Condition Monitoring Redefined

The Low RPM Challenge

Using traditional vibration measurement techniques to monitor bearings rotating below 100 RPM is very difficult. The useful signals emitted from potential spalls or cracks in the bearing raceways are very low in energy content. In a normal industrial environment, ambient noise will sometimes almost completely drown out the weaker, bearing-related signals.

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The patented SPM HD® method redefines the practice of condition monitoring on low RPM applications. The method is designed to provide instant condition information of rolling element bearings in green, yellow or red in a wide RPM range. The real challenge lies in low-speed applications, but the sensitivity of the method captures the interesting but weak, bearing-related signals while suppressing the signals of ambient noise.

During four years of field testing and real-life industrial use worldwide, the method has proven itself in numerous examples of successful bearing fault identification at very low RPMs, in many cases well below 10 RPM.

The Method

The use of high performance low-noise electronic components and extensive digital signal processing enables the method to detect extremely small shock pulses (see fact-box). Even well lubricated bearings in mint condition emit very small shocks that can be captured and measured. An incipient spall, so small that it is barely visible, still creates distinct shocks which are reliably detected. A traditional vibration measurement approach on the other hand will not detect these microscopic spalls because the energy is not high enough to trigger the transducer, at least not at low rotational speeds.

The method samples the transducer signal and produces four different results:

- HDm represents the highest shock pulse found during the measurement time, expressed in decibels. Normally the value for indication of the bearing's mechanical condition.
- HDc is the threshold level, where 200 shocks per second are detected. HDc is expressed in decibels, and is normally the value for indication of lubrication condition.
- Time Signal HD is the sampled shock pulse time wave form.
- Spectrum HD is the Fast Fourier Transform of the Time Signal HD value.

The reason for measuring the values on a decibel scale is the inherent high dynamics of the shock pulse signal. To take full advantage of the dynamics, the hardware implementation of the method uses a 24 bit A/D converter and a resulting dynamic range of more than 110 dB with no gain adjustment. The sampling rate is 102.400 samples per second and using HD Order Tracking, the signal is digitally decimated to fit the analyzing frequency range. The samples are adjusted to the current RPM using the patented order tracking algorithm, then a second algorithm enhances repetitive shocks while suppressing

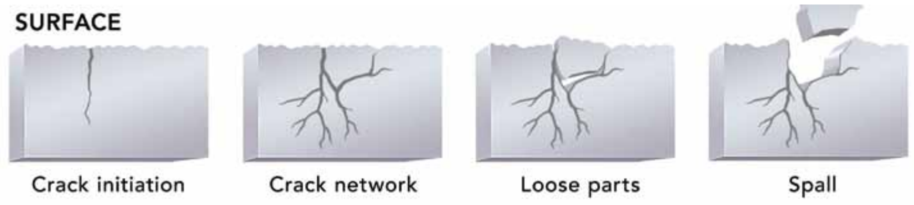

FIGURE 1. *A typical bearing spall development pattern.*

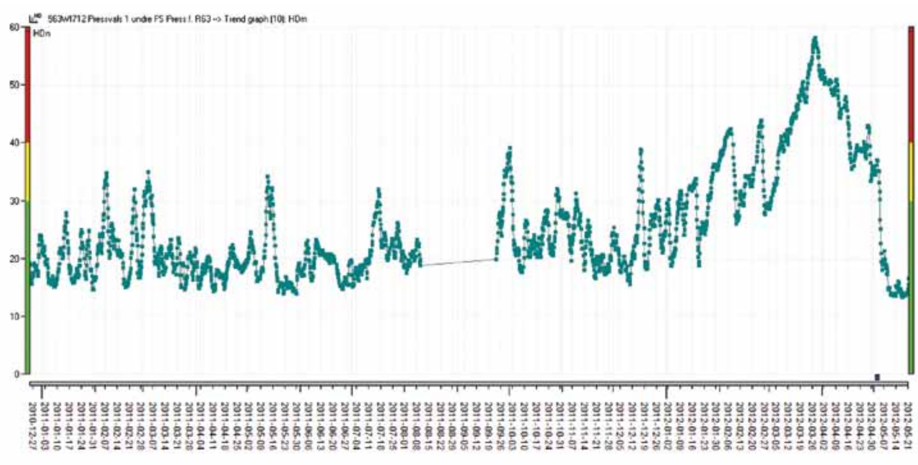

FIGURE 2. *Typical shape of HDm values at 5–6 RPM in a trend graph spanning over 1.5 years.*

random ones. The resulting Time signal HD is unusually distinct, mostly due to these and a number of other algorithms.

