The Challenges of Monitoring Mobile Mining Equipment

Vibration measurement has come of age in the last 20 years. While the practice of continuous on-line monitoring of critical machines in the oil, gas, and petrochemical industries has been common place for several decades, it is only recently that companies who had been using intermittent data collection techniques are now embracing continuous monitoring.

The new "horizon" is mobile equipment ... draglines, shovels, bucket-wheel excavators, stacker-r claimers, heavy haul trucks, are all equally important to production and just as "critical" as a gas compressor.

However, unlike stationary machinery, monitoring mobile equipment brings substantial challenges that must be addressed to ensure accurate, repeatable, and reliable data acquisition. Rapid speed and load variations are just one element of the application.

The logistics of sensor mounting, cabling, network communications, and general serviceability, bring unique complications to the task of monitoring these machines. We will discuss these obstacles and present new solutions that have the potential to bring significant reliability improvements to large mobile equipment.

Speed & Load Variations

Reliable, repeatable, vibration measurement has historically depended upon steady-state conditions, i.e., constant RPM, constant load. Repeatability, often regarded as the cornerstone of good vibration data collection, is essential for the accurate assessment of machine condition, and more so for intermittent monitoring strategies. The data must be representative of machinery health and reflect real changes due to incipient fault conditions and not changes due to variations in operating conditions. As an example, when speed varies over the duration of a typical measurement cycle, adverse effects result;

a) Affecting the reliability of the data AND more importantly
b) Compromising repeatability

One solution has been to perform the vibration measurement task on the machine in a "quasi" steady-state condition. Consider a typical mine shovel as illustrated here.

Machine States

Defining a repeatable "condition of operation" OR "machine state" which can be identified thru the measurement of certain parameters, such as RPM, direction of rotation, and load, will help ensure that vibration data acquired during this "machine state" will be reliable and repeatable.

In Figure 2 the variation with time of both the RPM and the corresponding vibration level would pose serious problems for meaningful trend data. The establishment of a "machine state" based on measured parameter(s), in this case RPM and direction of rotation, will ensure a measure of repeatability and give confidence to trended vibration levels – Figure 3.

Figure 1: Mine shovel

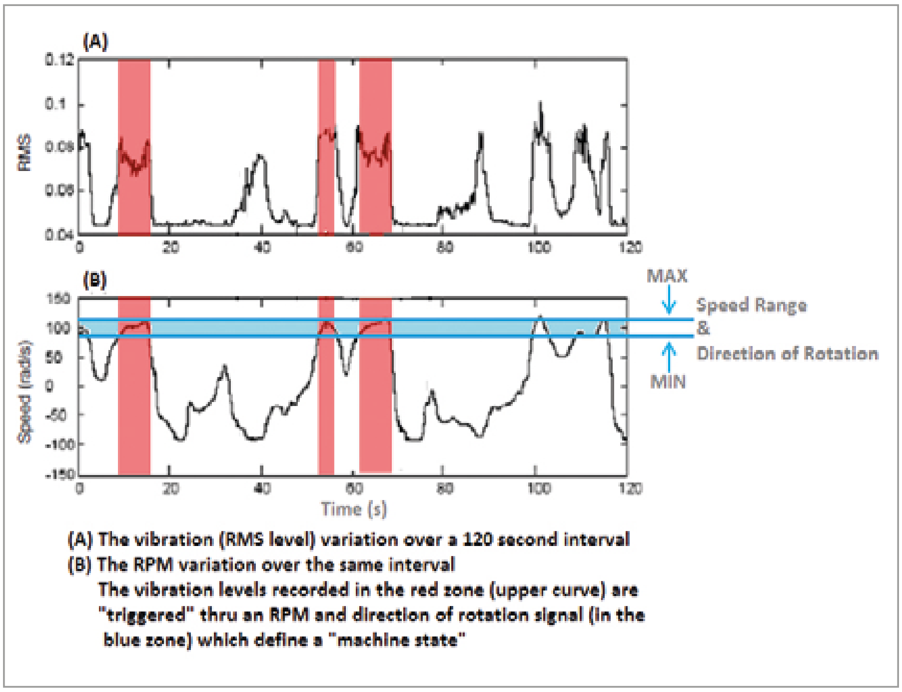

Figure 2: Machine States

During routine PM inspections the shovel is stationary on level ground and the 2000HP electric motors are run at constant speed under no-load. Vibration measurements at each of the motor bearings (NDE & DE) are reliable, repeatable and do not suffer from the variations due to operation of the bucket, crowd, swing, OR crawl.

