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The SPM Method as a Front Line tool For Condition Monitoring, Advanced Vibration and Lubrication Analysis.

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Slide #1
The name, SPM, is derived from the technology that SPM Instrument developed and patented in the early 70's in Sweden. The Shock Pulse Method is the monitoring and analyzation of high frequency compression (shock) waves generated by a bearing while rotating. From this research, empirical data was developed and patented to measure the theoretical film thickness of the lubricant in the rotating bearing along with an analysis of the overall condition of the bearing surfaces.

The way these signals are separated is really what makes this technology unique. Unlike vibration analysis that monitors a broad vibration band and then tries to isolate unique frequencies; SPM has developed a means to only "look" at the high frequency signals of antifriction bearings so as to ensure that the "signal quality" truly reflects a bearing signal. With the development of a defined database by SPM the analysis became practical. The ability to analyze lubrication changes versus surface damage becomes more practical and repeatable.

Through years of testing, this database has been developed and perfected so as to represent the "True" operating condition of the bearing being monitored. Regardless of whether the bearing is 5 days old or 5 years old the reading taken represents the operating condition at that time.

First step: define machine faults to be monitored-Slide #2
Condition monitoring should always start with a list of machine faults, specific for each machine. Only if the user knows exactly what he expects from the monitoring method, he can apply it efficiently and correctly, else there is a danger that he collects data (which costs money) instead of maintaining plant equipment in good working order,
The task specification controls the selection of measuring technique(s) and measuring points. The faults which can be expected are mostly typical for the machine and well known to the maintenance personnel.

Frontline Condition Monitoring – Slide #3
Now with the use of the Shock Pulse Method for bearing lubrication and damage detection and the addition of the SPM Spectrum the philosophy of Frontline Condition Monitoring is fully utilized. For the large number of bearings only the traditional Green-Yellow-Red analysis needs to be addressed. Once damage is detected only the addition of symptoms is needed to fully identify the actual component problem.

First step: define machine faults to be monitored-Slide #4
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Typical mechanical problems – Slide #5
This picture is used to explain that SPM's instruments and measuring techniques are highly competitive when compared with competing methods. Although both shock pulse measurement and vibration severity measurements are relatively simple techniques (which makes them suitable for front line operators with little special training), they can do the job of detecting machine faults, and do it, in all important cases, faster or as fast as other methods.
The bar chart shows the relative importance of mechanical faults which can be detected using available condition monitoring methods.

Multiple functions from Front Line to Full Analysis-Slide #6
The multiple functions of our dataloggers, provide the user with every option to monitor machine condition to the required extent and with least effort. For each fault condition, he can apply the most suitable method.

Machine vibration – Slide #7 What we loosely call 'machine vibration' is a very complex form of movement that has many different causes and that can be described and measured in many different ways. Vibration exists in all machines with moving parts, because some of the force, which makes the machine work, is directed against the machine structure and tries to shift it from its position. Thus, vibration is normal up to a degree, and all machines are constructed to withstand a certain amount of vibration without malfunctions. For diagnosing machine condition by means of vibration monitoring we have to:

- To find a suitable way of measuring vibration, and
- To decide what is normal and excessive vibration
  for the particular machine.

All vibration measurement starts with a **time record**, a registration of vibration over a length of time. A transducer converts the movement into an electric signal, which an instrument quantifies, displays and stores. The signal can then be evaluated in terms of 'good' or 'bad'.

The forces causing vibration – Slide #8
One way of looking at vibrations is to define the type of force, which causes it. Most industrial machines are rotating. The main force is therefore rotational, operating on masses, which are imperfectly balanced. This accounts for approximately 99% of the total vibration energy. Rotational forces are continuous and cyclic – the force does not stop (while the machine is running under power) and the movement is repeated once per revolution of a part.
About 1 % of machine vibration is due to shock. Shock forces are not continuous but can be repeated, either at regular or irregular intervals.
The remaining small amount of vibration, about 0.1 %, is attributed to frictional forces.

