
The Shock Pulse Method and the Four Failure Stages of Rolling Element Bearings

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1 Scope of this document

This document is intended to describe the four failure stages of rolling element bearings as seen from a shock pulse perspective. The document can be used as a guideline when interpreting shock pulse data.

2 Introduction

Since the introduction of the Shock Pulse Method (aka SPM method) in the early 1970s, countless shock pulse measurements have been taken on bearings in various stages of deterioration.

Sometimes, a text book example of increasing shock pulse trends could not be connected to any clearly visible faults in the bearing raceways. Occasionally, low shock pulse values from a bearing with no apparent increasing trend were followed by a negative surprise when the bearing malfunctioned shortly afterwards. In most cases, as you know, the SPM method has been able to successfully detect bearing faults well in time before bearing malfunction.

The idea with this document is to describe why the SPM method along with other enveloping/demodulation techniques react the way they do in the different stages of bearing deterioration.

Most of the theories described in this document are applicable to roller bearings, especially the increasing/decreasing trends described later are most pronounced in this type of bearings compared to ball bearings.

The root cause of bearing failures will not be discussed here; there are many good descriptions discussing in detail why bearings fail.

3 The four stages of bearing failures

It is commonly accepted to describe the bearing wear/failure process in four stages.

3.1 Stage 1

At this stage, damages are extremely small and normally located sub-surface. If a bearing is replaced at this stage, there are normally no visual imperfections in the raceways. It is assumed that the bearing still has 10-20% of its L10 left.

The SPM method will react at this stage and show slightly elevated HDm values. The HD Spectrum can show relatively clear, predominantly outer race, symptoms in the case of a fixed outer ring.

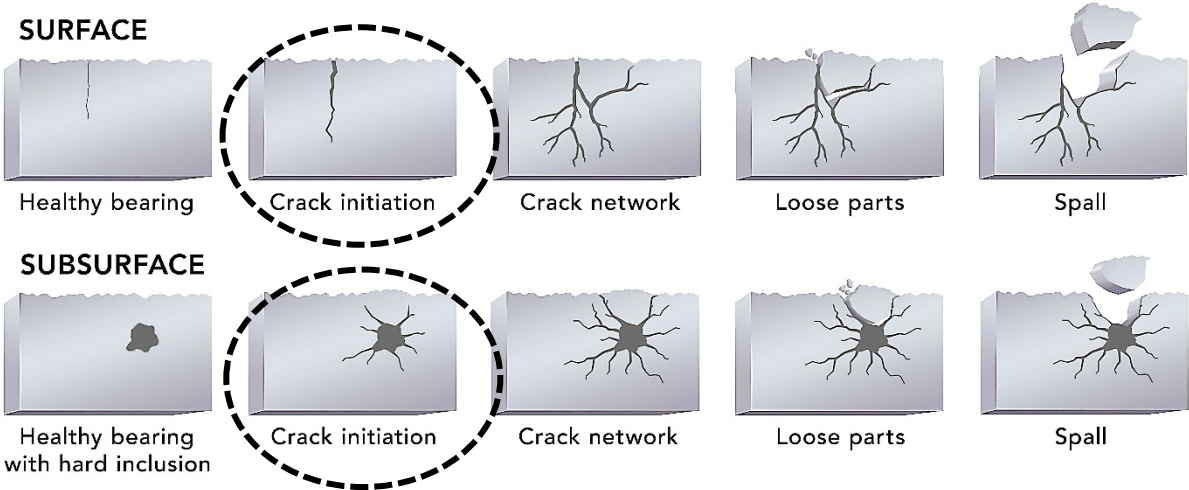
At this stage, the HDM values as well as the bearing symptom values typically do not show the classical slowly increasing/decreasing trends; it is more of a constant, slightly higher than normal amplitude.

There is a risk, at this stage, that the clear and crisp readings from the SPM HD method are interpreted as signs of severe damage. In the field, we have seen examples where, despite clear outer race signals, there were no visible damages on the raceways when the bearing was replaced. This situation is more common among analysts who are more experienced with interpreting vibration spectra. Because vibration sensors have much lower sensitivity to early bearing damage, a clear spectral match in the SPM HD spectrum can be incorrectly interpreted as more severe than it actually is.

