orbit

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A Technical Publication for Advancing the Practice of Operating Asset Condition Monitoring, Diagnostics, and Performance Optimization

Intelligent Machines

Orbit Magazine is going Digital!
See back cover for more details.

Editor's Notepad

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Greetings, and welcome to Orbit!

The theme of this issue, Intelligent Machines, corresponds to the first piece in the stream of information flow that makes up the Industrial Internet. We will discuss the second piece, Advanced Analytics, in the APR issue, followed by People at Work in the JUL issue. While the industrial machines that we protect and monitor are optimized to operate reliably and efficiently, they are not inherently intelligent when it comes to providing useful analytic data about their condition. Steam turbines, gas turbines, hydro turbines, reciprocating compressors, turbocompressors, generators, pumps, gearboxes, motors, etc., are simply machines that convert various kinds of energy into work (or vice versa) by following the laws of physics as we understand them.

So what do we mean by "intelligent" machines?

Anyone who has been involved with the instrumentation and control of industrial machines for many years has seen the evolution in design and application of transducer and monitor systems – first, as they transitioned from vacuum tube to solid-state circuits – and then as they moved from analog to digital designs.

Now that protection and monitoring systems produce digital data in addition to buffered raw signals, analog recorder outputs and automatic relay actuations, we can store this data in historians, and evaluate it using analytic software (the next step in the Industrial Internet chain) to extract useful information from the reams of ones and zeroes.

When you think about it this way, the Industrial Internet isn't really "new" at all. It is simply the logical extension of what we have already been doing for many years. By carefully installing appropriate sensors per recognized guidelines, establishing effective signal processing and data collection settings, and validating proper operation of the monitoring system, we can ensure that ACCURATE data from the monitored machines is sent to the Advanced Analytics in the next step of the process. By doing this, we are essentially adding the missing "intelligence" that our monitored machines lack in the first place!

Cheers!
Gary

I hadn't thought of recycling worn-out bearings into artwork, but this is a nice example! Photo submitted by Steve Gaskell. Used with permission of the Terry Lee Wells Nevada Discovery Museum, where this fun little character was spotted, vigilantly guarding access to an ac mains outlet.

In this Issue

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A Technical Publication for Advancing the Practice of Operating Asset Condition Monitoring, Diagnostics, and Performance Optimization

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Bently Nevada Product Manager, Don Marshall, describes how our distributed architecture design has been optimized to monitor aeroderivative gas turbines as well as other specific machine applications. That's a real GE LM6000 gas turbine behind him. It generated quite a bit of interest as event participates were surprised to see such a large machine on display!

42nd Annual Turbomachinery Symposium

The Bently Nevada* team has participated in the prestigious international Turbomachinery Symposium every year since the very first event back in 1971. Now combined with a Pump Symposium, the annual event is hosted by Texas A&M University and is held every autumn in Houston, Texas, USA.

The 2013 event had record attendance and featured lectures, tutorials, case studies, discussion groups, and short courses, as well as exhibits of the latest services and equipment, emphasizing the technological advances and troubleshooting capabilities of the industry. Our team shared the GE Oil & Gas booth, and demonstrated key product developments including our Advanced Distributed Architecture Platform Technology (ADAPT), the Motor Stator Insulation Monitor (MSIM), System 1* Evolution and System 1 Fleet software. (See page 11 of this issue for a short article about online monitoring with the MSIM system).

Our General Manager, Art Eunson, summed up nicely: "I've been going to the Turbosymposium for several years now, and have to say this year's event was the most impactful yet for the Bently Nevada team. We've been working hard to develop solutions based on input from our customers, and it was good to hear that they believe we are heading in the right direction with our key product developments."

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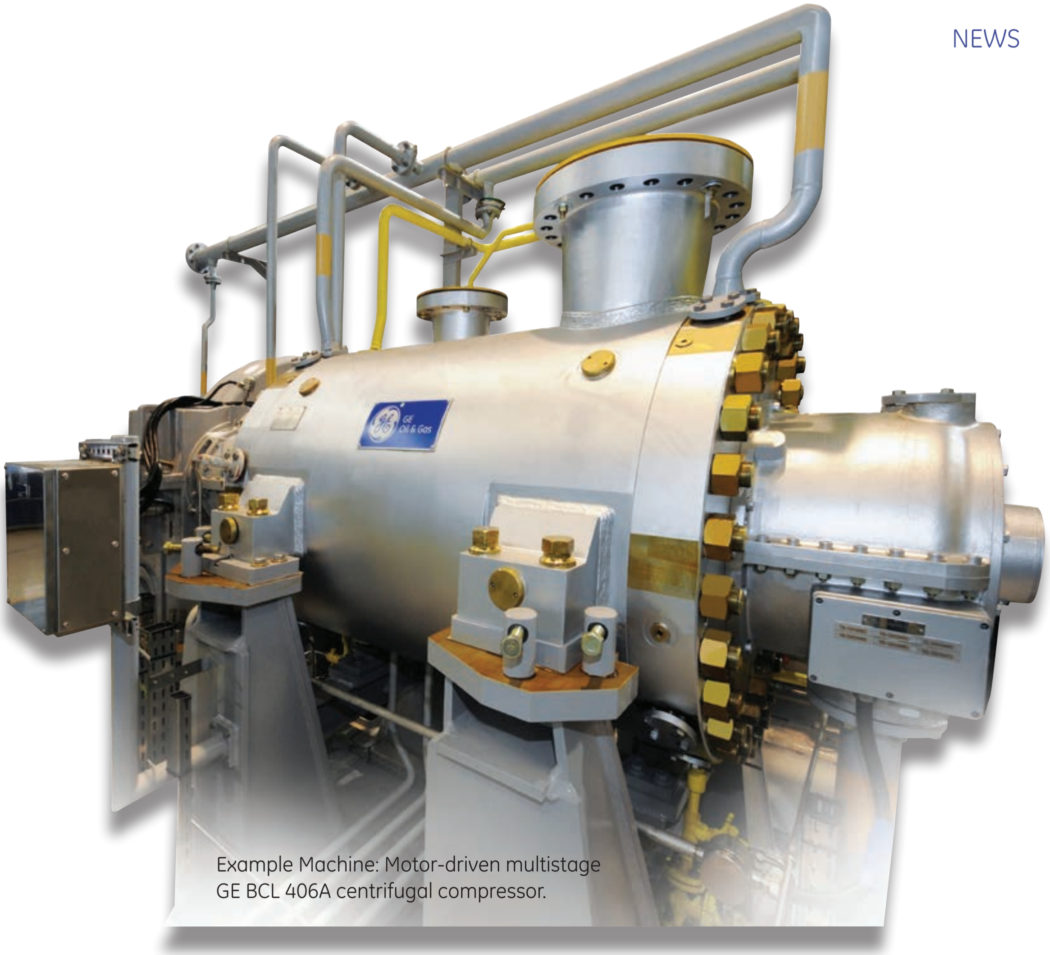
Example Machine: Motor-driven multistage GE BCL 406A centrifugal compressor.

Driver + Driven

Proficy* SmartSignal Introductory Package

This Orbit issue focuses on the "Intelligent Machines" part of the Industrial Internet, where properly-installed transducers and monitors with appropriate signal processing convert measured signals into accurate digital data for asset protection and condition monitoring. This data is available for evaluation by "advanced analytic" software such as Proficy SmartSignal and System 1* platforms.

After a period of learning the normal relationships between correlated parameters, SmartSignal modeling detects any anomalies that occur between actual and expected values – thus providing the "foresight" that something unusual may be happening, and a deeper investigation may be in order. With the early warning provided by a SmartSignal notification, you can use the diagnostic capabilities of System 1 software to gain more "insight" into the root cause of the problem.

Protection

Foresight

Insight

The Proficy SmartSignal Driver + Driven introductory package allows you to implement SmartSignal software on a small scale and realize its benefits as a tool in your asset condition monitoring strategy.

Package Capabilities

- Monitoring for two connected pieces of equipment: In a typical machine train, this includes both a "driver" and a driven machine.
  - The driver can be a reciprocating engine, turbine (up to 75 MW) or electric motor.
  - The driven machine can be a generator, compressor (centrifugal or reciprocating) or pump. NOTE: multiple compressors on the same shaft require an additional charge.
- One-year term license for local (onsite) viewing software.
- Monitoring software and hosting hardware at GE site.
- Implementation, maintenance, and remote monitoring services.
- A Discovery & Value Assessment of how this technology would help your facility when applied more broadly. If appropriate case data can be provided, the assessment will also include an Early Warning Case Study example on a past failure.

Frequently Asked Questions

Q: What is the standard cost per piece of equipment that we would see after the first year?

A: It is the same as the first year price. This easy introduction means that we do the setup work for a small scope, trusting it will continue and grow. The price will not change later.

Q: Is this a flat rate per piece of equipment or is it "tiered" as more equipment is monitored?

A: It is a flat rate until more than 10 driver+driven pairs are accommodated, then a coverage size adjustment can be made.

Q: What installation base is required? Do we need System 1 software or a 3500 system?

A: A plant historian connection is the only fixed requirement. Data can be communicated to the historian via any method, including wireless. Getting extra data from a 3500 rack or System 1 installation will be great, but it is not required.

Q: Do I need any additional software (historian, database, etc.) or equipment?

A: A business network connection to a plant historian is all that is required.

Ordering Information

- SmartSignal Driver + Driven package

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System 1* for Portables

Simplifying the Database Configuration Process

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System 1 for Portables breaks through the infamous configuration process of existing condition monitoring software and offers a simplified, time saving solution. Gone are the time consuming days of database configuration, which required broad expertise in vibration condition monitoring. The new interface is designed to be intuitive and to facilitate quick configuration for many different types of industrial equipment.

Our newest platform includes features that embed decades of Bently Nevada* and Commtest* vibration expertise directly into the software. These features include an asset library with many prebuilt assets, an integrated bearing database, route management, and Quick Config tool – all of which make the configuration process faster and easier than ever. Instead of days or weeks, you can now go from installing the software to collecting data in a matter of minutes.

Figure 1: An example motor and pump as created from the Asset Library "Trains" options.

Asset Library

An extensive list of prebuilt assets is available for you to use when building your "Enterprise" (condition monitoring database). These assets include all required shafts, bearings, and couplings (Figure 1). The asset library in System 1 for Portables includes many of the most common assets ranging from individual motors and pumps to complete machine trains that include driver, driven and gearbox equipment. The library also incorporates many of the common pumps specified in the American Petroleum Institute (API)[1] standards. These include overhung, between bearing and vertical pump designs. Other assets will be added to the library as future versions are released.

Bearing Database

As part of the software package, System 1 for Portables includes a fully integrated version of the International Source Index (ISI) database, The Bearing Expert[2]. This database includes a comprehensive list of rolling element bearings from many different manufacturers. When you use the database and select the correct manufacturer and part number for each bearing on your asset, all of the properties for that bearing will be automatically configured (Figure 2). By associating these bearing characteristics with the monitored asset, you will enable additional diagnostic tools, such as the ability to overlay fault frequencies on spectrum plots.

Route Management

In addition to creating and configuring assets, route management plays an important role in a portable data collection program. System 1 for Portables offers a simplified approach to creating and maintaining routes (Figure 3).

The software tools allow you to quickly establish routes using the assets already created in your database. Assets can be added to multiple routes, allowing for the ability to easily configure separate routes with varying levels of data collection for the same assets. As an example, more frequent "summary" data collection on a particular asset may simply measure bearing vibration in the horizontal and vertical axis, while less frequent "comprehensive" data collection would also include data collection in the axial direction.

Figure 2: This example shows the Bearing Database dialog with part number "6312" selected. Note: Small differences in bearing characteristics between manufacturers cause fault frequencies to vary somewhat, even for bearings that have the same part number.

