Transmission
& Bearing Corp.

Technical Notes by Dr. Mel

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Cracks Found, and to be Found, in Westinghouse Cast Steel Bearings with Conclusions and Recommendations for Resolution

Cracked Bearing Castings

3 Case Studies

Case 1:

The first time that the subject of cracking of cast Westinghouse bearings came to the attention of TRI was in 1996. A 16" diameter generator bearing was found to have cracks in an axial face, Photo 1. There is nothing that can be done to repair cracks in such a bearing operating in this environment because there is no certainty of permanence.

TRI manufactured a replacement bearing using a forged steel ring made of AISI 1030 steel. The customer specified that the bore geometry be an exact duplicate the original circular bore including the overshot oil spreader groove in the axial center of the upper half. TRI manufactured this bearing as specified, Photos 2 and 3. The Babbitt thickness that TRI uses is a thin layer, approximately 0.100 " per side.

Case 2:

A utility indicated that cracks had been found in certain faces of large generator bearings of a Westinghouse unit in a nuclear power plant.

Case 3:

TRI received an inquiry to replace a series of Westinghouse bearings with new bearings to accompany new retrofit turbine rotors in another nuclear power plant.

TRI proposed new bearings that would have a series of improvements including using forged low carbon steel instead of cast steel due to improved material qualities, thereby eliminating the possibility of cracking such as has been experienced in the industry with cast iron and cast steel bearings. One of these bearings is shown in Photo 4 mounted in the supporting yoke.

TRI Explains the Cause & Provides Solutions

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PHOTO 1

2. Causes of Such Cracks in Journal Bearings:

While there may be differences between the precise causes of the various cracked bearings, those already found and those to be found, the reasons include the following:

2.1. Stress Risers: Porosity and Inclusions in Castings; Sharp Corners in Surface Profiles

Cast steel such as used for the Westinghouse bearings is a porous structure and usually has a significant amount of inclusions (non- metallic material). The problem with porosity and inclusions is that they act as internal stress risers that can lead to cracks when static loads, vibrations, and thermal gradients occur. Sharp corners in the profile of the surface also act as stress risers and have led to cracks.

2.2. Cyclic Stress Issues:

There are both high cycle fatigue and low cycle fatigue issues at work in bearings:

2.2.1. High Amplitude Cyclic Stresses, Generally Related to Vibration:

High cycle fatigue usually relates to stresses due to vibration. For a 3600 rpm (60 Hz) machine, there are 5 million (5.184 x 10^6) rotations of each shaft per day, and each rotation causes an alternating stress cycle in the shafts as well as in the bearings and supporting structures. In other words, for a 60 Hz turbine-generator, there are 5.184 x 10^6 stress cycles per day for the shafts and bearing structures. For 8000 hours per year, there are 1.73 x 10^9 cycles per year, or 1.73 x 10^{10} cycles per decade, or for forty years since installation, almost 6.91 x 10^{10} cycles. For an 1800 rpm (30 Hz) machine in forty years, the number of stress cycles is half this amount, or 3.46 x 10^{10} cycles.

While the general conception taught in engineering school is that carbon steel reaches an "endurance

