Brüel & Kjær Vibro

APPLICATION NOTE

Detecting Faulty Rolling Element Bearings

Faulty rolling-element bearings can be detected before breakdown.

The simplest way to detect such faults is to regularly measure the overall vibration level at the bearing housing. A similar but significantly more effective way is to measure the crest factor of the vibration. However, the earliest possible warning is given by regularly comparing constant-percentage-bandwidth (CPB) spectra of the vibration. Bearing faults show up in such spectra as increases in a band of high-frequency components.

The more you know about the fault the greater the confidence with which you can predict breakdown. You can find out more about the fault using one or more of the following diagnosis techniques: zoom cepstrum and envelope analysis

What is a rolling-element bearing?

Rolling element bearings support and locate rotating shafts in machines. The term "rolling element" bearing includes both ball bearings and roller bearings. Rolling element bearings operate with a rolling action whereas plain bearings operate with a sliding action.

Why do they fail?

Rolling element bearings fail because of: manufacturing errors; improper assembly, loading, operation, or lubrication; or because of too harsh an environment. However, even if a bearing is perfectly made, assembled, etc. it will eventually fail due to fatigue of the bearing material

How do they fail?

Most failure modes for rolling element bearings involve the growth of discontinuities on the bearing raceway or on a rotating element. With time, the discontinuities spread and, if the bearing survives long enough, it may eventually be worn smoother.

How do they vibrate?

The vibration produced by a healthy, new bearing is low in level and looks like random noise.

As a fault begins to develop, the vibration produced by the bearing changes: Every time a rolling element encounters a discontinuity in its path a pulse of vibration results. The resulting pulses of vibration repeat periodically at a rate determined by the location of the discontinuity and by the bearing geometry. These repetition rates are known as the bearing frequencies, more specifically:

- Ball passing frequency of the outer race (BPFO) for a fault on the outer-race
- Ball passing frequency inner race (BPFI) for a fault on the inner-race
- Ball spin frequency (BSF) for a fault on the ball itself

- The fundamental train frequency (FTF) for a fault on the cage.

The bearing frequencies can easily be calculated from the bearing geometry using the formulae given in Fig. 1.

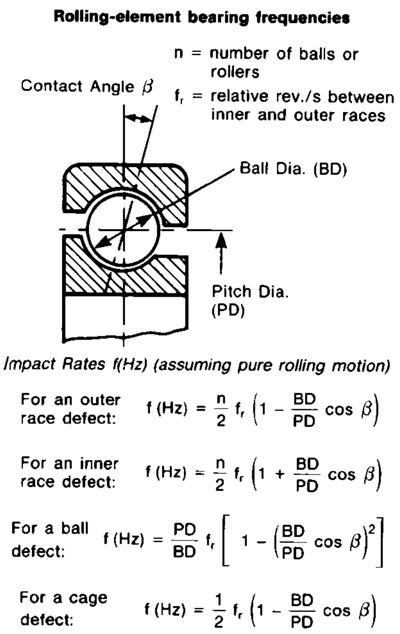

Fig. 1. Formulas for calculating bearing frequencies

Note that the relationships assume pure rolling motion while in reality there exist some sliding. Therefore, the equations should be regarded as approximate.

Unfortunately, in frequency spectra of vibration from rolling element bearings, the components associated with the bearing frequencies are usually "buried" in much higher-level components such as those associated with rotor unbalance.

Fig. 2, which shows a vibration spectrum measured at a motor six weeks before a rolling element bearing burnt out. Increases in two bands of high frequency vibration can clearly be seen. Experience has shown that such increases in bands of high frequencies are an indication of a faulty rolling element bearing.

Why?

Consider the following: The impact as the rolling element encounters a discontinuity is analogous to a bell being struck with a hammer. The structure consisting of the bearing, it's housing and the machine casing together acts like a bell, which is made to "ring" (i.e. resonate) by the impact.

The ringing frequency or resonance is a property of the structure and is not affected by how often or how hard it is struck. The resonance's of such structures are generally between 1 kHz and 20 kHz and, unlike the resonance of a bell, are not concentrated at discrete frequencies but rather in frequency bands, see Fig. 2.

Therefore, rolling element bearing defects show up in frequency spectra as increases in one or more frequency bands between 1 kHz and 20 kHz.

