Methodology for Diagnosing Ball Bearing Wear

By: Bill Watts, P.E. and Mike Johnson, P.E.
1 | Introduction

Probably no other specific machine fault diagnosis is as common and as important to machine life and reliable operation as ball bearing wear. With respect to both manual analysis and automatic diagnostic systems results, it is crucial that an analyst or system user recognize the logic behind this diagnosis. Although the topic is ball bearing wear, it should be more generally referred to as rolling contact bearing wear. The same discussion applies to cylindrical roller bearings.

For slow speed bearings (less than ~300 rpm), the narrow band logic discussed in this paper is sometimes valid; however in many cases other techniques that directly measure shock energy are more accurate.

2 | General Characteristics in Spectral Data

The geometry of a ball bearing (inner and outer race diameters, ball diameter, and number of balls) determines a small set of calculated fundamental bearing frequencies that are best expressed in terms of multiples (orders) of shaft rotational rate. Bearing wear or damage is generally characterized by one or more fundamental bearing tones (non-integer multiples of shaft rotational rate), harmonics (multiples of those frequencies), and/or shaft or bearing cage rate sidebands, and/or abnormal “humps” of random noise. Some analysts like to rely on knowing the exact fundamental tones and tracking the amplitudes of those specific tones. However, the exact model of bearing in a component is not always known and bearing tone frequencies can shift over time due to bearing deformation. Also consider that often the fundamental tones are low or even non-existent. The primary evidence of bearing wear may lie in higher frequency harmonics, sidebands and/or elevated random noise.

Bearing wear or damage can occur and progress in an infinite variety of ways. Thus it is reasonable that the vibration signatures indicating bearing wear can show evidence in infinite types of patterns. The prominent tones can occur almost entirely in the low or high frequency range data as well as both. Sometimes harmonics are dominant with very few sidebands, or sidebands can dominate with very few harmonics. The highest amplitude bearing tone may be a 1x sideband of the sixth harmonic. Either or both can be present with almost no abnormal random noise. However, serious bearing wear is usually accompanied by increasing levels of random noise. The frequency regions of the elevated noise also can vary. If you see a high frequency “hump” of abnormal random noise at a motor (which does not produce flow noise), particularly in the frequency range of 80xM to 110xM for a 2-pole motor, it may indicate bearing “squeal” due to lack of sufficient lubrication. If such noise is evident in the data without a strong pattern of bearing tones, then it is likely that the bearing only needs to be lubricated and not necessarily replaced. The important thing to remember is to look for a pattern or series of strongly abnormal non-synchronous tones with equal frequency spacing. Cepstrum analysis is capable of detecting and identifying this common spacing.

3 | Cepstrum Fundamentals

“Cepstrum” is a play on the word spectrum as one might suspect and is simply a spectrum of a spectrum. The original time signal is transformed using a Fast Fourier Transform (FFT) algorithm and the resulting spectrum is converted to a logarithmic scale. This log scale spectrum is then transformed using the same FFT algorithm to obtain the power...
cepstrum. The power cepstrum reverts to the time domain and exhibits peaks corresponding to the period of the frequency spacings common in the spectrum. The cepstrum of most machine vibration signatures shows a strong peak at the period of rotation of the shaft. This is a result of having a harmonic series present in the spectra with shaft rate frequency spacings. If another harmonic series is present, it will generate a peak in the cepstrum corresponding to the spacing. This spacing is what we look for in the detection of bearing wear. We may not have a neat harmonic series such as the typical 1x, 2x, 3x,... etc. arrangement, but the fact that there are several sets of peaks separated by say 4.9x results in a peak in the cepstrum corresponding to the period of 4.9x shaft speed vibration. Note that the cepstrum processing is useful in conjunction with an automated diagnostic system, but generally is not used in manual analysis/review.

4 | Process of Elimination
Whenever a bearing problem seems evident due to non-synchronous tone patterns, be skeptical and open minded. Ask a lot of questions. Are the spectra properly order normalized with respect to the reference shaft speed? If bearing wear is still indicated, review the machine’s known configuration and fundamental forcing frequencies. If motor bearing wear is diagnosed for a belt driven fan, ensure that the cited bearing tones are not in fact fan shaft rate (1xF) harmonics or belt passing frequency (BR) harmonics. Ensure that the cited bearing tones are not externally excited by another machine. Except for pump hydraulic vibration transmitted through piping from a companion pump, external excitation normally is at low frequencies. Ensure that the tones are not motor electrical vibration, particularly if the motor has a VFD (variable frequency drive). VFD controllers often produce a lot of high frequency, fixed frequency tones (versus fixed orders of shaft speed) spaced at twice electrical line frequency and sometimes 1xM. Ensure that elevated random noise at a pump or fan is not flow noise. There are times when minor bearing tones can be further elevated by flow noise, causing perceived bearing tones to be higher and look more abnormal than the than the underlying fault warrants.

Before confirming a diagnosis of ball bearing wear, therefore, ask the following questions: Is there valid data? Is the diagnosis based mainly on a sensor overload (“ski slope”)? Are the spectra properly order normalized? Depending on machine and component configuration, is it possible that the cited peaks are actually harmonics or sidebands of another forcing frequency? One needs to look for such peaks and eliminate them from bearing wear consideration. Is the diagnosis based on externally excited peaks? Is the diagnosis based on motor electrical tones? Is the diagnosis false or overstated due to abnormal fluid flow noise or other system conditions? Is the diagnosis overstated because it is based on a combination of valid bearing tones and unrelated tones?