Bearing monitoring through spectrum analysis – Slide #9

Even-bearing damage can be detected through vibration analysis. A bearing produces a group of peaks in the vibration spectrum, caused by the rolling elements passing, at different speeds, over the inner race and the outer race, and by spinning around their axis. A further peak is caused by cage rotation.
Given the small mass of the bearing in relation to the large mass of the machine, these peaks normally have very low amplitudes and many times are difficult to pickup with a spectrum before there is severe damage.

Function of a shock pulse transducer – Slide #10

A shock pulse transducer contains a reference mass (m) and responds with a dampened oscillation when hit by a shock wave, here produced by hitting the transducer with a screw driver. Attached to the reference mass is a piezoelectric crystal which produces a voltage when compressed by the movement of the reference mass. This voltage is proportional to the amplitude of the oscillation and thus to the energy of the shock wave. The principle is the same as used in accelerometers for vibration measurement.There is, however, an important difference. When a mass is excited at its resonance frequency, it will oscillate with much greater amplitude than at any other frequency. For vibration measurement, one normally stops measuring far below the resonance frequency of the transducer. Shock pulse meters, on the other hand, are mechanically and electrically tuned to operate exclusively at their resonance frequency of 32 kHz (f_m), were the resulting signal is strongest. This gives us a very sensitive transducer for shocks only, but which will not react to ”normal” machine vibration frequencies.

Transients from shocks in the time record – Slide #11

When a ball hits a damaged area in the raceway, it produces a shock wave. Shock waves are ”transients”; i. e. short-lived waves starting with relatively high amplitude that quickly dampen out. In a time record displayed by an oscilloscope, these transients are often clearly seen, superimposed on the continuous wave produced by shaft rotation. When the distance between transients is constant and corresponds to the ball pass frequency, this is clear evidence of bearing damage.
In the spectrum, however, peak amplitude is determined by the energy contents of the vibration at any given frequency. In relation to the energy at the shaft frequency, the energy of the shocks produced by the damaged bearing can be negligible. Thus, the ball pass frequency line has low amplitude and is easily lost among the ”noise”.

Resonance frequency – Slide #12

To find the signal from a damaged bearing, we can make use of the fact that a shock, being a one-time event, has no definable frequency. Its effect on the machine vibration is most obvious at the machine’s resonance frequency where even a small energy input causes a relatively large movement.
For this, we use a band pass filter that cuts off all frequencies below and above a chosen narrow frequency range, normally high above the range where the main machine vibration occurs.

Transients from shocks in the time record – Slide #13
In the area around the resonance frequency, we can record a time signal, which clearly shows the transients produced by the damaged bearing. Each shock is a single event, but is also repeated at a regular rate, the interval being the time between one ball passing the damage and the next.
The signal is treated by rectifying (which cuts off the negative amplitudes) and by enveloping (which produces well-defined peaks).

Transients from shocks in the time record – Slide #14
The enveloping technique used by vibration analysis attempts, by manipulating the signal, to make shocks visible and measurable in the frequency domain, simply because frequency analysis is the general technique used to detect machine faults.
The main strength of the Shock Pulse Method is its specialization on shock detection. Transducer and measuring instrument are designed to measure the magnitude of shocks directly in the time domain. All generations of shock pulse meters give readout of both the magnitude of the peaks (maximum value dBm) and of the signal level between peaks (carpet value dBc).
Together, these two values can be directly translated into bearing condition information, by utilizing the bearing bore diameter and rpm.

Shock Pulse Evaluation – Slide #15
Many years ago SPM took the Shock Pulse technology and developed it into the Shock Pulse Method. By actual testing in bearing test labs, empirical data was developed by using the bore diameter and rpm. With this info a dBi value is determined which positions the normalized condition color alarm scale onto the dynamic range of the shock pulse transducer. Thereby enabling users to be able to utilize a standardized alarm scale regardless of the rpm or bearing bore diameter.

Maximum value dBm – Slide #16
The dBm is the maximum value, the measured value of the strongest pulses detected during the measuring interval. While the bearing surfaces are undamaged, the difference between dBm and dBc is small. A high dBm and a large difference between dBm and dBc are caused by surface damage or foreign particles between rolling element and raceway.

