Thomas Brown P.E.

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LARGE BORE BEARINGS – REBUILD OR REPLACE?

ABSTRACT

The decision to rebuild or replace rolling element bearings is typically made based on visual inspection of the bearing and interpretation of vibration velocity spectrums. Incorporation of high frequency demodulated spectrum and load zone information into this process will enable mills to achieve greater reliability and lower costs when making rebuild vs. replacement decisions on rolling element bearings. This paper describes a methodology using the high frequency demodulated spectrums and load zone location information to improve the decision making process.

INTRODUCTION

A press or suction roll has been removed from a paper machine for its scheduled cleaning, overhaul and grinding. As part of this process you must decide what should be done with the bearings. Should you reuse them? Rebuild them? Or discard them and install new ones? What can you do with expensive large bore bearings used in a paper machine to improve the reliability and lower the costs?

Imagine you have removed bearings from a roll and are examining the rollers and raceways for frosting, denting, flaking / spalling or other damage. There is some polishing in the load zone indicating that the bearings have been assembled and operated correctly. You decide to send the bearings out for reconditioning / rebuilding. The roll is reassembled using the rebuilt bearing and you congratulate yourself on the savings. Six months after the roll is reinstalled in the machine the bearing fails causing unplanned downtime.

Determined to prevent another premature failure, the next time a roll is rebuilt, you purchase and install new bearings. Costs are higher, but the pain associated with higher costs is less than that caused by unplanned downtime. What happened? What can be done differently to prevent the failure and reduce costs?

Look at this situation a little differently. Using some easily attainable information one can make a decision that allows an increase in the service life of bearings with a high degree of confidence and reliability. To do this, one should first review how rolling element bearings fail.

BEARING FAILURE MECHANISMS

Understanding the mechanisms involved in a bearing failure leads one to making the right decisions that improve reliability and lower costs. The three principal mechanisms of premature failure of correctly installed bearings are steel cleanliness, inadequate lubricant film thickness and contamination. Design, speed and load influence these mechanisms. In the following discussion assume that the engineers did their homework, the equipment is designed, assembled and operated correctly.

The fatigue strength of a bearing depends greatly on the size, shape and number of non-metallic impurities in the steel. These impurities or "inclusions" are areas where high stresses are created. Smaller inclusions usually have lower stress levels than large ones. For a given size spherical inclusions usually have lower stress levels than long narrow ones. Consequently, cleaner steel with fewer and smaller spherical inclusions will have higher fatigue strength than steel with numerous large or long and narrow inclusions.

As the balls or rollers of a bearing pass over an inclusion, they cause high stresses that eventually cause small cracks to form after millions of cycles. Typically, these very small cracks start just below the surface. When the crack(s) grow to sufficient size and reach the surface, a piece of the raceway breaks away creating more damage. This type of fatigue failure is known as spalling.

During the past thirty years, bearing manufacturers have improved the cleanliness of bearing steels, by reducing the number and size of inclusions. Today we use steels that are on average twice as clean as steels manufactured just thirty years ago. The fatigue strength and life of bearings manufactured today are much higher.

Marginal lubrication will increase the surface stresses and cause premature cracking. As a ball or roller passes through the load zone of a bearing where stresses are the highest, it rides on a very thin film of lubricant that cushions and spreads the load over a larger area. The term used to describe this is elastohydrodynamic lubrication. As the pressure on the oil increases, its viscosity increases. When the lubricant is carried into the converging zone approaching the contact area, the ball or roller and the raceway deform due to the pressure of the lubricant. As the viscosity increases, the pressure is increased. This pressure is sufficient to separate the surfaces in the contact area. Because of the very high viscosity and the short time it is in the contact area, the lubricant cannot escape and the separation of the surfaces can be achieved. When adequate film thickness is maintained, the limiting factor in bearing life is the fatigue strength of the steel. If this lubricant film becomes too thin, metal-to-metal contact occurs. This creates high localized stress levels where surface roughness peaks contact each other. The higher stress causes surface cracks to develop that grow and create spalling. The bearing fails to reach the calculated life.

Of the three mechanisms, contamination causes most premature failures. Particles large enough to penetrate the lubricant film create small dents when trapped between a ball or roller and one of the raceways. The edges of the dents are raised when the raceway material is pushed away by the contamination particles. As the ball or roller passes over the raised edges, stresses occur that are higher than the fatigue strength of the steel. Eventually, a small crack begins to form. It grows until a piece of the raceway breaks away creating more damage and failure occurs well before the calculated life of the bearing is reached.