The limitation of testing in this manner is that fault conditions may only be evident while the equipment is under load, and so the data may be of limited use ... some would say "it's better than nothing"! But perhaps there is a better way thru selective triggering, based on RPM.

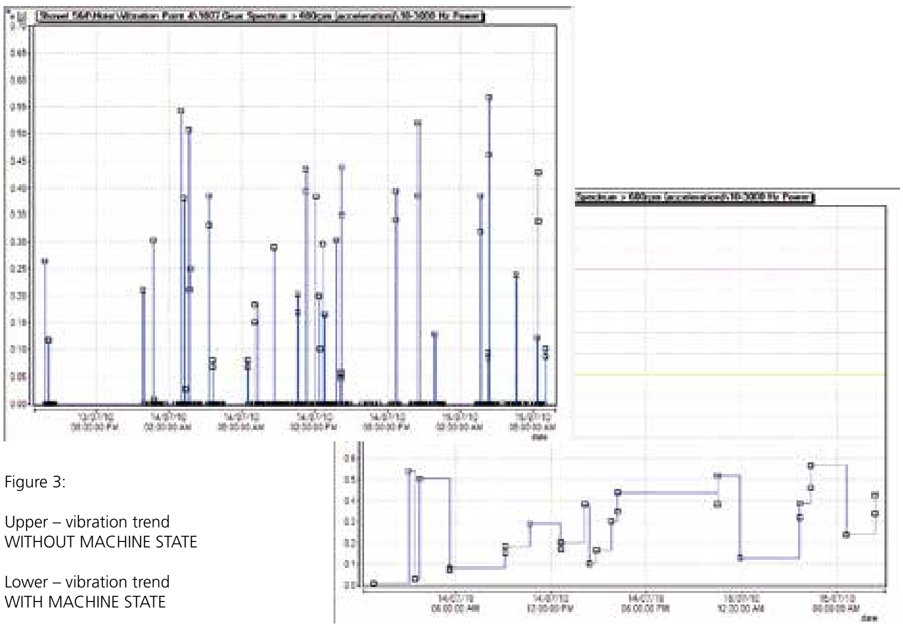

Figure 3:

Upper – vibration trend WITHOUT MACHINE STATE

Lower – vibration trend WITH MACHINE STATE

Order Tracking & Order Analysis

FFT Based and Digital Re-sampling Methods

In some cases the machinery RPM varies continuously, without even a short interval when the speed is in a pseudo-constant range, making the establishment of a "machine state" difficult, Figure 4.

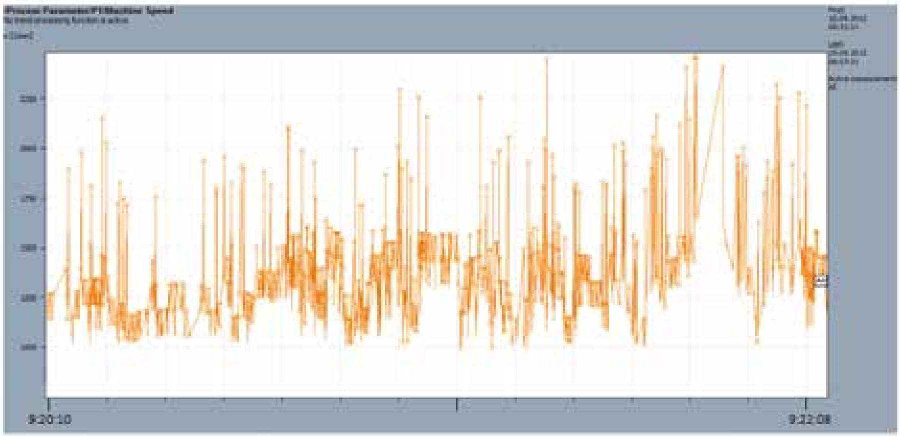

Figure 4: Continuous RPM variations

Normal FFT analysis would result in "smeared" spectral components due to the fast changing RPM over the period of one FFT record length, Figure 5.

