SKF @ptitude Exchange

Vibration Monitoring of Bearings

Example Bearing Failure Cases Detected by Vibration

Summary
Many decisions are made concerning the mechanical condition of production machinery in the daily operation of a production facility. Often these decisions are made based on opinions - not facts. Vibration analysis provides decision makers with better information to enable better decisions. Because all rotating forces are carried through the bearings, knowledge of the condition of these bearings and the machine is important in the daily production decisions. This paper demonstrates how condition monitoring can provide decision makers with better information for better decisions. The case study examples include damaged cages, inner and outer rings, and looseness. Low speed and journal bearing examples are also included.

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1. Introduction

Deciding which machines to rebuild is a common problem. If you look at five similar machines, and you have time to overhaul two of them during the next shutdown, which two do you select? Do you work on the two that have been in operation the longest, the two with the poorest performance numbers, or the two that the operators believe need rework? At various times each of these criteria has been used to pick the next candidate for overhaul. Along the same line of thought, how many times have we seen a smooth operating piece of equipment taken out of service for overhaul simply because it has reached its time limit as set by the manufacturer? This paper demonstrates how condition monitoring provides the information needed to make correct maintenance decisions.

2. Background

All rotating equipment has one thing in common: bearings. Bearing condition is of prime importance when monitoring equipment health. For example, if bearings are in good condition, even an out of balance, misaligned machine will operate. However, if bearings are damaged, the machine will soon fail even if properly assembled and balanced. Today, technology has developed new techniques for non-intrusive determination of bearing condition.

With the advent of portable vibration measuring equipment, some operators noted that the high frequency energy generated by a failing bearing would excite the natural frequency of the bearing. Based on this information, they could recognize a bad bearing.

The next step in this evolution was to use velocity measurements to look for specific frequencies generated by bearing elements as they rotated. With this improvement, the accuracy increased, but good technicians would often miss bearing flaws on very slow rotating machinery (considering anything below 100 RPM as slow). With the inclusion of enveloping algorithms, the accuracy improved. A few bad bearings still get misdiagnosed, but they are rare.

The techniques explained in this paper apply to all rolling element bearings and provide some information about the condition of sleeve or journal bearings. Moreover, this information applies to all bearing manufacturer's products. What is unique is that each vibration data collector manufacturer uses different algorithms in processing the electronic signal generated by the accelerometer. Therefore, the results and reliability of other data gathering equipment may not be equal to that used by the author.

The mathematical processing of an electrical signal known as enveloping has been in existence for over 20. However, only in the past few years, with the advent of portable equipment with sufficient storage and computer power, has the technology been made available to plant technicians and engineers in the field. A simple explanation of the process: by using selective high frequency bypass filters, the repetitive signals generated as the rotating elements pass over a flaw is mathematically enhances. Then, this processed signal is demodulated and presented to the user in the frequency range he desires. Therefore, if you have a pump with a bad bearing, the bearing signals, which are repetitive, are enhanced, while the non-repetitive flow and possible cavitation noise are degraded. It is not the purpose of this paper to provide a full mathematical explanation of the process, but if the reader is interested, consult other @ptitudeXchange articles.

3. Data Gathering Techniques

Just as vibration is created when you run your thumbnail down a comb, rolling element bearings generate a vibration as they roll over a defect in the race of a bearing. If the flaw is on the inner race, it generates a specific frequency different from the outer race frequency, as the relative speed of the rolling elements is different for the two races. (Faster on the inner race than the outer, when the inner is rotating). In like manner if there is a flaw on the rolling element, it also generates a vibration, although it is at a different frequency. And it follows that if the cage has a defect, it generates another frequency. So it is possible that a defective bearing could generate four specific frequencies, all at the same time; however, rarely more than two occur at once. Experience has shown that a stationary outer race, which is always in the load zone, is usually the site where “normal” initial degradation occurs. The inner race is rotating, so the load zone is spread over the entire race rather than at one point as in the outer race.

Common to most modern portable electronic data collectors is the accelerometer. These are generally constructed with a manmade piezo-electric crystal that generates an output voltage directly proportional to the acceleration force applied. The accelerometer is usually placed on the bearing cap, or as near as possible. Since one of the analysis techniques involves trending of vibration levels, it is important that the data collection location is marked and the same location is consistently used each time.

In those instances where it is not possible to safely position the accelerometer by hand, the accelerometer may be permanently stud mounted to the machine, and the signal wire terminated in a safe location. Generally, the accelerometer is mounted using a magnet. Both methods are acceptable for general vibration monitoring. In rare instances a stinger may be attached to the accelerometer to reach a bearing cap located in a tight space, but stingers alter the signal amplitude and frequency, and are not recommended for general usage.

For continuous machine monitoring, all of the points of interest use a stud or epoxy mounted accelerometer. The signal wires are then terminated at a common point where they are multiplexed and routed to a permanently mounted data collector. The signals from the data collector pass to a computer controller that is programmed to store and process the data. One accelerometer signal can be processed into four presentations: acceleration, velocity, displacement, and enveloped acceleration. These presentations may be processed for different frequency ranges as needed. In other words, the velocity signal may be presented in one spectrum from 0-30 Hz to check for balance and alignment. A second spectrum may be generated with a range of 0-1000 Hz to disclose the rotor bar pass frequency, checking for stator damage. In addition, other types of sensors can collect operational data such as shaft position, speed, temperature, flow, pressure, etc. Generally, any sensor that provides a voltage output can be monitored, and the signal can be collected and stored for evaluation.

Historically, velocity measurements are used to monitor general machinery conditions. Various engineering groups have derived acceptable amplitude limits for warnings and shutdowns. It was accepted that slow speed equipment was very difficult to monitor because the signals were usually so low that they would be buried in the data collector’s noise floor. There are good physical reasons for this; velocity is the resultant of dividing distance by time. In low speed equipment the distance it moves divided by a relative long time results in a velocity of extremely low amplitude. Since we have difficulty measuring velocity, measuring the acceleration enables us to measure the amount of forces generated inside the bearing. One can apply a force to a machine, which can be measured, but the machine may not move (no velocity). When a rolling element passes over a defect in a bearing a force vector is generated. As stated before, these minute repetitive forces are then processed in a manner that allows them to be evaluated with reference to their severity.

Unlike velocity measurements, which are not speed related, the evaluation of an enveloped signal requires knowledge of the rotating speed. When we say “speed related” we mean that a velocity reading of 0.35 inches per second (IPS) indicates a “rough running” machine, and it doesn’t matter if the rotation speed is 1785 RPM or 3560 RPM. However, with enveloped (gE) readings, machine speed is very important. A damaged conveyor bearing rotating at 10 RPM with an amplitude of 0.03 gE would be of concern; however, if this reading was taken on a pump bearing rotating at 1780 RPM, there would be no concern.

4. Bearing and Vibration Terminology

Bearings are constructed of four parts: rolling elements, an inner ring, an outer ring, and the cage. As previously stated, each of these components, if damaged, usually generates a unique frequency. As can be seen in the following frequency calculations, the frequency generated is based on the number of rolling elements, the shaft rotation speed, ball diameter, pitch diameter, and the contact angle. Formulas are provided below.

Bearing frequency formulas:

$$\mathrm{BPFO} = (N/2)\,(\mathrm{RPM}/60)\,(1 - (Bd/Pd)(\cos \varnothing))$$

$$\mathrm{BPFI} = (N/2)\,(\mathrm{RPM}/60)\,(1 + (Bd/Pd)(\cos \varnothing))$$

$$\mathrm{BSF} = (1/2)\,(\mathrm{RPM}/60)\,(Pd/Bd) * (1 - [(Bd/Pd)(\cos\varnothing)]^2)$$

$$\mathrm{FTF} = (1/2)\,(\mathrm{RPM}/60)\,(1 - (Bd/Pd)(\cos\varnothing))$$

Where:

BPFO = Ball Pass Frequency Outer Race

BPFI = Ball Pass Frequency Inner Race

BSF = Ball Spin Frequency

FTF = Cage Frequency

N = Number of balls or rollers

B_d = Ball diameter (in or mm)

P_d = Bearing Pitch diameter (in or mm)

$\varnothing$ = Contact angle, ball to race

These formulas apply to bearings mounted on the shaft with a rotating inner ring. If the outer ring is rotating, reverse the (+) and (-) in the formulas.