In summary, shock pulse measurement with SPM HD® is a technology specialized in detecting elastic waves/shock pulses emitted from spalls and cracks in bearings. The method is extremely sensitive, making it optimal for low RPM applications.

The Typical Development of Bearing Spalls

When a rolling element passes a given point of a bearing surface, the pressure on that point can be extremely high. As each rolling element passes, the high pressure pushes the lubrication media into the microscopic cracks normally found in the raceway surfaces. This is repeated throughout the bearing's lifetime. Over time, the repetitive stress can cause the microscopic cracks to form a network of larger cracks, eventually leading to a spall (**FIGURE 1**). Based on practical results described later on it can be concluded that it is relatively common for a metal part to be partially loose for some time before it detaches entirely. Until completely broken away, the semi-loose part will be constantly hit by the rolling elements, generating shock pulses. When a metal part comes off completely, it leaves sharp, protruding edges in the bearing raceways. While these edges are slowly worn down, they constitute yet another fault mechanism.

Detection of Early-Stage Spalling

As described above, a spall results in collisions between the rolling elements and either a semi loose part of the bearing or the sharp edges induced by a fresh spall. Even an extremely small spall still in its very early stages will emit shocks, although fairly weak in strength. These shocks will propagate in the bearing and eventually reach the outer parts of the bearing housing, where a shock pulse transducer will detect the shocks and indicate increased shock pulse levels. While the sharp edges of the spall are being worn down or when the semi-loose part comes off completely, there will be a decrease in the shock pulse levels, because the rolling elements will pass the spall, "carried over" it by

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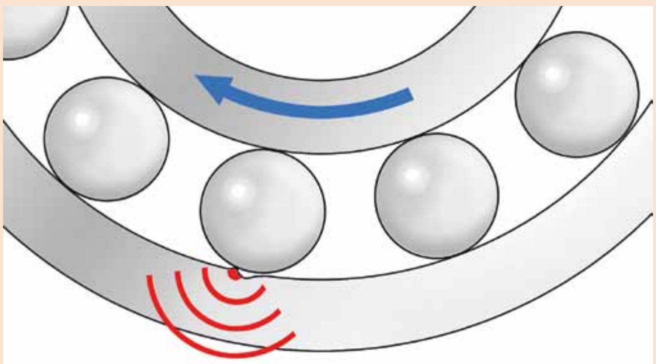
Shock pulses – Basic Principles

»**SHOCK** pulses are elastic waves in rigid materials (typically steel) with very short rise and fall times. They propagate in the bulk material with the speed of sound (typically 5000m/s). Shock pulses originate from the point of contact between two objects that collide, e.g. a roller hitting the sharp edge of a spall in the raceway of a rotating bearing.

The short duration of the elastic wave results in a signal containing broad spectra of energy, generally well above 50 kHz.

The shock pulse transducer is specifically designed to pick up shock pulses, responding in a very distinct and precise way when exposed to these pulses. Due to its sensitivity, even microscopic collisions are detected. The transducer is tuned to have its peak sensitivity at 32 KHz, resulting in suppression of lower and higher frequencies. The broad frequency content in the shock pulse signal triggers the 32 KHz oscillation in the transducer.

A shock pulse transducer therefore is not sensitive to lower frequencies typically originating from unbalance and misalignment. It is designed to capture shocks only. Shock pulses can travel for long distances in homogenous material but can be somewhat sensitive to material interfaces. ■



Even well lubricated bearings in mint condition emit very small shocks that can be captured and measured.

other surfaces around the spall creating no collisions. Judging from field experience, an initial spall results in high shock values which will remain high for some time until they either decrease slowly or drop abruptly. The "edge wear process" takes longer, hence resulting in slowly decreasing values, while the "semi-loose part" process results in the abruptly decreasing values.

A shock pulse trend showing the typical increasing/decreasing pattern followed by a longer period with low values can be a warning sign of imminent bearing failure. The next spall can be sinister, leading to rapidly increasing shock pulse values. The important conclusion is that a typical spalling process results in periods of increasing shock pulse values followed by periods of decreasing values. The periods of elevated shock values are indicative of an "active" spall (i.e. a spalling process giving rise to shock pulses). There are examples of low RPM applications where an active period was followed by low shock pulse values for over a year before the next spall occurred.

FIGURE 2 shows a typical shape of HDm values in a trend graph spanning over 1.5 years. In this 5–6 RPM application, the high peak values represent new active spalls. The bearing was replaced after the high peak seen in the right part of the graph. The spalls were initially located at the outer race. The very high values represent inner race spalls and finally a crack.