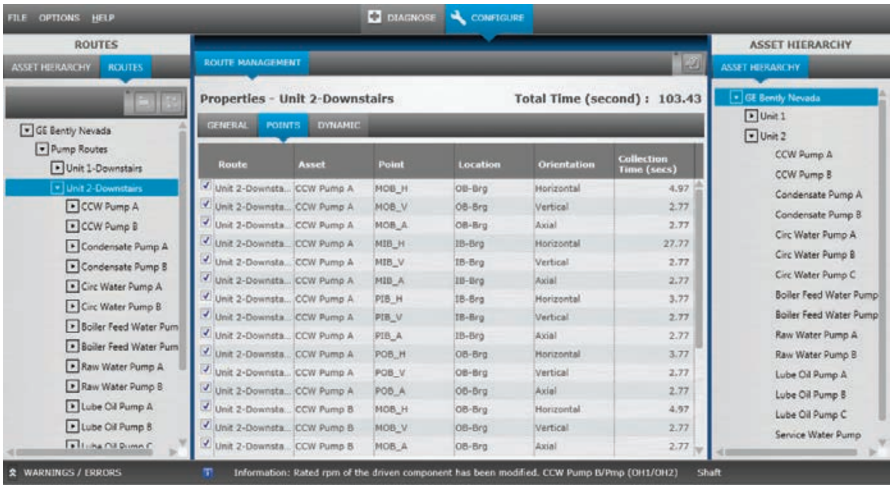

Figure 3: Route Management dialog, showing existing routes in left column, individual measurement points in the central table, and hierarchy of monitored assets in right column.

Quick Config Tool

In the past, one of the most tedious tasks when establishing and maintaining a portable walk around program was configuring the data collection settings. This required configuring data collection and signal processing settings based on knowledge of the assets to be monitored, their failure modes, and the specific symptoms of impending failures.

With the System 1 for Portables Quick Config Tool, data collection settings can be configured in just a few simple mouse clicks. The Quick Config tool configures all spectrums, waveforms, spectral band variables and alarm thresholds, based on the options you selected, as specified in the standard you have chosen.

The Quick Config tool can configure settings based on well-known standards such as the Technical Associates (TA) Proven Method[3] (version 4.0) or ISO[4] standards (Figure 4). It can use a limited set of asset properties, like speed, to configure these settings, but if additional properties beyond speed are entered, such as bearing models or number of impeller vanes, the resulting configuration will be more complete. After using this tool, essentially all that is left to complete is to add these measurements to a route and start collecting data.

Note: *The ISO option incorporates guidelines from the 10816 family and 14964 standards for a variety of different assets.*

Conclusion

By embedding industry-standard vibration analysis knowledge directly in the software, System 1 for Portables moves past the typical cumbersome process of configuring an Enterprise database and

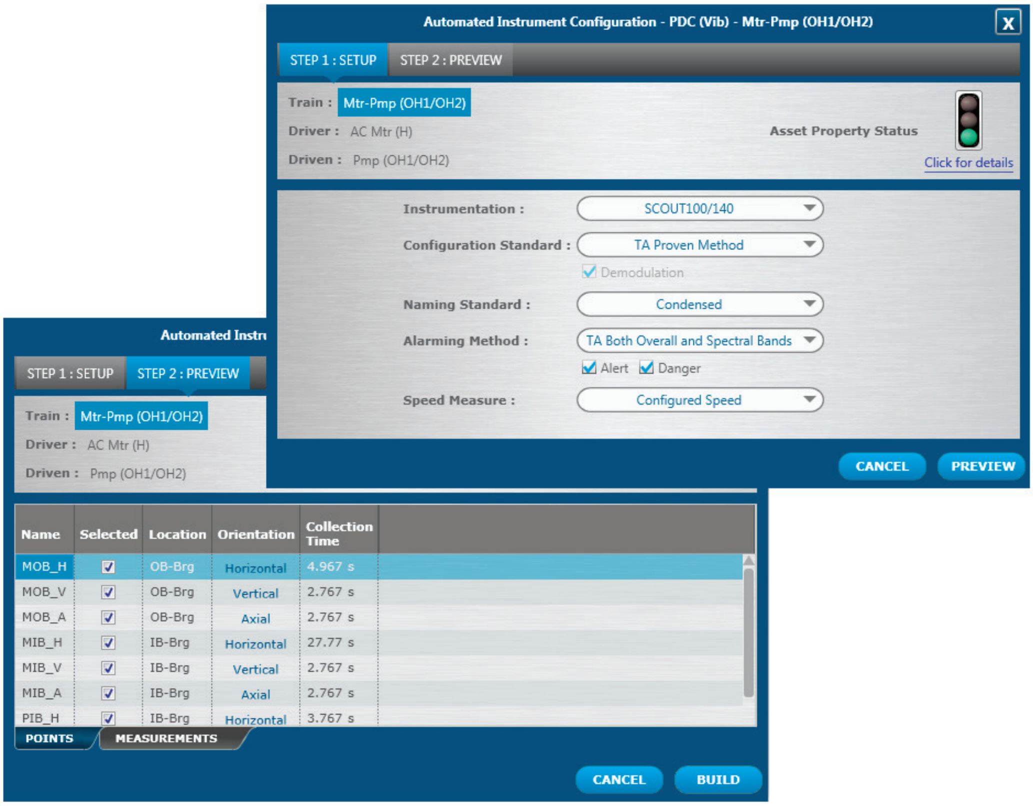

Figure 4: Automated Instrument Configuration dialogs of the "Quick Config" feature. The STEP 1 (SETUP) example at the top shows the configuration choices that were selected for a particular overhung pump. The STEP 2 (PREVIEW) example below it shows the locations and sensor orientation for sample collection, along with the collection time for each measurement, based on specifics of the required signal processing. Also in STEP 2 a preview of all configured measurements and alarm thresholds can be seen before building.

offers a simpler approach. With the new tools and features, software configuration can be completed faster and more consistently than ever before.

Watch for future Orbit articles as we dive deeper into some of the functionality of these tools, and others, that are available in System 1 for Portables.

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1. API and American Petroleum Institute are trademarks of American Petroleum Institute, Inc.
2. The Bearing Expert is a trademark of International Source Index, Inc.
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4. ISO is a trademark of the International Organization for Standardization.

Online Monitoring of Motor Stator Insulation Condition

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Industrial motors (Figure 1) drive many of the world's most critical assets. From oil and gas upstream and downstream installations to combined-cycle and nuclear power plants, three-phase ac motors are a constant presence in our industrial facilities. Whether the driven asset is a main air blower or wet gas compressor at an onshore refinery, a product export pump on an offshore platform, or a pump for boiler feedwater or reactor coolant at a power generation station, these motor-driven assets are critical to the viability of your operation, and to the success of your business.

FIGURE 1: Example – GE Pegasus** HMV Medium Voltage AC Induction Motor (Reference 1)

The Big Question

When motors fail, *how* do they fail?

The Consistent Answer

For medium-voltage (greater than 4 kV) motors, industry surveys consistently point to one answer: stator insulation failure.

Unlike purely mechanical rotating assets, motors incorporate fundamental electrical characteristics, with insulated stator windings and laminated iron armature and field cores to create rotating magnetic fields and convert them to useful torque. Predictably, when medium voltage motors eventually fail, the weakest link is the winding insulation. Many motors already have condition monitoring systems that will detect rotor failures (which make up 13% of total failures) and bearing failures (which are another 13% of total failures). However, until recently, no reliable online technology has existed to address the main failure mode, stator winding insulation failure – which accounts for fully 66% of motor failures (Figure 2)!

Knowing how motors will eventually fail helps point us to a monitoring solution. If only a technology existed that would allow owners and operators to track the insulation

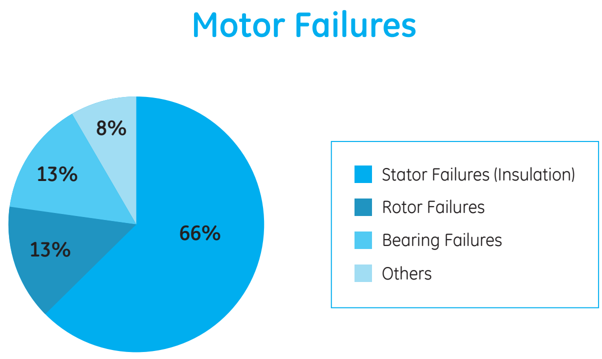

FIGURE 2: Identified failure modes from a multi-year survey of monitoring and diagnostics statistics of electrical machines and drives (Reference 2).

degradation over time, reliably and without needing to remove the motor from service, this would be a useful tool. Outages or down-time could be scheduled more effectively, unplanned events could be avoided, overall reliability would increase, and safety would improve.

For many years, industrial motor owners and operators have had to rely on one of the two following technologies to characterize the condition of the motor stator insulation. As you will see, neither of these methodologies is optimal.

Offline Portable Motor Testing Instrumentation

Several companies offer offline testing equipment that can give a reasonable characterization of the stator insulation condition. Unfortunately the motor and driven machines must be shut down, removed from service and "locked-out" for safety before testing can proceed. Many motor operators cannot afford this interruption to their process or business more often than once every 2 to 5 years or even longer. Testing at such a lengthy interval is of minimal value at best. The motor may be close to failure (or have already failed) by the time a scheduled test occurs.

Additionally, this testing is performed at ambient temperatures, so it cannot give a true characterization of the insulation condition while running under load at normal operating temperature. Worse-yet, several of the most valuable offline tests use low-current, high-voltage methods that actually degrade the insulation and contribute to early failure. When a motor with such a history eventually fails, the offline testing very likely contributed to the failure it was intended to prevent! Industry has had to rely on this technology because no reliable online test was available.

Online Partial Discharge (PD) Testing

Another method that has been used is an online technology called Partial Discharge monitoring. As insulation degrades over the life of the motor, very brief small discharge pulses occur through the insulation (often in voids within the dielectric). The PD monitoring system detects the increasing frequency of the discharges as the insulation deteriorates. Some systems also use ultrasonic acoustic sensors to listen for these discharges and plot the approximate location in an attempt to predict where and when the insulation will fail and hence when the motor will fail. While partial discharge technology does perform an online measurement, the technology relies heavily on complex algorithms and modeling for its prediction.

Partial Discharge monitoring has met with limited success due to the unreliability of the algorithms to predict where the failure in the insulation will occur. Often equipment operators have had Partial Discharge equipment that predicts a particular motor failure, only to find that the motor continues to operate trouble-free for several years past the point it was predicted to fail. Clearly, industry needs a better set of tools to ensure the reliability of their operations and the viability of their business.

Motor Stator Insulation Monitor (MSIM)

The Bently Nevada Motor Stator Insulation Monitor (Figure 3) is an online monitoring system that provides the industry's only continuous, direct measurement of stator winding capacitive and resistive leakage currents, offering the only credible online indication of motor insulation integrity using direct leakage current available outside of a laboratory.

This system was developed over several years in conjunction with the GE Global Research Center and has been designed for compatibility with the Bently Nevada 3500 Machinery

FIGURE 3: From left to right, MSIM monitor module, High Voltage Sensor and interface module, High Sensitivity Current Transformer (HSCT) and interface module.

Protection System (Reference 3). It is likely that the 3500 system is already installed in your facility on your most critical motor-driven equipment, making for an economical upgrade path if you decide to add MSIM capability. The system is also fully compatible with our System 1 software for long-term trending and diagnostics, either onsite or remotely.

MSIM System Benefits

The MSIM's technology enables you to monitor stator insulation condition continuously, eliminating surprises and providing valuable lead time for planning any required outages and repair activities. Shutting down the process in a controlled manner reduces the upsets that often result from an emergency trip. The system delivers several important benefits:

- Depends only on the configuration of the motor (6-lead external termination required) and is independent of the OEM.
- Works with induction and synchronous motors, with supply voltages up to 7.5kV and either 50Hz or 60Hz power supply (not compatible with DC motors or variable frequency drives).
- Continuous, online insulation integrity measurement does not require the motor to be removed from service for (potentially damaging) testing.
- Directly measures resistive and capacitive leakage current to provide Dissipation Factor (DF) measurement.
- Provides motor stator temperature measurement.

3500 System Integration

Because the MSIM leverages our existing 3500 series monitoring system technology, it provides additional "infrastructure" benefits:

- MSIM integrates with existing 3500 system, together providing protection and condition monitoring for both the drive motor and the driven machine.
- Accommodates MODBUS communications parameters for integration with your DCS.
- Configurable alarm setpoints (Alert & Danger) for all variables.
- Drives 3500 relay output for local annunciation.
- Local Display available as standard 3500 system options.
- Compatible with System 1* Optimization and Diagnostics Platform.
- Uses existing 3500 system training, reducing training investment.

