9. 6 Bearing Clearance

SLEEVE BEARING CLEARANCE DEPENDS ON MANY FACTORS

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Editor's Note: Sleeve bearings are also known as babbitt bearings, white metal bearings and plain bearings.

Can you settle a disagreement about the subject of sleeve bearing clearance? We have several contradictory guidelines, some of them from manufacturers. Which is best?

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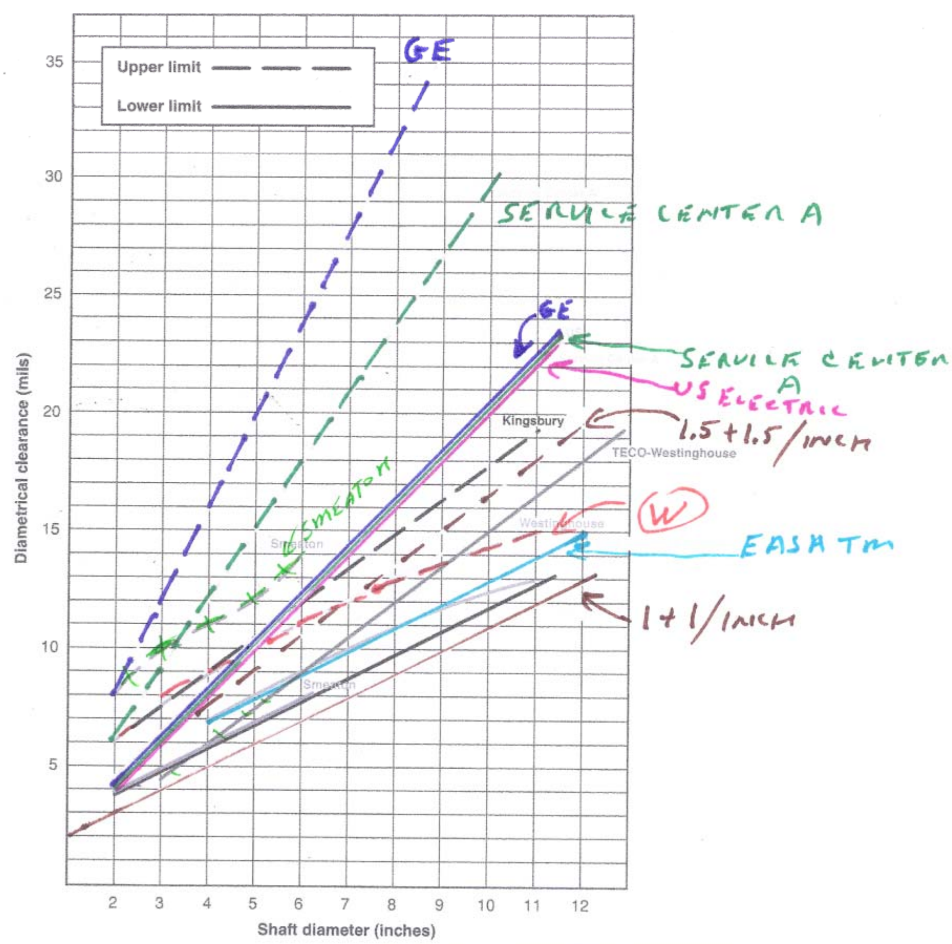
It is fair to say that our outlook on life is colored by experiences. In our industry, those experiences often are shaped by the customers we serve. A good example is this question about the proper clearance between a shaft and the sleeve bearing it rides in. Chances are each of us has a rule of thumb for bearing clearance, probably related to shaft diameter. Some of these may look familiar:

- One thousandth, plus 1 per inch of diameter
- Two thousandths, plus 1 per inch of diameter
- 0.0015" per inch of diameter
- 0.002" per inch of diameter

DEPENDS ON APPLICATION

They can't all be right, yet many of us may have used one of these rules (probably not the same one, either!) with great success. Which one, if any, is correct? The answer

FIGURE 1: SLEEVE BEARING CLEARANCES (BABBITT LINED)



depends on the application.