Another handy rule of thumb to use when you are in the field:

$$\mathrm{BPFO} = (\mathrm{RPM})\,(N)\,(0.4)$$

$$\mathrm{BPFI} = (\mathrm{RPM})\,(N)\,(0.6)$$

The first four formulas give the frequency results in Hertz (Hz). Hz is cycles per second. If you desire them in cycles per minute, (CPM), multiply by 60.

Vibration amplitudes are measured in the following units:

- Displacement (distance) is measured in "Mils" - one mil equals 0.001 inches. Metric measurements are in millimeters.
- Velocity (speed) is measured in Inches Per Second, IPS. For metrics, the units are mm/sec. For a quick approximation, 1 mm/sec equals 0.04 IPS
- Acceleration (force) is measured in G's, for both English and Metric units
- Enveloped Acceleration (Derived force) is a special measurement gE of acceleration, and there is no comparison or conversion to the standard acceleration measurements.

5. Signal Processing

Although this paper does not focus on signal processing, it is necessary to examine some characteristics of the process. All major data collectors receive the accelerometer signal, and either store or display it as a time vs. amplitude signal. This is the signal one would see if looking at an oscilloscope: amplitude on the "Y" axis and time on the "X" axis. A Fourier transform must be applied in order to see this same presentation in the frequency domain. The resultant is a display with the amplitude again in the "Y" axis but the "X" axis is now displayed as a frequency range, which the user can select in either Hz or CPM.

For history buffs, Jean Baptiste Fourier was a famous French mathematician who developed the basic theories for signal analysis. One great benefit in using an enveloped Fourier transform is that it provides us with positive evidence of the presence of bearing damage.

Although a pure sine wave only exists is in the laboratory, a loaded rotating bearing generates an approximation. If there is no damage, and the bearing is heavily loaded, the Fourier transform (FFT) produces a single frequency spike of energy at the bearing BPFO. The process is sensitive enough to detect the minute outer ring movement that takes place as three, then four, then three rolling elements pass through the load zone. If the bearing is not heavily loaded, no signal is generated so nothing appears in the spectrum. However, if there is damage, the sine wave is clipped or truncated. An FFT of a clipped sine wave results in the fundamental frequency, BPFO for example, plus harmonics of that frequency. If there is no BPFO signal, or if it is present and there are no harmonics then the user knows there is no damage in the bearing. If harmonics of the bearing components are present, there is damage. Then the user has to evaluate these damage indicators based on amplitude and shaft speed. For general machine condition, if the FFT displays multiple harmonics of the **shaft** rotation speed, this indicates looseness in the machine parts and not damage in the bearing.

6. Case Histories

6.1. Cage Problems

At a new construction site it is common to see many new pieces of production equipment sitting at various locations covered with plastic or a tarp, because they have arrived before the building was completed. If this occurs over an extended period of time, the bearings will be damaged. No matter what time of the year, metal gets warmer in the daytime and cooler at night, producing condensation. When this condensation occurs inside the bearing, trouble begins in two forms. First the hydrogen molecule in the water attaches to metal molecules resulting in hydrogen embrittlement. Second, the oxygen oxidizes the metal, creating rust. Then several months later, when the equipment is installed and activated, loud grinding and scraping noises emit from the bearings. This was the case at a new plant in Richmond, Virginia. They were able to obtain seven of the needed eight replacement bearings from the local bearing shop but could not locate the eighth. In desperation they obtained a bearing from a junk shop and proceeded with the installation. When this machine ran, it was vibrating much more than the other. Thus, we were called in to determine the cause.

We were told that the bearings were SKF 22222s, and that the fan speed was about 1600 RPM. Figure 1 is the frequency spectrum we collected on the suspect bearing. We can overlay on the spectrum the frequency markers for each of the bearing components. What is immediately seen is that the cage frequency (FTF) lines up with an energy spike. For clarity, the other three bearing frequency markers are not shown. The secret to frequency analysis is identifying the sources for the energy seen in the spectrum. In this case, the only thing in this machine that would generate 675 CPM is a damaged cage in an SKF 22222 bearing.

Based on this analysis, the bearing was removed and inspected. Figure 2 is a photograph of the bearing showing the damaged cage. Using the serial number on the bearing, it was determined that it was over 21 years old! Sometime during its life, someone had struck the brass cage and deformed it, either during an installation or removal.

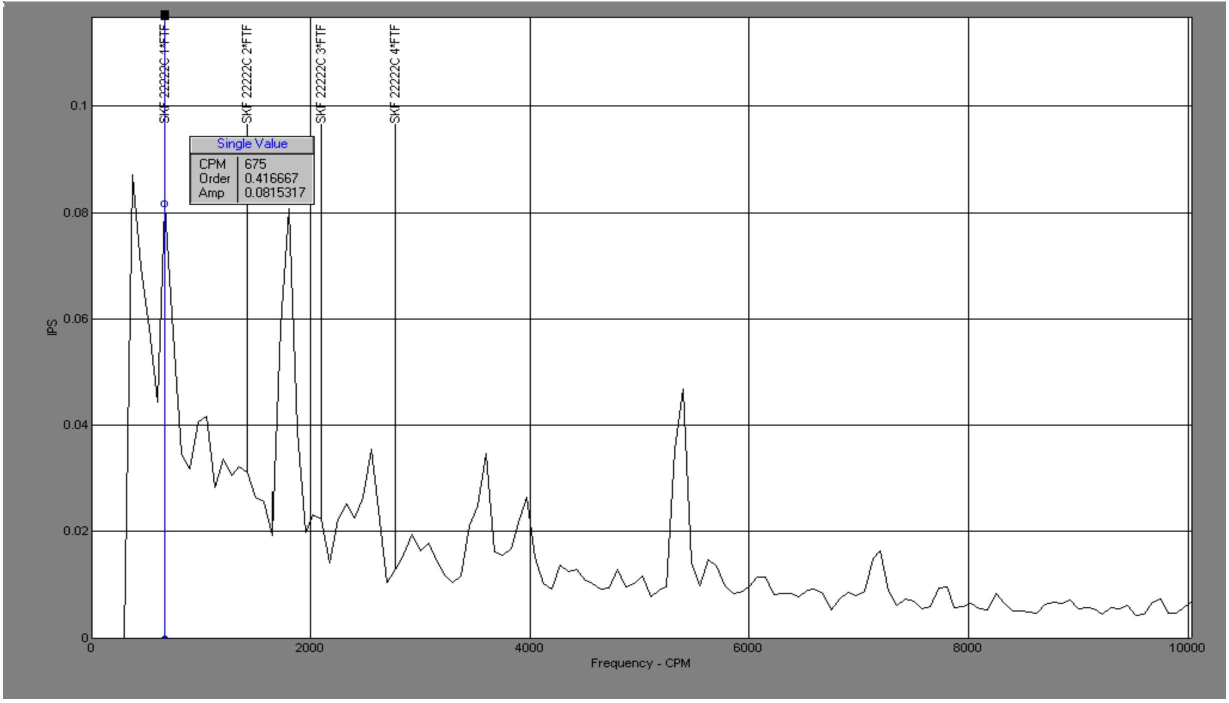


Figure 1. Velocity Spectrum Indicating a Damaged Cage.

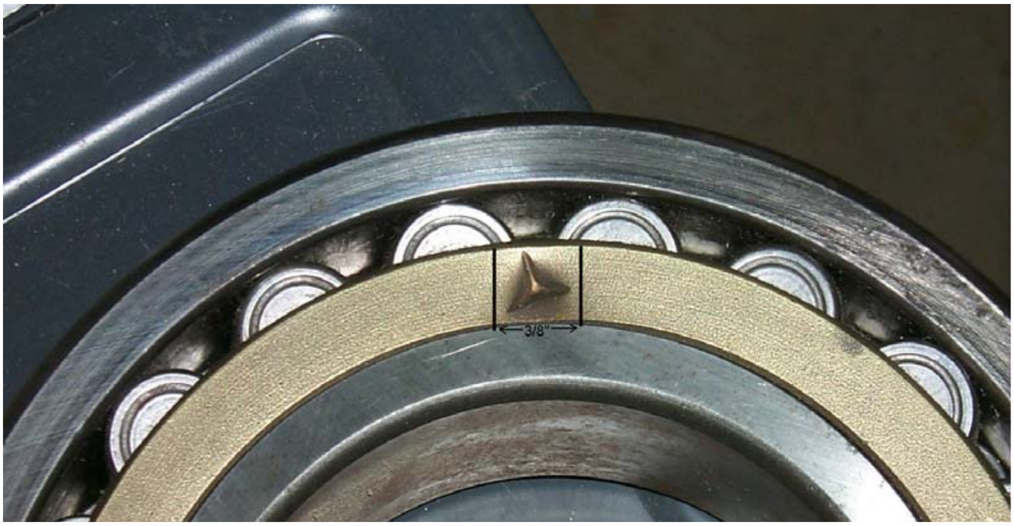


Figure 2. Damaged Cage, SKF 22222.