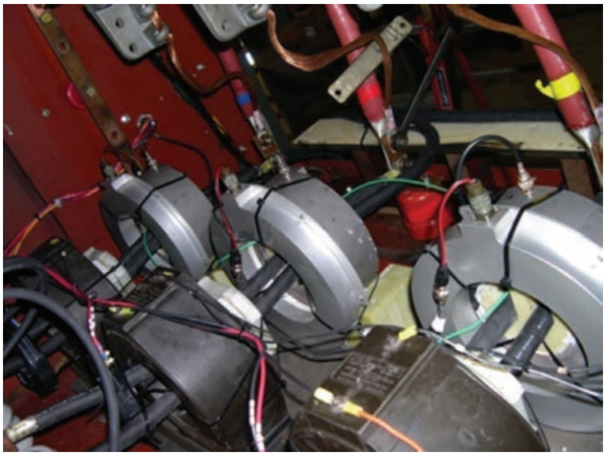

FIGURE 4: Photo inside motor termination vault. One HSCT is installed on each phase of power leads to the motor. Note: The HSCTs need to sense current in both conductors of each phase, so the MSIM system works with externally-terminated wye (star) connected stators, but not with internally-terminated or delta connected stators.

Technology Overview

The MSIM system consists of three voltage and three current sensors, a dedicated 3500 monitor and I/O module, and optional System 1 or DCS connectivity. In many ways the installation is very similar to other 3500 system installations.

The key to how the MSIM works is the HSCT technology (Figure 4). The HSCT directly measures the very small leakage current in the milliamp (mA) range in the presence of the normal running current of hundreds of amps. The 3500 interface module conditions and converts the HSCT sensor signal to the direct DF measurement.

In addition to the HSCT, the MSIM monitor uses High Voltage Sensors (HVS) with interface modules, along with motor stator temperature (RTDs or thermocouples) as inputs to the system.

Applications

Motors that can most obviously benefit from application of the MSIM technology are those that are classified as being highly critical to your business. Any situation where motor failure could cause a serious detrimental effect on your operation, whether it is to reliability, safety, production or environmental compliance, would be candidate for application of an MSIM system. While it is impossible to determine the actual criticality of a motor to a business without analysis, a few typical examples of highly critical motor applications are listed here.

Oil & Gas Upstream (offshore and onshore)

- Main Process Compressors
- Combustion Air Compressors
- Water Injection Pumps
- Export Pumps

Oil & Gas Downstream

- Main Air Blower
- Plant Air Compressors
- Wet Gas Compressors
- Feed Gas Compressors
- Recycle Compressors
- Regeneration Compressors
- Reciprocating Hydrogen Compressors

Power Generation

- Boiler Feedwater Pumps
- Boiler Circulation Pumps
- Reactor Coolant Pumps

Field Deployment

The MSIM system has been deployed successfully at several power generating stations in the USA (Figure 5). Extensive field testing on Boiler Feedwater Pump drive motors at these facilities has verified that motor insulation degradation CAN be detected online and trended to give operators and owners direct line of sight to machine condition and early warning of motor failures for their critical machinery, with very high confidence factors.

Test Data

We tested the MSIM system in a controlled laboratory setting to monitor actual insulation deterioration of stator windings. Figure 6 shows test results for a motor that was subjected to severe stress in order to "age" the stator winding over a highly-accelerated time frame. This allowed the testing to proceed over the course of a few hours instead of several years.

References

1. GE Motors Pegasus MHV Medium Voltage AC Induction Motors brochure, GEA-12310C.
2. Industrial Survey "Monitoring und Diagnose elektrischer Maschinen und Antriebe," Allianz Schadensstatistik an HS Motoren, 1996–1999, in VDE Workshop, 2001.
3. Orbit Vol 32 No 1 JAN 2012, Whitefield, C. David. "New Online Motor Stator Insulation Monitor (MSIM) for 3500 System."

For More Information

Contact your local GE Representative or find us online:

http://www.ge-mcs.com/en/contact-us.html

View and download references at our Motor Stator Insulation Monitor page:

http://www.ge-mcs.com/en/bently-nevada-monitoring/continuous-online-monitoring/motor-stator-insulation-monitor.html

FIGURE 5: Field installation at a power generating station. The aluminum-cased HSCT transducers are behind the normal protection CT transducers (with brown molded plastic cases) in this photo.

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**Pegasus is a trademark of the General Electric Company.

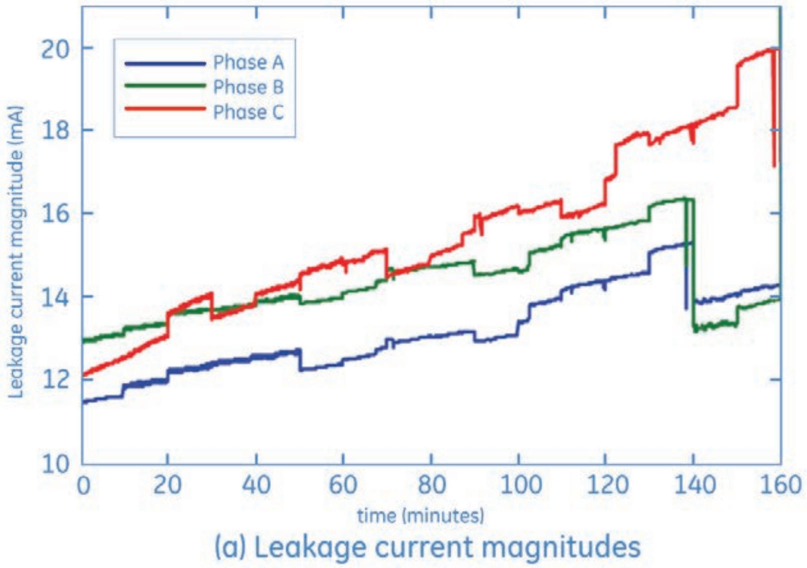
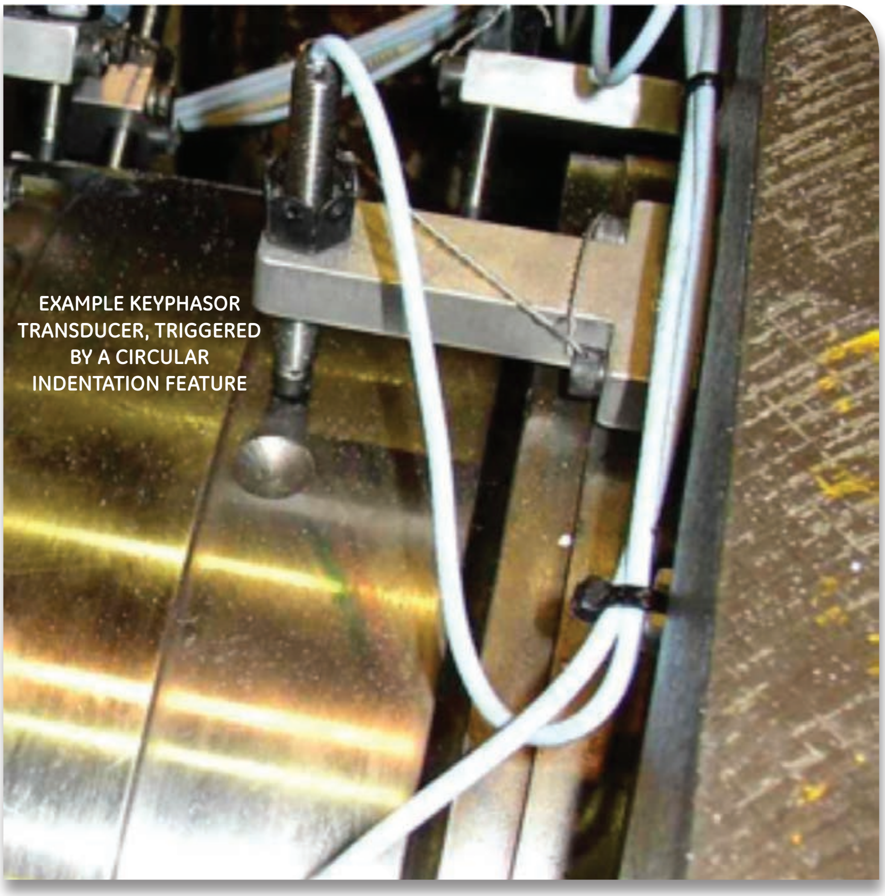


FIGURE 6: Online leakage current trend showing the final hours of motor life before full insulation failure. The capability to directly measure very small leakage currents in the presence of very high operating currents is unique to the MSIM system.


EXAMPLE KEYPHASOR TRANSDUCER, TRIGGERED BY A CIRCULAR INDENTATION FEATURE

Collecting Keyphasor* Waveform Data

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This issue of Orbit has a unifying theme of "Intelligent Machines." From the perspective of the Bently Nevada* Asset Condition Monitoring product line, we make machines "intelligent" by applying transducers, monitors and signal processing algorithms to convert analog signals to accurate digital data that can be processed by analytic software.

One of the useful things that the ADRE* 408 system allows you to do is to directly capture Keyphasor waveform data. This allows you to verify that the installation is generating a "clean" and consistent pulse at once-per-turn intervals triggered by the notch or projection feature on the machine rotor. This wasn't possible with our previous data collection systems unless you physically connected the Keyphasor (KPH) signal as an input to a dynamic data collection channel in addition to the KPH channel.

REMEMBER – IT OFTEN TURNS OUT THAT THE MOST IMPORTANT DATA FOR ANY MACHINERY DIAGNOSTIC TASK IS THE DATA THAT YOU FORGOT TO COLLECT WHILE YOU HAD THE CHANCE!

Whenever I teach folks how to use the 408, I always suggest that they capture the KPH signal as an asynchronous waveform. This is because the synchronous waveform signal processing will not start collecting data unless the KPH channel is being correctly triggered in the first place. So if the KPH channel isn't being triggered correctly, the synchronous waveform data will not be collected. If you are having trouble with your Keyphasor measurement, make sure that you set the 408 up to collect in a Delta Time mode, trigger it, and collect your Keyphasor waveforms as discussed here.

I recently discussed this concept with Roger Hamby, one of our Machinery Diagnostic Services (MDS) Engineers, and discovered that he recommends collecting the synchronous KPH waveforms when using the ADRE 408 to collect diagnostic data. His reasoning is that they are typically much cleaner to view than the asynchronous waveforms, and he establishes configuration settings to collect both types of KPH waveforms on every job.

Data Collection Settings

If you use our new Quick Config software to set up your databases, it automatically collects the asynchronous waveform data for the KPH signal. If you are configuring the signal processing settings manually, there are a couple ways of doing it. One way is to go to the waveform configuration tab for the KPH channel configuration and select the settings there.

The other, more convenient method is to make these selections from the Waveform tab of the Dynamic Channel Configuration dialog. Once you have selected the waveform collection settings that you want, right click in the beige cell in the upper left under "Channel Name" (red outline in Figure 1).

If you select the highlighted option from the shortcut menu, "Apply all waveforms to all active channels in database," it will apply your waveform collection settings to the Keyphasor channel as well as to the radial vibration channels in the database (Figure 2).

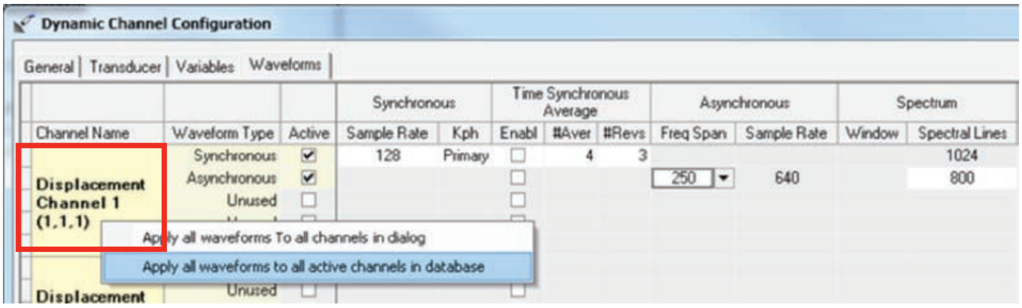

FIGURE 1: Dynamic Channel Configuration dialog, showing that both the Synchronous and Asynchronous waveform check boxes have been selected.