If your customer base includes slow-speed synchronous motors, you have probably seen motors operating fine with more than twice the recommended clearance. The person who works primarily on 2-pole petrochemical motors knows that they can vibrate when the bearing clearance is even slightly excessive.

One of the first things to consider when looking at guidelines for bearing clearance is whether it is radial or diametral. We are going to talk in terms of diametral clearance–total clearance–because we physically measure the shaft and bearing diameters to determine the clearance. Another reason to use diametral clearance: In operation, a horizontal machine rarely has the same radial clearance at the 12:00 and 6:00 positions.

To illustrate just how many guidelines there are for this simple topic, I have combined guidelines from five manufacturers and three other reputable sources into a single graph. First we need to recognize that most **horizontal** electrical rotating machinery uses what is called a **cylindrical overshot** bearing design. This term describes how the bearing is lubricated–with oil supplied by oil rings.

To understand why each of those rules-of-thumb exists, let's sum up the factors a designer of sleeve bearing motors must take into account. Remember the relationship between power, torque and rpm?

$$\text{Torque (lb-ft)} = \text{hp} \times 5252 / \text{rpm}$$

or

$$\text{Torque (N·m)} = \text{kW} \times 9550 / \text{rpm}$$

The higher the **torque** (lower speed and/or higher hp/kW rating), the larger the required shaft diameter. The **heavier** the rotor, the bigger the bearing must be. The **faster** the speed, the smaller the allowable journal diameter. The **longer** the bearing, the greater the clearance required to get the oil out.

CONSIDERATIONS IN SLEEVE BEARING DESIGN

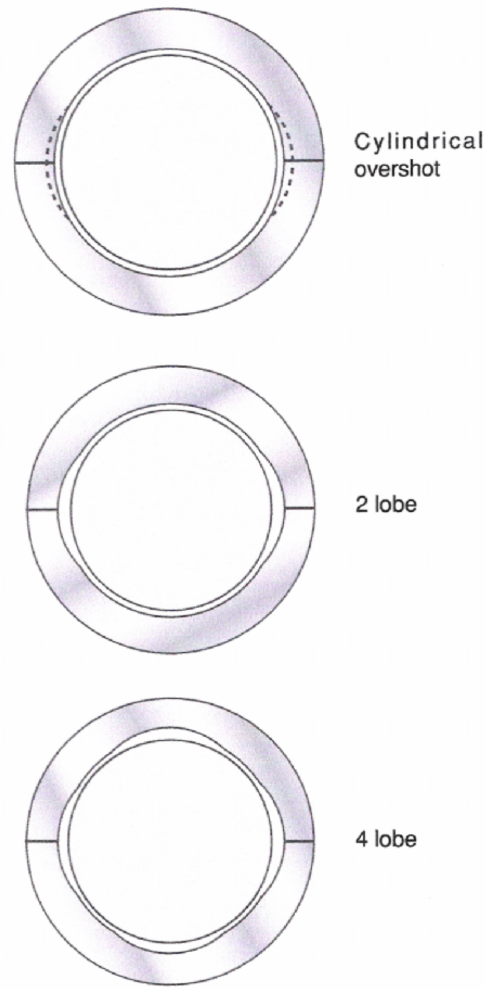
The major factors, in order of importance, that influence sleeve bearing design include:

- Weight to be supported
- Peripheral speed of shaft journal
- Viscosity of lubricant
- Operating temperature

Designers of electrical rotating equipment generally keep sleeve bearing load pressure around 145 psi (1 Mpa), as compared with the 580-725 psi (4-5 Mpa) used for internal combustion engines. Some older motors used even lower bearing load pressure, so vintage machines sometimes have a larger bearing than a modern motor with similar characteristics.

Excessive weight can distort soft babbitt, so bearing cross-sectional area increases in proportion to the load. Higher hp/kW ratings mean more torque, hence a larger shaft diameter. Peripheral speed increases with the rpm, or when the shaft diameter increases. For hydrostatic, cylindrical-overshot bearings (the sleeve bearings most common to electrical machinery) the upper peripheral speed limit is approximately 6,000 ft (1,830 m) per minute. Higher speeds require special designs, starting with 2-lobe, then 4-lobe bearings, as well as special lubrication methods (Figure 2).