Elasto-hydrodynamic lubrication. – Slides #17
In the loaded part of the bearing, the contact areas of raceways and rolling elements are under extremely high pressure. Both rolling element and raceway are deformed in the contact area and the oil in between reacts like a solid material.

Shock Pulse and Lubrication Detection – Slide #18
Due the sensitivity of the Shock Pulse Method, bearing lubrication condition is measurable through the signal monitored and known as dBc (decibel level Carpet). The dBc is measured in the time wave signal of the shock pulse transducer.

Factors influencing the lubricant film – Slide #19
In a given bearing application, some of the factors which influence the lubricant film are constant and cannot easily be changed by maintenance:– static and dynamic load
– geometry of bearing housing, shaft, and bearing
– rolling velocity
– necessary preload.
Other factors can be influenced, making it possible to optimize the lubricant film and thus the life expectancy of the bearing. Variable factors include the following:
– preload (if due to incorrect mounting)
– shaft alignment
– total load (by correct alignment and preloading)
– lubricant supply to the bearing
– lubricant type and quality.Bearing temperature depends on constant factors (velocity, surroundings) as well as on lubrication. In a given bearing application, a number of factors that influence the lubricant film are constant. These factors include static and dynamic load; the geometry of the bearing housing, shaft and bearing; rolling velocity and necessary pre-load. Maintenance personnel, making it possible to have a significant impact on bearing condition and life, can influence other factors. These factors include pre-load (due to incorrect mounting), shaft alignment, total load (by correcting misalignment and pre-loading), and lubricant supply to the bearing, lubricant type and lubricant quality. Bearing temperature depends on constant factors such as velocity and environment, as well as lubrication.

Shock pulse patterns – Slide #20
The filtered transducer signal reflects the pressure variation in the rolling interface of the bearing. When the oil film in the bearing is thick, the shock pulse level is low, without distinctive peaks. The level increases when the oil film is reduced, but there are still no distinctive peaks. Damage causes strong pulses at irregular intervals

Transients from shocks in the time record – Slide #21
The main strength of the Shock Pulse Method is its specialization on shock detection. Transducer and measuring instrument are designed to measure the magnitude of shocks directly in the time domain. All generations of shock pulse meters give readout of both the magnitude of the peaks (maximum value dBm) and of the signal level between peaks (carpet value dBc).
In 2002 SPM Introduced an expansion of the SPM Method and performed an FFT on the same 32 kHz signal utilized for all these years. This resulted in a more in-depth analysis capability. By identifying the different bearing frequencies (symptoms) we can now see the matches of those frequencies within the SPM Spectrum. Likewise typical symptoms such as imbalance or looseness can also be introduced for more accurate pattern recognition.

SPM Spectrum – Slide #22
The x-axis of the SPM Spectrum is scaled in Hz. The y-axis is in SD (Shock Distribution unit). The amplitude in the SPM spectrum should be used in conjunction with the SPM values. A new damage can cause high SD readings and an older more severe damage can have lower SD values. Primarily the SPM Spectrum is used for pattern recognition. It is known, but not quantified, that the delta (difference between high peaks and average level) in a spectrum is related to the bearing status.

Refiners-Slide #23
Refiners are a critical piece of equipment in the paper making process. Again as a Front Line tool the SPM Method remians the tool of choice. As seen in this on-line history identifying damage in progression, bearing replacement and new lower readings as a result of a new bearing.This was accomplished using only the shaft diameter and rpm.

Refiner-Slide #24
Here we have the normal Shock Pulse Method identifying a bearing in the RED zone. A subsequent SPM Spectrum on the same location identifies the problem area as the inner raceway. The pattern displays as an inner race defect with sidebands

Felt Roller-Slide #25
Now we will look at some case studies from different paper mills that enforce our philosophy of choosing the appropriate method for the application to improve accuracy and save time.

