Dodge® mounted bearings: understanding and utilizing fault frequencies

Preventative maintenance is a growing trend in industrial operations. One critical area of preventative maintenance includes vibration monitoring. A high-quality vibration monitoring program will analyze and trend many areas of an operating machine. Typically, the most critical area for analysis is directed at the bearings. Many questions often surface regarding bearing fault frequencies and how they relate to our bearings. The following FAQs should cover many of the common questions encountered.

What is a bearing fault frequency?

Bearing fault frequencies, sometimes called defect frequencies, are simply harmonics that coincide with recurring and consistent impacts between two bearing surfaces. The harmonic is simply a rotational speed or order as a relation to the prime rotating body. If bearing surfaces are smooth, then there are no amplitudes from the energy loss of a collision. However, as a bearing begins to fatigue or fail then imperfections on contacting surfaces create collisions which result in an amplitude emission of energy. This collision will occur consistently in proportion to the frequency of the primary mover.

The frequency allows the user to identify the component that most contributes to uneven operation. If component frequencies are known, then the user can look for amplitudes across the vibration spectrum that align with component frequencies. The user can determine the source of the problem once the disrupting harmonic is matched to the predicted component frequency.

What constitutes a defect?

From a vibration standpoint, any area of the bearing contacting surfaces that are not smooth, stiff or stable can emit energy losses in a measurable form. A fault is most often degradation of the bearing raceways from fatigue. The fatigue will first arrive in the form of small pits on the surface of the steel. These pits will gradually propagate into larger surface areas known as spalling. Other forms of faults include true bearing manufacturer's defects, poor steel quality, excessive looseness, and effects from contamination.

How are the frequencies determined?

Bearing fault frequencies are determined by the geometry of the bearing, the number of rolling elements, the type of bearing, and the type of rotation (inner or outer ring) are a function of the bearing rotational speed. Dodge provides fault frequencies for our bearings in the Engineering section of every Dodge catalog. We provide source equations in that section for convenience as well.

What do the fault frequencies mean?

 There are four main types of vibration frequencies that relate to the different components of the bearing. They include the ball pass frequencies of the inner and outer ring, the fundamental train frequency and the ball/roller spin frequency.

Inner Ring – This is commonly referred to as 'Ball Pass Frequency of the Inner Race' (BPFI) and is the frequency at which the balls or rollers will pass over or contact a single point on the inner race of the bearing. Another way to understand this is the number of times a roller will contact a point on the inner ring in one revolution of the inner ring. For example, a 208 Dodge ball bearing has a BPFI of 5.443. This means that 5.443 balls will contact a single point on the raceway in one revolution of the inner ring.

The following images will illustrate the relationship of roller and inner ring raceway contact for one rotation of the inner ring. Note for illustration purposes the red line indicates a stationary point on the outer ring, the green represents rotational alignment of the initial contacting roller and the blue will illustrate a match mark of the inner ring. The bearing was initially marked but the marks didn't show up well in the image.
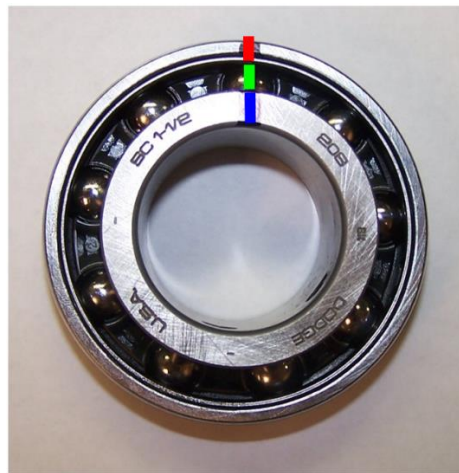

Figure 1. Starting points indicated for example

Figure 2. By rotating the inner ring, this illustrates the point at which the

blue inner ring match mark passes the first ball

Figure 3. The inner ring mark has just passed the 2nd ball

Figure 4. The inner ring mark has just passed the 3rd ball

Figure 5. The inner ring mark has just passed the 4th ball

Figure 6. The inner ring mark has just passed the 5th ball

The pictures show the number of contacts a point on the inner ring make with a ball with one revolution of the inner ring. The example shows that at least 5 balls crossed the pathway of the inner ring with room to spare. As a matter of fact, the BPFI is calculated at 5.443 so it could be stated that 5.443 balls would have contacted the inner ring in its single revolution.