FIGURE 2: BEARING SHAPES



Most rotating electrical machinery sleeve bearing lubrication is supplied by oil rings, so a minimum speed is required to ensure that the rings deliver sufficient oil to the bearings. That minimum speed is around 25-30 ft (7.5-9 m) per minute; be *very* cautious when an application, such as a VFD, significantly alters the original design. A force-lubrication system may be required, or even hydraulic jacking to lift the shaft onto an oil film before starting.

When the peripheral speed limit restricts journal diameter, the designer must increase the length of the sleeve bearing. That brings us to the ratio of bearing length to diameter (L/D). For reasons of economy, the preference is for a 1:1 ratio–e.g. a bearing with 3" bore diameter and 3"

FIGURE 3: SHAFT SAG

A heavy rotor increases shaft sag. The journal may rub the bearings at the places indicated by arrows. To prevent that, the designer increases the clearance.

length. There are drawbacks to a proportionally longer bearing. As the L/D ratio increases:

- Less oil flow exiting the bearing = higher bearing temperature
- Shaft deflection = diagonal contact with ends of bearing
- Longer machine = Higher production costs

The longer and heavier the rotor, or the more flexible the shaft, the more shaft deflection (Figure 3) should be expected. Shaft deflection may force the designer to increase the clearance between the sleeve bearing and journal. Longer bearings require longer shaft journals, which in turn require longer bearing brackets and larger machines.

Viscosity of the oil is less of a factor than the supported weight and peripheral speed, although one the designer must consider. The OEM manual specifies the recommended oils for the machine so, unless bearing design modifications have occurred, we as repairers should stick with the recommended lubricants. Sometimes, a 2-pole machine benefits from a lower viscosity oil, but such changes should only be made in consultation with the OEM or customer, and even then with caution.

VERTICAL MACHINES: WHY ARE THEY DIFFERENT?

To begin with, the same spindly shaft and heavy rotor does not result in the shaft deflection we experience in horizontal machines. While the shaft rests on the bottom of a horizontal bearing, it hangs more-or-less centered in the vertical thrust bearing. There is no radial sag to worry about. As long as there is sufficient radial clearance for the oil film, the vertical guide bearing needs no additional clearance. Guide bearings for vertical sleeve bearing machines are not the cylindrical overshot design, and should have much less clearance than horizontal machines with similar journal diameters. Contact the OEM or EASA Technical Support for guidance.

LABYRINTH SEALS

The best rule of thumb for labyrinth seal clearance is that there should be a little more clearance than the bearing clearance. The closer the labyrinth seal is to the shaft, the better it will seal. Of course, if it touches the shaft both may be damaged, and you can expect rapid increases in temperature and vibration levels (especially axial on the end that is rubbing.) Rather than determining labyrinth seal clearance from the shaft diameter, it is better to work from the sleeve bearing clearance. A good guideline, used by several manufacturers, is that the labyrinth seal should have 0.002 - 0.004" (0.05 - 0.10 mm) more radial clearance than the bearing. It should be obvious that the labyrinth seal clearance for a vertical machine can be set closer than for a comparable horizontal machine.

CONCLUSION

There are a lot of sleeve bearing clearance tables circulating around our industry, but some of them are specific to a specific type of motor–like low-speed synchronous motors–and should never be applied universally. In broad terms:

- Low-speed motors can operate with more clearance.
- Longer bearings require more clearance.
- Vertical sleeve bearings require less clearance.
- Hermetics require tighter clearance.
- Labyrinth seals should be as close as possible, without contacting the shaft.

About those rules of thumb: If you have had good success with one for your routine jobs, watch out for sleeve bearings that differ from your usual work. Examples would include 2-poles versus low-speed machines, a significantly different length/diameter ratio, or vertical machines. In those cases, contact the manufacturer or EASA Technical Support for help.

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