SKF Pulp & Paper Practices

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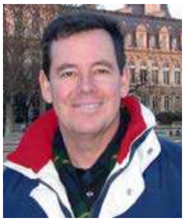
Monitoring slow rotating equipment with vibration analysis?

You might not be aware of it, but SKF has been monitoring bearings of all sizes in many different applications around the world for over 30 years now and this includes equipment rotating as slowly as one revolution per minute (r/min). We like to think that this experience combined with our bearing and application knowledge gives us a rather unique perspective on things.

In the current market climate, ensuring the reliable operation of all equipment in the pulp and paper mill is important including critical equipment using large size bearings rotating at very low speeds where an unexpected failure can cause over 40 hours of downtime.

There is a commonly held misconception that it is not possible to effectively monitor bearings running at very low speeds using available vibration monitoring techniques. In fact, it is quite possible provided you approach it in an appropriate way.

The rest of this issue of SKF Pulp & Paper Practices will be dedicated solely to the topic of monitoring bearings rotating at slow speed. There are many advantages to be had from the successful detection and diagnosis of developing problems – avoiding unplanned downtime, identifying the root cause of a problem and eliminating it for good, detecting developing bearing damage early enough that remanufacturing is a viable option.



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Low speed bearing monitoring – Challenges and solutions

A couple of years ago there was a resurgence of interest in low speed bearing monitoring as a result of increased focus on critical equipment (especially in the pulping and chemical recovery lines) and promotional activities in the marketplace. I heard various opinions ranging from it should be very easy to do to it is not possible at all with vibration monitoring.

Being familiar with SKF's long history of success dating back to the early 1990s on bearings turning at even less than one r/min, I was rather puzzled by this. I reached out to experts within SKF like David McCall in the USA and Lars-Erik Heed in Sweden and I got the impression that, in many cases, the issues boiled down to a misunderstanding or misapplication of existing SKF technology. However, there were also a few cases where developing failures seem to have been missed even if the monitoring system and settings appeared to be correct. We formed a group that looked more closely at the available information and found out that though there were indeed many successful cases of bearing damage detection at low speeds, there was a class of applications that needed to be better understood. As such, we decided to focus on bearings running below 20 r/min and on two different application cases: steady and non-steady speed.

Low speed bearing monitoring

The reliable operation of rotating machines is a must in today's competitive environment and rolling element bearings are the most critical mechanical components in almost all rotating assets in pulp and paper production. Thousands of bearings of various sizes and rotating speeds operate at any given time in a paper mill, but there is a relatively small group that carries the most economic impact – the large, relatively slow rotating bearings. The cost of these bearings is comparatively high and they are typically used in applications critical to production, such as: dryers, press rolls, kiln support rollers, wash presses and gearboxes.

Unplanned downtime events in these applications will last several hours or more with resulting costs potentially in the hundreds of thousands of dollars. Therefore, it is essential that developing problems in these bearings are found and diagnosed well in advance in order to plan and execute corrective actions with minimal negative effects on production.

Determining bearing condition through vibration monitoring is effective and well-established. Elements of this methodology include:

- Seismic sensors (accelerometers) mounted on the bearing housing
- Vibration data acquisition system (portable or online system) with the capacity to collect and analyze dynamic data (e.g. FFT and time waveform analysis), with feature extraction techniques (such as acceleration enveloping) that enhance detection and diagnosis
- Data storage and analysis software

While paper machine dryers, press rolls, and gearbox bearings do rotate slowly, the speeds are not so low that they present any particular difficulty using modern techniques. This is because impact energy is still significant at speeds between 80–300 r/min. As such, we will not discuss them any further here. However, at very low speeds (e.g. large size bearings running at 20 r/min or lower), it is often difficult to find damage early, if at all, due to inherent low impact energy and nearby noise sources. This has led to a common misconception that it is not possible to effectively monitor bearings at these very low speeds using vibration techniques.