The reason the SPM method can detect these sub-surface damages is that, due to lack of homogeneity in the raceway material, small compression waves are caused when the rolling elements pass points of sub-surface damage. When the lubricant medium in the bearing is exposed to a pressure change due to microscopic cracks, or when a hard inclusion creates a microscopic surface irregularity, very low amplitude shocks are created.

A vibration reading in velocity units definitely will not show any signs of bearing defects at this stage. An acceleration spectrum could, however very rarely, pick up signs of damage. A vibration enveloping reading with the band pass/high pass filters set to high frequencies (>10 KHz) can sometimes detect a sub-surface damage.

Fig 1. Examples of stage 1 defects, normally not visible on the raceways surfaces.



3.2 Stage 2

The sub-surface imperfections will grow and will eventually reach the raceway surfaces, causing spalls, cracks and flakes (and similar damages). The damages are still small, but there are occasionally metal-to-metal impacts between the sharp edges of the damages and the rolling elements. If the impacts are strong enough, the energy can cause the bearing structure to “ring” at its natural frequencies.

There is now approximately 5 to 10% left of L10.

The SPM method will normally show higher HDm values and spectrum symptoms. At irregular time intervals, strong, very clear and distinct bearing signals appear, lasting only a short time. At this stage, the surface damages are very small and the sharp edges around the damages are quickly wearing down. A typical shock pulse pattern is clearly elevated levels of HDm and spectrum symptoms lasting for only a short time. I have seen several examples of very clear and distinct signals from the outer race of a bearing with many harmonics and HDm values 10 to 20 dBs higher, lasting only for a day or two and then disappearing. This is a typical pattern for very early stage, small surface damages. A bearing that is replaced, especially early in stage 2, shows only very small, barely visible damages.

Vibration enveloping, with carefully tuned enveloping filters, can be used in stage 2. Vibration velocity still will not showing any clear signs, while vibration acceleration readings can show increased values during short time intervals.

Fig 2. A Colored Spectrum Overview picture showing an outer race signal. The activity lasts only for a couple of hours. Example of stage 2 damages; very small with sharp edges worn down rapidly.