Felt Roller-Slide #26
This is a typical Shock Pulse Bearing Condition chart. The x-axis represents the time frame. The Y-axis is signal strength intensity divided up as a Green-Yellow-Red condition code. As explained earlier the Alarm level is determined by the shaft diameter and RPM being programmed into the instrument and/or the PC software. That defines the baseline and from there the GreenYellowRed divisions are further defined. On the chart we see the readings in the Green zone until about March 2002. Then they take off into the Yellow then the Red zones. Plus we see the development of a large delta (dBm-dBc), which also indicates bearing damage in progress. This graph shows bearing damage in progress and we see that the bearing is replaced and the readings dropping accordingly

Felt Roller-Slide#27
On this slide we are shown an SPM Spectrum of a felt roller bearing that displayed a high dBm value (>45). The bearing frequencies were introduced as symptoms and quickly we found the BPFO was the predominant signal with multiple matches

Slide #28-no text

Dryer Bearing-Slide #29
Now vibration analysis would typically be used on dryer cylinder bearing applications and here would be a typical FFT done on one with the components identified by their frequencies. The technician would identify the matches and their intensities. This can be a difficult task sometimes because we are not looking at solely the bearing signatures but all the signatures.

Dryer Bearing-Slide #30
So to make it easier for the technician to make this call techniques like Enveloping were developed. They are utilized and again the spectrum matches would be identified in the software so that an evaluation can be made of the intensities. This in turn helps identify the component(s) causing the problem.

Dryer Bearing Slide #31
Now if the philosophy of Front Line Condition Monitoring was utilized then the process can be simplified and sped up. First of course the Shock Pulse Method would be utilized as the first stage. Because the shock pulse transducer only is "seeing" the bearing signal thereby making the analysis of bearing condition easier to see and with an earlier call. In the example above from an on-line system it is evident that the shock values have been increasing over time along with the delta (difference between dBm/dBc). Again these are prime an indicator that bearing damage is in progress. The dBm values are around 40 and we could definitely make the call when the values get above 50. But now let us look at the SPM Spectrum.

Drying Cylinder-Slide #32
In the SPM Spectrum we are doing an FFT on the unique Shock Pulse signal that only is developed from the compression waves being generated by the operating bearing. The individual frequencies or symptoms are again defined and it is merely moving the cursor from one symptom to the next. The symptoms that match the signal patterns are the components that caused the Shock Pulse Method to go into the red. The software identifies the matches and the Y axis(shock distribution scale) identifies which symptom is generating the most shocks. Between the SPM Method identifying the bearing to be concerned with and the SPM Spectrum identifying the bearing component with the greatest shock saturation the bearing call can be made far easier.

Agitator Bearings-Slide #33
No text

Agitator Bearings-Slide #34
With agitator bearings the "clean" bearing signal from the shock pulse transducer allows the technician to see the bearing track from Green to Yellow to Red. At around 45 dB the bearing was pulled and the subsequent readings decreased accordingly. On applications of this type where there are negligible secondary signal sources only the front line SPM Method need to be implemented for bearing condition monitoring.

Spreader Rolls-Slide #35
Likewise for monitoring spreader rolls the access to the bearing housing makes the Front Line SPM Method the preferred choice to identify bearing problems. In this record we see the bearing reading tracking into the yellow and then into the red. The call was made to replace the bearing around 50 dB and a corresponding schedule shutdown. Immediately after the switch out the readings tracked well into the Green zone. No further analysis was necessary.

Nash Pumps-Case Study-Slide #36

Nash Pumps-Case Study-Slide #37
On the Nash Pumps we can again monitor bearings with Front Line SPM Method solely to identify bearing damage and when it should be replaced. All that is needed is the shaft diameter and rpm and fast, accurate condition monitoring is achieved.

Nash Pumps-Case Study-Slide #38
An added benefit of utilizing the SPM Method on Nash pumps is the ability to perform the SPM Spectrum on the same time signal. From SPM experience, monitoring the Vane Pass Frequency in the SPM Spectrum enables us to see the impact of the 16 blades collecting a build up. We set up a symptom for Vane Pass frequency based on 16 times rpm. When the blades need cleaning the SPM Method will start tracking upward but by going to the SPM Spectrum you then lay the Vane Pass Symptom over the graph and if the frequency matches the cause is identified as not being a bearing problem. It is important to monitor this frequency because the Timken bearing typically used in this application allows only minimal end play. So excessive pulsation over time will wreck havoc on this bearing. Good examples of root cause analysis on a bearing failure at the mill.