Examination of field data has shown that, in most cases, this originates from one or more common mistakes in setting up the vibration measurement. Some common errors include:

- Incorrect enveloping filter selection
- Use of a low-frequency sensor (accelerometer)
- Incorrect mounting method
- Not accounting for possible changes in load conditions
- Inadequate measurement time length
- Not correcting for non-steady speed

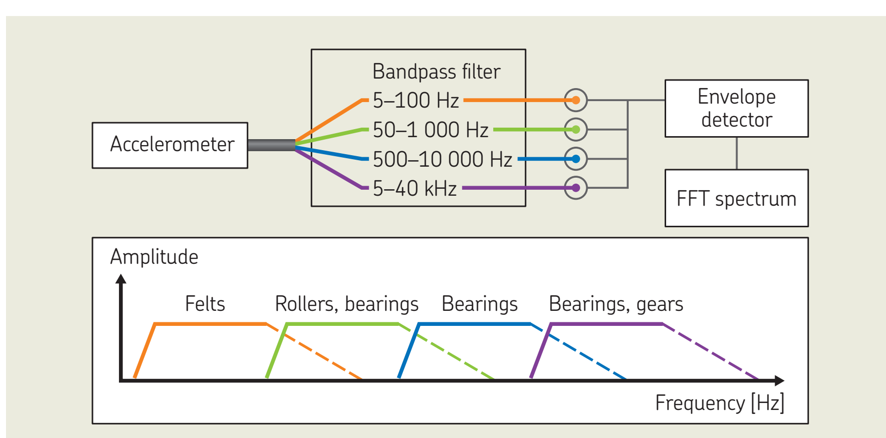

Fig. 1: Example of acceleration enveloping filters (SKF method)

For very low speed applications, the use of high frequency techniques such as acceleration enveloping has proven successful, but a common pitfall is the incorrect selection of enveloping filter. Most commercial instruments, in addition to standard vibration measurements, have selectable enveloping filter bands that focus feature extraction on a specific frequency range, both to minimize noise as well as collect signals from impacts (→ **fig. 1, page 2**). A common misconception is that the proper filters to use for low speed bearings are the lower frequency ones. In reality that is not the case as other factors such as damage size and shape, impact energy propagation to high frequencies, system resonances and noise sources in lower frequencies can (and do) mean that higher filters produce better results. Hence, when establishing a measurement strategy for a specific application, we start with several measurement types (and enveloping filters) then later trim down to the essentials based on actual results. This is part of an approach that we refer to as multi-parameter monitoring.

While it may seem that a low frequency, high sensitivity accelerometer is the best sensor for these low speed applications, examination of actual field data shows that this is not correct. In fact, we have found that the standard accelerometer (100 mv/G) performs better in the overwhelming majority of cases. There are a couple of reasons for this:

1 The response of low frequency, high sensitivity sensors is limited to typically 1–2 kHz, hence they are not suitable for higher acceleration enveloping filters

2 Due to high sensitivity, it is possible that noise sources could mask bearing impulse signals or even overload the sensor

Note that the examples that follow use data that has been collected with 100 mv/G accelerometers.

The sensor mounting method has a crucial impact especially when using high frequency feature extraction techniques (higher enveloping filters). The full frequency response of accelerometers can only be achieved with proper mounting (e.g. stud mounting). Using a magnet, for example, will drastically reduce the maximum frequency that the accelerometer can measure e.g. from 15–20 kHz down to about 3–5 kHz (→ **fig. 2**). Permanent mounting is the only way to get consistent higher frequency response, so we recommend stud mounting for best results.

We also recommend mounting the accelerometer on the bearing housing as close as possible to the load zone in order to get the best possible signal. This is particularly important in cases where the impact energy from bearing damage is expected to be weak e.g. in very low speed applications. Note that the propagation of high frequency vibration is negatively impacted by distance as well as mechanical interfaces. In practice, it may not be practical to mount the sensor in the ideal location, but this is not a show-stopper especially when using stud-mounted accelerometers. A bigger challenge is when bearing loading could change (e.g. change of load direction, no-load operating conditions). In such cases, it is often necessary to use a permanently installed online system to minimize the risk of a "false negative" as would happen, for example, if a measurement were taken when the bearing was not loaded.

Perhaps one of the most common errors made when trying to find problems in low speed bearings is not collecting a long enough time waveform to clearly show defect frequencies in the spectrum. A good rule of thumb is to get a waveform equivalent to at least 15–20 revolutions of the shaft. For example, for a bearing running at say 10 r/min (6 seconds per revolution), the waveform should be at least 90–120 seconds. In practice, the longer the time waveform, the better the results. This, however, has to be balanced against practical factors e.g. long data collection time, more memory used up for storage, etc.