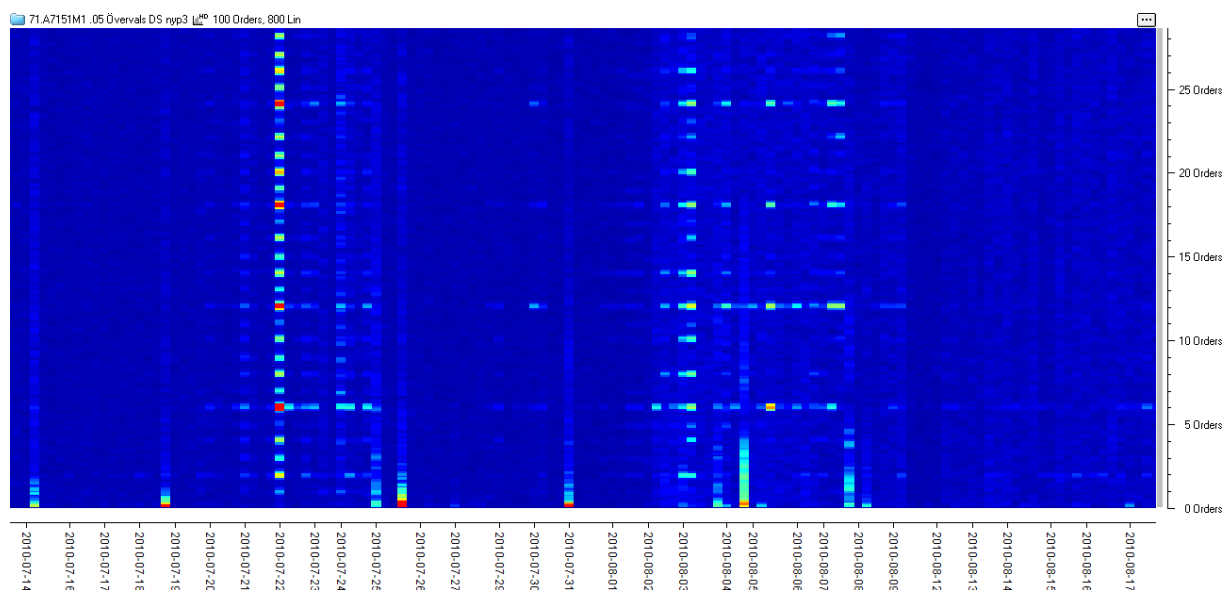


Fig 3. The corresponding HDm graph, showing the HDm raw values. Note the short duration of the high HDm values.

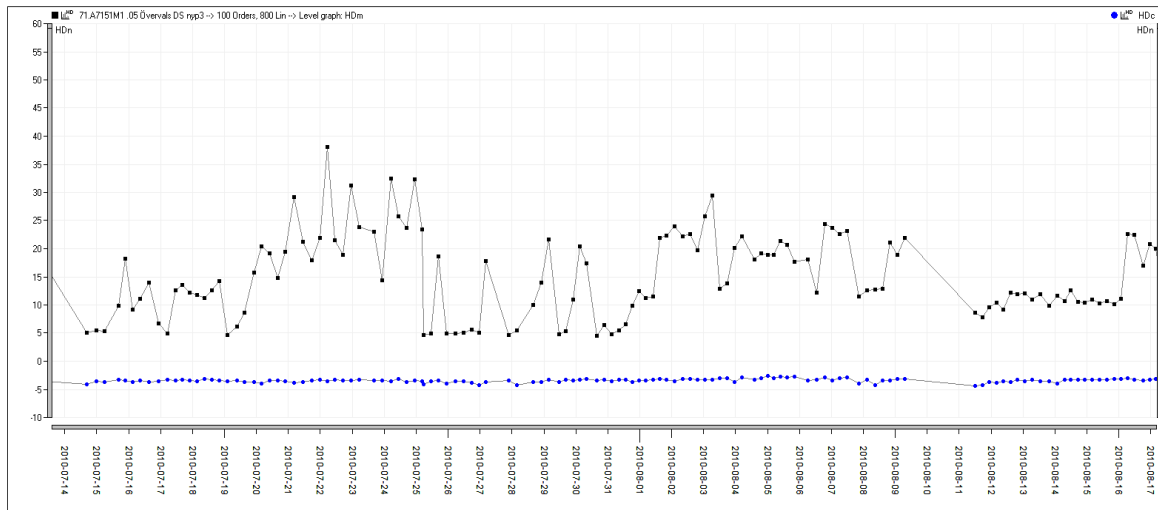
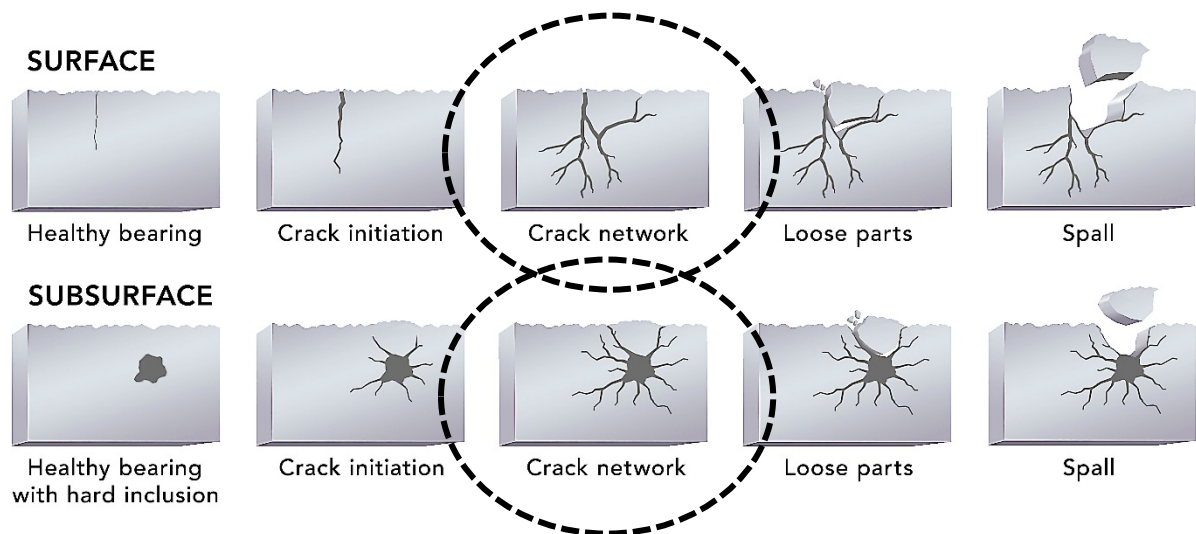