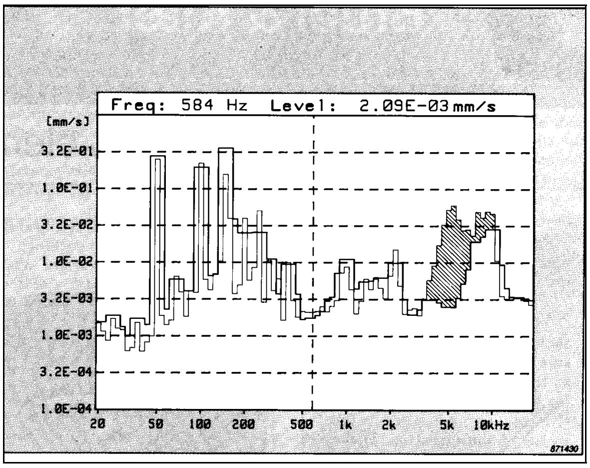

Fig. 2. CPB spectrum comparison of the vibration of a 110 kW motor. The dark line is the "good-condition", reference mask against the current spectrum (light line) is compared.

How can you detect a bad bearing?

Overall Vibration Level

The simplest way is to regularly measure the root-mean-square value (RMS), an average of the overall vibration level at the bearing housing. This technique involves measuring the RMS value of the vibration level over a wide range of frequencies. Measuring acceleration over a range of high frequencies (e.g. 1,000 Hz to 10,000 Hz) gives best results. Such measurements can be made using an accelerometer and a pocket-sized vibration meter fitted with an appropriate filter. Measurements are compared with general standards or with established reference values for each bearing.

By plotting the measurement results over time the trend in vibration can be followed and extrapolated to give a prediction of when the bearing needs replacement. However, because a rolling element bearing's overall vibration often increases only in the final stages of failure, this method gives last minute warnings of failures.

Advantages:
- Quick
- Simple
- Low capital outlay
- Single number result

Disadvantages:
- Detects fewer faults
- Detects faults later, close to failure

Crest Factor
is giving an earlier warning of bearing failure by using the same type of equipment used for measuring overall vibration, to regularly measure the crest factor of the bearing vibration (Fig. 3).

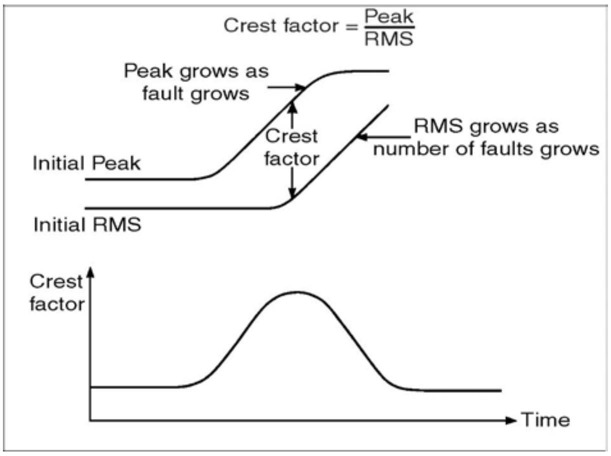

Fig. 3. The Crest Factor principle

The crest factor is the Peak-to-RMS ratio of the vibration. The peak detector in the vibration meter measures the vibration pulses produced by a bearing defect. Measuring acceleration over a high frequencies range (e.g. 1,000Hz to 10,000 Hz) gives best results.

The curve in Fig. 3 shows a typical trend for crest factor as bearing condition deteriorates. Initially, there is a relatively constant ratio of peak to RMS value. As a localized fault develops, the resulting short bursts increase the peak level substantially, but have little influence on the RMS level. The peak level will typically grow to a certain limit. As the bearing deteriorates, more spikes will be generated per ball-pass, finally influencing the RMS level, even though the individual peak levels are not greater.

Towards the end of bearing life, the crest factor may have fallen to its original value, even though both peak and RMS levels have increased considerably. The best way to trend the data is as illustrated; RMS and peak levels on the same graph, with crest factor inferred as the difference between the two curves.

Advantages:
- Quick
- Simple
- Low capital outlay

Disadvantages:
- Prone to interference from other vibration sources
- Does not detect as wide a range of faults as CPB Spectrum comparison

CPB Spectrum Comparison
The method that also detects other types of machine faults such as unbalance, misalignment, looseness etc., is CPB (constant-percentage-band-width) spectrum comparison, see Fig. 2.

The constant-percentage resolution (8% in Fig. 2) along the frequency axis of CPB spectra means that you can have a frequency range wide enough to detect rolling element bearing faults, while still having sufficient resolution to detect low frequency faults such as unbalance or misalignment.