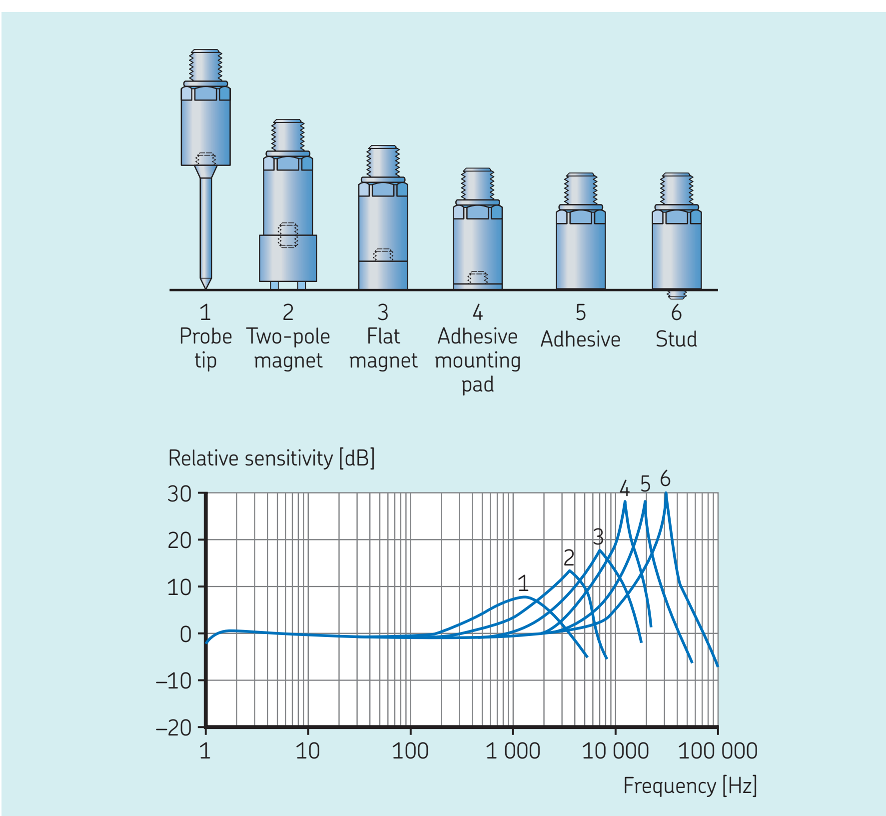

Fig. 2: Frequency response with different mounting methods

Example 1 – Lime kiln support roller bearing

To illustrate the effectiveness of our low speed monitoring techniques, let us consider the example of a kiln support roller bearing turning at around 6 r/min (→ **fig. 3**). The key measurement specifications were as follows:

Device: Portable data collector/FFT analyzer
Sensor: 100 mv/G accelerometer
Acceleration enveloping filter: 500–10 000 Hz (SKF Filter 3)
Measurement time: 213,3 seconds (note 1 revolution = 10 seconds, hence this represents more than 20 revolutions of the bearing inner ring).

Damage to the outer ring was first detected in April, 2006. The spectrum peaks from the acceleration enveloping measurement precisely match the expected defect frequency of the bearing, leaving no doubt that damage has occurred (→ **fig. 4**).