This case illustrates how we find damaged components using frequency analysis. It also points out the need to use care when purchasing bearings, even if you are under pressure to get a machine back in service. The major bearing manufacturers provide customer training on care and handling of rolling element bearings. Somewhere in the past, someone was not aware that you should not mount and dismount bearings with hammers and drift pins.

6.2. Cracked Inner Race

There are very specific tolerances for bearing fits on the shaft and in the housings, and if followed, one can expect a long bearing life. In the next example we see that if shaft fits are not maintained the results can be disastrous.

A bearing slowly rotates if it is loose on the shaft. The friction generates heat, which in turn causes the shaft and inner ring to expand. In this case, the shaft expanded more than the ring, to the point where all the fit tolerances were exceeded and the ring cracked. Figure 3 is the enveloped spectrum we collected while the unit was in operation.

The owner told us the unit was operating at 1200 RPM and the installed bearing was an SKF 2222. When we first looked at this spectrum without the bearing frequency overlay, it appears that we have multiple harmonics of the shaft speed, 1203 RPM, which would indicate looseness in the machine assembly. Figure 4 shows the value of further evaluation.

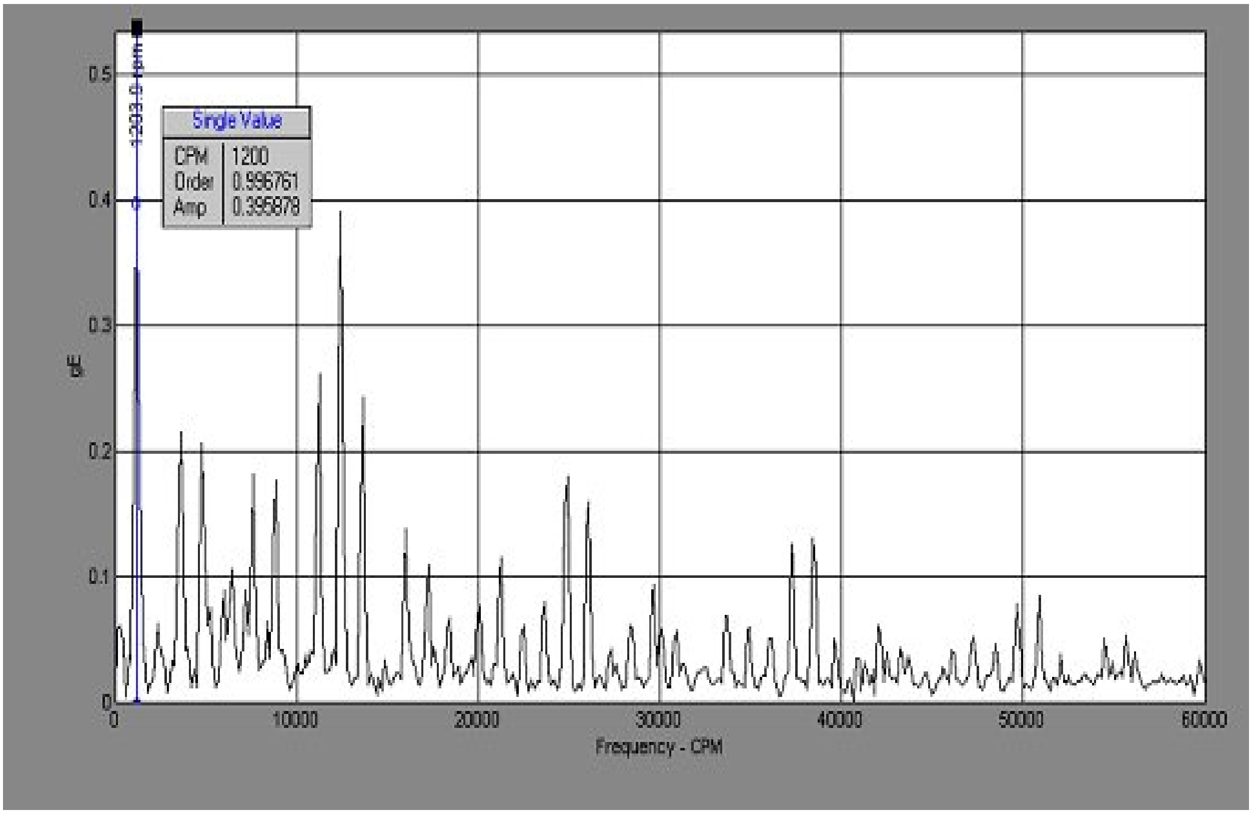


Figure 3. Enveloped Acceleration, Suspect Bearing.

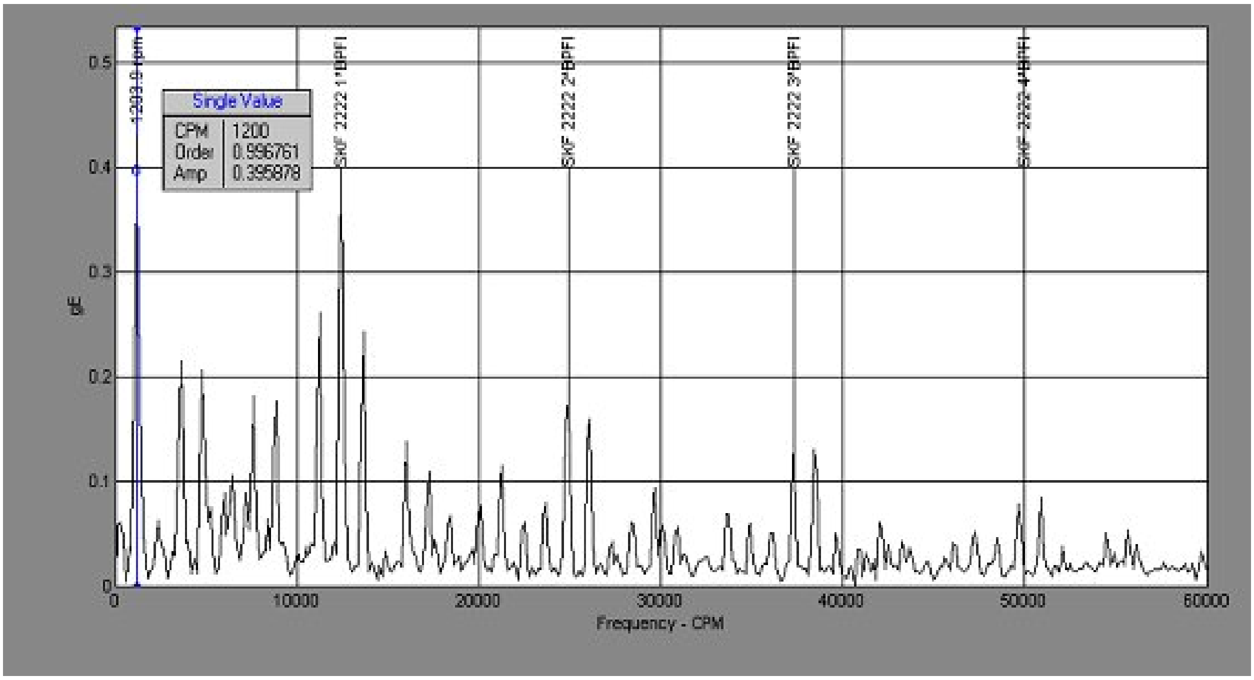
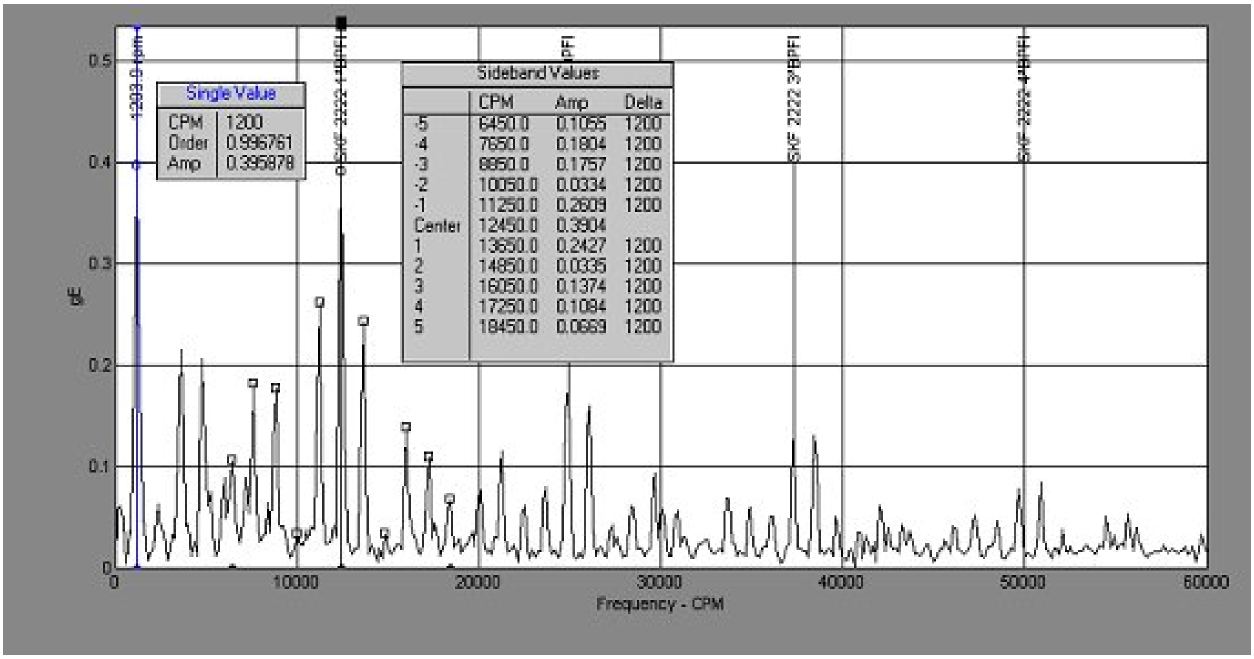