This example is a simple representation of the registry of vibration. If this bearing was running at 1000 RPM and a harmonic occurred at 5443 RPM then it could easily be concluded that there would be some sort of inner ring raceway defect. As a matter of fact in 1000 revolutions of that inner ring, 5443 balls have contacted that raceway defect.

Outer Ring – This is commonly referred to as 'Ball Pass Frequency of the Outer Race' (BPFO) and is the frequency at which the balls or rollers pass over or contact a single point on the outer race of the bearing. The calculated and published BPFO for this 208 ball bearing is 3.557. The following images illustrate this in a more simplistic form.

Figure 7. Starting points indicated for example

Figure 8. By rotating the inner ring, this illustrates the point at which the

first ball has passed a point on the outer ring

Figure 9. Continuing with the inner ring rotation. This is the point at

which the second roller crosses the stationary point on the outer ring

Figure 10. The third roller has now crosses the stationary point on the

outer ring

Again, with a single rotation of the inner ring at least 3 balls have passed a single given point on the outer ring. As a matter of fact, 3.557 balls would pass a single point of the outer ring in one full rotation. If a defect was present on the raceway of the outer ring, the vibration spectrum would show a peak harmonic of 3557 RPM for this bearing at 1000 RPM.

Ball/Roller – Often this is reviewed on a double order since a defect on the ball or roller will contact both the outer race and inner race in one revolution. The 'two-times ball/roller spin frequency' (2xBSF) is the frequency at which a single defect on a ball or roller contacts the inner and outer race of the bearing.

For illustrative purposes the following images show how many revolutions an individual ball makes in relation to the inner and outer ring with one revolution of the inner ring. If a defect were present on the roller then one revolution of the roller would contact both the inner ring raceway and outer ring raceway.
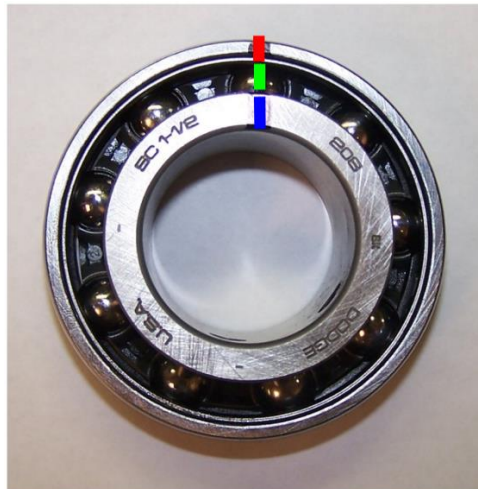

Figure 11. Starting points indicated for example

Figure 12. By rotating the inner ring, this illustrates the radial distance

the inner ring has rotated before the ball completed one (the first) full

rotation (related to the inner and outer ring raceway)

Figure 13. Continuing to rotate the inner ring, this illustrates the radial

Distance the inner ring has rotated before the ball completed the second

full rotation (related to the inner and outer ring raceways).

As you can see, for one full rotation of the inner ring a single ball would make more than two full rotations. The calculated and published ball spin frequency for this bearing is 2.282 meaning that the ball will actually make 2.282 full rotations for every full rotation of the inner ring.

Cage – The cage frequency is often called the 'fundamental train frequency' (FTF) and is the fundamental rotational speed of the bearing cage and ball or roller assembly. Instead of alerting of defects in the raceways, the FTF often indicates signs of excessive looseness or a fractured cage. The cage frequency is the only sub-synchronous frequency of the bearing, meaning that it is the only frequency falling below the rotational speed of the bearing. The cage frequency will almost always fall between 35% and 45% of the bearing rotational speed.