Water is a particularly nasty contaminant. As the water is subjected to the pressure between the ball or roller and the raceway, the hydrogen dissociates and is able to penetrate the surface of the steel where it is forced into the crystalline structure of the steel. The hydrogen dislocates the crystalline lattice. These dislocations eventually develop into cracks and subsequent failure.

In a perfect world, none of these failure mechanisms would happen. One would have no contamination in the lubricants, the oil film thickness would always be sufficient and there would be no impurities in the steel. But try as one may, things are not perfect. Contamination, inadequate lubrication, and inclusions are present. Great strides have been made in the development of cleaner steels, improved lubricants, better filtration, and tighter sealing, but perfection has not been achieved. Bearing failures remain a concern.

All of these failure mechanisms usually begin with microscopic cracks that cannot be seen with the naked eye and typically originate on or just beneath the surface. The important thing to remember is that these bearing failure mechanisms generate telltale high frequency signals often before the damage can be seen by the naked eye and well in advance of failure.

BEARING EVALUATION TECHNIQUES

There are different ways of detecting defects in bearings. They can be very simple and subjective, relying on the human eye, ear and touch or very sophisticated ones that can detect incipient failure of a bearing. When these means are used in concert, they give the vibration analyst a very powerful method to evaluate bearing and machinery conditions.

These detection techniques can be grouped into four categories:

Subjective measurement methods rely on sight hearing and touch. One can recognize the distinctive sound a bearing makes in the advanced stages of failure, touch a bearing housing to judge temperature and smell the distinctive aroma of oxidizing lubricants, or look at the raceways and rolling elements of a bearing to determine damage.

Low frequency measurement techniques in displacement, velocity or acceleration usually over the 600 to 600,000 CPM range are the most widely used. Unbalance, misalignment, bent shafts, rotor problems, looseness, resonance, gear problems, belt problems, bearing problems and other defects are analyzed in this range. These measurements are the workhorse of the vibration analysis field and have saved industry billions of dollars.

High frequency broad band measurements of vibration at frequency ranges from 5 kHz to 120 kHz are used to identify lubrication problems and initial stages of bearing failures.

Demodulated high frequency measurement technology provides a means to identify specific bearing defects earlier than low frequency measurement techniques and often before they become visible to the naked eye. These methods use filtering and demodulation to strip away the low frequency content of a signal and process the remaining high frequency content to create characteristic signatures that are used to identify specific defects.

Low frequency measurements have been used for decades to detect, diagnose and correct a wide variety of machinery defects ranging from unbalance to bad bearings. These have and will continue to be the workhorse of the vast majority of vibration analysis. In the low frequency range, a machine's vibration signal is dominated by specific vibrations related to the rotating parts. These signals include unbalance, misalignment, resonance, looseness, rubs, hydraulic / aerodynamic forces, and electrical problems. A specialized field in this range is modal analysis that describes the resonant shapes of structures. Also included in this range is the analysis of fluid film bearings that are usually found on turbomachinery.

Bearing defect frequencies are also found in the low frequency range. These are not always apparent unless the defects are severe or the other machine rotational components are very low amplitude. Because of the difference in amplitude of the bearing frequencies versus the other rotational frequencies, the low frequency range is not the best range for early detection of bearing defects. When bearing defect frequencies are seen in the low frequency range, most of the damage has been done. It not a question of if a bearing will fail, it is one of how soon will complete failure occur.

To provide vibration analysts with an earlier warning of incipient bearing failure, higher frequency ranges were investigated. It was found that there are many low amplitude vibration signals related to bearing deterioration in the high frequency range, but they were masked by the higher amplitude low frequency signals. Researchers also found that the low frequency signals associated with machinery operation like unbalance, misalignment, etc. drop off rapidly in higher frequency ranges.

Two pioneering methods in the high frequency range were shock pulse and spike energy. These methods used simple handheld meters and special accelerometers to provide an overall value that could be correlated to bearing deterioration. The developers found that there were basic defect mechanisms that create high frequency vibrations. These included:

> Fatigue cracks. The surface or subsurface cracks could originate at indentations caused by contaminants, impurities in the bearing steel, local overstressing caused by brinelling, or false brinelling and damage during handling or installation.
>
> Surface damage or pitting caused by contamination particles or electric current passing through the bearing.
>
> Surface damage caused by the reduction or loss of oil film.

