Why do motor shafts and bearings fail?

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Ideally, motors should be connected to the driven equipment by means of a flexible coupling. This method of installing motors to the equipment eliminates shear and bending loads from the motor shaft and bearings, assuming the motor is aligned correctly.

Of course, in the real world, there are many times when power must be transmitted from a motor to the process equipment by means of a belt drive.

When a belt drive is necessary, it is important to select one that will provide the least load on the motor shaft, such as a timing belt drive. Whether a timing belt or v-belt drive is used, however, the drive gear or sheave should always be mounted as far onto the motor shaft as possible without rubbing the motor housing end bell.

Belts

Belts should be tightened only enough to prevent their slippage. Experience has taught me that the engineer who designed the drive has used service factors to ensure the belts will transmit the required power to the equipment without slipping to give an acceptable belt life. When the belt manufacturer describes how belts should be tightened, however, the assumption is that the intent is to try and transmit the maximum power the belts were designed to transmit. That's where the problem can develop. When the mechanic carefully tensions the v-belts to the manufacturer's specifications, he can inadvertently create unnecessarily high loads on the motor shaft and shaft end bearing.

If motor bearing and shaft failures are occurring with v-belt drive applications, revaluate the actual drive requirements for the equipment, based on operating electrical current readings, then consider possible options such as following:

1. Reduce the belt tension.
2. Move the drive sheave closer to the motor shaft end bearing.
3. Reduce the number of v-belts to match the motor horsepower.
4. Replace the v-belts with a timing belt drive or, preferably, a combination of the above.

These options can significantly increase the motor's life.

Shafts

Why is it so important to reduce the load on the motor shaft and bearings? In v-belt applications, bearings and shafts on motors usually fail due to fatigue, assuming no jams or other weird things are happening.

The stress that the motor shaft must endure is made up of three components:

- Shear (caused by the initial belt tension and belt pull required to drive the equipment)
- Bending moment (created by the resultant belt pull against the shaft multiplied times the distance from the center of the sheave to the face of the motor)
- Torsional moment (produced by the motor in trying to rotate the equipment).

By reducing the belt tension to only that required to start and drive the equipment, both the shear load and bending moment affecting the shaft will be reduced. Locating the gear or sheave as closely as possible to the motor face further reduces the bending moment on the shaft.

The relationship between the motor shaft life and stress (which is related to the load) is exponential, not linear. For example, by reducing the shaft stress by 10%, the fatigue life increases by 1.8 times; a 20% load reduction gives 3.4 times longer life; and a 50% reduction yields an astounding 47 times the original life.[1]

The approximate relationship between stress and life for mild steel without welds is expressed as follows:

$$\sigma a = \sigma b(N_b/N_a)^k$$

where

σa = Fatigue strength for fatigue life of N_a

σb = Fatigue strength for fatigue life of N_b

N_a = Fatigue life for fatigue strength of σa

N_b = Fatigue life for fatigue strength of σb

k = 0.18 for mild steel in tension, compression, or both (approx.)

[1]Blodgett, Omer W., Design of Weldments, Sect. 3.2 "Designing for Fatigue Loads," James F. Lincoln Arc Welding Foundation, Cleveland, OH.

Bearings

What about the bearings? When purchasing motors with 444T frames and larger it is important to specify that it should be designed for a v-belt drive application, when that is required. Then it is important to make sure the vendor provides a motor with a heavy-duty roller bearing rather than a ball-type bearing on the shaft end.

Bearings are selected to provide an acceptable life for the product into which they are installed. The size and type of bearings are selected by the designer, who takes into account the operating conditions, load, rotational speed, the reliability required for the equipment, and cost. With this information, the designer selects a bearing that meets or exceeds the L_{10} life rating for that load and application.

The L_{10} life rating for ball and roller bearing is defined in millions of revolutions (or hours) of operation with a given radial load before the first sign of fatigue failure occurs. This is the minimum bearing life expected for 90% of a group of identical bearings operating under the same load and conditions. This also means, however, that 10% of the bearings are expected to fail before the stated life is achieved. The good news is that the average life for a bearing taken from this same group will be about five times as long as the L_{10} calculated life.

Now, assuming that a high-quality bearing was sized and mounted correctly for the application and has been getting proper lubrication, it will theoretically fail due to fatigue stress caused by the load and the number of rotational cycles incurred.

Again, the relationship between the life and load is not linear but exponential. For ball bearings, reducing the equivalent radial load yields a longer bearing life. For example, reducing the load by 10% yields 37% increase in life, 20% reduction yields 95% more life, and 50% load reduction will give an astounding 800% increase in life.[2]

The relationships between bearing life, capacity, and radial load are expressed as follows:

$$L_{10} = (C/P)^p$$

where

L_{10} = Calculated bearing life rating in millions of revolutions for radial bearings

C = Basic dynamic load rating of the bearing

P = Dynamic bearing load

p = 3 for ball bearings and 10/3 for roller bearings

Of course, the actual service life for a bearing will be quite different from the calculated L_{10} life because failures will usually result from contamination, corrosion, or misalignment. If unexpected frequent bearing failures are occurring, however, it is necessary to stand back and take another look at the application in terms of loads, speeds, and contamination.

The common motor that powers most equipment today is a NEMA Design B, three-phase induction motor. These motors have noteworthy torque characteristics; for example, the output torque will momentarily reach up to 200% of rated torque during starting or stalling conditions. V-belt drives can give some protection against shock loads produced by frequent starts and overload conditions, provided the belts are not overtightened. Therefore, re-evaluating the v-belt drives is usually a sure way to improve process equipment reliability.

Case example

Frequent and unexpected failures of the motor shaft and bearings were occurring on a 150-hp motor that drives a sludge dewatering centrifuge. Upon investigation, I found that the centrifuge was originally designed to operate with a 300-hp constant-speed motor, but a 150-hp motor with a variable-frequency, adjustable-speed drive was installed. Although this was a good energy- and cost-saving strategy, the v-belt drive that was designed to transmit 300 hp was inadvertently left in place. By reducing the number of belts and moving the motor only about 2 1/2 in., we reduced the bending moment on the motor shaft by about 80% and simultaneously reduced the bearing load by about 50%. The adjustment on this motor essentially eliminated shaft and bearing failures due to fatigue. TJ

[2] SKF Product Service Guide No. 190-710, p. 406.

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