5 | Fault Severity
People often ask: What is acceptable amplitude for a bearing tone? There is no specific answer in our view. Assume spectral data show a fundamental outer race bearing tone (3.1x = 3.1 times shaft rotational rate, for example) with an amplitude of 111 VdB (0.20 inch/sec peak velocity). That is a high level bearing tone by most standards. However, if there are very few harmonics or sidebands, and negligible abnormal random noise, then the data probably may not warrant a severity greater than “slight”. On the other hand, assume that the data show an extensive series of 3.1x harmonics throughout the high frequency range, accompanied by 1x sidebands and strongly elevated random noise. The maximum bearing tone amplitude is only 85 VdB (0.01 inch/sec peak) at 74.4x frequency. Such data can easily reflect a fault severity of “serious” or even “extreme” even though the maximum bearing tone amplitude is only one twentieth of that in the first example. Consequently, severity should be based on a combination of factors. They
include the extent of the pattern (or patterns) of bearing tones over a broad frequency range, the amplitudes of the tones, the strength of harmonics and/or 1x or cage rate sidebands, the exceedences of many of the tones above the component’s average (plus one standard deviation) baseline signature, and the amount of elevated broadband random noise. Generally the higher frequency harmonics and noise are given added weight when judging severity.

If the machine is tested on a periodic basis, then trending over time becomes a very important factor. On the one hand, we have seen cases where the perceived severity of bearing wear was at least a solid “moderate”, but the vibration signatures changed little over many months, or even a couple of years of operating time. In other cases, the signatures can change from completely normal to serious or extreme bearing wear in a matter of days or weeks. That is why a strict machine testing schedule is necessary to monitor machine condition and operation.

To provide a visual example for each severity level (extreme, serious, moderate, and slight) of rolling contact bearing wear, the next 6 pages show machine configuration and spectral data from the lower pump bearing on a vertical pump. Data were collected using a triaxial sensor stud mounted to a notched bronze disk rigidly attached to the bearing housing. The last page provides a reference with data from a relatively fault free pump.

### About the Authors

With Azima DLI since 1985, Bill Watts P.E. provides technical support and analytical services for the company’s marine and commercial customers including analysis and reports, and database maintenance. He is also actively contributes to the refinement and maintenance of the Azima DLI Expert System used for automated vibration based machinery diagnostics.

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### About Azima DLI

Azima DLI is the leader and premier provider of predictive machine condition monitoring and analysis services that align with customers’ high standards for reliability, availability and uptime. Azima DLI’s WATCHMAN™ Reliability Services utilize flexible deployment models, proven diagnostic software in ExpertALERT and unmatched analytical expertise to deliver sustainable, scalable and cost-effective condition-based maintenance programs. The company’s bundled solutions enable customers to choose comprehensive, proven programs that ensure asset availability and maximize productivity. Azima DLI is headquartered in Woburn, Massachusetts with offices across the U.S. and international representation in Asia-Pacific, Central America, Europe and South America.

If you have any questions or would like to set up a demonstration, contact us at:

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## Vibration Test Analysis Guide

**Machine:** COOLING TOWER PUMP  
**Plant Applicability:** RIO VISTA, COYOTE POINT, MAVERICKS  
**Units:** 1, 2, 3, 4  
**CMMS:** 52110  
**MID:** 2055

### Machine Specifications

<table>
<thead>
<tr>
<th>Driver: Motor</th>
<th>Intermediate:</th>
<th>Driven: Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFR: WARD ELECTRIC (MAWDSLEY)</td>
<td>MFR: CARVER</td>
<td>MFR: CARVER</td>
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<tr>
<td>Model: 350800300</td>
<td>Model: 8 RMA-25</td>
<td>Model: 8 RMA-25</td>
</tr>
<tr>
<td>HP: 300</td>
<td>RPMs:</td>
<td>Output:</td>
</tr>
<tr>
<td>Input: 460 V 258 A</td>
<td>Input:</td>
<td>Output:</td>
</tr>
<tr>
<td>RPM: 1782</td>
<td>Output:</td>
<td></td>
</tr>
<tr>
<td>Type: 508TP</td>
<td>Type: SINGLE STAGE, DOUBLE SUCTION, CENTRIFUGAL</td>
<td></td>
</tr>
</tbody>
</table>

## Test RPMs and Operating Conditions

Motor: 1789  
1. Test on line after complete warm up  
2. Align discharge for full flow taking care to ensure pressure is steady.

## Analysis Ranges

- **Ref RPM:** 1 X MOTOR  
- **Orders:** 10, 100, 20

## Vibration Block Diagram

- **Motor 1 Rat:**  
- **Motor 2 Rat:**  
- **Pump 3 Rat:**  
- **Pump 4 Rat:**  
- **Cooling Tower Pump:**

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EXTREME BEARING WEAR. Bearing tone harmonics and sidebands with excessive high frequency random noise (floor is 10 to 20 dB above avg+sigma).
Moderate accelerometer overload (ski slope) in low range data - Axial and Tangential axes.
SERIOUS BEARING WEAR. Bearing tone harmonics (low and high range) and increasing levels of high frequency random noise (floor is 5 to 10 dB above avg + sigma).
MODERATE BEARING WEAR. High range bearing tone harmonics and high range random noise just above avg + sigma.
SLIGHT BEARING WEAR. High range bearing tone harmonics and high range random noise at the avg + sigma level. Note the absence of amplitude at the fundamental bearing tone (4.87xP).
INSIGNIFICANT BEARING DEFECT. Bearing tone (3.07x) in the low range does not have any harmonics or elevated high frequency random noise, so the bearing may have a defect that is not creating a significant problem. It is not unusual to see bearing tones like this that persist for 5 to 10 years.