The quest for earlier detection of bearing faults has continued to drive the development of high frequency spectral analysis. Signal processing techniques have been developed that separate low frequency modulating components from the high frequency signals. Research and field experience has shown that using these high frequency demodulation or enveloping techniques, it is possible to detect bearing problems well in advance of failure. Analysts using demodulated spectrum analysis in conjunction with lower frequency vibration spectra not only recognize faults earlier, but also with greater reliability. There are several variations depending on the equipment manufacturer, but they all produce similar results.

5191 Country Lane, Duluth, MN 55810 • Voice 218-729-4646 • Fax 877-585-8982
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Bearing defects which high frequency demodulation and enveloping techniques have proven effective in detecting include:

Micro denting caused by contaminant particles, brinelling, false brinelling or electric current.

Surface fatigue cracks. These may be started from the stress risers caused by microdenting or from marginal lubrication.

Subsurface fatigue cracks. These could originate at impurities or inclusions in the bearing steel

Improper loading of rolling element bearings from incorrect shaft fits, incorrect housing diameter, improper preload or excessive thrust loads.

These defects are the indicators of incipient failure. In the earliest stages, they cannot be seen with the naked eye and are difficult to detect with low frequency vibration analysis until considerable damage has been done. Using the information obtained using high frequency demodulation in the bearing rebuild or replace decision making process is the key to improved bearing reliability and lower costs.

MONITORING BEARINGS USING HIGH FREQUENCY DEMODULATION

The analyzers available today use different techniques to process and analyze high frequency signals. The vendors of these products have produced equipment that is able to give the information needed to evaluate bearings. Which technique used is not nearly as important as consistently using the technology to monitor large bore bearings. Remember that high frequency demodulation can detect flaws before they are visible and well before they become apparent in the classical vibration spectrum.

The following description will emphasize the critical elements necessary to successfully monitor bearings using high frequency demodulation. The three critical elements required to monitor equipment using high frequency demodulation are transducers, filter set up and interpretation of the data.

Transducers

Transducer selection and installation are critical when collecting high frequency demodulation data. In almost all cases, an accelerometer must be used for high frequency demodulation measurements. Velocity pickups have a limited range; above 1,000 to 2,000 Hz (60,000 – 120,000 cpm) they are not very effective. Some vendors have filters with high pass filter corner frequencies that are low enough to permit use of velocity pickups. However, with very few exceptions, an accelerometer should be used because they can detect the higher frequencies as well as the lower frequencies in 5 HZ (300 cpm) range.

The location and mounting of the accelerometer used to gather high frequency demodulation data can make a tremendous difference in the quality of measurements. If the same accelerometer, location and mounting are not used from one survey to the next, the data can be missed completely. It is important to mount the accelerometer as close to the bearing load zone as possible. At each interface the carrier passes through it loses about 60% to 80% of the high frequency energy. The best mounting for detecting high frequency signals is a stud mount. The second choice is a mounting pad glued to the bearing housing so the accelerometer will be placed consistently from one measurement survey to the next. The least desirable method is placing the accelerometer on the bearing housing with a magnet.

Finally, there must not be any paint on the housing where the accelerometer is attached and high frequency readings must never be taken using a “stinger” mounted on the accelerometer. Failure to do either of these will result in creating false problems or missing problems all together.

Filter setup

The most important point when setting up data collectors is the selection of the correct high pass frequency. Incorrect selection will give the analyst inaccurate data that cannot be trended reliably. There are many choices of filters on some analyzers, but often only one combination of high pass and low pass filters will detect problems. Guidelines for filter setup are provided by the different vendors. The important thing for the analyst to understand is the high frequency demodulation process and how the spectrum parameters should be setup instead of trying to choose the “best” hardware and software. The major vendors have high frequency demodulation products that are capable of providing the information required provided the analyst has correctly setup the spectral parameters.

Data interpretation

The following description is meant as a guide only and must not be taken as an absolute standard that can be applied to all machines. A normal demodulated spectrum will show a smooth noise floor at a low level that can be used as a reference. There will not be any bearing defect frequencies present in the demodulated spectrum.

During the first stage of bearing deterioration, defect frequencies will appear several decibels above the reference noise floor. Running speed harmonics may also appear depending on the internal clearance of the bearing. The conventional spectrum will not show any defect frequencies. If the bearing is removed from service at this stage and inspected, defects will usually not be visible.