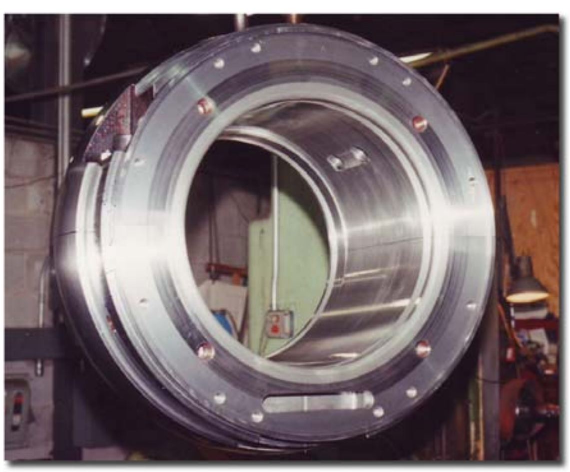

PHOTO 2

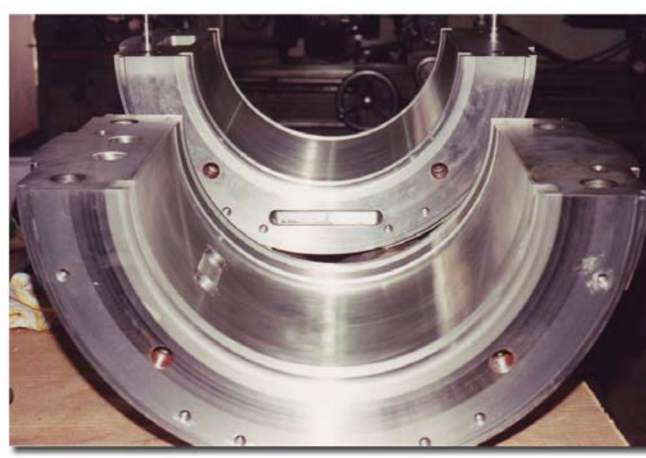

PHOTO 3

PHOTO 4

limit" such that the yield stress remains constant for an indefinite number of cycles, experience has shown that is simply not true, particularly if there are inclusions or localized stress risers (sharp corners) in the structure. A typical endurance plot in a text book stops at around 10^6 or 10^7 cycles, which is small compared to the number of cycles that these machines have experienced. Typically, endurance stress curves are created by averaging higher and lower failure stresses, and consequently, such endurance stress limits can only be used as a rough guide. The porosity and inclusions of cast steel act as stress risers, and the effect that they have on the actual endurance stress capability of a bearing varies substantially from bearing to bearing because the porosity and inclusions vary from bearing to bearing. This substantially reduces the predictability of finding cracks and/or the degree to which a crack will propagate into a bearing.

The static load of a rotor is exerted by a journal on an oil film and then in turn by the oil film on the mating Babbitt surface of the bearing. When the bearing is loaded downward near the bottom center, the bearing deforms into an ellipse, with the long axis in the vertical direction and the short axis in the horizontal direction for almost any method of support. This elliptical shape occurs both when the bearing is supported with full contact of a spherical surface on the lower half, Photo1, or when the bearing is supported by two supports, one at each side at 45 degrees from the bottom, or when the bearing is supported by a yoke. Photo 5 demonstrates the elliptical shape of the elastic deformation of a yoke under load without the bearing installed. When a bearing is installed in the yoke, the bearing will have the same elliptically shaped deformation as the yoke experiences.

In operation, during each cycle of rotation, the journal lifts and falls, and the bearing experiences cyclic oil film pressures that act on the Babbitt surface of the bearing lower half, adding to the static film pressures. These alternating film pressures (psi) contribute to the compressive stresses on the Babbitt surface and modify the stress distribution throughout the bearing. The alternating film pressures induce alternating stresses (psi), which may cause local stresses in the bearing steel backing to go cyclically from zero to tension, or to go from zero to compression, or to go from compression to tension, depending upon location in the bearing.

The stress distribution in an elliptical shape tends to be compressive on the inside of the bottom and top halves, and to be in tension on the outside of the bottom and top halves. Near the horizontal joints on each side, the pattern reverses.

The method of support influences the amplitude of the stress cycle. In generators, many bearings are supported by a continuous support of spherical shape along the bottom half, the best means of support. Many Westinghouse Turbine bearings are supported by two alignment pads on the lower half, each one 45 degrees from the vertical centerline. In this arrangement, the bearing acts as a bridge between the two supports, and the bridging effect accentuates the deformation of the elliptical shape, increasing the peak amplitude of the combined static and cyclic stresses.

2.2.2. Cyclic Stresses due to Impacts Between Bearing and Bearing Pedestal:

Westinghouse bearings typically are installed with clearance between the top bearing alignment pad and the bore of the housing. This permits the bearings to bounce on the alignment pads during higher