Fig. 3: Lime kiln support rollers

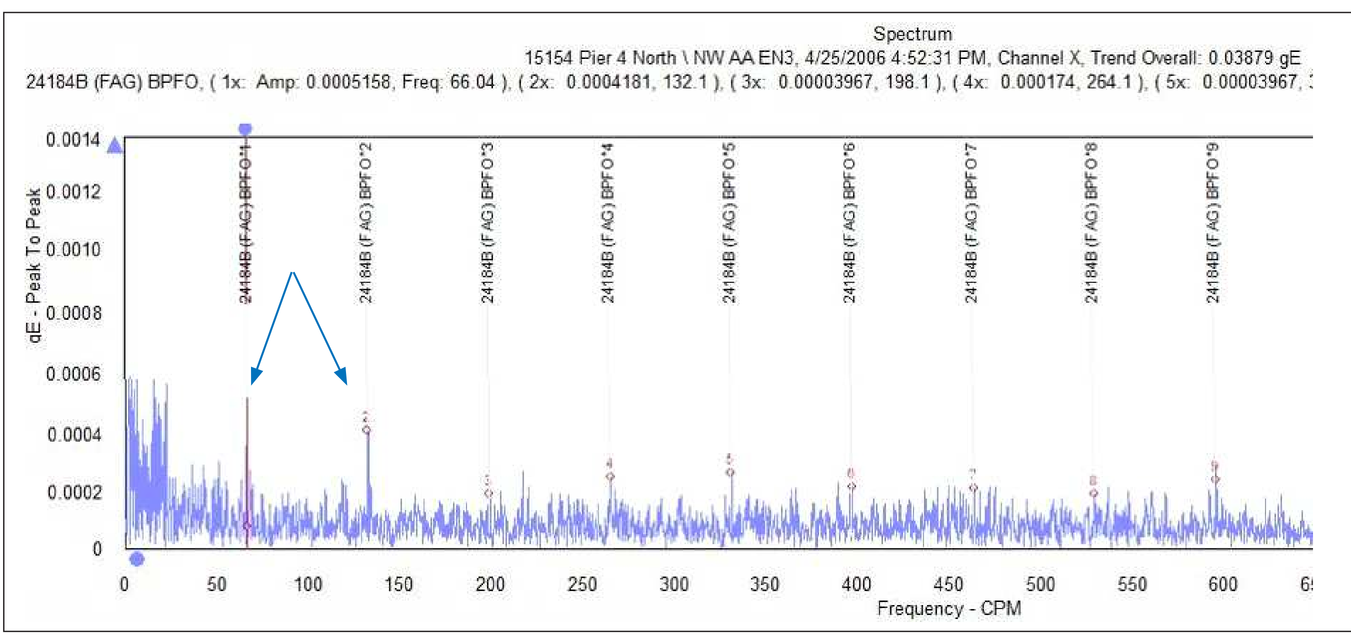

Fig. 4: Acceleration enveloping spectrum showing damage on bearing 24184B outer race