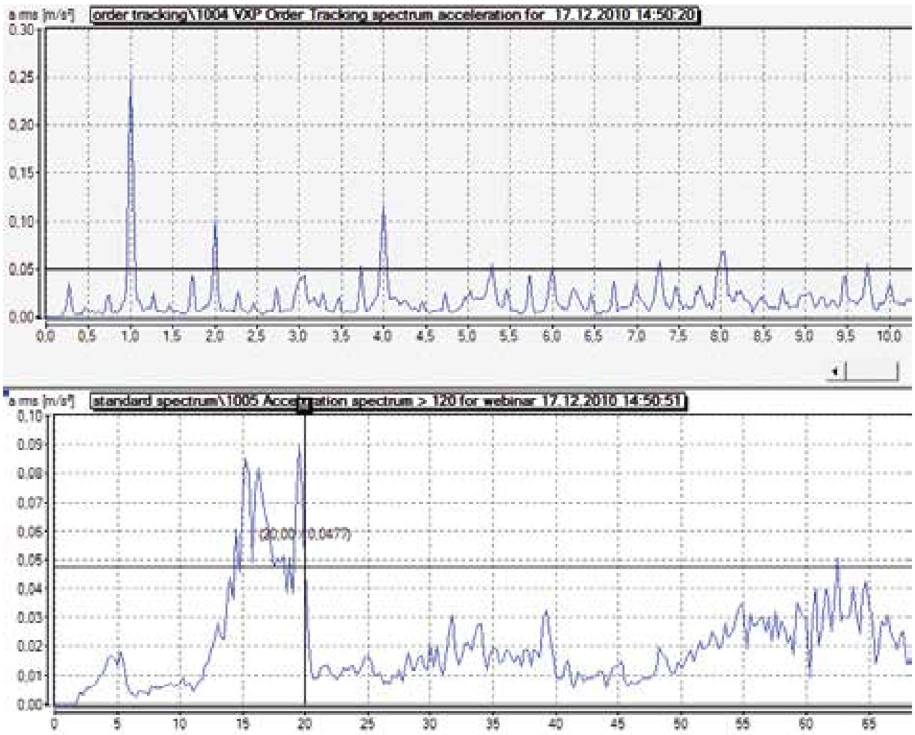

Figure 5:
Upper - Normal FFT Spectrum
Lower - "Smearing" of the frequency spectrum due to RPM variation

The "smearing" of the frequency components arises due to the fixed sampling rate of the FFT process, the rapid change in RPM, the fixed FFT record length, and the corresponding variation in level and frequency of the vibration.

Order tracking is a process whereby a specific frequency component i.e., the 1X, is extracted from a composite of frequency spectra versus RPM. The method is particularly useful for run-up OR coast-down measurements where the speed changes occur over a short span, typically 1800RPM to 300RPM, and at a relatively moderate slew rate. The raw data when presented in an X, Y, Z, display is known as a "waterfall" plot, while the extracted components are referred to as "slices" (along the Z-axis), Figure 6.

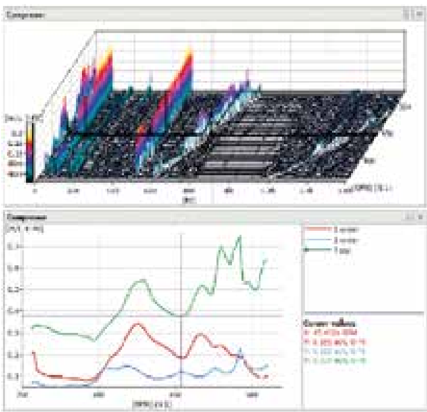

Figure 6:
Upper - Waterfall, amplitude vs frequency vs RPM
Lower - Slice along the Z-axis (RPM) of an order