Figure 14. Starting points indicated for example

Figure 15. By rotating the inner ring one full rotation the cage has

only rotated 40% of a full rotation

Continuing to compare the illustrations to the published vibration fault frequencies, the FTF frequency for a 208 ball bearing is 0.3953 which is similar to the visual above of 40%.

One important item to note is that there is an interesting relationship existing between BPFI and BPFO. The sum of these two values should always equal the number of rollers in the bearing. This is easily utilized if a user is spot checking a manufacturer's provided values or if insufficient bearing data is available.

When do I take the bearing out of service?

Bearing defect frequencies are just that, frequencies at which defects surface in a bearing. A bearing should not have defects so when defect frequencies are present it signals that the bearing has a problem. Upon identification the user should begin to investigate the issue, schedule a bearing replacement, and begin trending the amplitude at that frequency to determine the severity. The remaining life in the bearing depends on load, speed, lubrication, alignment, history of maintenance and several other factors. If the frequencies have been monitored and have only recently surfaced then generally the bearing will only have 1% to 5% of the L10 life remaining. The remaining life prior to full failure might range from a few hours for an extreme application with high speeds and medium to high loads or the life might be months if it is a low speed application with light loads. Regardless, the bearing should be monitored.

Once the bearing fault frequencies become visible in the vibration spectrum the bearing will begin to make noises audible enough to be heard in the general vicinity of the bearing. The bearing's operating temperature may also start to rise. Lubricating mounted bearings at this point will temporarily decrease noise and temperature levels but the benefits are short lived and will generally last only 6 – 18 hours of operation.

If defect frequencies surface early in the life of the bearing it is important to check the bearing for proper installation, efficient lubrication, correct load application and proper shaft and/or housing fit. Improper conditions such as these can trigger frequencies before the failure migrates to the raceways and rollers.

To quantify the exact time at which a bearing should be removed depends on many factors. Criticality of the application should certainly be considered. If bearing frequencies surface on a critical piece of equipment then the bearing should be replaced immediately. However, if the user is limited in managing production downtime or if replacement bearings are unavailable then the user should consider other factors. One of these factors includes the number of sidebands surrounding the BPFI and BPFO. The more (1 x RPM) sidebands surrounding these orders represents an increase in the failure severity. Sidebands (1 X RPM) surrounding BPFO are the most serious to the point where the bearing has started to impede the motion of the shaft. Another factor to consider includes the number of bearing frequency harmonics present. In other words, if the user identifies 1 X BPFO, 2 X BPFO, 3BPFO or more then the bearing is likely in the later stages of failure.

It is important to note that there is no definite vibration severity level for bearings. Many companies have done vast research to define allowable vibration amplitudes but no consistent values are available, including from Dodge. Much of the reason is due to the variety of machines existing and how those machines influence defect frequency amplitudes. Additionally, the various vibration signal pathways to the transducer tend to dampen bearing defect amplitude readings making consistency from machine to machine impractical.

Is vibration monitoring effective at low speeds?

Yes, low-speed monitoring is effective but the user should select the proper transducer and insure the analyzer does not filter low frequency responses.

What is a vibration spectrum?

A vibration spectrum is a plot of vibration amplitude against a frequency. The vibration amplitude is measured in terms of displacement (mils), velocity (in/s) or acceleration (g's). The most common measurement utilized for fault frequencies is velocity (in/s) however, at very slow speeds displacement is often utilized. Acceleration is sometimes utilized to identify spike energy losses of bearings prior to fault frequency originations. It is important to have an in-depth understanding of transducers and proper measurement units for the frequency spectrum being analyzed.

Frequency is commonly utilized in revolutions per minute (rpm). However, units of Hertz (1/s) and orders (multiples of RPM of primary mover) are also common.

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