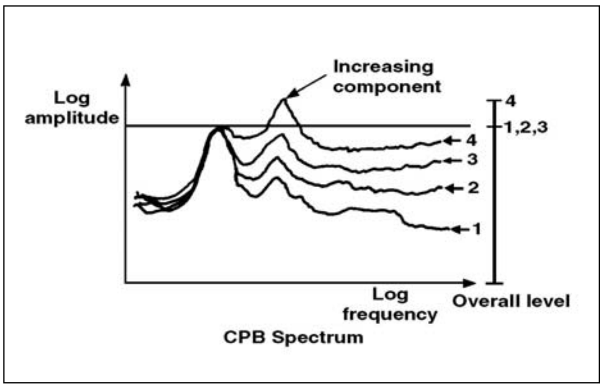

Fig. 4. A CPB spectrum comparison gives earlier warnings than monitoring of overall vibration - the level of overall vibration only increases after an increasing component has become the highest peak in the spectrum

The overall vibration level is largely determined by the level of the highest peak in the spectrum of the vibration. Therefore, the overall vibration level only increases after an increasing component has become the highest peak in the Spectrum, see Fig. 4.

In this way, CPB Spectrum comparison gives earlier warnings than overall vibration monitoring.

Advantages:

- Detects a wide range of machine faults
- Provides frequency information that can be used for fault diagnosis
- Same equipment can usually be used to do further fault diagnosis

Disadvantages:

- Larger capital outlay

How can you find out more about the fault?
All of the above methods can result, manually or otherwise, in a prediction of when the machine needs to be overhauled. The more you know about the fault the greater the confidence in which you can make the prediction is.

You can find out more about the fault using one or more of the following diagnosis techniques:

- Envelope analysis
- Zoom cepstrum
- Cepstrum

Envelope Analysis can extract the periodic impacts, and the modulated random noise produced within a deteriorating rolling element bearing. It can do this even when the impacts and the noise may be relatively low in energy and "buried" within the other vibrations from the machine.

In envelope spectra, as shown in Fig. 7, regular impacts in the bearing show up as a peak (possibly with some harmonics) at the bearing frequency (see Fig. 1) corresponding to the location of the fault (e.g. the inner race, outer race, cage or a ball). Envelope analysis differentiates between the periodic impacting of a rolling element bearing fault and the random impacts of other phenomena such as e.g. cavitation in a pump. A rolling element bearing produces random noise. The Envelope spectrum measures the modulation of the random noise produced in the bearing. This is used to diagnose and quantify smoothened bearing defects as well as bearing mounting errors.

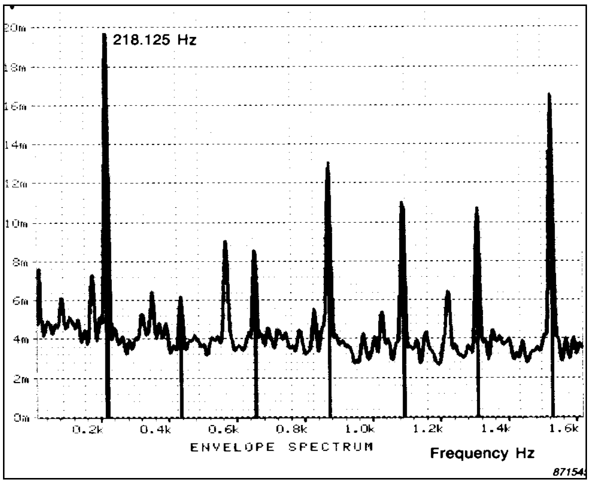

Fig. 7. The envelope spectrurn corresponding to Figs. 5 and 6, showing a harmonic series of the BPFO (Outer race defect)

Zoom
"Zooming" on an area of a frequency spectrum greatly increases the resolution in which that part of the spectrum is displayed. Therefore, by zooming, what is displayed, as a single peak in the ordinary Spectrum may be revealed as two or more components in the zoom spectrum.