This technique of order tracking is used most often as a diagnostic tool, as opposed to a continuous on-line monitoring method, and is principally employed to identify machinery resonances within the operating speed range. The extracted slices versus RPM (Z-axis) provide the analyst with a clear picture of how the amplitude of the individual frequency components such as the 1X may be exciting certain natural frequencies in the machine structure. Again, the measurement must be carefully configured to avoid smearing, taking into account the FFT record length (T*), RPM interval, and slew rate.

$$T = \frac{LOR}{Fmax} = \frac{1}{\Delta f}$$

where:

T - FFT record length in seconds
LOR - Lines of resolution
Fmax - Maximum frequency range
Δf - FFT line spacing (bandwidth)

Order analysis on the other hand synchronizes the FFT sample rate with the machine RPM. In the past this procedure was performed in real-time using a tracking frequency multiplier whereby the sampling frequency was derived as an integer multiple (order) of the RPM.

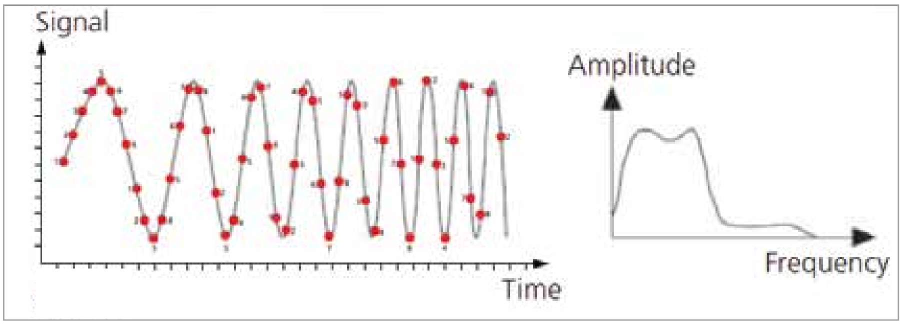

Figure 7: Fixed FFT sample rate resulting in smearing with changing RPM

In modern digital signal analysis, the time signal and RPM signal are recorded, and the order analysis is performed as a post-processing function whereby interpolation of the RPM signal yields a "re-sampling" rate applied to the time signal and the subsequent FFT creates the order spectrum.

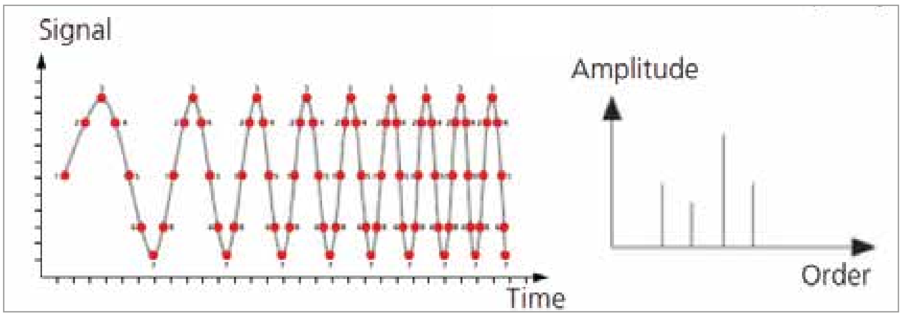

Figure 8: Synchronized sample rate with RPM results in discrete orders

State-of-the-art on-line continuous vibration monitoring systems using order analysis provide operators with a reliable and repeatable method of comparing order spectra vs time to visualize trends that arise due to machine condition and not RPM Figure 9.