Figure 4. Suspect Bearing with Bearing Inner Ring Frequency Defect Markers.

The bearing frequency overlay clearly shows us that we have a problem with the inner ring. We can see the fundamental inner ring frequency with harmonics. Inner ring defects have a unique characteristic in that they almost always produce sidebands of the shaft speed. Using software, we can overlay sideband markers and see that they are the shaft speed. These sidebands are created by the natural modulation caused by the flaw rotating in and out of the load zone.



Single Value

CPM	1200
Order	0.996761
Amp	0.395878

Sideband Values

	CPM	Amp	Delta
-5	6450.0	0.1065	1200
-4	7650.0	0.1804	1200
-3	8850.0	0.1757	1200
-2	10050.0	0.0334	1200
-1	11250.0	0.2609	1200
Center	12450.0	0.3904	
1	13650.0	0.2427	1200
2	14850.0	0.0335	1200
3	16050.0	0.1374	1200
4	17250.0	0.1084	1200
5	18450.0	0.0669	1200

Figure 5. Suspect Bearing with Shaft Speed Sideband Markers around the Inner Ring Bearing Frequency.

With this evidence in hand, it was reported that the bearing had a damaged inner ring and the overall amplitudes indicated a need for immediate action. Figure 6 is a spectrum taken on the same bearing at the same location and at the same time as those above. The only difference, besides the upper frequency limit, is that the acceleration signal is processed to read out in velocity. Compare Figure 4 with Figure 6. The cursor is placed on the bearing frequency and the amplitude reads 0.0004 IPS. No one would ever consider changing a bearing with this low an amplitude; however, we have enveloped acceleration readings that show a problem. The visual proof is the photo of the inner ring after it was removed. This should convince anyone that enveloped acceleration is a much more sensitive method of analyzing bearing conditions.

Figure 7 is a photograph of the bearing. A piece of paper was inserted into the crack to make it more visible. Proof that the bearing had been turning on the shaft is seen on the inside of the ring, it is scratched, has black and blue heat marks, and is coated with fretting corrosion. Of course this is one of those “which came first” problems: the crack or the looseness. Once the ring cracks it certainly turns on the shaft, and if it was not scratched and blued before, it soon will be. A likely sequence of events is that the bearing was mounting too tight, the inner ring is forced to break, and looseness resulted. An alternative sequence would be too much looseness, resulting in fretting, which then initiated the crack. In any event, the bearing was damaged and needed replacement.

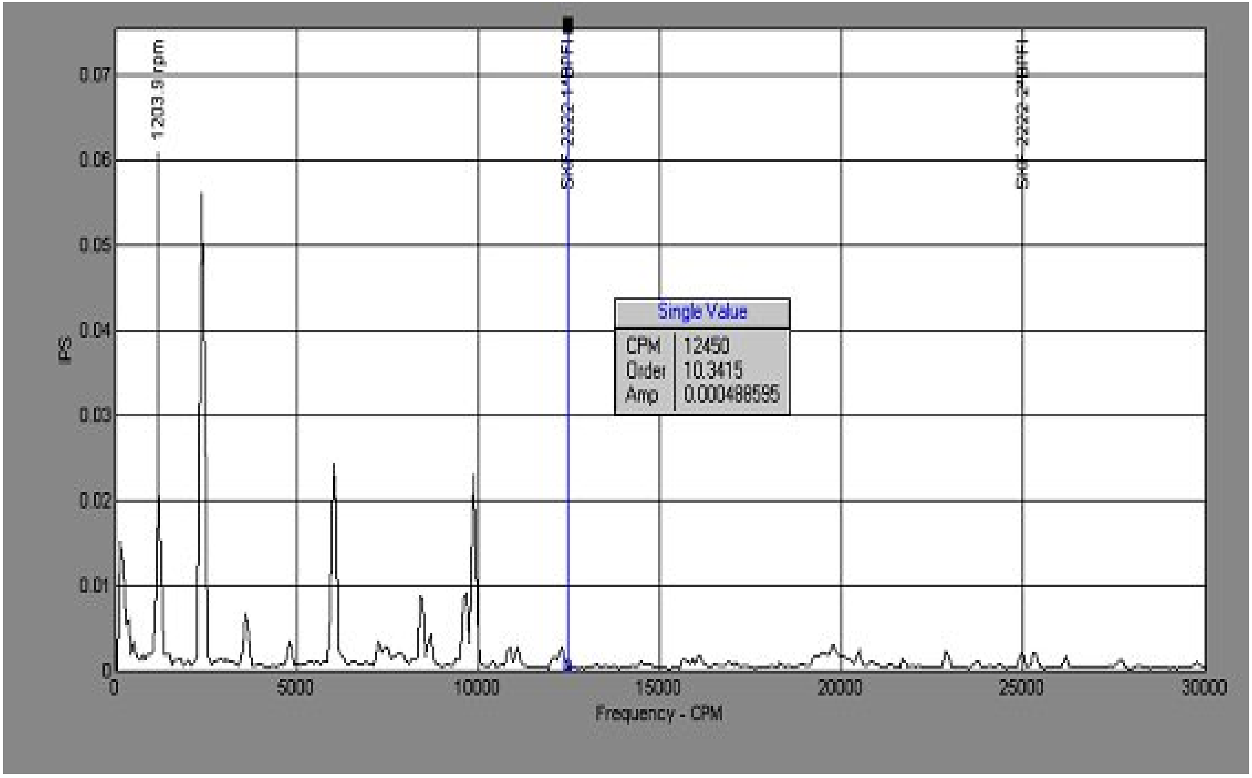


Figure 6. SKF 2222 Velocity Measurement, Cracked Ring.

