Monitoring Plain Bearings with Ultrasound

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Introduction

Friction; friend or foe? The answer all depends on your particular situation. Driving your car aggressively over wet or icy roads? Friction, as well as a good set of tires, is your friend and will save you from some stressful moments. If you’re in the reliability game and are tasked with extending the life of your bearings, then friction is the enemy. While zero friction is neither practical nor even possible you search for the best ways to minimize these forces between the elements of your bearings.

For rotating machines, most of the time it is necessary to reduce friction to increase efficiency, decrease power losses, and support loads. The element of choice is the well known team of bearing and lubricant. Bearings in their different configurations are one of the most efficient ways to reduce friction between a stationary and a rotational part of a mechanism.

There exists two broad classes of bearings; plain bearings and rolling-contact bearings. Which type of bearing is used depends on several factors related to the design of the machine and it’s process. Sometimes both type are used in the same machine doing different job. In this paper we focus on plain bearings.

Choosing the best technology to monitor friction and condition in plain bearings is a challenge. Due to the physical characteristics of plain bearings, using vibration analysis (VA) is more effective for rolling-contact bearings and less so for plain bearings. We see ultrasound (US) trending more frequently for condition monitoring of rolling-contact bearings and it also shows promise for plain bearings. Understanding the physical difference of the two bearing categories is critical to developing condition monitoring strategies for plain bearings using US.

Rolling-contact bearings consist of several elements (cage, inner and outer race, roller elements to name the important ones). This category of bearing relies on rolling instead of sliding to decrease friction. Plain bearings have a more simple design. in their most basic form plain bearings consist of two surfaces; one stationary and one rotating. The rotating part slides over a lubricant film in order to reduce friction.

Plain bearings have some advantages, the most relevant are;

- As longs as the lubricant film is maintained there is separation between the stationary and moving part thereby keeping the friction low
- Plain bearings have a very high load-carrying capability
Plain bearings have a better capacity than rolling-contact bearings to withstand shocks and vibration.

- The lubricant film dampens vibration and noise making plain bearings more quiet than rolling-contact bearings.
- Plain bearings are less sensitive than rolling-contact bearings to contaminants in the lubricant.

### Types of plain bearings

There are four types of plain bearings. This is a paper about condition monitoring plain bearings. Beyond naming them it does not go more deeply into describing them but the interested reader can learn more with a simple web search.

1. **Journal (sleeve bearings)** - They are cylindrical, the inner surface can be lined with babbitt, bronze or other material softer than the rotating journal.
2. **Segment Journal** - Similar to Journal bearings, difference is the stationary bearing consist of segments or bearing shoes.
3. **Thrust bearing** - These bearings are used to support axial loading.
4. **Self-Lubricated bearings** - These are journal bearings with a solid lubricant deposited over the internal bearing surface which is activated by friction.

### Plain bearing lubrication

Plain bearings rely on a fluid film lubrication to keep the stationary and rotational parts separated with very low friction between them. When an external high pressure lubricant supply is used the journal is lifted and the lubricant film keeps the surfaces separated. This is known as hydrostatic lubrication and special care is needed to maintain a steady lubricant flow. This type of lubrication is used mainly for big machines such as turbines where heavy journals need to be “floating” in oil at the start up to avoid rubbing and wear.

For medium and small size plain bearings the film is achieved by the rotating action of the shaft which forces an oil wedge between the shaft and bearing developing hydrostatic pressure which lifts the shaft. This type of lubrication is known as hydrodynamic and the oil wedge is maintained as long as the shaft rotates.

Oil or grease are both suitable for lubricating plain bearings. But using one or the other depends on the shaft speed, load and temperature. In general for low speed it is better to use grease and for high speed oil.

### Plain bearings failure modes

Plain bearings have some advantages over rolling-contact bearings, but also some disadvantages. One of them is that a sudden loss of fluid film will cause an almost instantaneous metal to metal contact with serious consequences like wear and temperature increase. Loss of lubricant is not the
only error that can cause problems. Contaminants in the lubricant, incorrect assembly, poor workmanship, corrosion, oil whip and oil whirl between the elements can damage the bearing.

Problems related to the ingestion of hard contaminants range from a light wear of the inner liner surface to scoring of the journal. Good housekeeping practices and filters in the breathers help to avoid contamination.

Mistakes in the assembly cause excessive fretting damage and flexing in the O.D. of the shell and housing. Other problem related to the assembly are excessive interference and misalignment. Corrosion is caused by chemical attack to the inner liner from chemical components in the oil which originate from certain additives or oil degradation itself. Oil whirl and whip happens when the oil can't form a stable oil wedge.

**Using Ultrasound for monitoring plain bearings**

In recent years improvements to instrumentation and software has challenged the concept of ultrasound applications as ONLY a simple inspection tool for leak detection. Many successful reliability teams have adopted US as an important tool for condition monitoring and predictive maintenance. Monitoring rolling-contact bearings and acoustic assisted lubrication are performed daily using US. This has freed up valuable time for vibration analysts to focus on assessing critical assets first identified by US as being in a problematic state.