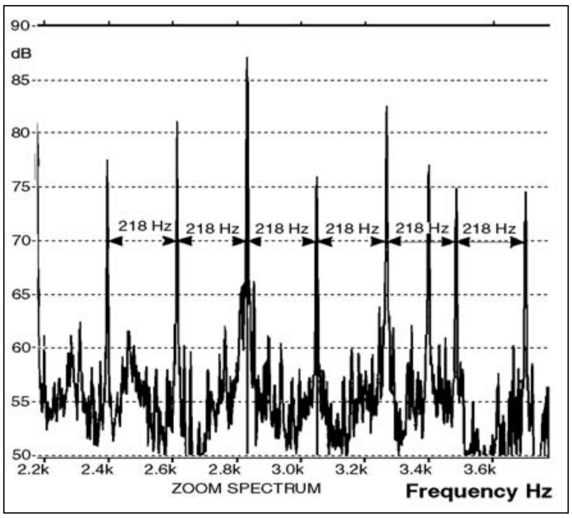

Fig. 5. Zoom spectrum showing harmonics corresponding to the ball-pass frequency outer race (BPFO). When the bearing was stripped down, eight months after the fault was first detected, a spall was discovered on the outer race.

Zooming also lowers the displayed noise floor, allowing lower-level components to be seen more clearly.

Zooming on the tooth meshing frequencies of a gearbox may reveal side band components whose spacing corresponds to one or more shaft speeds of the gearbox. Increases in the number or level of such sidebands can indicate a faulty bearing on the corresponding shaft, shaft misalignment or a deteriorating gear wheel.

Sometimes, zooming reveals harmonics of a bearing frequency, see Fig. 5. Increases in such components can indicate a faulty rolling element bearing. Normally these components are "smeared" by the small variations in the running speed of the bearing or hidden by higher-level components.

Cepstrum

A faulty bearing, gearwheel or misaligned shaft in a gearbox can reveal itself as an increase in the number or level of sidebands around the component corresponding to the tooth meshing frequencies in the spectrum.

Cepstrum analysis identifies families of sidebands and harmonics in a spectrum and reveals their relative importance, see Fig. 6.

The greater the number of components in a family of sidebands/harmonics - or the greater the average level of a family of sidebands/harmonics, the higher the corresponding peak in the cepstrum is.

Cepstra are relatively insensitive to changes in machine load, therefore, it can be useful for trending. Cepstra for measurements made at different points of the same gearbox are likely to be very similar, i.e. cepstra are relatively insensitive to changes in the transmission path between the accelerometer and the source of the vibration.

Cepstra are also useful for the accuracy with which they display the spacing of the sidebands or harmonics.

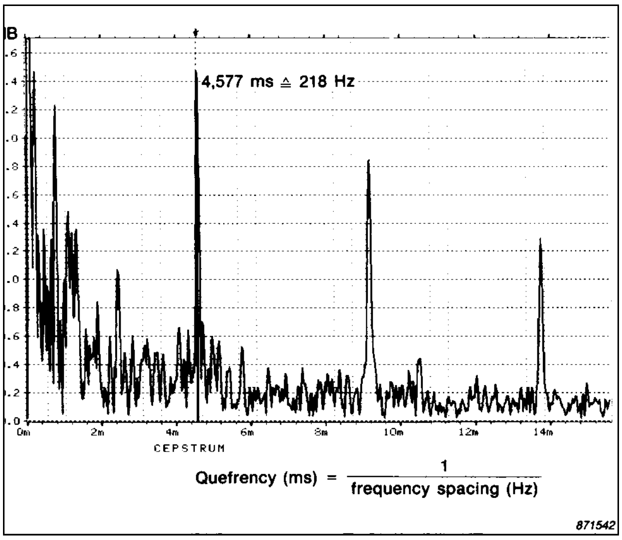

Fig. 6. The family of harmonics in Fig. 5 shows up in the cepstrum as a distinct peak whose quefrency corresponds to the frequency spacing of the harmonies. A number of rahmonics (equivalent to harmonies in a normal spectrurn) are also present.

Why Brüel & Kjær Vibro?

Because any predictive maintenance program quickly lose credibility through false alarms or missed breakdowns. The quality of the measuring equipment is critical to its success.

Brüel Kjær Vibro make a complete range of vibration monitoring equipment and in the world of measurement, the name Brüel Kjær Vibro is synonymous with quality. The primary objective for the broad product range and services offered by Brüel & Kjær Vibro is to provide solutions for almost all monitoring in predictive condition maintenance strategies.

Brüel & Kjær Vibro provides everything as a single source supplier. From the vibration sensors and extensive range of installation accessories, up to the measurement hardware, software, the engineering, and commissioning services we provide together with the life long support of the supplied instruments and systems.

This means you can trust the products that have evolved through several decades of experience of both Brüel & Kjær Vibro and that the respective components and their configuration is the best available. The enormous number of deliveries, references and satisfied customers in all areas worldwide supports this!

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