Figure 7. SKF 2222 With Cracked Inner Ring.

6.3. Damaged Outer Raceway

It is not often that we are able to obtain damaged bearings after they have been replaced, as repairs often take place during off shifts. However, in these first few examples the customer was interested in having a first hand look.

On a cooling fan operating at approximately 1480 RPM, we collected data that indicated possible damage in the outer ring of an SKF 2218, a double row ball bearing. Figure 8 is the velocity spectrum we collected. The amplitude of the velocity measurement for the BPFO is only 0.021 IPS, but there is a harmonic present. Although there is damage, we can see the harmonic. Action would normally not be taken with just the velocity reading. As in the previous case, we collected another spectrum processing the signal using the enveloped acceleration algorithm.

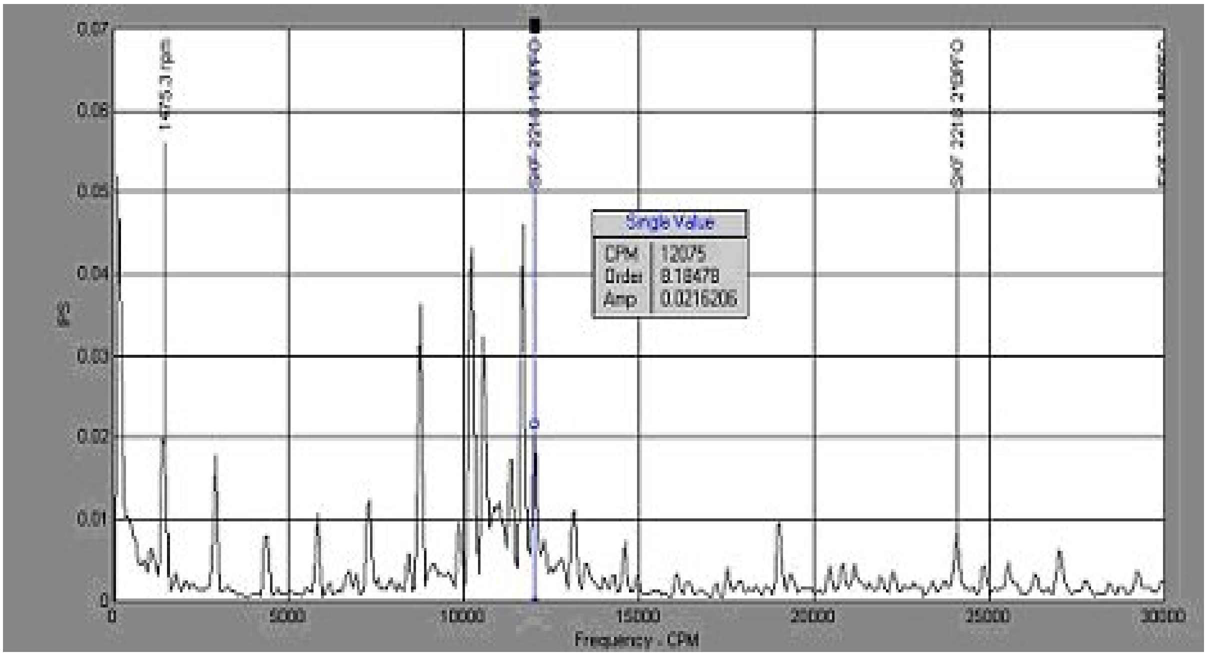


Figure 8. SKF 2218 Velocity Measurement.

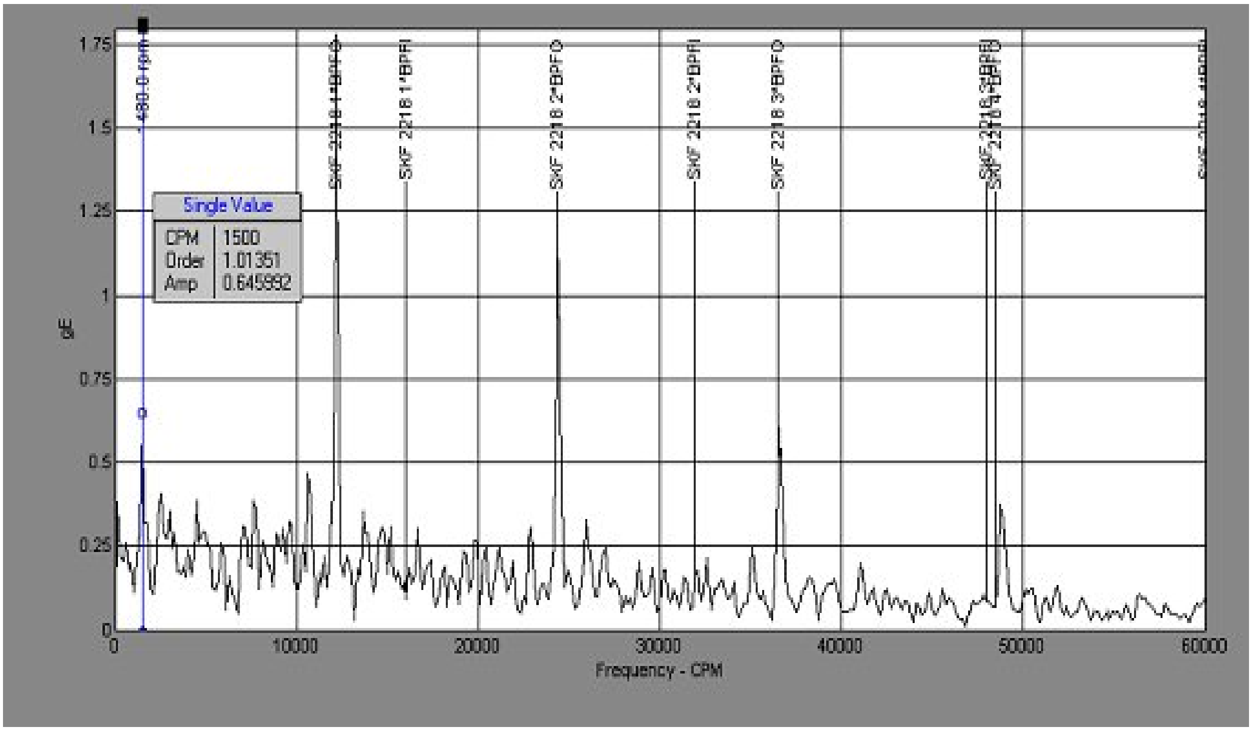


Figure 9. SKF 2218 Enveloped Acceleration Measurement.

