The Danger with Set Screw Locking Bearings

By Victor Wowk, P.E.

A set screw locking bearing is shown in Figure 1. This is a common arrangement on HVAC (Heating, Ventilating and Air Conditioning) equipment and general industrial machines. It is an assembly of a cast iron, or steel, pillow block that is bolted to support structures. A rolling-element bearing, with balls or rollers, is captured in the pillow block. The bearing inner ring is extended on one side of the shaft. The inner ring is drilled and threaded to accept one or two set screws that grip the shaft with friction such that the shaft and bearing inner ring rotate together. The shaft torque resisted by the bearing friction is transmitted through the set screws, and specifically at the tip of the screws that contact the shaft. That is, all of the shaft torque against the load does not go through the set screws, only a small portion of that caused by the frictional drag in the bearing.

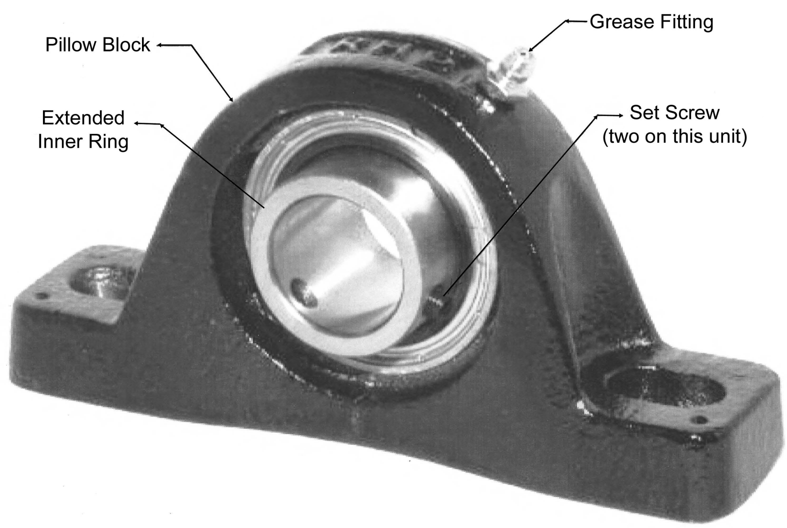

Figure 1. Set Screw Locking Bearing

The bearing inner ring is hardened steel, Rockwell C 60-64. The shaft is typically low-carbon mild steel or stainless steel and is much softer around RC 20. The set screws are intermediate in this hardness range. Consequently, the shaft is the softest material at the joint, and will become the sacrificial piece if the setscrews come loose and there is relative motion between the shaft and bearing inner ring.

When the setscrews become loose, the shaft continues to spin within the bearing inner ring because the friction in the bearing provides some drag, and the shaft is grooved in a grinding action, as shown in Figure 2. This comes to the attention of the facility mechanic because the machine is vibrating, or worse, “thumping.” There may also be powder debris around the bearing, on the shaft, or on the support structure. This is a dangerous condition.

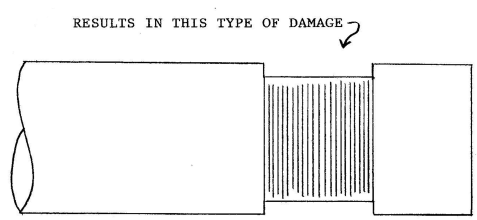

Figure 2. Grooved Shaft

It is dangerous because it calls for early and unnecessary maintenance attention. It is unnecessary because other attachment methods, to be described later, do not spin. There is a risk of shaft breakage if allowed to proceed too far with additional collateral damage. Technicians have been killed, and lost appendages, when called to investigate the "thumping."

These set screw locking bearings have been the source of huge financial burdens to facility maintenance departments and the source of huge workers' compensation claims for injuries. We are called to address a grooved shaft about once a month in our machine repair business in our little corner of the planet. Many more are repaired in-house without calling in outside support. Sooner or later, every facility will have trouble with these bearings as long as they remain in service, especially on machines that rotate at higher speeds above 1,000 rpm. The repair is expensive; far more than the differential cost for an alternative. The set screw locking bearings are the most expensive long-term choice.