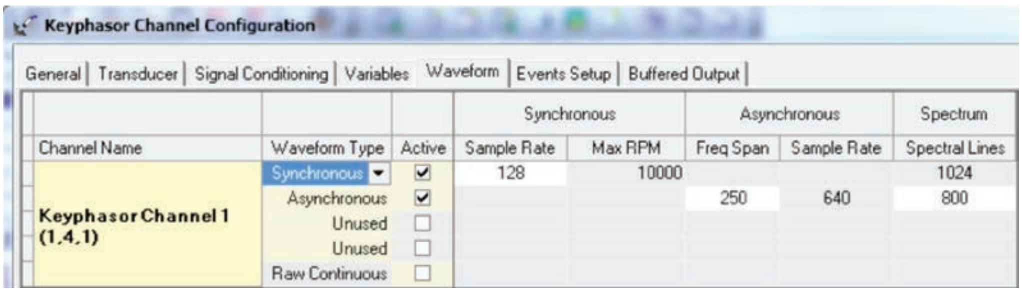

FIGURE 2: Keyphasor Channel Configuration dialog, showing that the collection settings were applied from the shortcut menu command in Figure 1. In this example the synchronous sampling rate was set to 128 samples per revolution, which is 7680 Hz for 3600 rpm. The asynchronous sampling rate was set to 640 Hz, which is 2.56 x the selected Frequency Span of 250 Hz. (The 2.56 multiplier meets the Nyquist criterion of being at least 2 times the frequency span, and adds a little bit more margin to account for the low-pass anti-aliasing filter that is applied for asynchronous sampling).

Real-World Example

Here is a real situation where one of our MDS engineers was working on a steam turbine that had an Axial Keyphasor transducer (Figure 3).

It turned out that the axial float of the turbine rotor was initially not set correctly, and when the unit started up, the probe was too close to the shaft to recognize the once-per-turn triggering events as being legitimate (the KPH channel was temporarily in "Not OK" due to the low dc gap value).

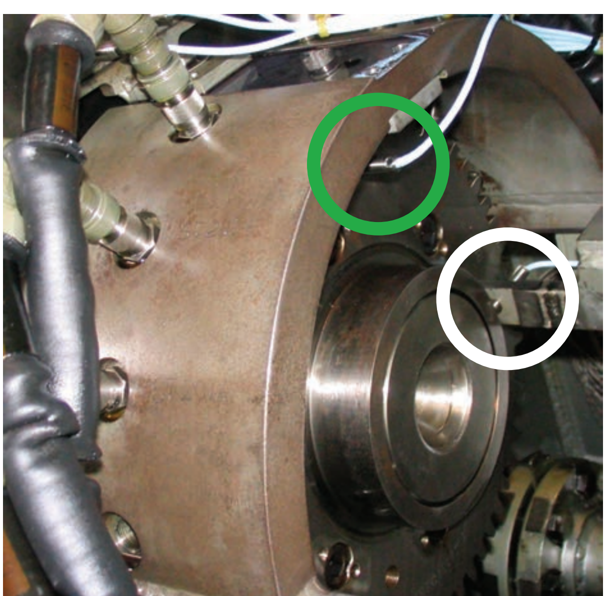

FIGURE 3: Example steam turbine similar to the one in this article. This view shows the end of the rotor inside the "front standard." Multiple speed sensors are mounted radially to observe passage of the toothed wheel. The Keyphasor probe (in green circle) is mounted axially and views the face of the toothed wheel. The eccentricity probe (in white circle) is mounted radially and views the collar.

However, even though the KPH channel wasn't triggering, we were still able to capture the asynchronous waveform (Figure 4), which verifies how low the dc gap voltage actually was at this time. Figure 5 shows a speed trend during turbine coastdown, which shows that the KPH signal dropped out during the shutdown as well.

Observe that the scale on the left vertical axis shows the dc voltage of about -1.70 VDC. This was below the OK limit of the probe, and was certainly outside of its linear range. We were probably lucky that the probe tip wasn't damaged by physical contact with the rotor! The scale on the right vertical axis shows that the peak amplitude of the ac signal component was about 0.12 vac.

Note that the original waveform plot was 3.2 seconds long (2048 samples / 640 samples per second). Using the "rubber-banding" feature in Sxp software, I reduced the time shown to only 0.42 seconds to show the individual pulses more clearly.

Figure 6 shows the KPH asynchronous waveform about 11 minutes after the measurement shown in Figure 4. As the rotor shaft heated up and grew away from the probe, the dc voltage became more negative (about -4.42 vdc). Also, the amplitude of the KPH signal became stronger, at about 0.3 vac pk.

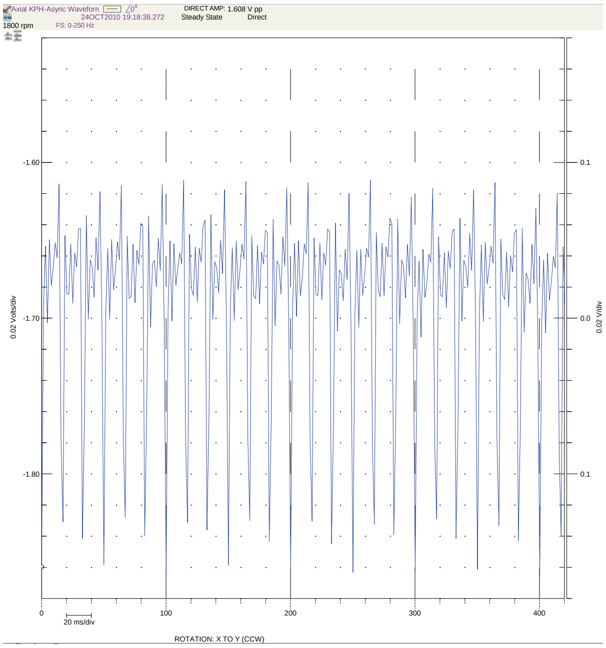

FIGURE 4: Asynchronous waveform of axial KPH signal during steam turbine startup (time 19:18:38.272).

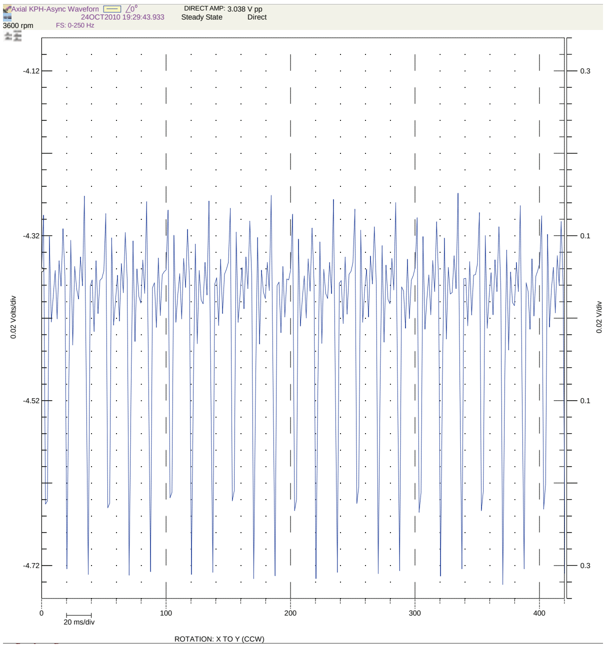

FIGURE 6: Asynchronous waveform of axial KPH signal during steam turbine startup (time 19:29:43.933).

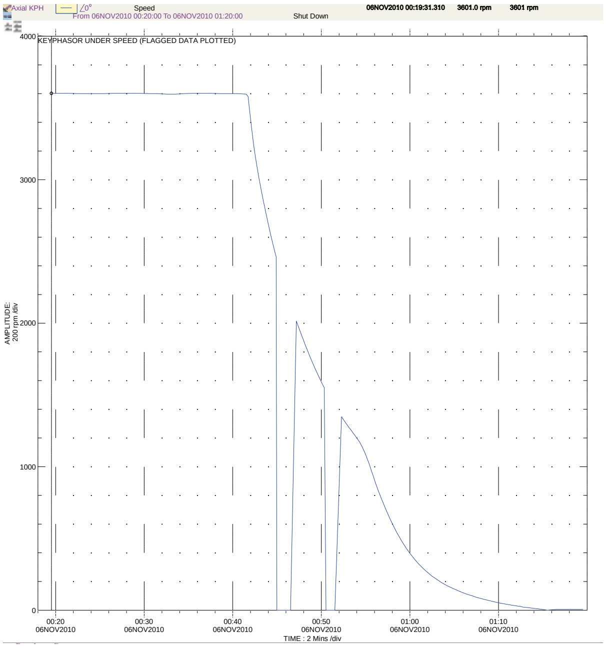

FIGURE 5: Speed trend plot during steam turbine shutdown shows two brief intervals (about 2 minutes each) where the KPH signal dropped out.

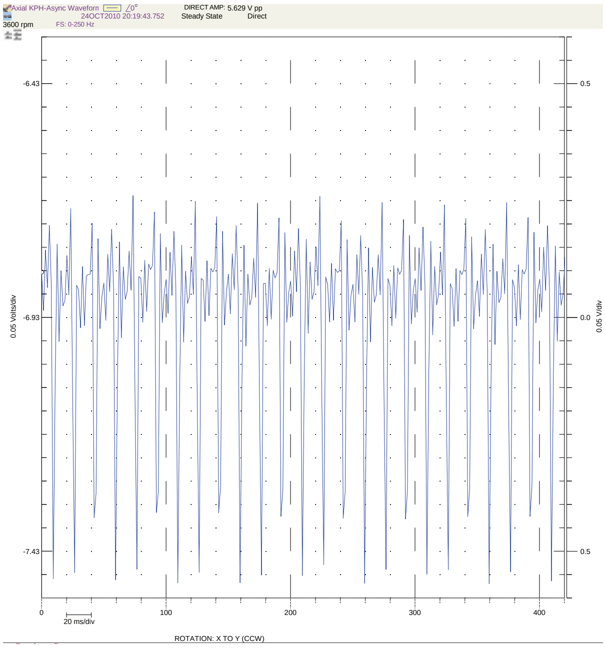

FIGURE 7: Asynchronous waveform of axial KPH signal at full speed, 3600 rpm, after steam turbine rotor thermal growth has stabilized (time 20:19:43.752).

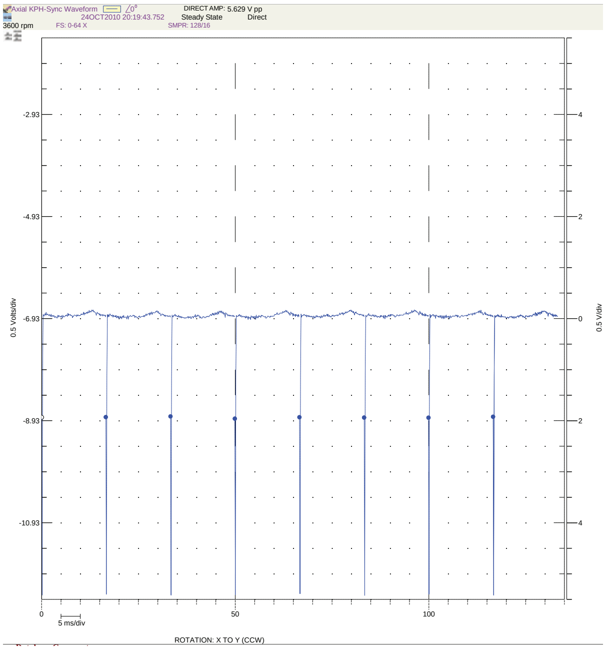

FIGURE 8: Synchronous waveform of axial KPH signal at full speed, 3600 rpm, after steam turbine rotor thermal growth has stabilized (time 20:19:43.752).

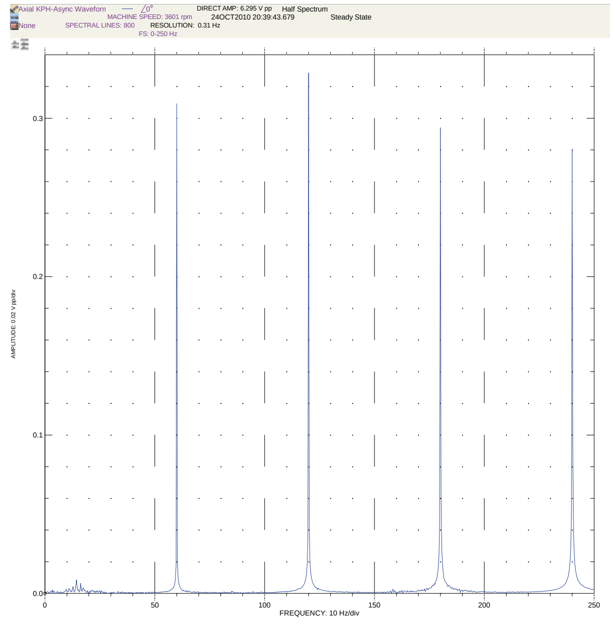

FIGURE 9: Spectrum of asynchronous KPH waveform. Dividing the 640 Hz sampling rate by 2.56 (for Nyquist criterion & anti-aliasing low-pass filter) gives us the 250 Hz frequency span. Because of this short span, we are only able to see the fundamental frequency (60 Hz) and the first three harmonics for the asynchronous waveform.

