STI Vibration Monitoring Inc.

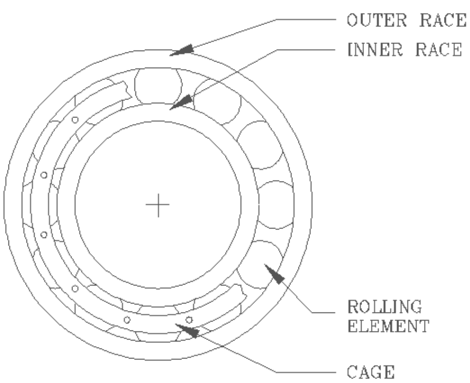
# Field Application Note

## Rolling Element Bearings — REB

The basic purpose of a machine bearing is to provide a near frictionless environment to support and guide a rotating shaft. Two general bearing styles are utilized at this time: the journal bearing and the rolling element bearing. For lower horsepower and lighter loaded machines, the rolling element bearing is a popular choice.

Until the 1940's, the journal bearing was the prevalent style used on machines. As metallurgy and machining techniques progressed, the rolling element bearing gained greater usage. Today many of the smaller process support machines have rolling element bearings.

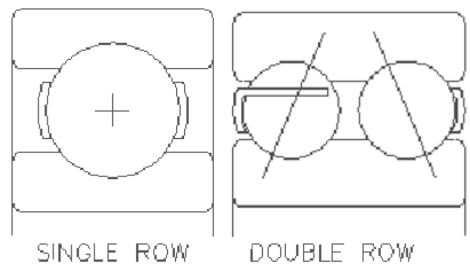
**BEARING DESIGNS**




Rolling Element Bearings have four components: an inner race, an outer race, a rolling element, and a cage to support, space, and guide the rolling elements. The rolling elements found in today's rolling element bearings include: balls, rollers, and tapered rollers. All rolling element bearings have one thing in common: all parts must be in physical metal to metal contact at all times. Installation instructions specify the amount of bearing pre-load to maintain the component contact.

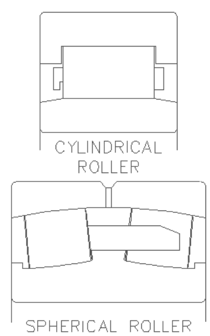
Rolling element bearings have some unique concerns not found in journal bearings. A rolling element bearing will always force a vibration node at its location. Because of the metal to metal contact, this bearing will provide very little vibration damping. Although these bearings are a very precisely machined part they have a limited lifetime. Each component of the bearing will generate specific frequencies as defects initiate and become more prevalent.

**Spherical Ball**



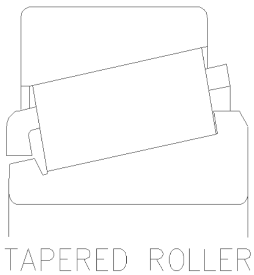

Spherical ball bearings, as the name implies, utilize spherically shaped balls as the rolling or load carrying element. The number of balls used in a bearing varies depending on the application. This rolling element bearing type is designed to carry both radial and axial loads. By modifying the design, this bearing can also accommodate large axial loads.

**Cylindrical/Spherical Roller**




This type of bearing utilizes cylindrically shaped rollers as the load carrying element. This bearing type is designed to carry large radial loads. This bearing, in its basic configuration, is not well suited to counter axial loads. The rollers may actually be slightly barrel shaped in certain designs. Barrel shaped rollers and their associated outer race allow for some self alignment of the bearing. Needle bearings are a special adaptation of the cylindrical roller bearing.

### Tapered Roller/Land




This bearing design is a special adaptation of the cylindrical roller bearing. This bearing is designed to counter axial thrust loads along with carrying radial loads. Due to the geometrical summation of the radial and axial loads, this bearing has a lower radial load limit than a similarly sized cylindrical or spherical bearing.

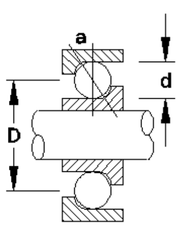
Certain applications may employ tapered rollers along with tapered races, hence the name. Special bearings may have inner and outer races with differing angles.

## VIBRATION MONITORING APPLICATIONS

Rolling element bearings, by their design and installation, provide a very good signal transmission path from the vibration source to the outer bearing housing. Also, these bearings require monitoring of the unique bearing frequencies generated by the various parts of the bearing, in addition to the rotor fault frequencies.

### Bearing Frequency Calculation

Although modern rolling element bearings are very precisely machined, they do have micro-defects which are potential sites for future damage. Due to the precise tolerances, improper installation practices can reduce bearing life. Extensive information has been compiled about bearing defect frequencies.