The Physics of the Failure Mechanism

The short answer is "undersize shafts." How this occurs will be described shortly, but what defines shaft size? Bearing manufactures have published shaft tolerance guidelines. One such chart is reproduced in Figure 3. Notice that commercial shaft tolerances for low-carbon steel rods is considerably undersize compared to the recommended size limits. These undersize shafts make it easier for the mechanic to slide the bearing onto the shaft, then lock it down with a set screw. This is

Recommended Shaft Tolerances			Not Recommended
Nominal Shaft Size Inches	Set-Screw Locking		Commercial Shaft Tolerances for Cold Finished Low Carbon Steel Rods
0 - 1 1/2"	+.0000 - .0005		+.000 - .002
1 9/16 - 2 1/2"	+.0000 - .0010		+.000 - .003
2 5/8 - 4"	+.0000 - .0010		+.000 - .004
4 3/16 - 6"	+.0000 - .0015		+.000 - .005
6 7/16 - 8"	+.0000 - .0020		+.000 - .006

All machine shafting should be precision ground. This guarantees roundness, straightness, and finished to size. For long-term reliability, high temperature, or critical applications, it should also be stress relieved.

Total Indicator Runout at any point on the shaft should be less than .001 inch T.I.R.

Figure 3. Shaft Tolerances for Setscrew Locking Bearings

convenient for the mechanic, but not a good thing. I like to see a little effort when placing a bearing onto a shaft. This gives me a good feeling that it is not too far undersize. It would be better to actually verify a good fit with micrometers. The bore size of the bearing inner ring is precision ground to within a few micro-inches (.000 0XX inches) and is controlled by all bearing manufactures to comply with ABEC-1 (Annular Bearing Engineers Council) standards. When the shaft is undersize, here is how the failure progresses:

1. The bearing goes on easily. When the first setscrew is tightened, the shaft is pushed against the far side of the inner ring. This creates an unbalance, which can be corrected with mass balancing after assembly, but more seriously, it distorts the shaft somewhat, and being offset from the roller plane, the inner ring is crooked on the shaft

2. Since there is local distortion at this joint, every rotation produces a tiny "wiggle" of the inner ring pivoting on this point of contact of set screw on shaft.

3. This micro-vibration abrades material at the point of contact, eventually causing a loosening of the setscrew.

4. Since the friction generated at this point of contact must transmit torque, the loss of frictional contact will be reduced to the level that it does not hold the two together.

5. The shaft is continuously spun by the motor torque to drive the load. The shaft spins relative to the bearing inner ring which has a slight drag from the roller friction and viscous drag from the grease, or other lubricant.

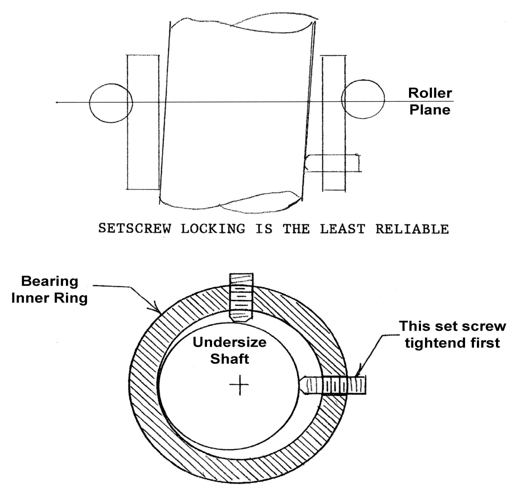

Figure 4. Undersize Shaft is offset

6. The shaft continues to spin at full speed driving the load, while the bearing inner ring slows. There is a grinding action of metal on metal.

7. The shaft steel, being softer than the hardened inner ring, has more material removed faster, and becomes the sacrificial victim.

Managing the Situation

This scenario described above is not likely to happen if the shaft is up to full size or near full size, i.e., less than .0005 inch undersize. So one management method is to measure every shaft diameter with micrometers prior to bearing installation to know what you have to deal with. A set of precision micrometers should be in every maintenance department.

If this undersize shaft must be used, then additional procedures can be implemented to manage this situation. They are:

1. Counter sink about 1/8-inch depth into the shaft where the setscrew is to seat, and grind the tip of the setscrew to a point. (Most setscrews are "cup point.") This "pointy" set screw will sit in this countersunk depression and penetrate deeper into the soft shaft steel. This is less likely to loosen, and if it does, then the tip of the set screw will jam against the side of the countersunk pocket and continue to transmit torque.

2. Check set screw tightness periodically
   • After one hour of run time
   • Again after one day
   • Weekly thereafter

3. Daily walk-thru listening for "thumping"

4. Continuous vibration monitoring

Repair Methods

When you are called to address a "thumping" machine and observe that the shaft is already grooved, then there are several repair options.

1. Replace the shaft and bearing. The bearing inner-ring bore size may also have enlarged. This may be an urgent safety decision if the grooving is too deep and the shaft has lost strength. Generally, 25-percent of reduction in shaft diameter is risky to use because the majority of torque transmission and deflection resistance is at the outermost fibers.