About 50 minutes later (Figure 7), the steam turbine rotor reached steady state thermal conditions and the KPH signal settled at a constant value of about -6.93 vdc with a peak amplitude of about 0.5 vac. It should be noted that while ADRE didn't start triggering at the time of the first KPH sample shown (Figure 4), it was functioning normally during the times of the other two samples.

> ***Note:*** *The dc voltage change of about 5.2 V represents a minimum of 26 mils of displacement change, since 5.2 V / (200 mV/mil) = 26 mil. This is a larger than expected value for axial float, and is indicative of an issue here. It is also a good example of why we normally recommend using radial KPH transducer installations, rather than axial installations, as in this example.*

Figure 8 shows the synchronous waveform plot for the KPH signal at the same time as the plot shown in Figure 7. As you can see, the dc value is the same, but, the ac value is much better defined. This is because for the synchronous samples, we are triggering the samples by the KPH pulse, and therefore our timing for data collection is perfectly synchronized with the repeating pattern of the KPH signal.

In the asynchronous case, the individual digitized samples were taken at equal intervals based on the 640 Hz sample rate. But since the sampling was not synchronized to rotation speed, they essentially occurred at "random" times relative to the repeating characteristics of the KPH signal. While this topic is beyond the scope of this article, it is often more effective to "oversample" by choosing a frequency span of at least 5 KHz, in order to improve resolution of the collected sample.

The frequency span limitations imposed by sampling rate can be seen more clearly by looking at the spectrums of the two samples (Figures 9 & 10). Remember that square waves such as the synchronous KPH waveform

FROM THE PERSPECTIVE OF THE BENTLY NEVADA ASSET CONDITION MONITORING PRODUCT LINE, WE MAKE MACHINES "INTELLIGENT" BY APPLYING TRANSDUCERS, MONITORS AND SIGNAL PROCESSING ALGORITHMS TO CONVERT ANALOG SIGNALS TO ACCURATE DIGITAL DATA THAT CAN BE PROCESSED BY ANALYTIC SOFTWARE.

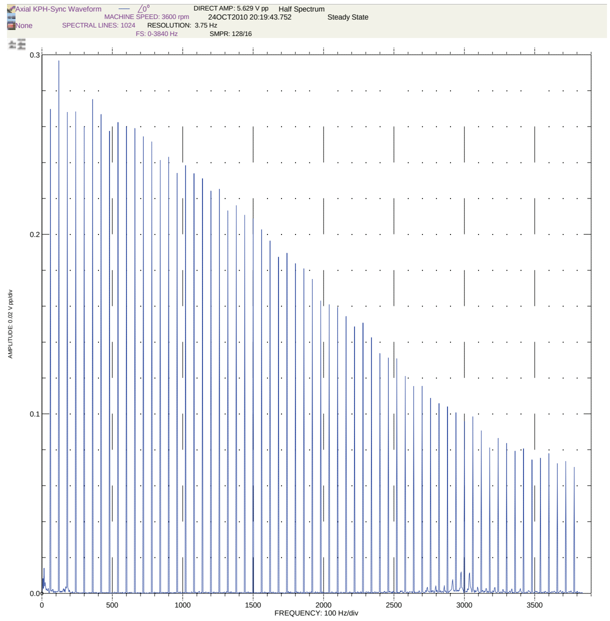

FIGURE 10: Spectrum of synchronous KPH waveform. Dividing the sampling rate of 7680 Hz by 2 per minimum Nyquist requirement (no anti-aliasing filter used for synchronous sampling) gives us the 3840 Hz frequency span, allowing us to see several dozen harmonics in the series.

are made up of every odd order of the fundamental frequency, which is 60 Hz (3600 rpm) in this example.

You will see that while there are no discrete frequencies with amplitudes above 0.3 V pp., the orders of the frequencies for the spectrum of the Keyphasor sample extend well past the 250 Hz sample range chosen for asynchronous sampling. And, as the Keyphasor pulse is not a perfect square wave, we are also seeing even orders as well as odd orders.

In conclusion, being able to sample the Keyphasor waveforms is a valuable tool, and you should consider collecting them in every ADRE database, especially for machines that you haven't collected data on before. I am now amending my recommendation to my students to collect BOTH the synchronous and asynchronous waveforms, and using the 408's ability to collect multiple waveforms of each variety. I would further suggest collecting the long asynchronous waveform (250Hz) as well as the short waveform of about 40 to 75 times running speed.

See you next time the KPH rolls around!

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ADRE 408* DSPi Signal Processing

AC vs. DC Mode

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ONE OF THE MOST BASIC CONCEPTS IN VIBRATION MONITORING IS THE IMPORTANCE OF UNDERSTANDING THE SIGNAL PROCESSING SETTINGS THAT ARE BEING APPLIED TO THE MEASURED SIGNAL DURING SAMPLE COLLECTION.

This tip is based on an inquiry that we received from a customer. The ADRE user was wondering why the signal waveforms they were seeing were different for the same very low-frequency vibration signal that was being sampled in both the AC and DC Modes. The cause ended up being that these two modes have some subtle differences in signal processing, which the user hadn't realized. This is a great example of a case where readings differ for some reason that isn't initially obvious (References 1 & 2).

Background

When configuring data collection settings for a Dynamic (waveform) Channel in the ADRE 408, it is important to take into account the signal conditioning features, and understand the impact that they will have on the signal processing that will be performed. The coupling and sampling modes are shown in Figure 1 as they are displayed in the ADRE SXp software interface.

Coupling

Observe that there are two available signal coupling options in the ADRE 408 unit – ac and dc. These correspond to classic analog oscilloscope display settings, where ac-coupling samples only the dynamic component of the signal, relative to a line that represents the average value of the waveform. Similarly, dc-coupling samples the signal with the dynamic component as well as its actual dc offset value, as displaced from the 0 volt reference.

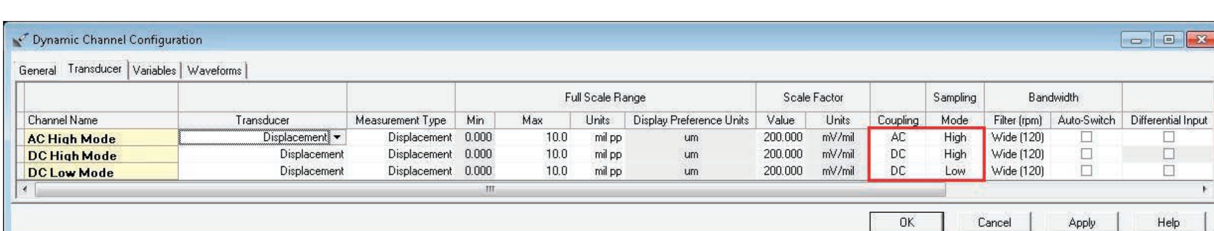


FIGURE 1: Dynamic Channel Configuration dialog in ADRE SXp software. The red rectangle indicates where coupling and sampling mode settings are selected.

Sampling

Associated with the Coupling setting is the Sampling Mode, which can be selected for either "High" or "Low." The high sampling mode is optimized for collecting samples with high frequency content, while the low sampling mode is more appropriate for collecting low-frequency signals. The selected sampling mode determines whether a high or low frequency bandpass filter is applied to the signal.

> ***Note:*** *A low bandpass filter has a longer settling time than a high bandpass filter. The table in Figure 2 shows the frequency corners for the different modes.*

Coupling	Mode	Range
AC	High	1.6 Hz to 50 kHz
AC	Low	N/A
DC	High	1 Hz to 50 kHz
DC	Low	0.167 Hz to 20 kHz

FIGURE 2: Two sampling modes (High and Low) are supported at the channel level. Observe that the low frequency bandpass filter is only available in the DC mode. These filter frequency specifications are ±1 % of Full Scale Range and ± 0.011V below 1 V pp.

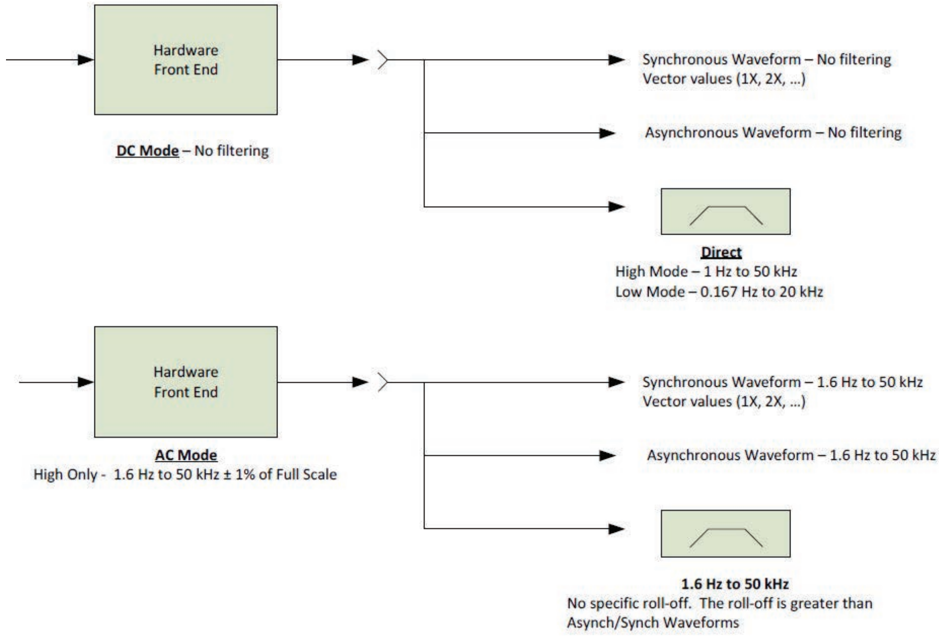
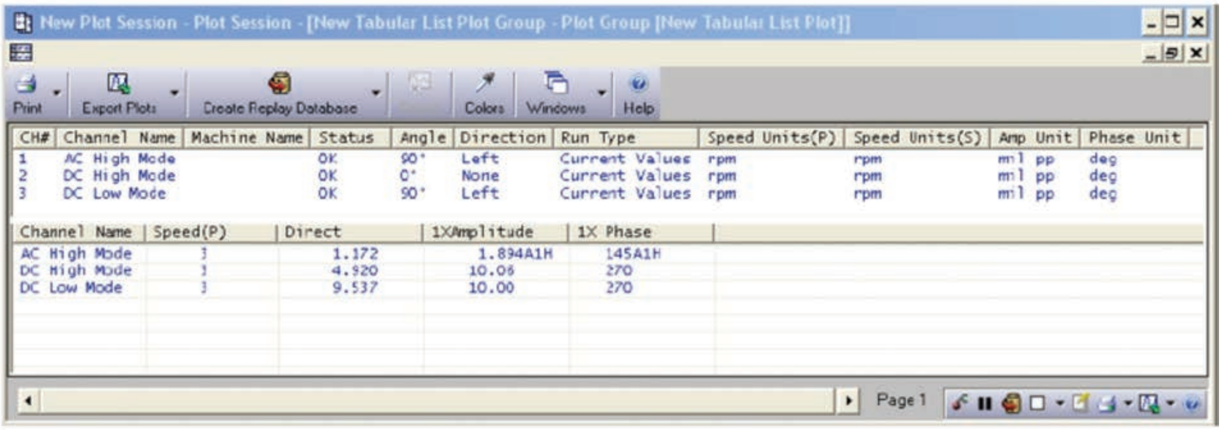


FIGURE 3: Signal processing paths for the DC mode are shown in the upper half of this drawing. The AC mode paths are shown in the lower half of the drawing.



CH#	Channel Name	Machine Name	Status	Angle	Direction	Run Type	Speed Units(P)	Speed Units(S)	Amp Unit	Phase Unit
1	AC High Mode		OK	90°	Left	Current Values	rpm	rpm	mil pp	deg
2	DC High Mode		OK	0°	None	Current Values	rpm	rpm	mil pp	deg
3	DC Low Mode		OK	90°	Left	Current Values	rpm	rpm	mil pp	deg

Channel Name	Speed(P)	Direct	1XAmplitude	1X Phase
AC High Mode	3	1.172	1.894A1H	145A1H
DC High Mode	3	4.920	10.06	270
DC Low Mode	3	9.537	10.00	270

FIGURE 4: Tabular List Plot shows values after signal processing was performed on the identical input signal by three Dynamic Sampler channels with slightly different configuration settings.