At the second stage of deterioration, the defect frequencies in the demodulated spectrum will increase in amplitude usually 5 to 10 decibels above the noise floor. Harmonics of the fundamental defect frequency may begin to appear. The bearing may still have significant service life left. Defects may be found at this stage with very careful inspection.

In the third stage as the bearing condition worsens, the defect frequency(ies) begin to appear in the low frequency velocity spectrum. Running speed sidebands will appear around the defect frequency and harmonics in the demodulated spectrum. More importantly, the noise floor will have risen about 10 decibels and the defect frequencies will be about 10 decibels above the noise floor. The defects will be clearly visible at this stage although they may be small at the onset of this stage.

When the bearing reaches the fourth stage, it needs to be scheduled for immediate replacement. More harmonics of the defect frequency(ies) will begin to appear in both the velocity and demodulated spectrums. More running speed sidebands will also appear. The noise floor in the demodulated spectrum will have grown another 10 decibels so it is now 20 decibels above the reference noise floor.

In the fifth or final stage of failure, the peaks in both spectrums may decrease. In the velocity spectrum, the peaks may be replaced by broadband noise. The defect frequencies in the demodulated spectrum may decrease and the noise floor may also decrease. If a bearing is allowed to run to this stage, it cannot be reused or rebuilt.

There are several important points to remember when monitoring and trending bearings using high frequency demodulation. Experience has shown that the most reliable trending of defect amplitude occurs at the fundamental defect frequency. When evaluating bearing condition, do not rely completely on changes in amplitude of defect frequencies. Look for the appearance of more defect peaks associated with the bearing such as the appearance of another race frequency, ball or roller frequency, cage frequency and running speed sidebands. Finally, the change in the noise floor is just as important as the changes in specific frequencies in assessing the condition of the bearing.

INSTALLATION, REMOVAL AND EVALUATION OF BEARINGS

Installation

Marking of a bearing's location relative to the housing is key to making the correct decision(s) that will help lower costs and improve reliability. The most important part of this process is making a reference mark on the bearing housing. This mark should be in a location where it cannot be corroded away, painted over or removed by grinding. An ideal location is underneath the outboard cover. The reference mark should be placed at the same location on the circumference of all roll housings. For instance, the mark could be placed at the location of the mounting pad or feet. Other locations might be at the bottom or top of the housing as it is installed in the machine. Whatever location is used it is important to be consistent.

An identifying mark can be made using an electric etching tool or steel stamps. After the reference has been made, make sure that the raised edges of the marks have been stoned flat and that the marks are still legible.

The second part of documenting the installation of the bearing is to note the location of the bearing relative to the reference mark. Large bore bearings often have a unique serial number and may have a high spot marked on the outer ring. If the bearing and housing are marked to accommodate the high spot note the position of these marks relative to the housing reference mark. Also, note the location of the serial number relative to the housing reference mark and if it is on the inboard or outboard side of the housing. If a new bearing does not have a high spot marked on the outer ring, and is always installed with the serial number at the housing reference mark, this serves as a convenient reminder that the bearing has not been removed since it was installed new. This alignment can also serve as a check that the outer ring has not rotated in the housing.

There are many marking methods. It is important to use one that is consistent, convenient, understandable and can be documented with minimum errors. This information is critical to the decision making process. If the inner ring is stationary, the same procedure can be applied to the inner ring.

Before the roll is removed

As soon as the roll is scheduled for removal from the machine, make sure the high frequency demodulated spectrums have been taken. Without the spectrums, evaluation of the bearing is uncertain at best.

Bearing removal and inspection

When a bearing housing is opened up, one of the most important things that will increase reliability is knowing where the location of the load zone on the outer ring is in relation to the housing. In most bearings the load zone is located in approximately a 90-degree arc on the outer race. This means that if the position of the load zone is moved 90 degrees every time the roll is rebuilt, four service cycles can be completed with what is essentially a new load zone for each cycle provided the rollers and inner ring are not damaged. If a reference mark was made on the housing and the position of the bearing serial number in relation to the reference mark was documented, then documenting the location of the load zone is straightforward.

If the housing does not have a reference mark, make one before the bearing is removed from the housing and document the location of the bearing serial number relative to the reference mark.