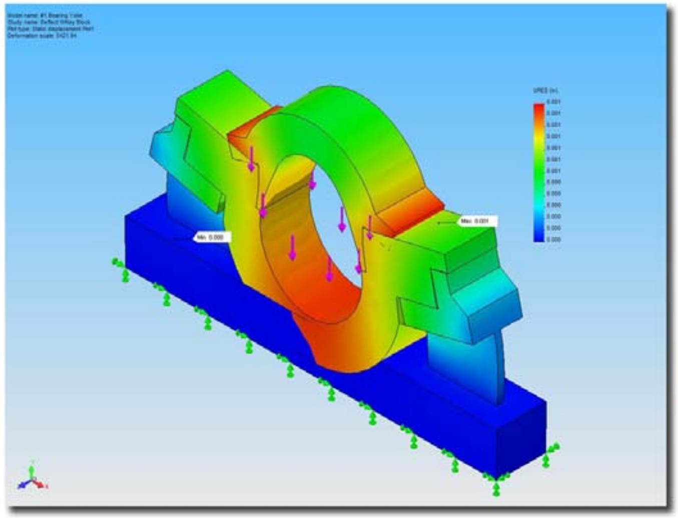

PHOTO 5

amplitude rotor vibrations, such as may occur when going through a critical speed, and this bouncing acts as an impact with localized stresses that are extremely high. It only takes a few events, or perhaps only one such event, to create a sufficiently high localized stress to induce an incipient crack in a casting. Such a crack may be so tight and so small that it may not be able to be recognized by MPI techniques. It may be only a few thousandths of an inch long and it likely will not cause an immediate failure. However, once started, the crack acts as a very high stress riser, and cracking may propagate to form a fully developed crack.

2.2.3. Low Cycle Stress Conditions, Generally Related to Thermal Conditions:

- During Normal Operation:

Consider a freely supported steel bar 16 inches long that changes temperature by 10 degrees. It will change length by 0.001 inches.

Now consider a large steel bearing with dimensions in excess of 16 inches. During normal operation, every bearing is hotter in the axial center and near the bore than on any external surface. The internal portion of the bearing may approach 180 to 190 degrees F, while the external surfaces may be as low as 110 degrees, the normal oil supply temperature. As a result, this bearing may have temperature gradients of perhaps 60 degrees over 10 to 20 inches. Because the internal or hotter sections of the bearing expand in size, and the external or cooler portions do not expand by the same amount, such thermal gradients induce substantial tensile and compressive stresses in the part. Generally, the outer or cooler surfaces are in tension and the internal or heated sections are in compression. Please note that during a cold start, it is possible for a bearing to be 180 or 190 on the inside and less than 110 degrees on the outside, causing higher stresses.

The result is that large bearings endure low cycle fatigue conditions from the thermal cycles that occur every time a turbine-generator is started and stopped.

- Quenching During Babbitt Centrifugal Casting:

Another form of low cycle fatigue occurs during centrifugal Babbitt casting. Each bearing is heated to approximately 450 to 475 degrees F, and while spinning, liquid Babbitt at 800 degrees F flows in, contacts the steel backing, and spins up to the rotational speed of the steel shell. Then the steel shell is quenched on the outside with water, usually cold water between 70 to 120 deg F. Within 10 to 40 minutes or so, depending upon bearing size, the bearing has returned to room temperature. During this water quenching process, the external surfaces are cooled first, putting them into a substantial tensile stress condition, while the inner / hotter sections are in compression. This quenching activity has been known to crack cast iron bearing shells during the quenching process.

- Oil, Water, and Hydrogen in the Pore Structure of a Casting:

During operation, the pores in cast bearings fill with oil and water, and permit hydrogen to be absorbed easily. Prior to any Babbitt casting process, all bearing shells, and particularly cast steel bearings, are supposed to be heated slowly and for many hours to drive off any absorbed liquids and hydrogen gas.

When a bearing is heated, these absorbed liquids and gases expand in the pores, and generate internal pressures that tend to cause tensile stresses in the structure of the cast material. Such tensile stresses can be a contributing factor to initiating cracks.

3. Conclusions and Recommendations:

3.1. The combination of static stresses, alternating cyclic stresses, and thermally induced stresses leads to tensile stresses that are of substantial magnitude in certain surfaces of bearings. Cast bearings have inclusions and porosity which act as stress risers. Larger bearings carry heavier loads than smaller bearings, and therefore, are likely to have higher amplitude stresses, both static and alternating.

On the other hand, the yield stresses and endurance stress levels of large cast bearings are a function of material only, not size. They do not increase with bearing size.

A conclusion is that because the stress levels increase in large bearings relative to the yield and endurance limits, it follows that larger bearings made of cast steel are likely to be more susceptible to experience cracking than are smaller cast steel bearings.

3.2. It is known that due to rotor vibration issues, many cast steel fixed bore bearings in 3600 rpm (60 Hz) Westinghouse HP, IP, and LP turbines as well as generators have been removed and replaced with tilting-pad bearings. These tilting-pad bearings are made with materials other than cast steel, and so these bearings are no longer in the population of cast steel bearings that are in service in Westinghouse LST-Gs.