> ***Note:*** *AC Coupling removes the DC component within the Dynamic Signal path. DC coupling is required to obtain accurate data at very low shaft speeds (for example, 1 rpm), while AC-Coupling allows maximum data resolution due to channel gain.*

From an instrumentation standpoint, Figure 3 shows the different electrical paths that produce the Synchronous, 1X and 2X filtered values, Asynchronous waveforms and "Direct" (broadband) values:

Laboratory Verification

We reproduced the customer's settings in the lab using a function generator programmed to produce a sine wave signal at 2 Vpp @ 0.05 Hz (the synchronous frequency corresponding to a slow-speed machine turning at 3 rpm).

This signal was fed into three different Dynamic Sampler channels configured as shown in Figure 1. Observe that in the Tabular List plot (Figure 4), all three of the channels are displaying different readings for Direct, and 1X Amplitude and Phase values.

Question: What caused the observed discrepancies in these measured values?

Answer: These apparent inconsistencies were caused by the differences in the low frequency cutoff frequencies for each of the channels.

All three of the channels were working exactly as designed, and it was simply the differences between filter settings that were processing the signal in different ways as summarized here:

- The AC High Mode attenuated everything below 1.6 Hz (96 rpm). With an input at 0.05 Hz (3 rpm) every reading is attenuated (synchronous, asynchronous, 1X and Direct).
- The DC High Mode only attenuated the Direct values below 1 Hz (60 rpm).
- The DC Low Mode is similar to the DC High Mode but the attenuation for the Direct value starts at 0.167 Hz (10 rpm).

Figure 5 shows the same electrical paths as Figure 3, with the effects of the signal processing on the input signal.

Figures 6 through 8 are the actual waveform plots, which show the effects of different amounts of amplitude attenuation and phase distortion from the low frequency corners of the bandpass filters in the signal path.

Observe that both of the samples that were originally collected in DC Coupled mode are being displayed here in AC Coupled mode for more consistent plotting comparison with the sample that was collected in AC Coupled mode. The DC Coupled samples are still intact with their dc offset values in the database, but the SXp software simply provides the ability to *display* these samples in an ac-coupled format for convenience when needed.

WHEN CONFIGURING DATA COLLECTION SETTINGS FOR A DYNAMIC (WAVEFORM) CHANNEL IN THE ADRE 408, IT IS IMPORTANT TO TAKE INTO ACCOUNT THE SIGNAL CONDITIONING FEATURES, AND UNDERSTAND THE IMPACT THAT THEY WILL HAVE ON THE SIGNAL PROCESSING THAT WILL BE PERFORMED.

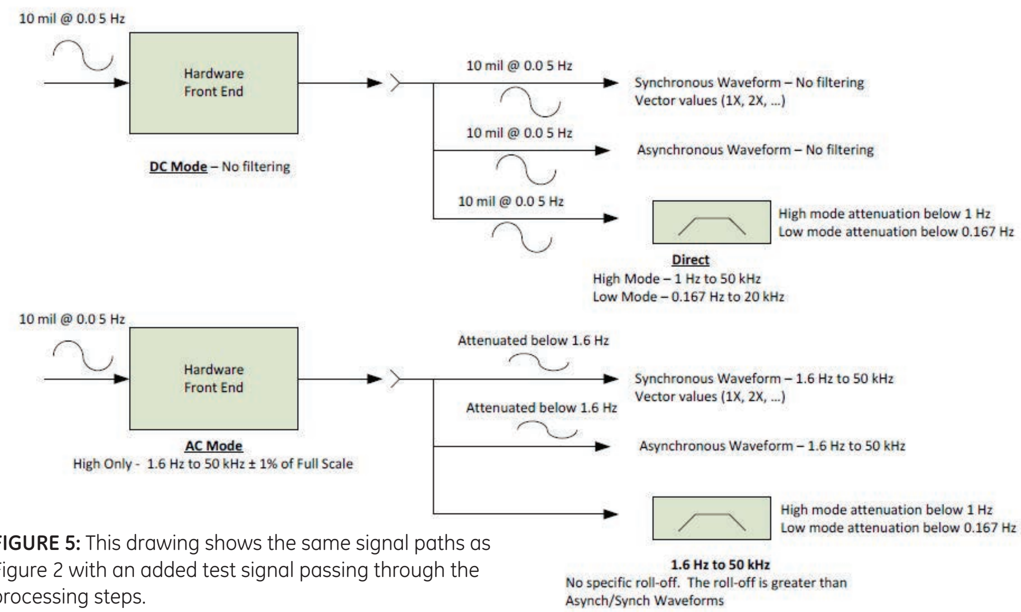


FIGURE 5: This drawing shows the same signal paths as Figure 2 with an added test signal passing through the processing steps.

AC High Mode Results

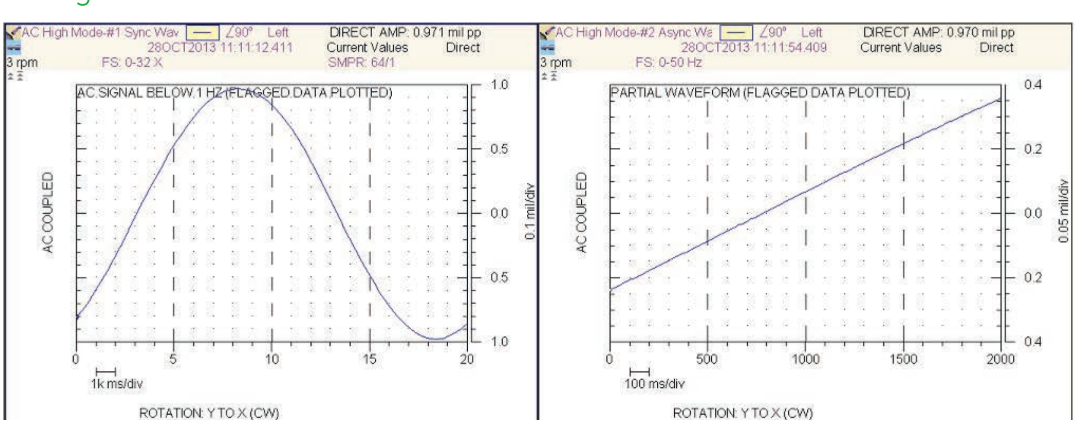


FIGURE 6: AC High Mode plots showing synchronous waveform (left) and asynchronous waveform (right).

DC High Mode Results

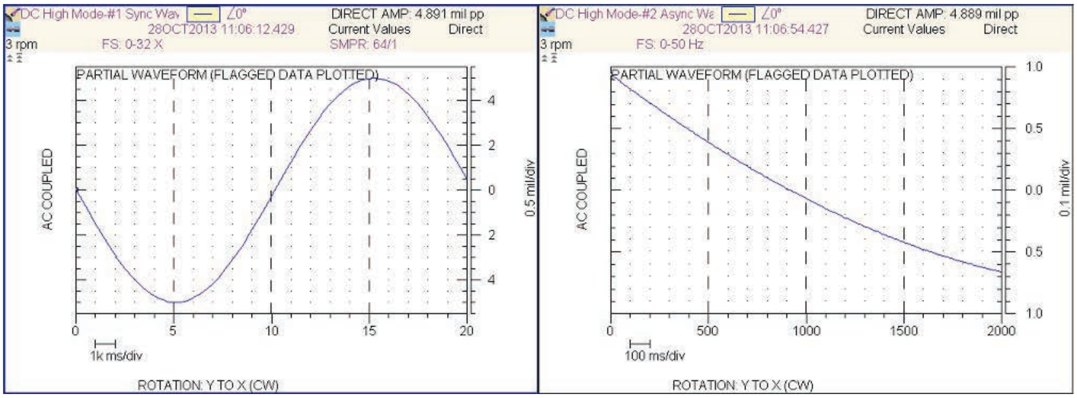


FIGURE 7: DC High Mode plots showing synchronous waveform (left) and asynchronous waveform (right).

DC Low Mode Results

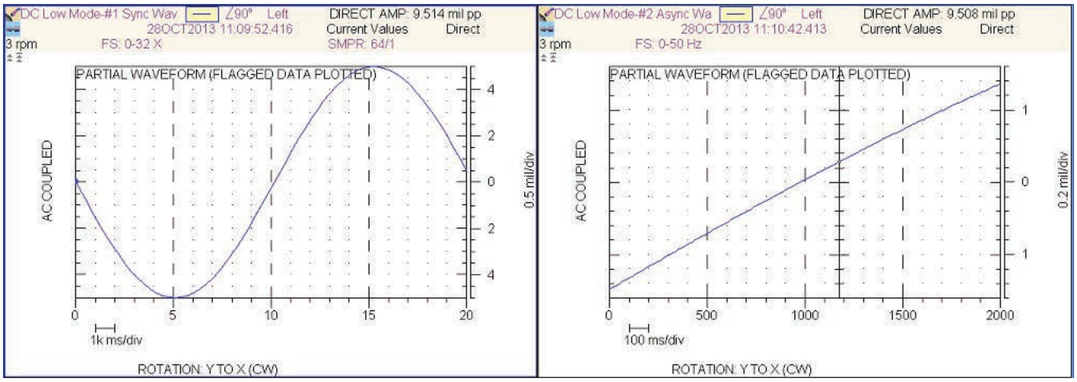


FIGURE 8: DC Low Mode plots showing synchronous waveform (left) and asynchronous waveform (right).

Note also that the difference in displayed time (20 seconds for the synchronous waveform and 2 seconds for the asynchronous waveform) results from the difference in sample rates and frequency span associated with the waveform data collection settings. One complete sinusoidal vibration cycle is visible in the synchronous waveforms, since 20 seconds corresponds to one complete shaft rotation at 3 rpm. However, only one tenth of the full cycle is visible in the asynchronous waveforms, since the total time of the waveform record is shorter.

Conclusion

One of the most basic concepts in vibration monitoring is the importance of understanding the signal processing settings that are being applied to the measured signal during sample collection. This case was a great example of how readings may appear to be anomalous, until you go "back-to-basics" and take a close look at what the data collection settings actually are, and what they mean.

References

1. Orbit Vol.25 No.2, 2005. Sabin, Steve, "Understanding Discrepancies in Vibration Amplitude Readings Between Different Instruments, Part 1 of 2."

2. Orbit Vol.26 No.1, 2006. Chitwood, Randy; Hamad, Akram; Qureshi, Munir; Sabin, Steve, "Understanding Discrepancies in Vibration Amplitude Readings Between Different Instruments, Part 2 of 2."

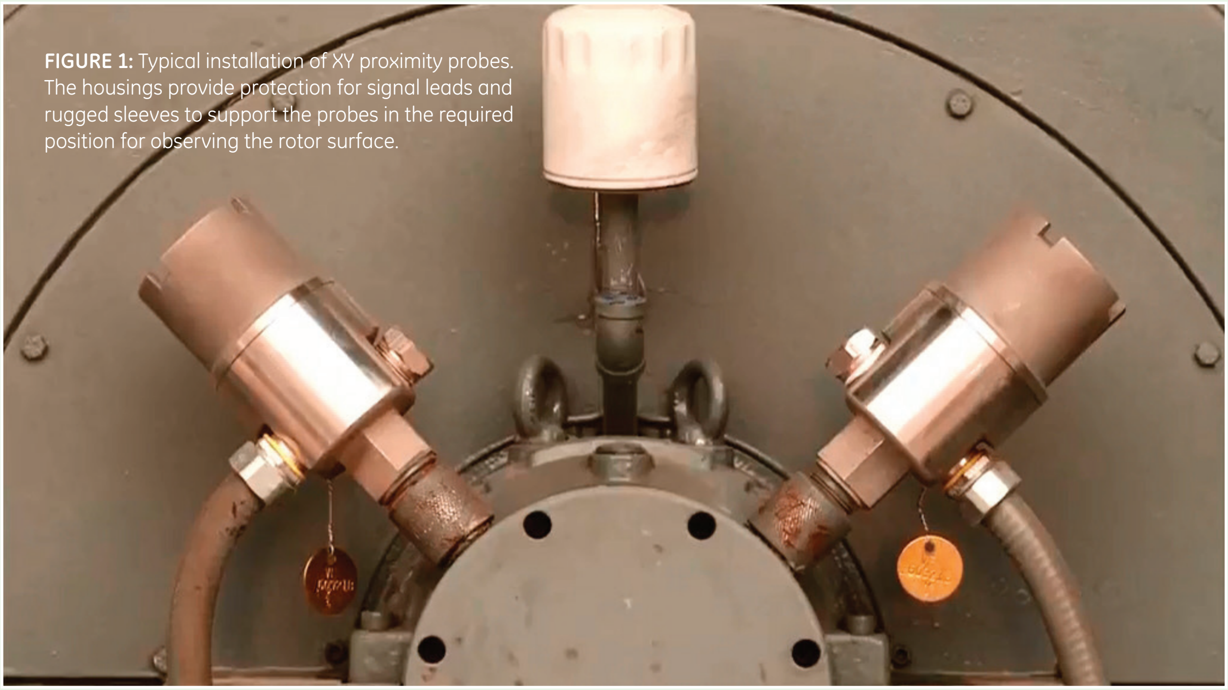


FIGURE 1: Typical installation of XY proximity probes. The housings provide protection for signal leads and rugged sleeves to support the probes in the required position for observing the rotor surface.