Fig 4. Stage 2 damages, barely visible when inspected.



3.3 Stage 3

The surface damages are now more pronounced. Several areas with spalls and similar surface damages can be observed. Less than 5% of the L10 life remains. *This is the optimal time for bearing replacement.*

The shock pulse values show long periods of high levels and the classic increasing trends followed by decreasing levels can often be observed. The Colored Spectrum Overview function can be used to reveal if there is a spall process going on in the bearing. Depending on load, RPM, temperature and other application related parameters, the periods of increasing trends may last for many days or weeks, followed sometimes by slowly decreasing levels or abruptly decreasing levels. The slowly decreasing levels is a sign that the sharp edges around a fresh spall are wearing down, while an abruptly decreasing level is a sign of metal parts breaking away from the raceways.

In stage 3, the overall velocity trend starts to increase and acceleration trends are still useful. Vibration enveloping shows a similar pattern as the SPM method with the increasing/decreasing trends.

Fig 5. An example of a bearing in stage 3 with a classic increasing outer race amplitude lasting for several weeks. The outer race signal decreases rapidly indicating a metal part broken away. This pattern is a sure sign of a bearing damage.

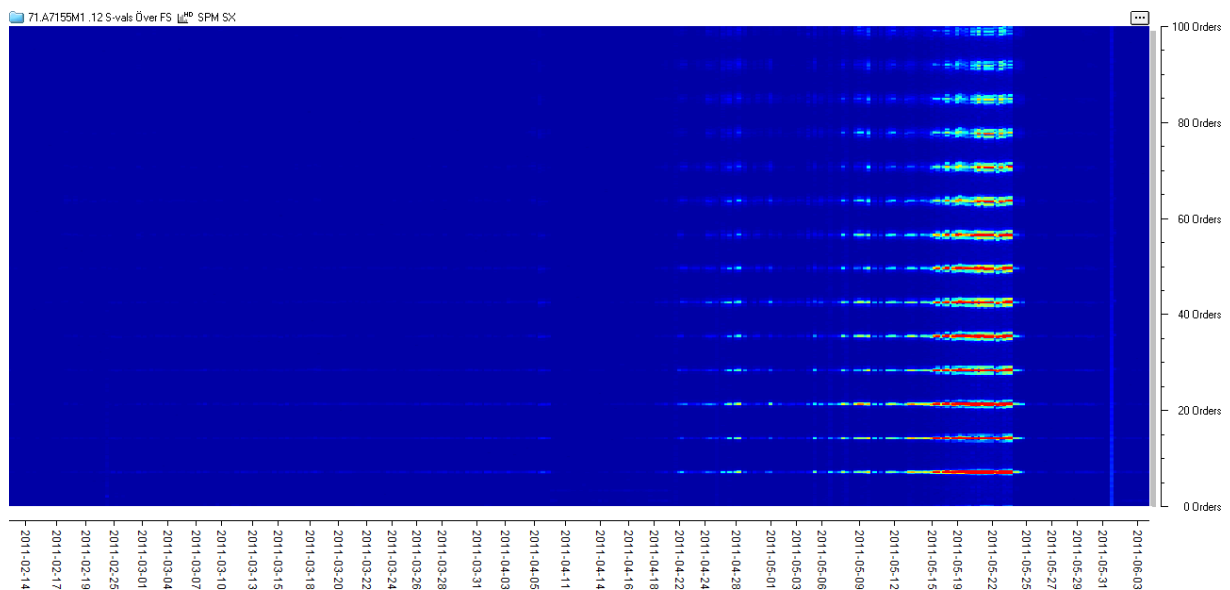


Fig 6. The corresponding HDm trend; a moving average graph where the gradually increasing trend pattern is clearly seen.