2. Slide the shaft over and install a new bearing, or move the new bearing over to a good part of the shaft, and re-drill for hold downs. Figure 5 shows such a repair.

3. Metal spray buildup on-site, and re-machine to size to fit a new bearing. Low-temperature metal spray (less than 300º F) is preferred to welding because it is machinable and is less likely to cause heat distortion of the shaft. Metal spray, when done properly, is a permanent repair.

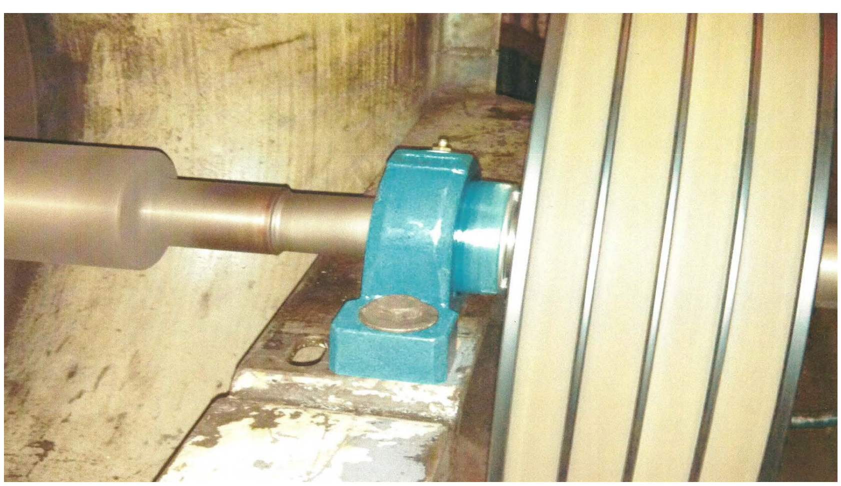

Figure 5. New Bearing Installed to Right of Grooved Shaft

Alternatives

Set screw locking is the least reliable method of securing a bearing to a shaft. It should only be used on low torque (like rotary switches on electronic instruments) and low speed (less than 20 rpm) mechanisms. There are better choices that do not spin. They are:

1. Keys to transmit torque. This is not often seen on facility equipment, but keyed inner rings are available.

2. Threaded shafts with a locknut that secure the bearing against a shaft shoulder

3. Eccentric locking collars

4. Tapered shafts with tapered inner rings and a nut on a threaded shaft

5. Tapered adapters with split sleeves that squeeze down onto a shaft, and also centers it to preserve balance

6. Various proprietary mechanisms, such as:
   - Grip Tight® Dodge
   - Squeeze Lock® SealMaster
   - Taper lock bearings from several manufactures is another alternative

Another alternative is to design the shaft to use plain, sleeve, or babbit bearings. The shaft always spins on a lubricant film and the babbit is softer than shaft steel so the babbit wears, preserving the shaft. It is easier to replace bearings rather than the shaft.

A final alternative is to just delete the bearings. This is always a fall-back engineering option—to just deplete a problematic part. Belts and pulleys are an out-of-date technology that can be replaced with a variable-speed drive and a motor coupled directly to the driven rotor. This is mechanically more reliable because it deletes parts, i.e., belts, pulleys, shaft, and two bearings go away. A variable-speed drive adds electronic complexity, but is safer for mechanics and easier to repair.

Engineering Solutions

What should be done, from an engineering perspective, to address this unsafe and costly situation in industry with set screw locking bearings?

First, I wish that manufactures would stop making them. This, I know, is unlikely because they have a financial incentive to continue selling more replacement bearings. They are also sensitive to the lowest-cost purchaser. Original equipment manufactures who continue to make or use set screw locking bearings identify themselves as “cheap” with little regard for quality, reliability, or customer safety. If manufactures, or OEM's, feel so strong that their product is good, then they should offer a lifetime guarantee that their bearings will never spin before the rollers wear out.

Second, machine designers should exclude these bearings in their assemblies.

Third, engineers who write specifications should not allow them to be substituted.

Fourth, general and mechanical contractors who do installations should not allow them on their new construction projects.

Fifth, architects and engineers should reject submittals that show them.

Sixth, owners should not accept them on their premises.

Seventh, maintenance technicians should replace them with something better at the first opportunity.

Finally, the federal government, with their oversight on public safety, should step up to their responsibilities and, at least, study the situation. Ultimately, OSHA (Occupational Safety and Health Administration) should ban set screw locking bearings, just like the FDA bans dangerous chemicals, the DOT bans unsafe products, and the FAA regulates components on aircraft.

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