Radial Transducer Orientation

The cover photo of this issue raises an interesting question. For horizontal machines, why are XY proximity transducers so often installed at 45 degrees right and 45 degrees left of a vertical reference point (Figure 1), while industry-recognized standards for casing-mounted accelerometers or velocity sensors recommend mounting as close as possible to true vertical and true horizontal orientation? Several factors are involved, but the basic reason is that the transducers are being used to measure very different things.

Proximity Transducers

XY proximity transducers are used to measure the movement of the monitored machine rotor within the clearances of its fluid-film bearings. By using the signals from a mutually perpendicular (orthogonal) pair of transducers 90 degrees apart, we can accurately display the "orbit" path that the shaft centerline makes within the measurement plane (Reference 1).

In addition to the requirement that the transducers are mounted 90 degrees apart, it is vital that the signals from both sensors are processed *simultaneously* in order to accurately generate the 2-dimensional representation of rotor position as the rotor vibrates within the bearing. As long as the probes are orthogonal, their radial orientation on the machine doesn't impact the measurement accuracy.

Installation Considerations

Because proximity probes are most often permanently installed at machine bearings, it makes perfect sense to avoid mounting a probe in the true horizontal orientation as it would conflict with the split line of the bearing housing. There are quite often other obstacles such as lifting lugs (or vent lines, as in Figure 1) on the top of the bearing housing that also make it impractical to install a probe in the true vertical orientation.

Note: Sometimes it makes more sense to install an XY probe pair in the lower bearing housing, where the probes, mounting brackets, and extension wiring can remain installed and undisturbed when the upper half of the machine casing, upper bearing supports, and rotor are removed for major maintenance activities.

Seismic Transducers

Accelerometers or velocity sensors are used to measure the movement of the outer surface of the bearing housing – most often on machines with rolling element bearings. Because these bearings have negligible clearances, we are indirectly measuring the movement of the rotor as well as the machine housing, foundation, and everything else that is connected and moving together as a semi-rigid system.

In addition to inferring rotor movement (which can be caused by unbalance forces, rubs, misalignment, and other potential problems), seismic transducers are very often used to capture characteristic fault frequencies from rolling element bearings – as well as overall (broadband) amplitudes for general condition monitoring.

A once-per-turn phase reference signal is required for machine balancing and for specialized diagnostic techniques such as Operating Deflection Shape (ODS) and Time Synchronous Averaging (TSA) analysis, which will be topics of future articles. However, routine vibration samples for condition monitoring are very often captured using asynchronous samples - which are not referenced to a once-per-turn pulse. For this reason, a single transducer is typically used to measure machine vibration at bearing housings – one measurement point at a time – using one channel of a portable vibration data collector.

Since signals from seismic sensors are rarely used to collect "orbit" data, there is no need for them to be installed in orthogonal pairs. And unless synchronous samples are being collected there is no need to process two signals simultaneously. For many portable vibration data collection applications, it is appropriate to use a single accelerometer to measure vibration at all of the pre-established measurement locations – one at a time – on each monitored machine.

Anisotropic Systems

Many machine-foundation systems are "anisotropic," which means that their stiffness characteristics vary with measurement direction. For such a system, the true vertical and horizontal measurements often capture vibration that closely represents the extremes of foundation stiffness and resultant vibration response for the system.

An extreme example that is easy to visualize would be a machine that is mounted on a tall steel pedestal that can vibrate like a tuning fork. Such a system can easily have much higher stiffness (with higher corresponding natural frequency) in the vertical direction as vertical forces would affect the pedestal in compression. At the same time, it would have much lower stiffness (with lower natural frequency) in the

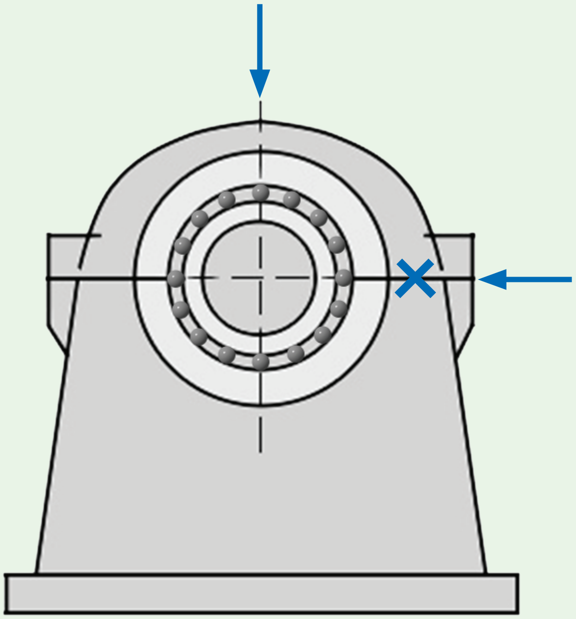


FIGURE 2: Typical true vertical and horizontal sensor locations for seismic transducers on a bearing are indicated with blue arrows (axial location identified by a blue "X").

horizontal direction, as horizontal forces would affect the pedestal by bending it laterally back and forth.

When a routine data collection route requires that only a single measurement be made on a particular bearing, it is very often taken with the transducer temporarily attached to the top of the bearing housing, which is a convenient location for many horizontal machines. However, when a more complete set of samples is needed, most recognized guidelines recommend measuring as close as possible to the vertical, horizontal, and axial directions (Figure 2) for consistency, and because these directions so often represent the broadest range of variation in system stiffness.

The axial measurement provides one more diagnostic tool that is especially sensitive to certain machine malfunctions. Commonly, a single sensor is used to take all three of these measurements sequentially, although triaxial sensors are sometimes used to measure vibration in three axes without the need to move the sensor to three separate measurement points.

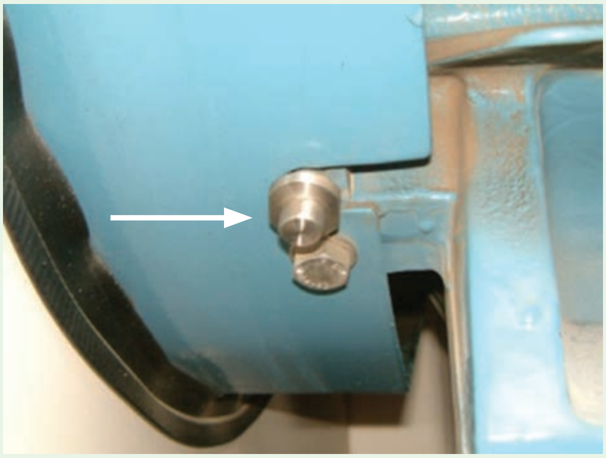


FIGURE 3: A quick-connect fitting (white arrow) was permanently installed on the bottom of a bearing housing on this particular machine. The machine was mounted fairly high next to a personnel walkway, so this sensor location was also more practical to reach than a location on the top of the machine would have been. This particular fitting requires ¼ turn to attach or remove an accelerometer using a corresponding quick connect base. Observe that this fitting is attached directly to the cast frame of the machine, and not to the end bell. This provides a more direct vibration path from the bearing to the sensor.

Load Zone Effects

An important concept with all bearings is that radial loading very often occurs in one predominant direction, called the "load zone" of the bearing. When worn or damaged components of a rolling element bearing (such as a cracked race or element) pass through this load zone, the impulses that are generated are often emphasized by the increased radial force, causing a higher amplitude vibration that is easier to detect. For many horizontal machines, the force of gravity pulling on the massive rotor causes the load zone to be near the bottom of the bearing, which can make it more effective to install a vertical accelerometer on the lower surface of the bearing housing, rather than on the upper surface (Figure 3).

References

1. Orbit Vol. 14 No. 4, December, 1993. Jordan, Mark A., "What are orbit plots anyway?"

http://www.ge-mcs.com/download/orbit-archives/1991-1995/December%201993/1293jordan.pdf

3500/46M Hydro Monitor

Smart Monitoring for the Intelligent Machine Age

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Older machinery protection systems, and even transmitters (Reference 1) and simple vibration switches marketed today, only produce a "Direct" (broadband) vibration measurement. Since the Direct value contains contributions from all sources of measured vibration, it is the one measurement that can provide a comprehensive representation of the overall health of the machine. However, relying on this measurement alone has drawbacks.

One problem is that because the Direct measurement is typically used to alert operators or trip the machine, Direct alarm thresholds are set relatively high to suit all situations and prevent false alarms and trips. Consequently, these alarms and trips ignore notable vibration changes in all but the worst-case operating condition.

Another limitation is that Direct vibration alone merely provides an indication that there is (or has been) a problem, but provides little or no useful information to help you answer the next logical questions of what is causing the problem, and what operational or maintenance actions should be taken to mitigate or correct it.

This article describes how an effective machinery protection/condition monitoring system solves these problems, and how the 3500/46M Hydro Monitor addresses the unique needs of hydro turbine generating units.

Phase measurement unlocks predictive maintenance value

Today's microprocessor-based machinery monitoring systems can perform signal processing functions that once required bulky portable analyzers. This enables the monitor to break out several components and characteristics of the broadband vibration that can serve as useful diagnostic "clues." A good analogy is a musical chord. An untrained ear can only tell that the overall sound is dissonant, but cannot tell which of the notes is out of tune. However, if each note that makes up the chord is played individually, even an untrained ear can usually pick out which note is causing the dissonance. Similarly, exposing individual values that make up the broadband vibration can help classify the type of machine problem.

THREE GORGES DAM IN CHINA IS THE WORLD'S LARGEST HYDROELECTRIC PROJECT

The key to unlocking these individual values is to incorporate a once-per-turn phase reference measurement made by a Keyphasor* monitor. Previous Orbit articles have defined and described the concepts of phase angle and the Keyphasor measurement (References 2 & 3), and the following is a summary of the functionality and benefits that a Keyphasor measurement provides.

- A Keyphasor transducer is necessary for in-place machine balancing; anyone doing balancing needs the once-per-turn reference that the Keyphasor channel provides.
- A Keyphasor signal enables the calculation of "synchronous" data – data that is taken by synchronizing the vibration waveform sampling rate with the running speed of the machine. This preserves the accuracy of phase angle measurements and the amplitudes of vibration components that track with machine speed.
- A Keyphasor signal allows the monitoring system to filter around (isolate) only the vibrations that have the same frequency as running speed or multiples of running speed (1X, 2X, etc.) - even during machine speed changes.
- A Keyphasor measurement provides a phase angle value associated with the filtered amplitudes of each transducer measurement. Phase can be just as useful as amplitude for detecting changes in the machine behavior. In fact, phase angle may change even when there is no increase (or even a decrease) in vibration amplitude.
- Portable analyzers and data acquisition equipment need a Keyphasor signal to generate the values and graphical plots necessary to definitively identify a machinery problem.

The value of filtered amplitude and phase angle values (e.g., vector values) for machinery monitoring and predictive maintenance is widely recognized. This concept is acknowledged in a well- known international standard on hydroturbine vibration monitoring (Reference 4). Main points are summarized here:

- Broadband vibration amplitude (without frequency or phase information) is usually adequate for operational monitoring and acceptance testing.
- However, vibration vector information is especially useful for machinery diagnostics and long-term condition monitoring.
- Some changes in the dynamic state of the machine cannot be detected and identified by broad-band measurements alone.