Plain bearings are widely used in turbo machinery and many other types of machines in the plant. Different to rolling-contact bearings that enter a starved lubrication condition slowly and are therefore easier to trend, plain bearing lubrication require a steady fluid film to work. Any situation that alters this oil flow leads to almost instantaneous contact-to-contact metal. It can be stated therefore that the window to failure for plain bearings is much smaller than it is for rolling-contact bearings.

The data gleaned from monitoring plain bearings with US has some differences compared to rolling-contact bearings. These differences are shown in the following paragraphs:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Rolling-contact bearing</th>
<th>Plain bearing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasonic signal intensity</td>
<td>strong</td>
<td>weak</td>
</tr>
<tr>
<td>Materials impedance effect</td>
<td>negligible</td>
<td>low (1)</td>
</tr>
<tr>
<td>Measurement points</td>
<td>One</td>
<td>More than one (2)</td>
</tr>
<tr>
<td>Type of sensor preferred</td>
<td>Needle</td>
<td>Magnetic foot</td>
</tr>
<tr>
<td>Sampling time</td>
<td>Short</td>
<td>Short to medium (3)</td>
</tr>
<tr>
<td>Problems detected</td>
<td>Starving lubrication</td>
<td>Lost lubrication</td>
</tr>
<tr>
<td></td>
<td>Contaminants</td>
<td>Hard contaminants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Misalignment (4)</td>
</tr>
<tr>
<td>Window to action</td>
<td>Medium to long</td>
<td>Short</td>
</tr>
</tbody>
</table>
Health assessment based on static ultrasonic data

Covering all the possible failure conditions in a plain bearing is not the scope of this paper. There are three primary failure modes that are identifiable by trending static ultrasound data and analyzing dynamic ultrasound data. In order to easily visualize the different positions of the journal inside the bearing imagine the bearing as a clock with a clock wise rotation.

Normal

Let us presume to begin with a well lubricated, normal plain bearing. We explained already that the plain bearing relies on a fluid film to separate the journal and inner shell. As the journal rotates the pressure effect of the oil wedge moves the journal towards 7 o'clock. We should expect the highest static ultrasound data at this point. Inspectors have two think in two dimensions now. Following a line at the 7 o'clock point take several static readings across the face of the bearing. All should be similar. An ultrasonic data collector with very good sensitivity is required because friction levels are low. The acoustic impedance of the shell and inner liner affect the acoustic energy reaching the contact sensor. The ultrasonic crest factor should be low. Crest factor is a numerical value that describes the ratio between RMS value and Peak dBuV. This is a condition indicator that provides insight for inspectors. CF allows them to differentiate between friction and impacting as the cause for high static values.

Does your UT provide indication of CF?

Readings taken at 12 and 3 o'clock position should be lower than 7.

The time wave trace should be uniform without many spikes of energy.

Hard contamination

A steady supply of lubricant keeps friction levels low but hard contaminants (soft contaminant are embed in the soft metal liner) scratch the journal surfaces and are revealed by random high static peaks (RMS peaks) and increasing crest factor values.
The time wave form shows random peaks if the contaminants are floating. In the event the hard contaminants remain in the same position, the time trace will show sinusoidal peaks.

The presence of contaminants will be predominantly seen at 6 and 7 o’clock positions because clearance between the shell liner and journal are smallest here.

**Oil Starvation**

A low supply of oil causes problems to lift the journal and consequently metal to metal contact is possible. Static signals at 5, 6 and 7 o’clock increase against the normal values and readings at 9, 12 and 3 likely remain the same or decrease a little bit. Temperature also increases so be sure your ultrasonic data collector can also capture a non-contact temperature value into the trend. The time waveform shows a general increase. The CF should remain low without the presence of impulses.

**Misalignment**

In mid and large size plain bearings, comparing static ultrasound readings across several points, it is possible to uncover a misalignment situation. To illustrate this, we will analyze a hypothetical bearing which has 9 measurement points over the journal projected area.

Points 1, 4 and 7 are located axially on the left side of the bearing, at the 9 o’clock position. Points 2, 5 and 8 are at 12 o’clock and points 3, 6 and 9 are at 3 o’clock. As we said before, under normal operation the maximum load (friction) should be at 7 o’clock (points 1, 4 and 7) and lower friction at 12 (points 2, 5 and 8). If the journal is aligned these values should remain stable over time.

For points 1, 4 and 7 the readings should be similar (highest in the bearing) and points 3, 6 and 9 also similar between them and a little higher than points 2, 5 and 8.

If points 1 and 9 increase and 7 and 3 decrease, or 7 and 3 increase and 1 and 9 decrease it is a clear indication of an un-even journal rotation. Capturing dynamic signals with sample time set long enough to reflect 3-5 shaft rotations you will see a clear variation in signal along the time axis.

Testing plain bearings has proven challenging using traditional condition monitoring techniques. Oil analysis remains an important technology here. Advancements in Ultrasound Technology made by manufacturers such as SDT are providing additional tools for assessing condition in plain bearings. Follow the techniques here and use both static and dynamic data to observe changes. Always remember that the window to failure is a little bit smaller with plain bearings than it is with roller bearings and plan your uptime with the precision of ultrasound.
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