Welcome to the age of predictive maintenance technologies. More and more of our customers are using tools such as vibration analysis to assess the health of their rotating equipment.

Many of our customers are using this technology to assess new and rebuilt rotating equipment once it’s installed and running.

This serves two main purposes:
1. It demonstrates the quality of the newly acquired/repaired equipment (taking the burden off the supplier/service center should the equipment vibrate once it’s installed).
2. It provides a baseline for trending.

Unfortunately, these initial vibration readings can be pushed into an “alarm status” by many customer-related issues such as poor coupling alignment and/or machine installation. This is why it’s so important for today’s repair facility to provide the customer with “baseline” vibration data gathered during its final test run, providing evidence that the rotating equipment ran within general vibration guidelines before being shipped.

Vibration frequency analysis can expose many mechanical and electrical problems in an electric motor. The purpose of this article is to discuss one of these: Bearing Defects.

**Rolling Element Bearing Defects**

Defects in general rolling element bearings can be generated by fatigue, wear, poor installation, improper lubrication and occasionally manufacturing faults in the bearing components shown below.

Being the typical bearing found in electric motors, the rolling element (or anti-friction) bearing is made up of the following components as illustrated in Figure 1:

1. Outer Race
2. Inner Race
3. Cage

4. Rolling Element (ball, roller or tapered roller)

Figure 1 also shows the Pitch Diameter (Pd) which is the span between the centers of two opposite rolling elements.

![Rolling Element Bearing Components](image)

When a bearing spins, any irregularity in the raceway surfaces or in the roundness of the rolling elements excites periodic frequencies called fundamental defect frequencies.

These are:
1. FTF – Fundamental Train Frequency (frequency of the cage)
2. BSF – Ball Spin Frequency (circular frequency of each rolling element as it spins)
3. BPFO – Ball Pass Frequency of the Outer race (frequency created when all the rolling elements roll across a defect in the outer race)
4. BPFI – Ball Pass Frequency of the Inner race (frequency created when all the rolling elements roll across a defect in the inner race)

Fundamental defect frequencies depend upon the bearing geometry and shaft speed. Once you identify the type of bearing installed, you can either calculate the defect frequencies yourself or request the defect multipliers from the manufacturer. (Providers of vibration analysis software often incorporate a database that contains these multipliers from various bearing manufacturers.)
Example 1:
If you have the defect multipliers at your disposal, the process of calculating the defect frequency is as follows:
1. Look up the bearing number that is exhibiting the suspect vibration frequency on a table like the one below:

<table>
<thead>
<tr>
<th>Bearing ID</th>
<th># of Rolling Elements</th>
<th>TIF</th>
<th>BSF</th>
<th>BPFO</th>
<th>BPFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>9436</td>
<td>19</td>
<td>.434</td>
<td>3.648</td>
<td>8.247</td>
<td>10.753</td>
</tr>
<tr>
<td>9437</td>
<td>19</td>
<td>.434</td>
<td>3.648</td>
<td>8.247</td>
<td>10.753</td>
</tr>
<tr>
<td>9442</td>
<td>22</td>
<td>.443</td>
<td>4.191</td>
<td>9.740</td>
<td>12.260</td>
</tr>
</tbody>
</table>

2. Multiply this number by the shaft speed mated with this bearing and you have the defect frequency that would be generated by a defect on the element in question. See Figure 2.
9.740 x 351 rpm shaft speed = 3419 cpm

For those interested in calculating the defect frequencies, the formulas are listed below. Today, it is difficult to get these parameters. Typically the manufacturer will simply supply one with the multipliers.
You’ll need to find the following key parameters:
1. Rolling Element Diameter
2. Pitch Diameter
3. Number of Rolling Elements
4. Contact Angle
5. Speed

Formula 1: \( FT = \frac{S}{2} \left[ 1 - \left( \frac{Bd}{Pd} \times \cos \Theta \right) \right] \)
Formula 2: \( BS = \frac{Pd}{2Bd} \times S \times \left[ 1 - \left( \frac{Bd}{Pd} \times \cos \Theta \right)^2 \right] \)
Formula 3: \( BPFO = \frac{Nb}{2} \times S \times \left[ 1 - \left( \frac{Bd}{Pd} \times \cos \Theta \right) \right] \)
Formula 4: \( BPFI = \frac{Nb}{2} \times S \times \left[ 1 + \left( \frac{Bd}{Pd} \times \cos \Theta \right) \right] \)

Where:
- \( FT \) = Fundamental Train Frequency (Hz)
- \( BS \) = Ball Spin Frequency (Hz)
- \( BPFO \) = Ball Pass Frequency of Outer Race (Hz)
- \( BPFI \) = Ball Pass Frequency of Inner Race (Hz)
- \( Nb \) = number of rolling elements
- \( S \) = speed (revolutions per second)
- \( Bd \) = ball diameter (in or mm)
- \( Pd \) = pitch diameter (in or mm)
- \( \Theta \) = contact angle (degrees)

Be advised that there will be occasions when the calculated defect frequencies don’t exactly match the bearing defect frequencies that appear in the vibration spectra.
Typically this is due to higher than normal thrust loads which cause the bearing to run at a different contact angle. These abnormal thrust loads can be caused by sources such as misalignment.
Also, not all bearing manufacturers use the same number of rolling elements in a particular bearing size.
The most common bearing problem is the outer race defect in the load zone; inner race faults are the next most common. It is very rare to see a fault at the bearings ball spin frequency or BSF.

**Figure 2. Outer Race Bearing Defect**

If the frequency and harmonics (multiples) of it are present on the vibration spectra, you most probably have an outer race bearing defect. It could be a spall on the raceway, electrical fluting, false brinelling acquired during bearing storage or equipment transport, etc.

*Continued on Page 1*
Action Step: The presence of any of these four fundamental fault frequencies should result in the repair technician replacing the bearing and ensuring the housing fits and shaft journals are within tolerance.

Finally, it’s worth discussing the presence of mechanical looseness, which manifests itself as harmonics of 1x running speed, on a new or rebuilt bearing housing or journal. This indication of looseness could be coming from poor base mounting or one of the following:
1. Loose housing-to-outer race fits
2. Loose journal-to-inner race fits
3. Excessive internal bearing clearance

**Sleeve Bearing Defects**

Sleeve bearings do not make use of rolling elements; rather, the shaft rides on a layer of lubricating oil inside the bearing bore. The lubricant is either sealed inside the bearing, gravity fed to the bearing or pumped in (pressure fed).

Sleeve bearings which have excessive wear/clearance exhibit a vibration spectrum similar to the one in Figure 3. Notice the series of running speed harmonics (up to 10 or 20). Wiped sleeve bearings often show much higher vertical amplitudes than horizontal. A higher axial reading on one end than the other provides further indication, with the higher vibration level on the end with the damaged bearing.

**Summary**

The final vibration test in the service center helps ensure the customer is receiving a top-notch repair. You’ll rest easier knowing that your repair work passed general vibration guidelines and your sales team will love selling this added value to your customers.

By providing documented vibration spectra with a rotating equipment repair service, the customer is less likely to immediately call your service center when the newly repaired equipment is reinstalled and vibrates. They’ll be more prone to verify things within his control such as the mounting and coupling alignment.

**Figure 3. Looseness from Wear/Clearance Problems**

In contrast, mechanical looseness caused by loose mounting bolts or cracks in the frame structure or bearing pedestal typically look like the spectrum in Figure 4.

**Figure 4. Structural Looseness**

Excessive looseness can also cause subharmonic multiples at exactly 1/2 or 1/3 x rpm (.5x, 1.5x, 2.5x, etc.).