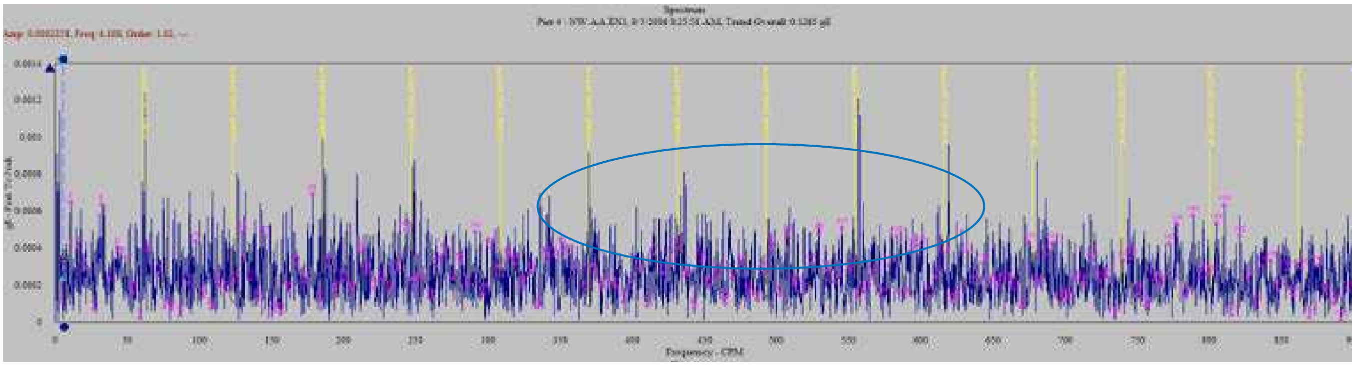

Fig. 5: Spectrum taken five months later showing less distinct peaks

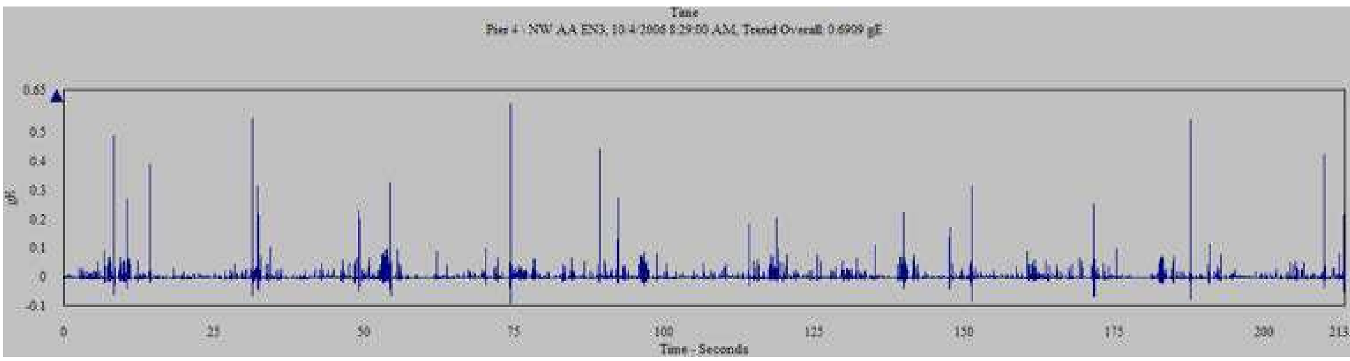

Fig. 6: Time waveform showing multiple high energy impacts from bearing damage

As a bearing deteriorates, it is not unusual for peaks in the spectrum to change patterns or lose their distinctness due to potential growth of the damage area and/or potential multiple impact points. **Fig. 5** shows the spectrum five months later. Note that the peaks (particularly the first and second harmonics) are less dominant, but higher order harmonics are slightly visible.

At this point the damage had grown quite significantly and the bearing needed to be replaced soon. The time waveform display taken just before the bearing was replaced in October (→ **fig. 6**) shows multiple roller impacts on the raceways indicating severe damage. This was verified when the bearing was replaced (→ **fig. 7**). As can be seen from the damage pattern, the bearing was subjected to large axial forces.

Summarizing the key points of this case:

1 Vibration monitoring was effective in finding and successfully tracking bearing damage at this low speed. The right measurement parameter (acceleration enveloping) and sufficient measurement time were the keys.

2 The lead time of almost six months from initial detection to severe damage allowed for proper planning and thus avoidance of many hours of unscheduled downtime, resulting in hundreds of thousands of dollars in savings.

One characteristic of this case that made detection and analysis relatively straightforward is that despite the bearing rotational speed being very low, it was fairly steady during data acquisition. In addition, the loading was also fairly consistent, so even though the measurement interval was several weeks and measurements were taken with a portable data collector, it was still possible to effectively track damage progression.

Fig. 7: Severely damaged bearing outer race

Example 2 – Twin roll press bearing

The situation changes, however, in cases where the rotational speed is not steady. A good example of this is a twin roll press which typically runs from about 6 to 12 r/min (→ **fig. 8**).

The press rolls, which are driven by hydraulic drives, constantly change speed due to loading conditions. **Fig. 9** shows the typical scale of speed changes during normal operation.

Wash presses of this type have caused monitoring problems (i.e. undetected failures) in the past in spite of proven success with vibration techniques in these speed ranges. The main problem, as it turns out, is the failure to account for non-steady operating speed. Since the speed changes during data acquisition, it was necessary to use a technique called "order tracking" to avoid a phenomenon in the resulting spectrum

Fig. 8: Twin roll press

Speed starting at 3:01:32 ending at 3:17:

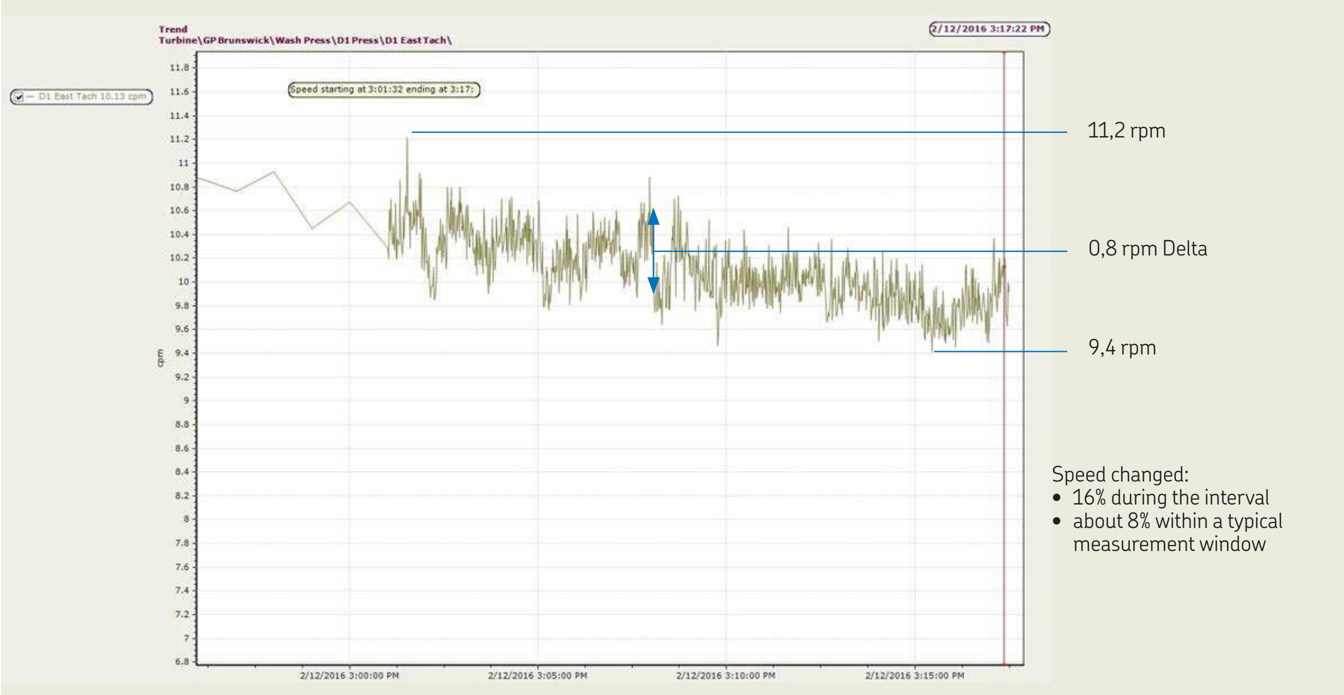

Fig. 9: Example of non-steady speed during operation

referred to as ”smearing”. The effect of smearing is shown in **fig. 10**.

Order tracking uses a speed reference (e.g. tachometer pulse) to compensate for non-steady speed (→ **fig. 11**). The result is a time waveform with samples in the “right” places (even though the speed is changing during measurement).

Below are some key measurement specifications for this wash press example:

Device: Online system with enveloping and order tracking capabilities
Sensor: 100 mv/G accelerometer
Tachometer: Inductive sensor (for reference pulse)
Acceleration enveloping filter: 5–40 kHz (SKF Filter 4)
Number of Orders: 100

Since an online system collects data automatically, it has the advantage of recording data at much shorter intervals than is practical with a portable system. This was an important feature in finding and tracking the bearing fault in this specific case. **Fig. 12** shows the trend of the bearing frequencies as measured with acceleration enveloping with order tracking. It can be seen that the inner ring damage trend increased significantly at the end of March, then went down at the beginning of April. Without an online system it is possible that this event would have been missed. Indications of outer race damage about a month later also pointed to increasing damage severity.