The bearings that are least likely to be changed to another bearing type in order to solve a rotor vibration issue are those bearings that support heavier rotors and those bearings that are part of 1800 rpm (30 Hz) machines.

A conclusion is that cast steel bearings that are most likely to experience cracking as discussed above

PHOTO 6

include those that were installed in nuclear powered Turbine-Generators that were built in the 1960/1980 era.

3.3. A conclusion is that bearings that are made from forged or hot-worked steel are not likely to experience cracking.

3.4. This recommendation addresses bearings made of cast iron or cast steel that are in Westinghouse Large Steam Turbine-Generators.

If these cast bearings have not been inspected recently, each of them should be inspected when any of the following events occur:

- During the next major outage, each bearing should be removed and inspected.
- If there is an unexplained change in the DC gap voltage, vibration pattern, or operating temperature, the affected bearing should be inspected.
- During any subsequent outage when the bearing is exposed or removed, at least each face should be inspected

Even though the odds of a bearing cracking to failure are small, the greatest justification for inspection is that the consequences of such a bearing failure could very well be catastrophic (interpretation: severe damage to the entire machine, including the possibility of breaking up at speed). The nuclear industry appears to be getting a new lease on life, and it is critical that failures of any type be minimized to near zero, particularly an event such as damage due to a cracked bearing when the crack can be avoided easily by NDE means: visual, MPI or dye penetrant. Exotic methods and extensive training are not required to find these cracks.

3.5. TRI recommends that it is appropriate to change out every bearing in a Westinghouse Large Steam Turbine-Generator that is now a cast iron or cast steel bearing, and replace each one with a bearing made from forged or hot worked steel backing and thin Babbitt linings.

3.6. TRI recommends that an improvement can be made by installing another support point (an alignment pad) in the bottom center of the bearing to reduce the bridging effect.

3.7. TRI recommends that if a crack is found in a bearing, the bearing must be replaced. Do not consider a weld repair; there is no certainty of permanence.

3.8. TRI recommends that bearings for all Turbines and Generators should be made using forged or hot worked carbon steel and not cast steel, for the following very good reasons:

Forged or hot worked steel has these improved properties:

- Higher yield and tensile strengths, higher endurance stress levels, greater ductility, and not brittle,
- No significant porosity and very few inclusions are present to act as local stress risers,
- No need for dovetails (mechanical Babbitt anchors) because tinning compounds today permit excellent bonding between Babbitt to forged steel backing,
- Easier to tin and Babbitt,
- Less likely for the Babbitt-steel bond to break and Babbitt to peel away, and
- High pressure lift oil can be fed directly through drilled holes in the steel because the forged steel can withstand the pressures involved, whereas cast steel requires steel pipes to be installed through holes in the cast steel because high pressure oil can crack the casting and/or oil can pass through the porosity of a casting, thereby reducing the effectiveness of the lift oil system.

As a summary, TRI's Consulting Engineers have been solving rotor vibration and bearing damage issues since 1961, representing almost fifty years of dedicated service to the rotating machinery and power generation industries. TRI has been designing journal bearings of all types to solve these issues for all of this time, and have been manufacturing bearings since 1973. In recent years, TRI designed and built a large centrifugal Babbitt casting machine, Photo 6, for bearings up to 70 inch OD and 20,000 lbs, which covers every bearing in any Large Steam Turbine-Generator that we know of.

The discussions herein and the photos provided clearly demonstrate that TRI understands the issues and has the capability to design and manufacture any size bearing for any Westinghouse LST-G.

Consequently, TRI requests that you please consider having TRI Engineers evaluate any rotor vibration and/or bearing issue that you have, and if replacement bearings are appropriate, TRI suggests that you request TRI to manufacture suitable

This Technical Note was written by Dr. Melbourne F. Giberson, P.E., President of TRI Transmission & Bearing Corp., Turbo Research, Inc. The objectives of Technical Notes are to disseminate information and experience on understanding problems and how to solve them. We attempt to send this Technical Note only to those people for whom the information might be useful. Over the years, many people have asked to be added to the distribution list (see our website). Occasionally, a few individuals inform us that they do not wish to receive the information. Should you desire not to receive future Technical Notes, please advise TRI by info@turboresearch.com or click visit the removal page on the TRI web site MFG 05/2010