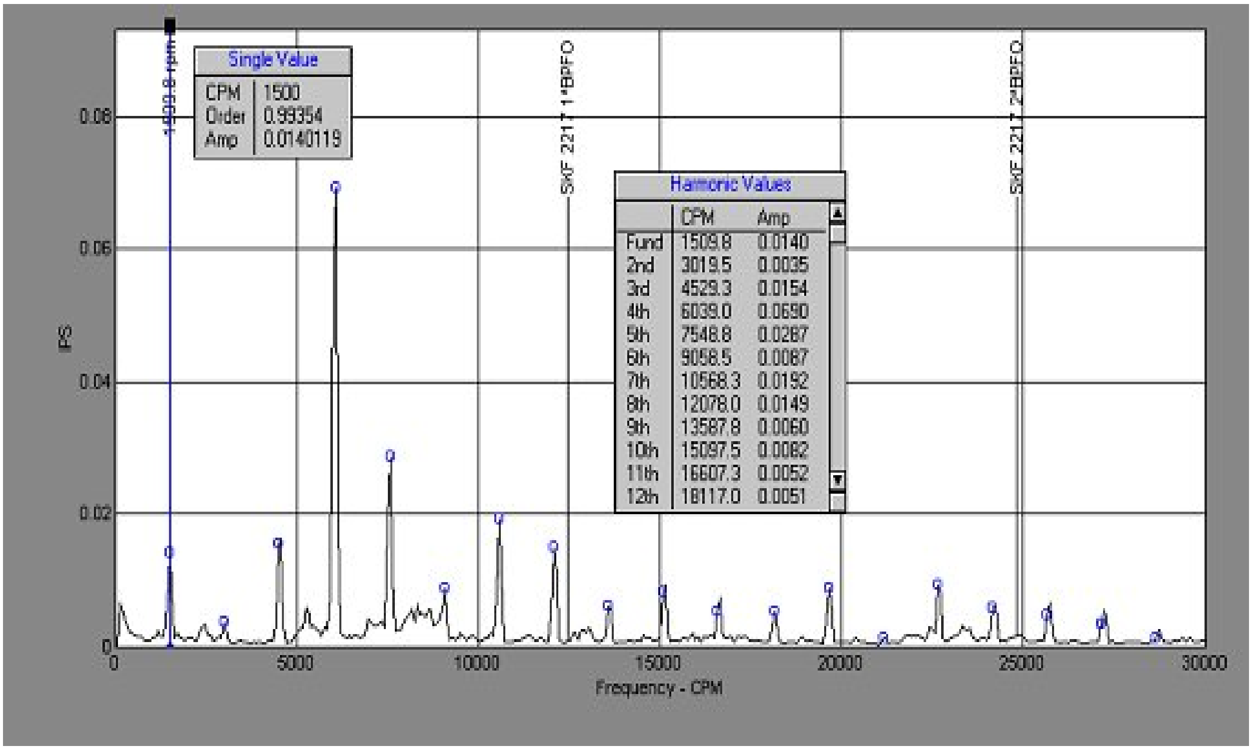
This time we overlaid both the BPFI and BPFO to verify that the damage was only in the outer ring. Note that the amplitude of the fundamental BPFO is nearly 1.25 gE. At this rotation speed, any amplitude over 1.0 gE is cause for concern. Figure 10 is a photograph of the damaged bearing's outer race. The photograph only shows two small ball tracks, but examination with a 20X lens revealed pitting and spalling primarily in the load zone, with some carryover around the entire ring. Once spalling begins, the degradation process can be very rapid as the small particles stick to the rolling elements and are imbedded and over rolled throughout the remainder of the bearing ring. At this point, a prediction of remaining bearing life would only be a guess, as there are too many variables and any amplitude trends would be approaching a non-linear function. Again, this is damage that is readily apparent using enveloped acceleration, and would not be apparent with only velocity measurements.


Figure 10. SKF 2218 Outer Ring Damage.

6.4. Loose Bearing Installation

There are occasions where velocity is the best measurement. If you have ever been in a room where a extremely loud sound is being created, you know how difficult it is to point to the source. It just seems to be coming from everywhere. When looseness becomes extreme the same effect occurs with the accelerometer. What you find with the enveloped signal is a lot of frequency spikes that are somewhat difficult to interpret. Figure 11 is the velocity spectrum of a taper lock bearing that was loose on the taper and the shaft. From a diagnostic point, multiple harmonics of the shaft speed are usually an indication of machine component looseness. Note in the velocity spectrum that the fourth harmonic is larger than the others. Generally, when the fourth harmonic of shaft speed is larger, it is an indication that the bearing is loose in the housing. Also, if the third harmonic is largest, it usually means the bearing is loose on the shaft. Here we had a situation that appeared to signify that the bearing was loose in the housing, when in fact everything was loose.

Figure 12 is the same location measured with enveloped acceleration. This is a case where the velocity spectrum provides clearer information. We can observe the running speed harmonics in the enveloped acceleration, along with a lot of other "stuff." This is the reason we collect data using several parameters when trouble shooting. Figure 13 is a photograph of the taper. It is scratched and has fretting corrosion inside and outside, physical evidence the taper was loose on the shaft and the bearing was loose on the taper. This was probably due to wrong mounting.



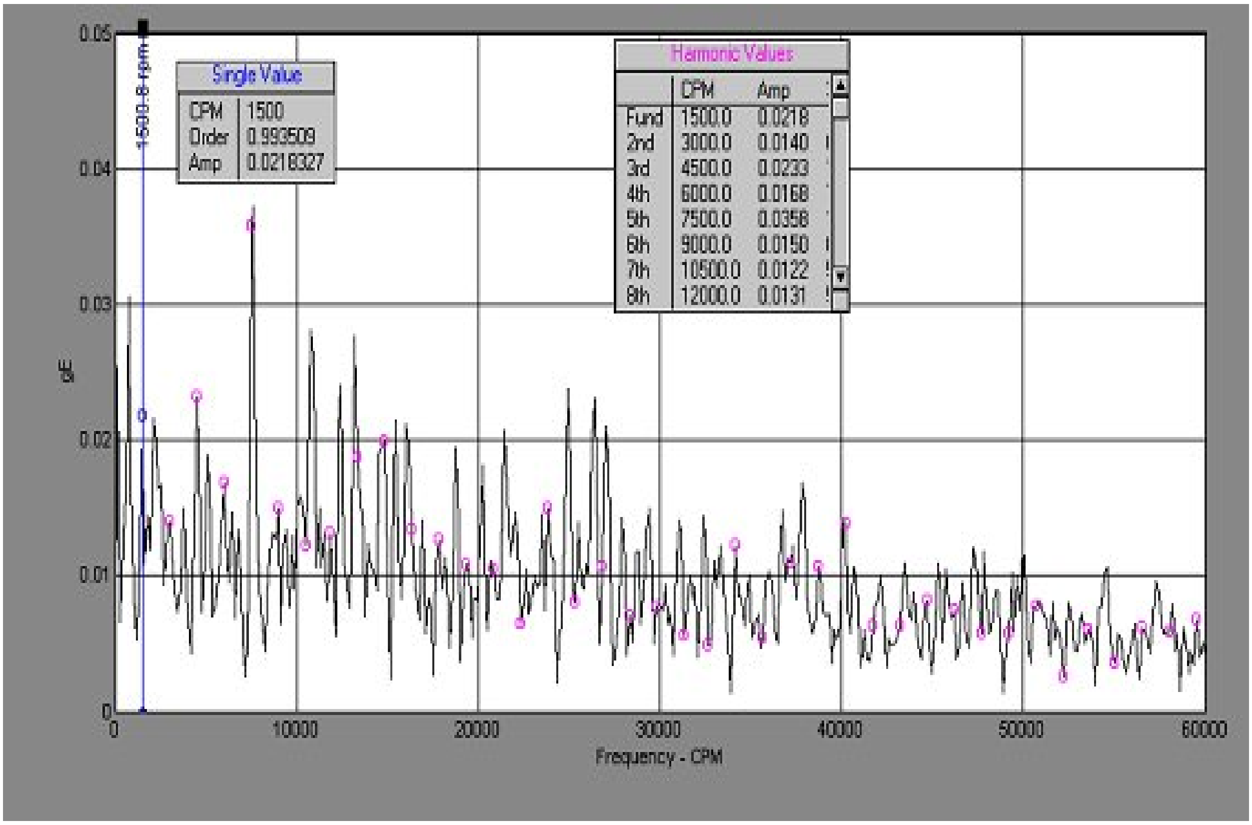
Single Value

CPM	1500
Order	0.99354
Amp	0.0140119

Harmonic Values

	CPM	Amp
Fund	1509.8	0.0140
2nd	3019.5	0.0035
3rd	4529.3	0.0154
4th	6039.0	0.0690
5th	7548.8	0.0287
6th	9058.5	0.0087
7th	10568.3	0.0192
8th	12078.0	0.0149
9th	13587.8	0.0060
10th	15097.5	0.0082
11th	16607.3	0.0052
12th	18117.0	0.0051

Figure 11. Velocity Spectrum With Multiple Harmonics of Shaft Speed.



Single Value

CPM	1500
Order	0.993509
Amp	0.0218327

Harmonic Values

	CPM	Amp
Fund	1500.0	0.0218
2nd	3000.0	0.0140
3rd	4500.0	0.0233
4th	6000.0	0.0168
5th	7500.0	0.0358
6th	9000.0	0.0150
7th	10500.0	0.0122
8th	12000.0	0.0131

Figure 12. Enveloped Spectrum of the Loose Bearing.

Figure 13. Fretting Corrosion on Taper Lock.

6.5. Low Speed Applications

The most efficient way to reduce shaft speed is to pass it through a reduction gearbox. One common applications is on conveyor belts where slow speed is required to move materials. Figures 14 shows the velocity spectrum from a reduction gearbox where the output shaft speed is 8.4 RPM. As stated earlier, on low speed equipment the velocity spectrum does not provide useful information on bearing conditions.