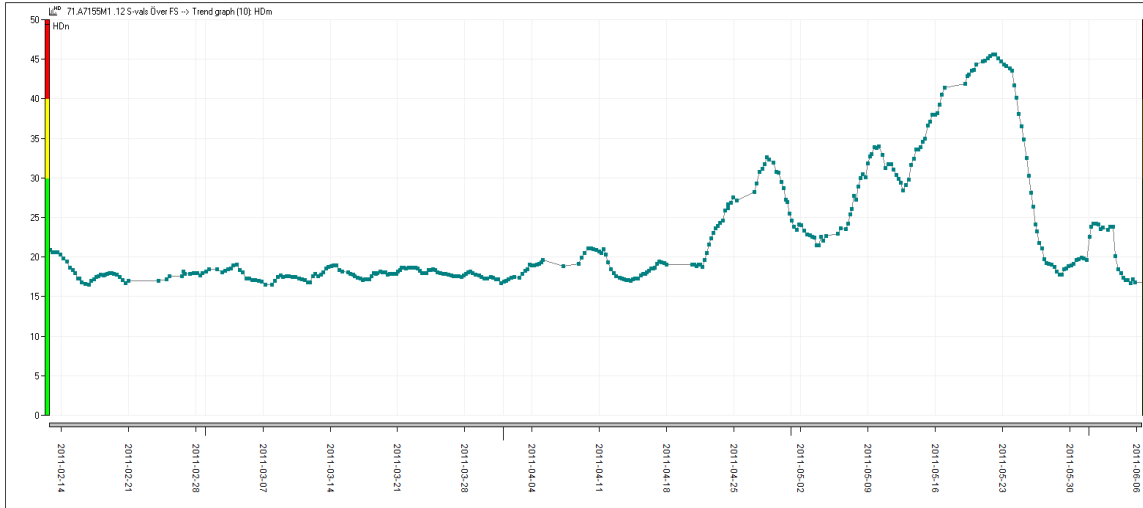
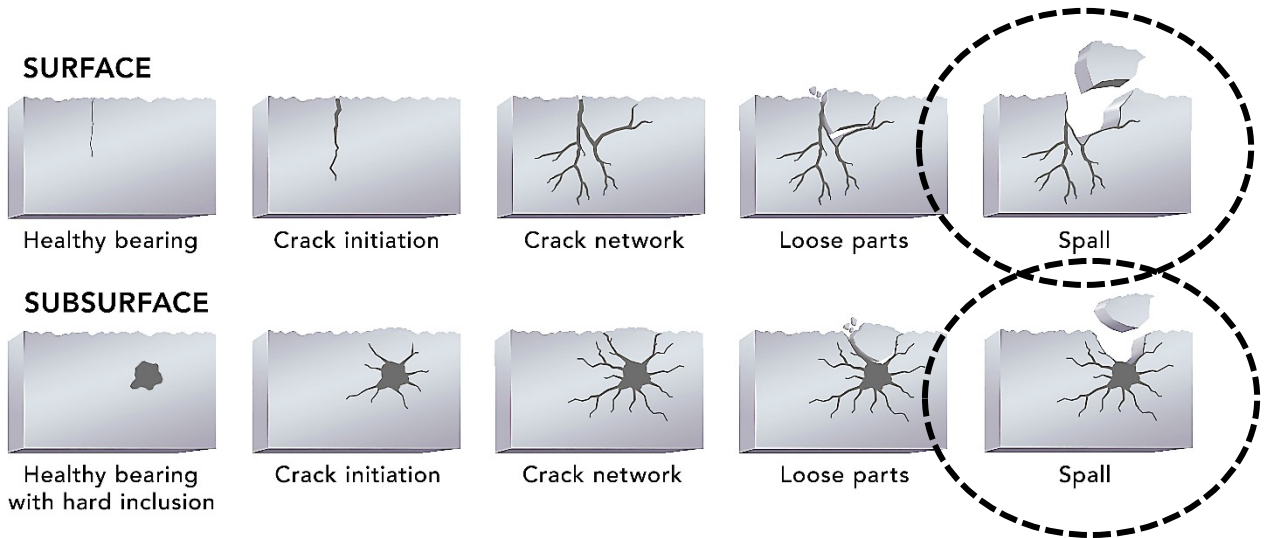