**N = NUMBER OF ROLLING ELEMENTS**

$$\text{BALL SPIN} = \frac{D}{2d}\,\frac{RPM}{60}\left(1 - \left(\frac{d}{D}\right)^2 \cos^2 a\right)$$

$$\text{OUTER RACE} = \frac{N}{2}\,\frac{RPM}{60}\left(1 - \frac{d}{D}\cos a\right)$$

$$\text{INNER RACE} = \frac{N}{2}\,\frac{RPM}{60}\left(1 + \frac{d}{D}\cos a\right)$$

$$\text{CAGE} = \frac{1}{2}\,\frac{RPM}{60}\left(1 - \frac{d}{D}\cos a\right)$$

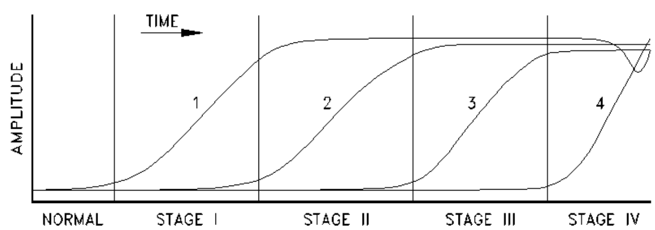
The figure lists the bearing defect frequency formulas for a defect on the balls or rollers, outer race, inner race, and cage. The assumption for these formulas is that the outer race is stationary while the inner race rotates.

If the bearing dimensions are known, the individual bearing defect frequencies can be calculated precisely, or a general rule of thumb can be applied. Using the generalized form the inner race frequencies would be N x RPM x 60% and the outer race frequencies would be N x RPM X 40%. If the bearing manufacturer model numbers are known several computer programs are available to calculate the necessary frequencies.

## FAILURE MONITORING

This style of bearing is typically monitored using a case mounted transducer: an accelerometer or velocity pickup. A displacement sensor observing the shaft relative vibration would show little, if any, vibration due to the vibration node created by the bearing.

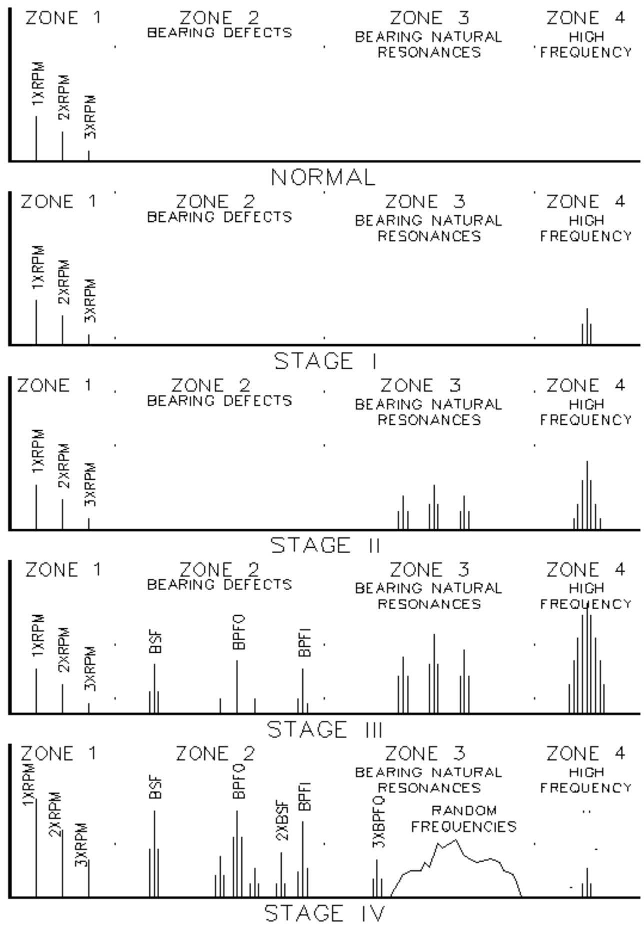
Using signal integration techniques, found in many industrial data collectors, specific frequency ranges relating to certain defects can be emphasized. Acceleration signals, obtained from case mounted sensors, emphasize high frequency sources, while displacement signals emphasize lower frequency sources, with velocity signals falling between the extremes. Recent innovations for determining bearing condition are Acceleration Enveloping, Spectral Emitted Energy (SEE), and Spike Energy. These measure high frequency resonances generated by bearing defects. As a trended variable, in conjunction with other parameters such as displacement, velocity or acceleration, they can give the earliest indication of bearing defects.



