gpm. Five gpm is equivalent to 0.668 cubic feet of water per minute. Since the annular space between the enveloping tube and the pump shaft is about 7.75 square inches, the flow velocity in this space is about 12.4 ft/min or 0.207 ft/sec at 5 gpm, or 0.414 ft/sec at 10 gpm. This is very slow, and is just slightly higher than flow velocities associated with natural convection with modest temperature differentials. Because of the flow constriction of the bushings, local flow in the area of the bushing is faster than that estimated for the annular space between bushings.

When there is gland water, water in the clearance between the shaft and the Cutless bushings forms a typical lubrication wedge. This wedge also helps "cushion" and dampen lateral motion of the pump shaft. The surface speed of the shaft at 1180 rpm is 11.26 ft/sec.

The 410 hardened stainless steel shaft has a hardness of about 225 BHN. Consequently, it has a tensile strength of about 106,000 psi and a yield strength of about 92,000 psi. At 250 degrees F, the 410 stainless steel shaft has not significantly lost any material strength.

Discussion

If gland water is removed while the pump is running, the following will occur.

The level of water in the enveloping tube will drop to a point slightly below that of the river. The level will not exactly match that of the river because the pressure at the bottom hub of the impeller, that is, at the "eye" of the impeller, will be slightly less than the ambient pressure at the same elevation elsewhere in the "E" bay. When the pump is operating at full load, this decrease in pressure will be about 0.75 psi. This figure is based upon the loss of pressure head at that elevation that is due to flow velocity near the inlet of the pump.

Consequently, the water level in the enveloping tube will be about 1.73 feet lower than the level of the river. Assuming that the river is at a "typical" elevation of perhaps 880', then the lower half of the enveloping tube will still have water in it. Thus, about half of the bushings will still have water for lubrication.

The upper bushings, however, will likely eventually becomes dry and will loose the wedge of water between the rotating shaft and the Cutless bushings. Thus, dry contact between the shaft and the pump shaft may occur.

Frictional contact between the bushings and smooth, polished shaft will eventually cause the surface of the bushing to heat up and form a hard glaze on the surface. Heated nitrile rubber become brittle and hard. Further, as the nitrile rubber heats up, it volatilizes and outgases. The net result of out gassing is that the heated rubber will lose volume and shrink. This is, of course, why overheated rubber exhibits deep cracking.

If the temperature exceeds 400 degrees F, the nitrile rubber will have lost so much material strength that further frictional contact with the shaft will simply tear away material on its surface. This process will continue until the inside diameter of the bushings is sufficiently wallowed out to match the total lateral motion of the shaft.

It has been hypothesized that the Cutless bushings will "grab" the shaft and cause it to seize. This is improbable unless there is significant misalignment. The shaft can not contact all the rubber in the bushing, that is, the shaft can not be "grabbed" by the rubber like a prony brake clinching it. At most, with a continuously applied lateral force, the shaft can only contact half of a bushing's inside diameter, that is, 180 degrees of the inside diameter, at one instant.

Further, in order for the shaft to be "grabbed" a lateral force must press the shaft continuously into the rubber at one spot. However, the lateral motion caused by centerline eccentricity or mass distribution eccentricity is sinusoidal. It does not press the shaft continually into the bushing in one spot. Instead, it "bangs" around in the hole as the shaft rotates. Actual contact between the shaft and the bushing is intermittent.

It is true that drag on the shaft will be increased if the bushings run dry. However, the pump motor-driver is rated for 300 hp with 15% excess. It has more than enough torque to overcome the increase in drag.

This was demonstrated in December 2001, when the impeller and bowl of the "D" service water pump where jammed together sufficiently to prevent rotation of the impeller. The torque of the motor completely twisted off the 410 hardened stainless steel coupling.

If the lateral force on each bushing, when it is dry, were about 100 pounds, which is grossly high, the frictional force between the shaft and each bushing will be 50 pounds. This will create a frictional torque drag of 55 in-lbs or 4.6 ft-lbs at each bushing. Since perhaps six of the bushings will eventually become dry, this is an increase in torque of 27.3 ft-lbs. At running load, the pump motor driver is capable of developing 1,334 ft-lbs of torque. Thus, the drag of six dry bushings will "steal" about 2% of the motor's torque.

Typical vibration measurements on the service water pumps indicate that the vibrational velocity is about 0.1 or 0.2 inches per second. The service water pumps are allowed to have a vibration level of about 0.7 in/sec before they have to be serviced.

At 0.1 in/sec, the peak-to-peak displacement is about 0.0008 inches. At 0.7 in/sec, the peak-to-peak displacement is about 0.0056 inches.

The maximum allowable diametrical clearance between the shaft and the bushings is 0.026 inches. The initial clearance can be as tight at 0.006 inches, but would normally be around 0.010 or 0.012 inches.

If the pump were allowed to operate until the 0.7 in/sec vibration level were reached due to sideways wobble, the vibrational "shake" pattern of the shaft still fits inside the diametric clearance of the bushing.

If allowed to continue further that 0.7 in/sec, the bounding limitation appears to be the vibrational tolerance of the lower bearing in the driver motor. Increased vibrational levels in the lower bearing of the motor-driver can cause its life to shorten. If the induced vibrations were sufficiently severe to cause high radial loading, the bearing will degrade, become damage, and eventually fail.