Fig 7. Stage 3 damage, clearly visible damages when inspected.



3.4 Stage 4

The bearing is now severely damaged. Surface damages are found in several locations; the inner and outer raceways and the rolling elements have all been affected. Less than 1% of the L10 life remains.

There is a very high risk of total bearing failure. The sharp edges around the surface damages that were created in stage 3 are worn down, forming "round edges". There may be loose metal particles in the bearing, occasionally sticking to the raceways and creating random strong impacts.

The shock pulse values may decrease in this stage. Due to the "rounded" edges, there are few repetitive metal-to-metal impacts so the shock pulse values may be low. Vibration enveloping and acceleration trends show the same pattern with decreasing values while a velocity trend shows an increasing trend. At this stage, the increased clearance in the bearing creates 1X frequency components that increase in amplitude.

At the end of stage 4, a short time before a complete bearing failure, the shock pulse trend as well as the vibration enveloping trend may increase dramatically. This is caused by bigger metal particles or cracks in the raceways, contributing to strong impacts of random nature.

Fig 8. An HDm graph showing a bearing in stage 4 with relatively low values with a steep increase just before complete bearing failure. Note the high HDm levels; 80 dB (normalized). The difference between the normal level of 20 dB and the maximum level of 80 dB makes a 60 dB increase; that equals a 1000-fold increase on a linear scale!