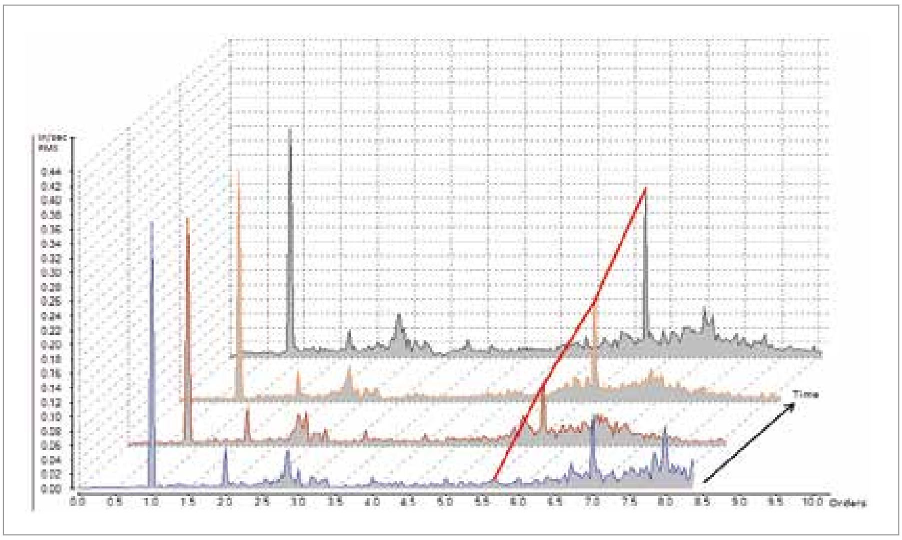

Figure 9: Order Spectra vs time

Hardware Installation & Logistics

The selection of machines and corresponding measurement points follows criteria similar to the monitoring of stationary equipment, i.e., criticality ranking, maintenance history, accessibility, safety considerations, etc.

However, there are a few points peculiar to mobile mine equipment requiring additional scrutiny:

a) Sensor connectivity and accessibility
b) Equipment location within the mine site
c) Network communication and PC software configuration

Sensors such as accelerometers are built to withstand harsh industrial conditions but where cable runs in stationary installations are in a relatively static environment, mobile equipment sensor cables require additional protection against chafing, etc. Small diameter hydraulic hose has been used successfully in these installations, Figure 10.

Figure 10: Mini-accelerometer, enclosure and hydraulic hose cable protection

Drilling and tapping for transducer mounting may not be permitted particularly during warranty periods since many OEM's are unfamiliar with the principal behind vibration monitoring and/or may simply object to the attachment of "non-approved" apparatus by third parties.

Some major manufacturers do make provision for accelerometer mounting, but this is often an "after thought" and is usually not the ideal measurement point.

Current monitoring systems employ TCP/IP network communications and can be equipped with a wireless modem for communication with the in-house Wi-Fi network.

Some manufacturers of on-line vibration monitoring solutions offer hosting of the application and data via cloud servers. This option is becoming increasingly popular and offers many solutions to the

Figure 11: Accelerometer mounting block – DE Motor

questions of in-house network security, outside vendor access (for technical support, system updates, etc.)

The networking element of the installation requires careful planning, disclosure, and a full understanding of ownership of the data. The IT department are the key players in the installation of the software, configuration of the network, and granting access to the vendor via the cloud, TeamViewer™, or remote desktop applications!

Lastly, mine equipment which is completely mobile such as heavy-haul trucks may be required to stop at a "data waypoint" due to Wi-Fi coverage, to upload measurements to the network.