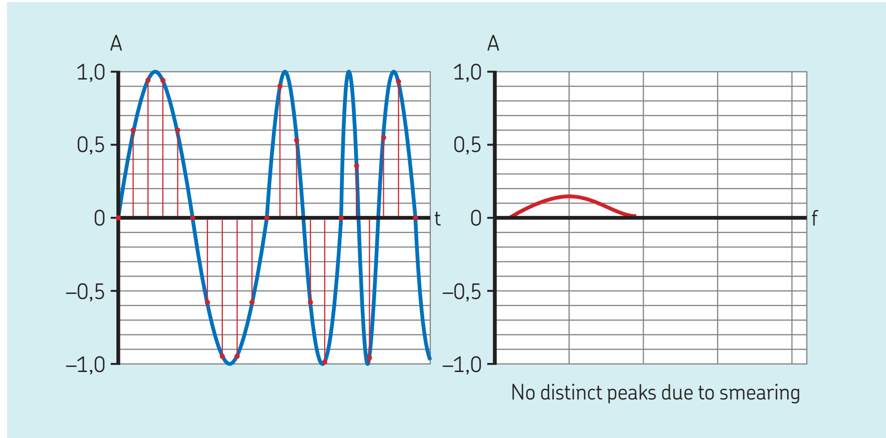

Fig. 10: Fixed sampling during non-steady speed operation results in smearing

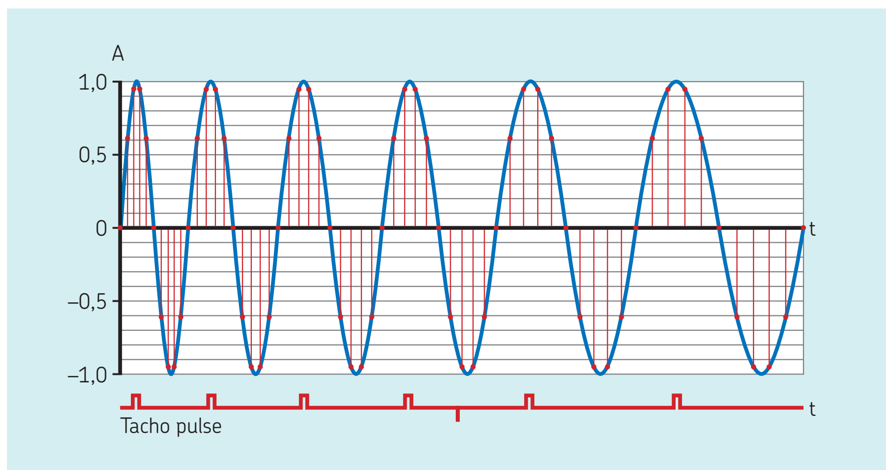

Fig. 11: Order tracking

Fig. 12: Trend of bearing frequencies

Fig. 13 shows the frequency spectrum at the end of March with very clear inner ring defect peaks, harmonics, and sidebands. This frequency pattern type seen at this high enveloping filter range indicates a small but sharp-edged bearing defect.

It was observed that the frequency peaks, which had been quite clear, disappeared after some time. **Fig. 14** shows the frequency spectrum in July which, in contrast to **fig. 13**, shows no peaks that match the bearing frequencies. It was suspected that the inner ring may have started to slip on the shaft (which could happen with a cracked inner ring), prompting the decision to replace the bearing at the earliest opportunity.

In September, a spectrum taken just before the bearing was replaced showed peaks at the rotation speed and its harmonics indicating looseness (→ **fig. 15**).