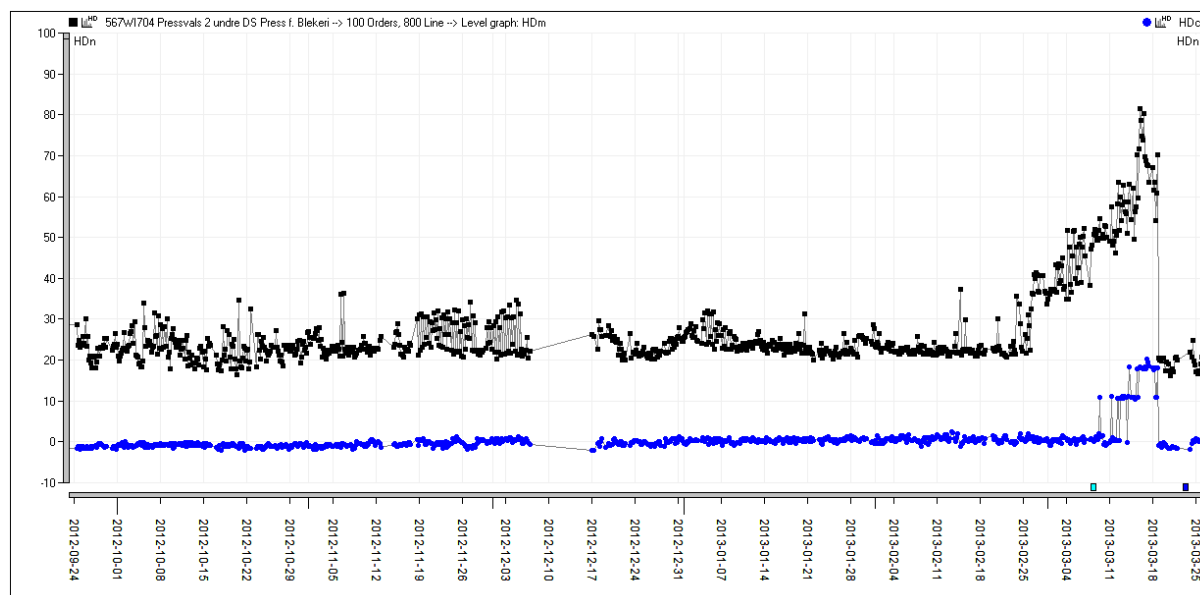
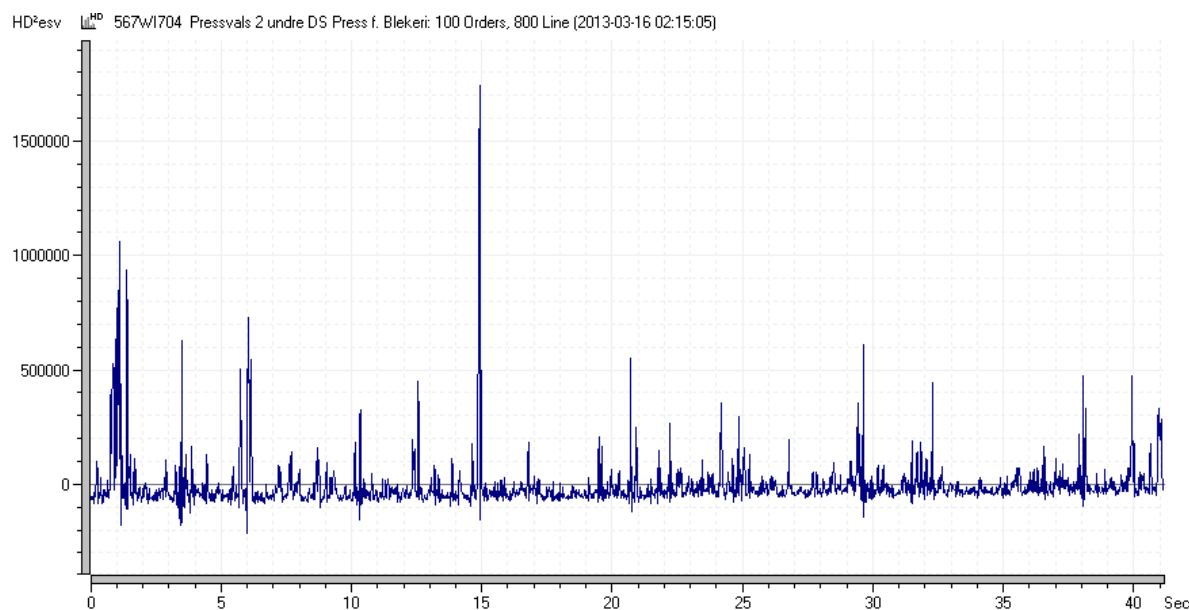


Fig 9. An SPM HD Timesignal at $HDm = 79$ dB. Random high values indicating loose metal particles inside the bearing.



4 Conclusions and discussion

It is vital for the interpretation of shock pulse readings to understand the bearing deterioration process. *The shocks originate from mechanical impacts and the nature of the impacts changes depending on where in the wear process the bearing is.*

In general, the SPM method and specially the High Definition version (SPM HD) is a very good method for early bearing damage detection. It covers a very broad RPM range, from ultra-low RPMs (< 1 RPM) to above 20 000 RPMs. The sensitivity of the method however can create situations where, following clear bearing symptoms, a bearing is replaced too soon. A bearing replaced in stage 1 or 2 may have only sub-surface damages or barely visible marks on the raceways.