Before the bearing is removed from the housing and journal, measure the internal clearance. The documentation of the location of the reference mark, serial number and load zone on the outer ring relative to the housing will provide a baseline for failure analysis if necessary and installation of a new or rebuilt bearing. After the bearing is removed and cleaned up for examination, document the location of the load zone. Mark the location and date of the load zone on the serial number side of the bearing using an electric etching tool. Next, answer the following questions: is the load zone in the expected position, is it the normal length, and are both roller paths equally loaded?

If the load zone is not what you expect, look for the following things:

> Has the housing been distorted? Measure the ID to make sure it is the correct diameter and it is in fact round.
>
> Is the load zone length what you expected? If it is longer, what was the internal clearance? In many cases, a longer than normal load zone is accompanied by internal clearance that is at minimum or below.
>
> If both roller paths are not equally loaded in a floating bearing, look for the following: wear in the housing that causes a race to bind, incorrect covers that do not allow the bearing to move, machine framework that has shifted or misalignment of the bearing housing to the roll.
>
> Fixed bearings on the other hand will often have one roller path that is more heavily loaded. If the wear appears excessive, look for bearing housing to roll misalignment, roll misalignment, drive misalignment or coupling problems.

Occasionally, bearings will have more than one load zone, or a load zone that extends around most of the raceway. If the bearing has more than one load zone, first look at the operation of the roll. As a roll goes from the unloaded position to the loaded position, the load on the bearing will shift usually by 180 degrees. If a roll in a press is run for extended periods of time to wet felts or wash up, the weight of the roll will create a second load zone. This zone should be smaller and less well defined than the zone created when the roll is loaded. Depending on the alignment of the housing to the roll and the alignment and condition of the pivot arms, these zones may vary between roller paths.

Several possibilities exist if the load zone extends around the race. First, was the bearing shifted during the last roll overhaul? Movement of the bearing in the housing when it is reassembled will change the load zone. Small internal clearance will cause the load zone to extend around the raceway as the bearing warms up.

The decision making process

The following scenarios are based on the presence of defects in the outer race and the corresponding frequencies. If the inner ring of a bearing is stationary, then the decisions will be based on the presence of inner race defect frequencies. In either case, if the rolling element or cage frequencies are present, then the bearing being evaluated should be removed for rebuild or replacement.

If the high frequency demodulated spectrum does not show any signs of bearing defects, the noise floor has not risen above its baseline level, and no other abnormalities can be found in the velocity spectrum, the bearing may be cleaned, visually inspected and reused. At this juncture the load zone may be rotated or left in the original position.

If the high frequency demodulated spectral information shows the bearing has deteriorated to the first stage, three choices exist. First, the bearing may be replaced with a new one. Second, the bearing may be returned for rebuild, reinstalled and the load zone rotated. Third, the bearing may be cleaned, visually inspected and the load zone rotated when the bearing is reinstalled. Remember that the defects at this stage are usually not visible. Rotating the load zone insures that the deteriorated area is moved away from the high stresses.

When a bearing has reached the second stage, two choices are possible. First, replace the bearing with a new one and second, return the bearing for rebuild. If the second choice is selected, the load zone must be rotated when the bearing is reinstalled.

If the serial number of a new bearing is located at the reference mark in the housing when it is installed for the first time, it can be used as a starting point for rotating the ring. At the next roll overhaul, it would be moved to the 3:00 position. At the subsequent roll overhaul, it would be moved to the 12:00 position and finally to the 9:00 position. If the bearing reaches this point without being rebuilt, then it should be returned for rebuild. Other methods of determining rotation can be used particularly when the high spot is marked on the outer ring. The key is consistent documentation.

What about bearings that are used in different rolls that have different load zones or a roll that is used in multiple positions where the load zone is not the same? Good documentation and careful evaluation of the vibration information is the key to reliability and low cost.

When a bearing can be used in more than one roll, marking of the load zone and tracking of the vibration information using the bearing serial number must be done. Marking the load zone is a straightforward process that can be done when the bearing is removed from service. If the bearing is returned for repair or rebuild, it is imperative because the load zone pattern is often removed during rebuilding. Tracking the bearing in a particular roll in a given position can be done using vibration monitoring software, so the spectrums can be correlated to a particular bearing history. Alternatively, this information may be tracked using a computerized maintenance management system. When the bearing is installed on a different roll, the information recorded during disassembly can serve as a guide to assembling the roll with the previous load zone positioned away from the expected load zone.

Using all the vibration analysis tools and information available coupled with careful documentation of the bearing installation will increase the reliability of a paper machine at the lowest possible cost.