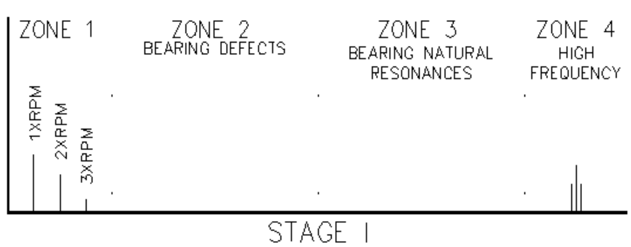

1 FILTERED HIGH FREQUENCY (SEE, GSE)
2 ACCELERATION (G, GENV)
3 VELOCITY (IN/SEC)
4 DISPLACEMENT (MILS)

The figure depicts the overall amplitude levels obtained from a bearing as it progresses through continuing phases of failure. This chart depicts overall vibration levels only. As time progresses the earliest indication of failure are obtained from filtered high frequency signals because these signals are generated by the resonance of the bearing and by bearing component defects.

The figure depicts the overall amplitude levels obtained from a bearing as it progresses through continuing phases of failure. This chart depicts overall vibration levels only. As time progresses the earliest indication of failure are obtained from filtered high frequency signals because these signals are generated by the resonance of the bearing and by bearing component defects.

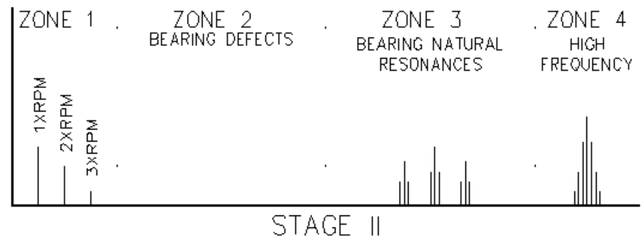



Viewing the four monitoring parameters as spectra, additional information can be obtained about the failure modes. This figure shows the spectrum frequency content during four stages of bearing failure. A normal bearing or newly installed bearing will show no frequencies except those associated with shaft phenomenon such as balance or misalignment.



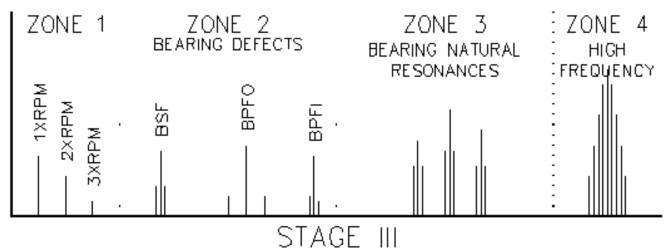

**Stage I**

Stage I has some very high frequency content in the Spike Energy region. This zone is in the ultrasonic region which requires a sensor specifically designed to detect in this region. Special circuitry filters pass only those signals. Physical inspection of the bearing at this stage may not show any identifiable defects.



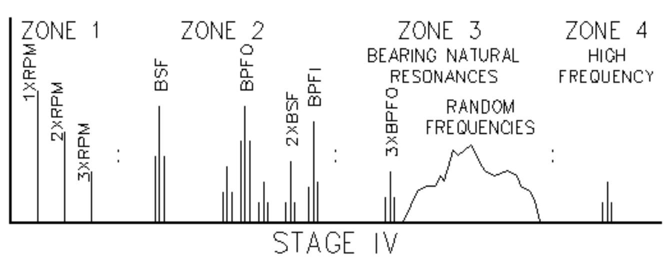

**Stage II**

Stage II begins to generate signals associated with natural resonance frequencies of the bearing parts as bearing defects begin to "ring" the bearing components. A notable increase in Zones 3 and 4 region signals is associated with this stage. Beginning signs of defects will be found upon inspection.




**Stage III**

Stage III condition has the fundamental bearing defect frequencies present. These frequencies are those discussed previously in this paper. Harmonics of these frequencies may be present depending upon the quantity of defects and their dispersal around the bearing races. The harmonic frequencies will be modulated, or side banded, by the shaft speed. Zone 4 signals continue to grow throughout this stage.




Stage IV is the last condition before catastrophic failure of the bearing. This stage is associated with numerous modulated fundamental frequencies and harmonics indicating that the defects are distributed around the bearing races. Due to the increased degradation of the bearing the internal clearances are greater and allow the shaft to vibrate more freely with associated increases in the shaft frequencies associated with balance or mis-alignment. During later phases of stage IV, the bearing fundamental frequencies will decline and be replaced with random noise floor or "hay stack" at higher frequencies. Zone 4 signal levels will actually decrease with a significant increase just prior to failure.