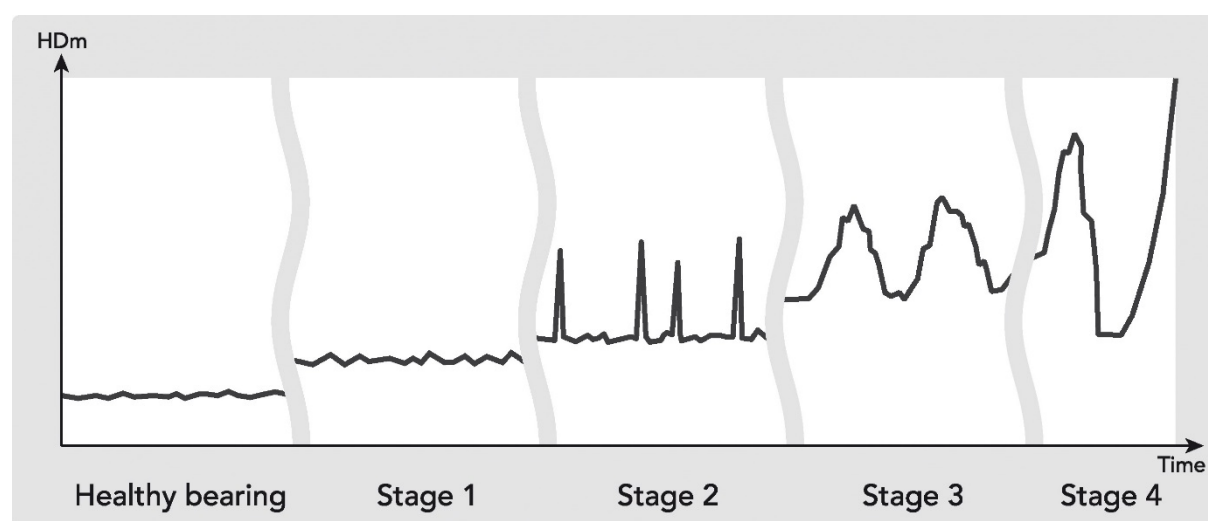
Other enveloping techniques (like vibration enveloping or PeakVue) can also react relatively early, while a velocity reading does not show any increased levels at all.

Late in stage 4, where all or most of the sharp edges has been worn down, the shock pulse levels may be low, leading to a conclusion that the bearing is in good health. The same behavior applies for other enveloping techniques. Random strong shocks in the time domain is a clear sign of a bearing in a stage 4 damage process.

Even in a perfectly healthy and well-lubricated bearing, small shocks are generated in the material interface between the rolling elements and the raceways. These shocks are highly dependent of lubrication condition. The SPM method is a good tool to use for determining the operational condition of the bearing. Prior to any damage in the bearing, the HDc parameter can be trended and analyzed in order to prevent bearing damages.

Standard velocity measurements are too insensitive to pick up on bearing damages; the trend may be increased only late in stage 3 or 4, giving a minimum of forewarning time.

Fig 10. A typical shock pulse trend over the four different stages.



Some real world examples demonstrating some risks with bearing damage detection:

1. SPM HD readings were taken on a machine with relatively old bearings. The HDm values were low, but the SPM HD spectrum showed clear outer race patterns with clear harmonics. The bearing was replaced but no visible damage could be seen. The customer was unhappy and blames the system for taking phantom measurements. This is an example of a bearing in stage 1 or early stage 2.
2. SPM HD was trended with a newly installed online system. The HDm values were mostly low and the SPM HD spectrum showed no clear bearing symptoms. The bearings had been running for many years with some occasional bearing failures. On one measuring point, there were random, very high HDm values and the spectrum contained a lot of "noise". In between the high values the trend was flat and low. Suddenly the HDm trend increased with 60 dB and the bearing failed completely within a couple of days. The system is blamed to provide inadequate forewarning time. This is an example of a bearing in late stage 4.

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3. A bearing mounted in a low RPM machine was measured with a handheld instrument once a month using SPM HD. The HDm values were low and no clear symptoms could be observed in the spectrum. This is an example of a bearing in stage 2, where small spalls were occurring in between the measuring occasions. The sharp edges were worn down in a couple of weeks so there were no shock pulses to measure when the handheld measurement was taken. An online system would have caught the spalls.

5 Useful links

Very good information from Mobius, describing the four stages in more detail:

<http://www.mobiusinstitute.com/articles.aspx?id=2088>

Another useful article from reliabilityweb.com describing among other topics the four bearing stages:

http://reliabilityweb.com/index.php/articles/vibration_analysis_reporting_-_bearing_failure_stages_responses/