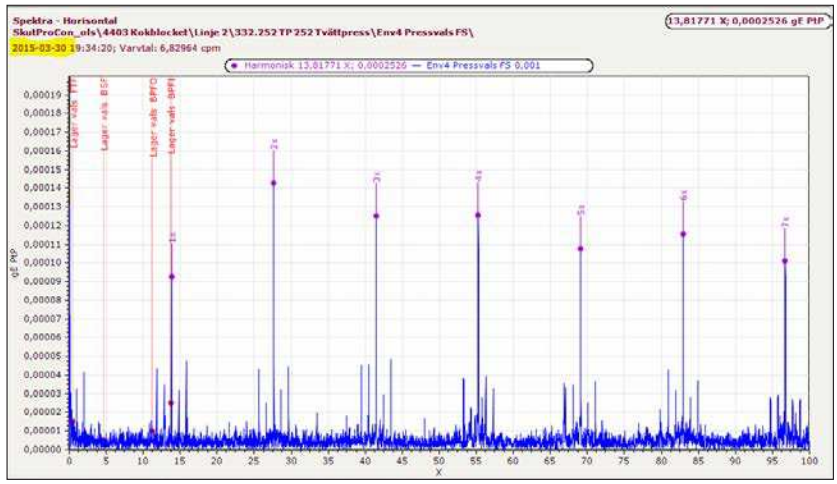

Fig. 13: Frequency spectrum showing clear inner ring bearing damage

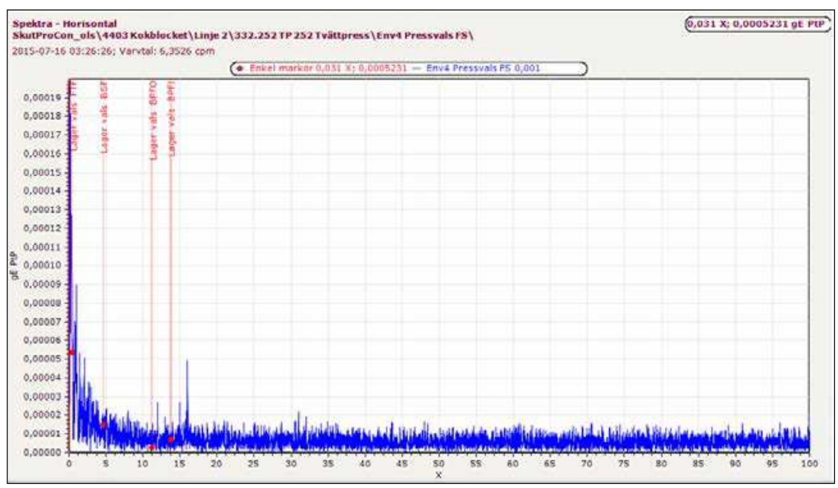

Fig. 14: Spectrum taken in July; bearing defect peaks have disappeared

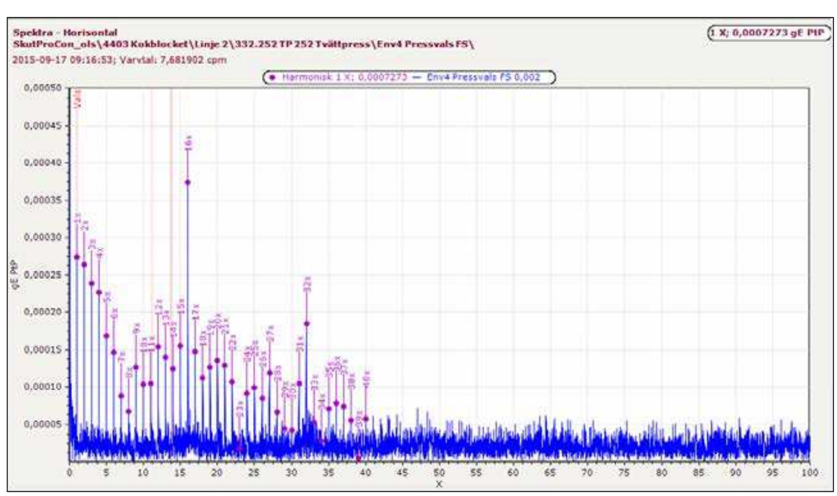

Fig. 15: Spectrum showing running speed harmonics, an indication of looseness

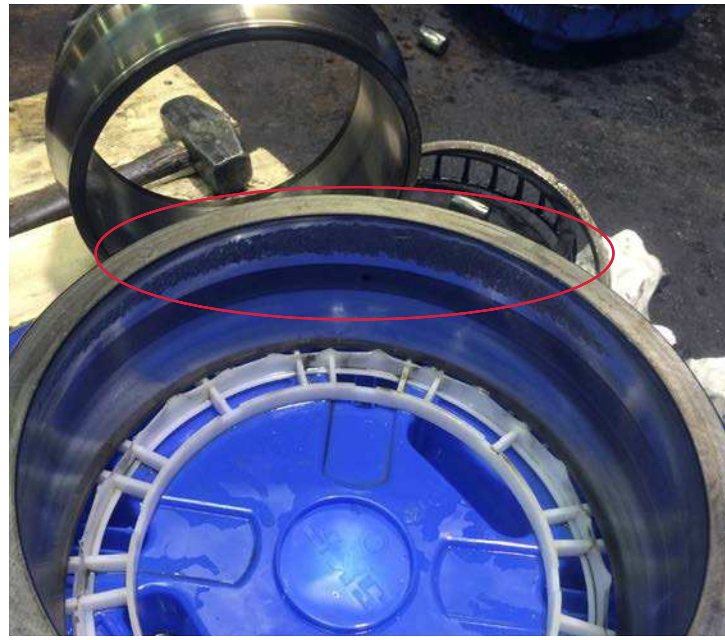

Fig. 16: Damaged bearing inner and outer rings

Fig. 16 shows the bearing after it was dismounted and cleaned for root cause failure analysis. Both the inner ring crack as well as damage from one side/roller set are clearly visible. The latter indicates the possibility of overloading in the axial direction or wear from contamination or insufficient lubrication.

Twin roll press bearings have a service life of about five years or more, but it is not uncommon to find instances where they last less than two years especially with certain designs. Typical problems include:

1. Contamination from process fluids through seals that lose effectiveness
2. Residual axial stress from lack of sufficient expansion due to wear on housings

Achieving full service life is possible depending on the root cause. Some actions that can be taken include:

1. Modifying the seal design and improving seal lubrication
2. Improving bearing lubrication by installing an oil circulation system with efficient water/oil separation
3. Replacing spherical roller bearings with CARB bearings

In one memorable customer case, improvements increased bearing service life from 18 months to over five years resulting in total savings estimated at US$ 500 000.

Key points from this example:

1. Application conditions, e.g. non-steady speed, must be well understood so the right techniques can be used
2. Better data from an online system can be the difference between finding or missing a developing problem in very low speed applications

Conclusion

Large, low speed bearings are found in many critical applications in pulp and paper mills. Vibration techniques and instrumentation are available to monitor them effectively, but undetected failures in some very low speed applications have put this in doubt in some people's minds. The main reasons for missing bearing failures are incorrect application of techniques and/or lack of understanding of operating conditions. The successful detection and diagnosis of two cases with bearings running below 10 r/min demonstrate the effectiveness of vibration monitoring when applied correctly.

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