The signals at the low end of the spectrum are not valid. When an accelerometer signal is integrated to obtain velocity, the internal electronic noise in the data collector is also integrated, producing a false vibration signal. This is common to all data collectors. The usual practice is to filter out the signal by starting the spectrum at 60 or 120 CPM. In this case we started at “0” to show where the 8.4 RPM would be. Figure 15 shows the enveloped acceleration spectrum.

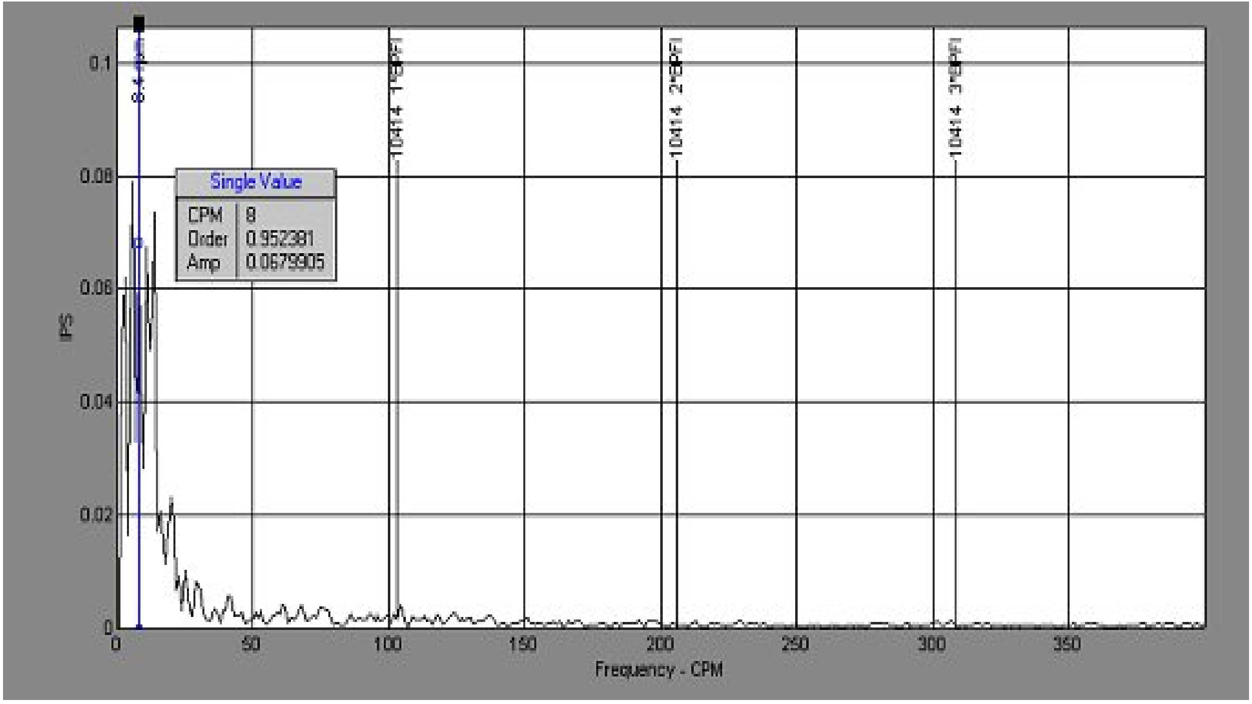


Figure 14. Velocity Measurement at 8.4 RPM.

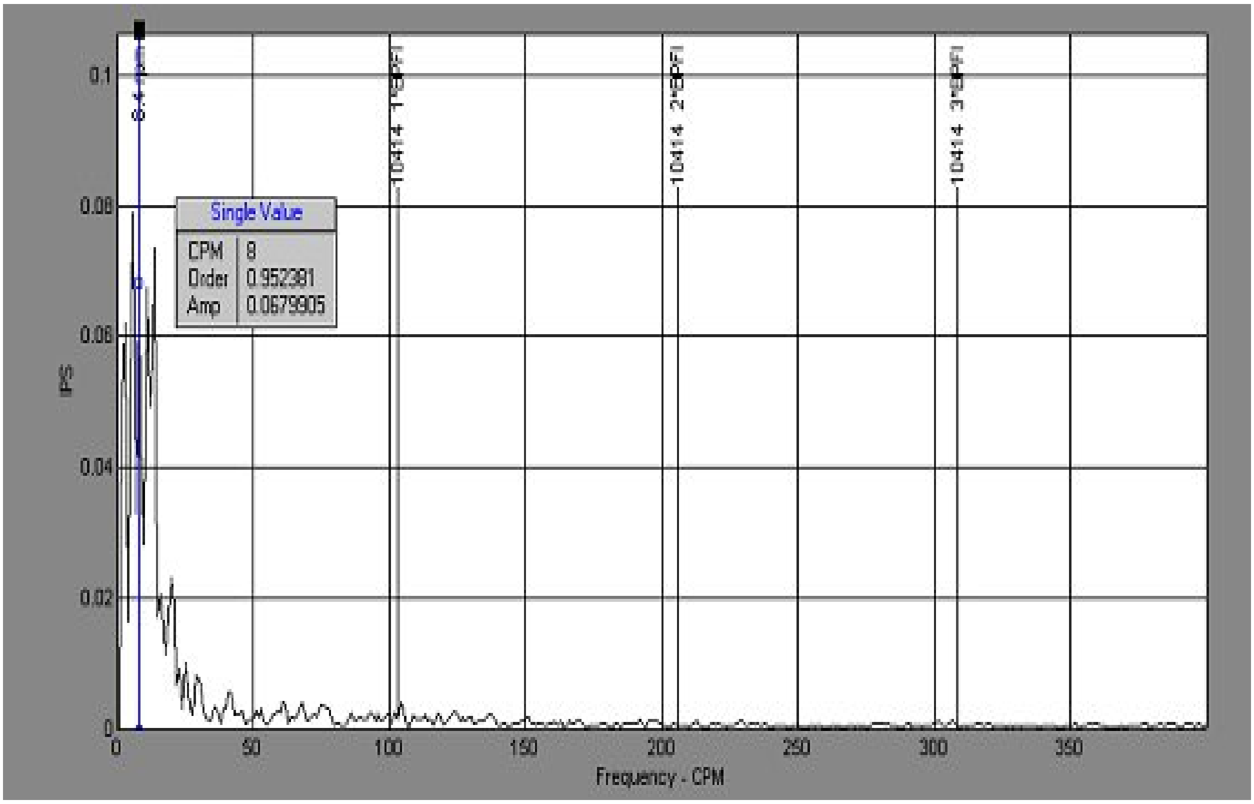


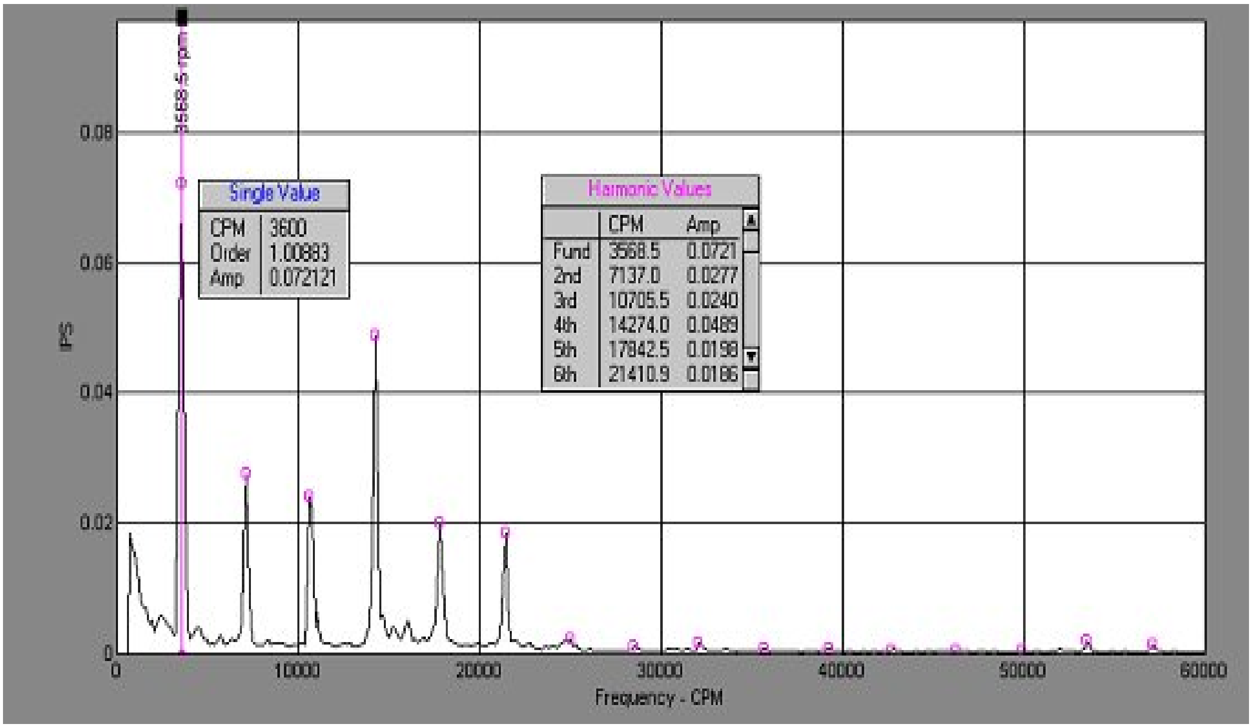
Figure 15. Enveloped Acceleration at 8.4 RPM.