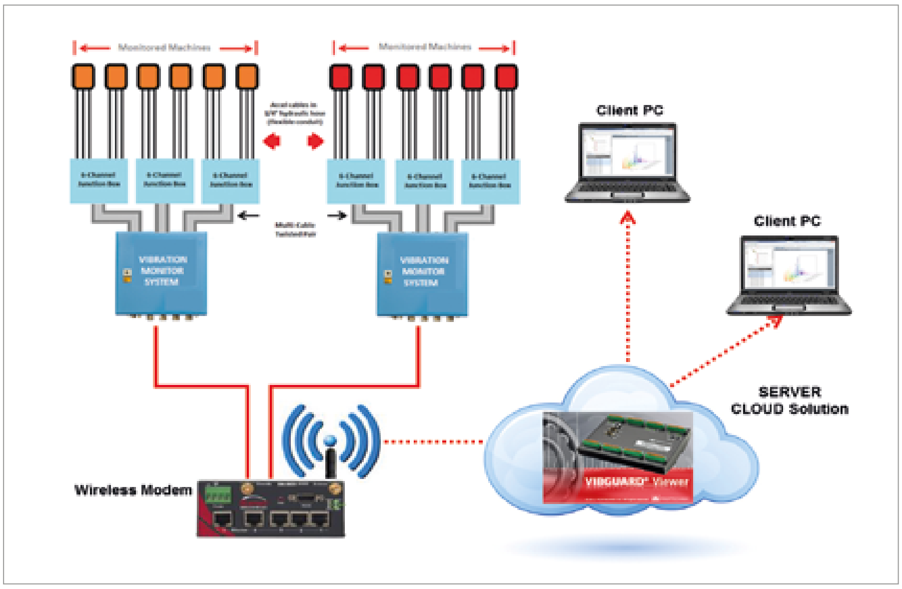

Figure 12: Vibration monitoring overview

PC Application – Configuration

Mine managers, operators, planners, and maintenance personnel ARE NOT VIBRATION ANALYSTS. They need timely, actionable information about equipment health via a quick and simplified user interface, without waiting days for VA reports.

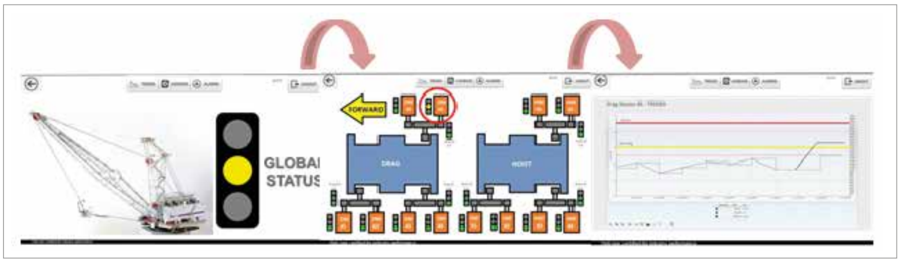

Fig 13: A simplified HMI* provides timely machine condition data. * Human Machine Interface

Summary

Mobile mine equipment represents huge capital costs ... it is expensive to operate, expensive to maintain, and critically important to mine productivity. Vibration monitoring has provided significant savings for many years in the maintenance and operation of stationary plant equipment.

Today, with advances in signal processing, transducer design, and networking options, mobile machinery operators can now begin to take advantage of the benefits derived from vibration monitoring – reduced downtime, lower operating and maintenance costs, decreased spare parts inventories, optimized PM schedule, improved equipment availability. The path to reliability-centered maintenance is becoming clearer. Remember ... "When you want something you never had, you need to do something you've never done."

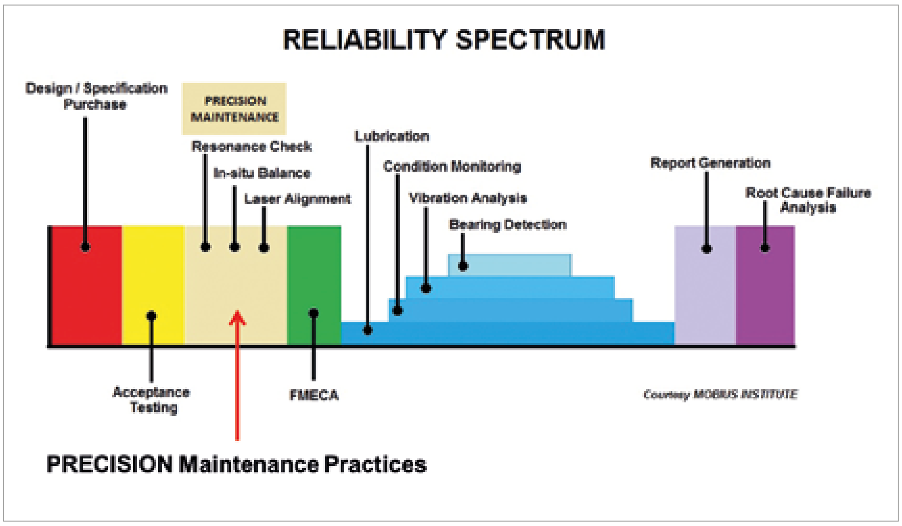

Fig 14: Reliability Spectrum

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About PRUFTECHNIK

The PRUFTECHNIK Group, with its subsidiaries and partners in more than 70 countries worldwide, continues to set new standards with innovative technological advancements in the field of machine alignment and vibration measurement technology in order to maximize and optimize the operational safety of machines and plants.

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