Conveyor Drive Systems-Slide #39
For conveyor systems the SPM Method remains the method of choice due to the ease of use, speed of data collection and accuracy of analysis.

Conveyor Drive Case Study #40
Typical SPM chart for pillow block bearings on the drive systems of conveyors. Lubrication problems were not corrected in early stages and we see increases in dBm/dBc with no increase in delta. During this time minor damage is occurring on the bearing. The lubrication is finally corrected and dBm increases into the red as damage progresses over time. The damage progression could not be reversed because the lubrication warnings were not heeded. Replacement brings all readings back into the Green zone.

Motor Case Study-Slide #41
The SPM Method has its most common usage on electric motor bearings.

Motor Case Study #42
As more and more motors at mills go to variable frequency drives we se the SPM Method combined with SPM Spectrum as an excellent warning for early damage from electric arcing.

Screen Case Study #43
These screens from Valmet and others come from the manufacturer with an SPM transducer installed and wired to an accessable location. Again the SPM Method provides a Front Line tool to identify bearing lubrication and damage problems as shown in this record.

Gearbox Case Study #44
Gearboxes continue to be a great candidate for utilizing all the SPM Methods to provide a fast accurate means to diagnose problems.

Gearbox Case Study #45
The Shock Pulse Method works for bearing problems.

Gearbox Case Study #46
Using the SPM Spectrum allows the user to clearly identify bearing problems from secondary signal sources. The matching of symptoms(bearing components) makes the decision making process a lot smoother.

Fans-Slide #47
Belt driven and direct drive fans are found to be the equipment most susceptible to lubrication problems leading to early bearing damage. The SPM Method proves to be the fast, easy way to do some preventive maintenance

Fan Case Study #48
This case study is from an on-line system on a fan drive at a cement plant. What we see here is frequent spiking and the effects of lubrication correction in the early and middle stages. The effect of the lubrication correction keeps the bearing from developing permanent damage. The user then realized that the frequency of lubrication correction might mean the grease being used was not suitable. So a different grease was introduced and the results show a dramatic reduction in the frequency of greasing and a lower overall signal pattern. The SPM Method is perfect for preventive maintenance needs.

Paper Machine Experience #49
SPM experience in paper mills from around the world allows us to assist and advise our users as to what methods are best suited for the application.

Paper Machine Experience-Slide #50
Thereby minimizing the readings needed to be collected. Only those most effective methods will be utilized.

Financial Summery of Hallsta Paper Mill #51
.So now let us get down to the dollars and cents results from the mill that utilizes SPM Method, SPM Spectrum and EVAM. This represents their yearly production.

Financial Summery of Hallsta Paper Mill #52
This is what 8 inspectors do on a monthly basis.

Bench Marking CBM #53
As an example of the results of CBM, a study was made covering the monitored equipment in a paper mill. SPM methods had been used for about 8 years and there were records showing the fault detection and replacement times.

Financial Summery of Hallsta Paper Mill #54
The study covered 6200 measuring points on 2300 components, i. e. machines or machine parts.

Financial Summery of Hallsta Paper Mill #55
List of monitored machines for this study.

Financial Summery of Hallsta Paper Mill #56
The user was able to have a 95% confidence level on the different applications for the average prewarning times. When the bearing condition first goes from Green to Yellow and lubrication correction does not reverse the trend these values represent the average warning time for bearing replacement. With this knowledge the user today uses these average values to determine the corrective action and the time to replace.

Financial Summery of Hallsta Paper Mill #57
The main arguments for CBM are the considerable cost reductions achieved by reducing the time it takes to make a necessary repair. A planned replacement means less waiting time and less repair time. To this, add the cost for secondary damage resulting from a breakdown. Nevertheless experience has shown that repairs from CBM run only a third of the time when compared to a run to failure philosophy.

Financial results of CBM at Hallsta Mill Site #58
Downtime in a paper mill is very expensive. The average profit contribution per inspector is about $800,00.00 per year. The user determined this calculation when they looked at the number of incidents where they were able to go to a planned shutdown. This represents the results from only the paper machines.