Figure 15 indicates a problem on the inner race of this FAG 10414 bearing. The fundamental BPFI has harmonics, and at a speed of 8.4 RPM, the amplitude of 0.006 gE is severe. From a production standpoint, the replacement time for this bearing is 2.5 days. When this amount of time can be scheduled, operating costs are reduced. On average, unscheduled repairs cost 10 times the cost of a scheduled repair.

6.6. Journal Bearings

Journal bearings, also called sleeve or plain bearings, are best monitored by an oil analysis program. Theoretically, if the proper oil film is maintained between the shaft and the journal, wear does not occur. In real life we know this does not happen. Oil analysis is the first indication of excessive wear. If the owner does not have an oil analysis program then the first indication of a problem will probably be an increase in the vibration level at a frequency equal to the shaft speed. As the bearing continues to wear, the shaft will not be properly supported and will begin to “bounce around,” generating a spectrum with multiple harmonics of the shaft speed. In addition, we have found that oversize or worn journal bearings produce these harmonics, and the fourth harmonic has greater amplitude than the others.

Figure 16 illustrates a velocity spectrum of a recently overhauled screw compressor. The overall amplitude was excessive, and machine shut down was recommended. When the machine was taken off line, they realized the journal bearing that had been installed during the overhaul was oversized. The male rotor movement exceeded the screw mesh clearances, which could have resulted in a catastrophic failure.



Single Value

CPM	3600
Order	1.00883
Amp	0.072121

Harmonic Values

	CPM	Amp
Fund	3568.5	0.0721
2nd	7137.0	0.0277
3rd	10705.5	0.0240
4th	14274.0	0.0489
5th	17842.5	0.0198
6th	21410.9	0.0186

Figure 16. Velocity Spectrum of Oversized Journal Bearing with High Fourth Harmonic.

6.7. Odds and Ends

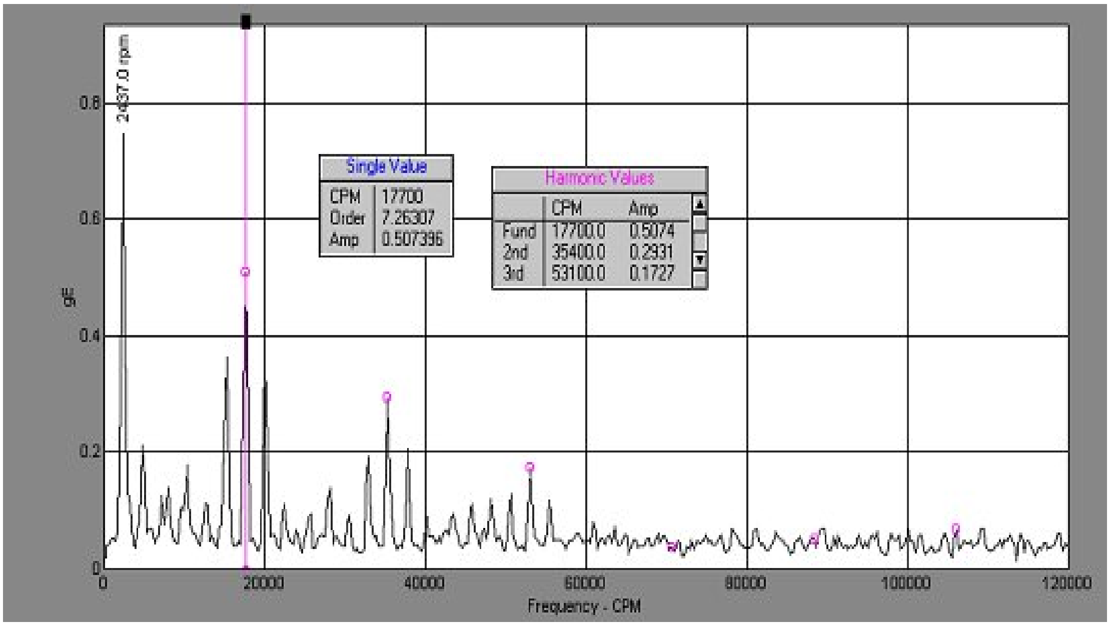
Often the owner of the machine has no idea what bearings are installed. Usually, the machine has been in service many years with several overhauls by several people and no one wrote down what bearings were used. A helpful characteristic of the bearing fault frequency calculations is that when the contact angle is greater than "0" the multiplier will result in a frequency that is a non-integer multiple of the shaft speed. In Figure 17, the cursor is placed on an unknown frequency spike and the Order information in the Single Value box tells us it is 7.263 gE. Then, we can place the harmonic marker on this mystery frequency and see that we have harmonics. Based on this information it would be prudent to do a physical inspection of the bearing. In Figure 17 the owner had deliberately damaged the bearing to see if we could find it among several others in the machine. We did.

Remember that the computer-bearing fault frequencies are calculated based on new bearing dimensions. The bearings you are inspecting are probably worn, and consequently the actual frequencies generated may not fall exactly on the observed frequency.

Through experience we have found that most inner ring failures are caused by poor installation. When the bearing is placed on the shaft by pushing on anything but the inner ring, damage occurs. Force on the cage damages the cage and pushes the rolling elements against the lip of the races, causing damage to the rings. Even if the damage does not effect machine operation, it results in noisy bearings.

Care should taken to prevent water from entering the lubrication. One percent water in the lube system reduces bearing life by 90%

And finally, over half of machine failures are caused by the loss of the rolling element bearings. Why? Because of misalignment! Other than thrust bearings, rolling element bearings are designed to carry a radial load. When misalignment occurs, an axial component is generated. When this becomes excessive, the bearings begin to fail. Probably the one procedure that saves the most money in any maintenance department would be to improve alignment methods. For this, we strongly recommend laser alignment equipment.



Single Value

CPM	17700
Order	7.26307
Amp	0.507396

Harmonic Values

	CPM	Amp
Fund	17700.0	0.5074
2nd	35400.0	0.2931
3rd	53100.0	0.1727

Figure 17. Unknown Bearing With Energy at 7.263 Times Shaft Speed and Harmonics.

7. Conclusion

Any technology or methodology that provides us with better information about the condition of our machine bearings enables us to conduct more efficient operations. This efficiency is seen in better scheduling of overhauls, a reduced overtime budget, an increase in time between failures, and an increase in production. Knowing the condition of our bearings provides the information we need to increase profits. This article showed various case histories of damaged bearings that were diagnosed using vibration analysis.

8. Resources

For more information on vibration analysis techniques, reference resources on *@ptitudeXchange, such as:*

- Bearing Failure Case Study, MB02009
- Early Warning Fault Detection in Rolling Element Bearings Using Microlog Enveloping, CM3021
- Vibration Principles, JM02007
- An Introductory Guide to Vibration, JM02001