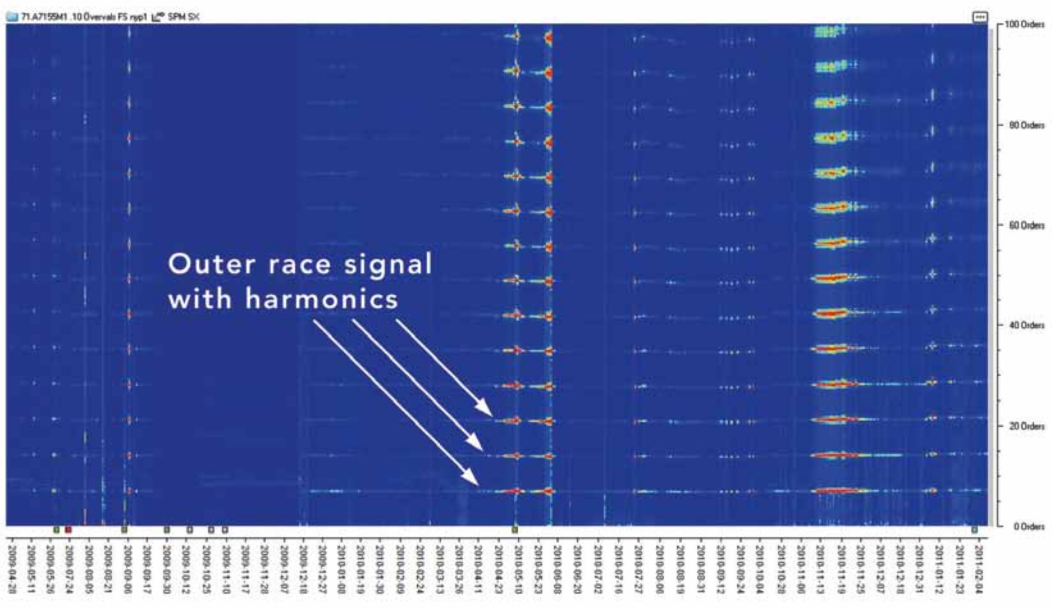


FIGURE 3. *This Color Spectrum Overview contains several thousand spectrums spanning over 21 months. The red color indicates fresh spalling, clearly visible in the increasing and decreasing signal pattern typical for this application.*

Colored Spectrum Overview – Basic Principles

The Colored Spectrum Overview resembles the waterfall diagram, but is viewed from above and can contain many more spectrums. Far more efficient than the waterfall diagram, it presents a three-dimensional view of up to several thousand spectrums with color-coded amplitudes in one picture. The purpose of the Colored Spectrum Overview is to simplify the process of identifying in spectrums the patterns and trends that indicate damages.

Imagine a large number of spectrums arranged in a waterfall plot, viewing the spectrums directly from above. Assign a color "dot" to each individual spectrum line, with dark blue representing low amplitudes and red representing high amplitudes. Using for example 1600 lines and 2 000 spectrums results in a color picture with 1600 X 2000 pixels = 3.2 million pixels where each single pixel is color coded, representing the amplitude of a particular line (bin).

The y-axis represents frequency in orders (or in Hz) while the x-axis represents the date and time of the measurement, with the oldest measurement to the left. A frequency peak occuring in several spectrums will show up as horizontal lines in the color picture (FIGURE 3).

In the above example, the x-axis represents the date of the individual measurements, while the y-axis unit represents 0 to 100 orders. A horizontal line indicates a peak in the spectrum that can be seen in spectrums from several dates; it is consistent.

FIGURE 4. *Severely damaged outer race of the twin wire press bearing. The damage process was monitored for more than a year, enabling the replacement to be planned at the best possible time.*

Summary

The SPM HD® method is excellent for condition monitoring of low RPM applications. Using SPM HD®, a spalling process can be closely monitored over a period of many months. The typical signal patterns in these cases are either:

- slowly increasing shock pulse values followed by a slow decrease; typical for metal parts from the raceways that are partly broken loose
- slowly increasing shock pulse values followed by a rapid drop, typically where damages are caused by sharp edges of a spall when it is completely broken away.

The SPM HD® method not only shows the existence of a potential damage, but the unique sensitivity of the method makes it possible to monitor the damage process in great detail, even down to individual spalls. As the damage progresses, the severity can be followed and replacement planned at the best suitable time. ■