3500/46M helps identify the problem

With a Keyphasor signal available in the 3500 monitoring system, the 3500/46M (and other 3500 vibration monitors) provides a number of useful variables in addition to overall vibration (Figure 1). Guide bearing (shaft relative) vibration, casing absolute (acceleration, velocity) vibration, and generator air gap channel types will have different variables as appropriate to their intended applications. All of the variables' values can be viewed and compared in real time on a local display, and sent via Modbus to a SCADA or control system for trending. Changes in these values can provide clues to the cause or characteristics of a machine problem.

Generally, changes in 1X Amplitude and Phase are related to imbalance and misalignment. Phase angle is useful for detecting shifts in the inertial, hydraulic or magnetic forces acting laterally on the shaft or runner, such as from loss of material from one side of a runner, blockage of one bucket of a runner, a deviation from the normal flow through a needle valve, and other problems.

Changes in Not 1X vibration are typically symptoms of rubs, fluid-induced forces in the bearings or at the runner, or rough load zone and vortexing. The "N" value in NX Amplitude can be set to "2" to indicate rotor cracks and other changes in stiffness, or to the number of runner buckets to detect hydraulic imbalances associated with wicket gates or nozzles.

The 3500/46M also provides an average proximity probe gap measurement for radial vibration measurements. This can be used to monitor shaft journal position within the guide bearing, which could change due to misalignment

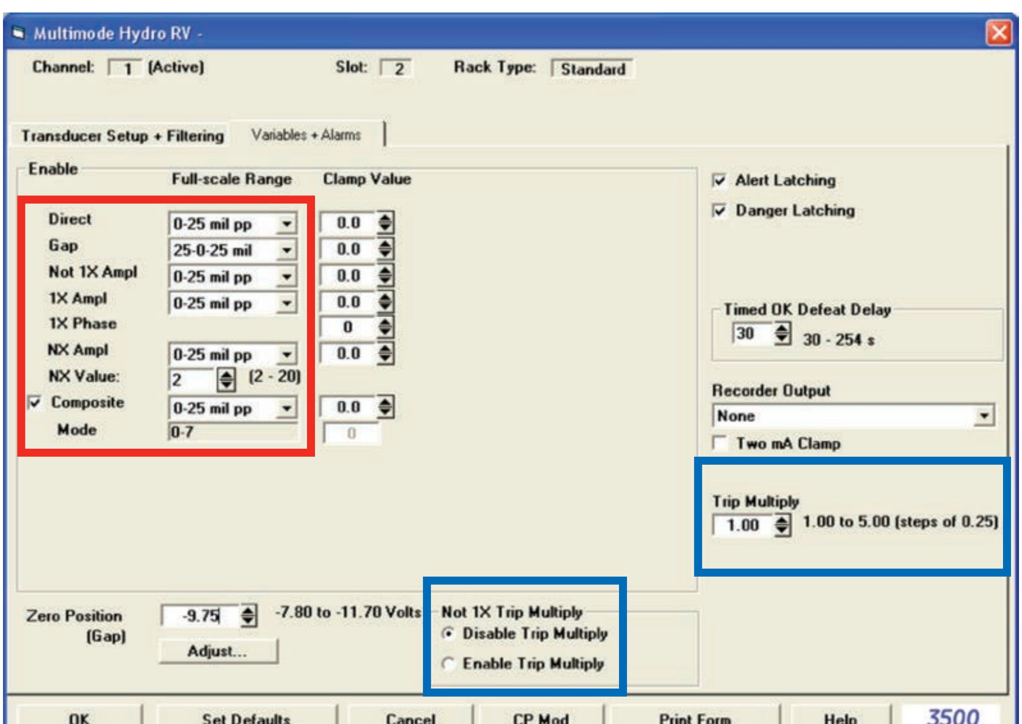

FIGURE 1: 3500 configuration software screen showing the variables (in red rectangle) available from the 3500/46M Multimode Hydro Radial Vibration channel type, and Trip Multiply settings (in blue rectangles).

and preloads. Gap alarms can be set to indicate when the normal bearing clearances have been reached or exceeded (corresponding to potential or actual bearing wear). Also, this gap measurement, in combination with the NX measurement set to the number of runner buckets, is used in the 3500/46M Hydro monitor to calculate a "Composite" value that can indirectly detect a shear pin failure in the wicket gate positioning linkage.

Setting Effective Alarm Levels

Now that we have several values to give a more complete picture of machine condition, the other challenge is to set alarm levels that are appropriate for different machine operating conditions. Using another musical analogy, most compositions contain both loud and soft segments, and the softer passages usually cause the audience to quiet down and listen more carefully to hear the subtle melodies. Similarly, a good monitoring system should adjust its alarms to "listen" more or less closely when varying conditions change the "acceptable" vibration levels for long periods of normal operation or for short periods during a start-up sequence and other operational transitions.

One relatively simple way of dealing with the transient conditions is to use the Trip Multiply feature found in the 3500/46M and other 3500 vibration monitors. Trip Multiply temporarily elevates alarm levels by a factor set for each channel in the configuration software (see Figure 1). Note that the Not 1X alarms can be excluded from the Trip Multiply activity for that channel, which might be desirable if vibration excursions other than 1X are of concern during the transitory conditions. The Trip Multiply condition is actuated for all monitors in a 3500 rack using a pair of contacts on the 3500/22 TDI Rack Interface I/O module, or for groups of monitors using a Modbus digital input via the 3500/92 Communications Gateway.

Multimode Monitoring

Pumped-storage units have two directions of rotation with vastly different hydraulic conditions. Kaplan units with adjustable blade angles can have significantly

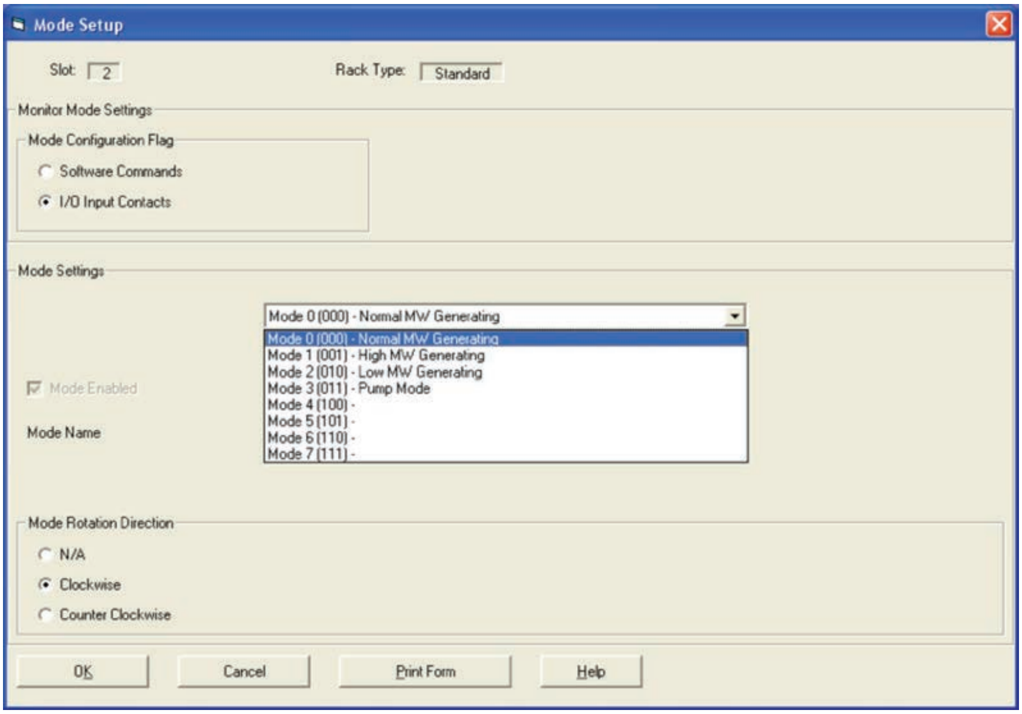

FIGURE 2: Mode Setup dialog in 3500 Configuration Software. Mode drop-down list shows that four modes have been defined in this example.

different levels of "normal" vibration, and any hydro turbine usually has at least one zone of high vibration associated with certain unavoidable head, speed, and load conditions. To accommodate these situations, the 3500/46M has a "Multimode" feature that allows you to establish up to eight (8) distinct machine modes, each with its own unique set of alarm parameters. The user-defined modes are enabled and named in the 3500 configuration software (Figure 2). Typical modes would accommodate operating conditions such as forward rotation, reverse rotation, loaded, unloaded, high head, low head, etc.

Once the modes have been defined, you can select each mode and set the alarm parameters for the variables of each channel as appropriate for that mode. You can enable or disable the setpoints, define the setpoint levels, and adjust the alarm time delays as needed (Figure 3).

The multimode channels of a monitor must be "told" what operating mode the machine is in, so that they can use the correct alarm settings for each mode. Mode change commands from the control system or other source can be input via wiring terminals on the 3500/46M Multimode

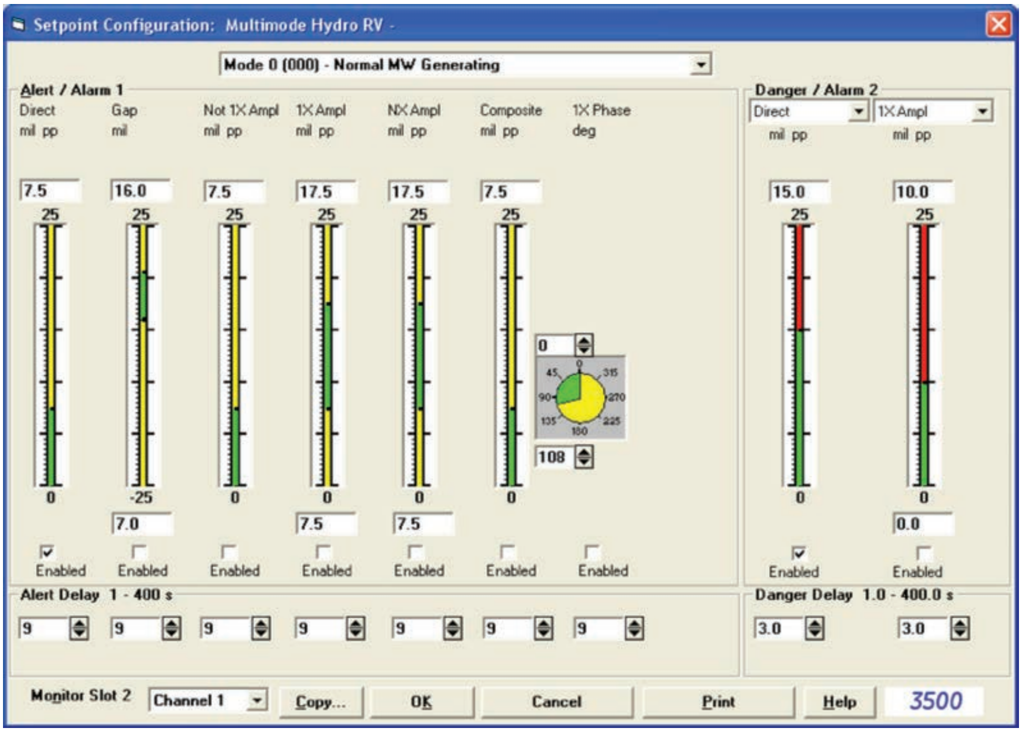

FIGURE 3: Setpoint configuration screen in the 3500 configuration software for one of the modes for a Multimode Hydro Radial Vibration channel type. In this example, alarm settings are being established for the "Normal MW Generating" mode.

THE FEATURES OF THE 3500/46M HYDRO MONITOR CAN EXTEND YOUR MONITORING SYSTEM FROM A DEVICE THAT SIMPLY TELLS YOU WHEN TO SHUT A MACHINE DOWN, TO A POWERFUL PREDICTIVE MAINTENANCE TOOL THAT HELPS YOU KEEP YOUR HYDRO TURBINE GENERATING UNITS HUMMING SMOOTHLY.

I/O modules, or digitally via a Modbus write command feature of the 3500/92 Communications Gateway Module.

Toward More "Intelligent" Machines

In the age of smartphones that incorporate music players, cameras, portable digital assistants and mobile GPS devices, it no longer makes sense to use a "dumb" monitoring system to make intelligent machinery protection and condition monitoring decisions. Microprocessor technology has made it possible to embed powerful signal processing capabilities - once available only in bulky and cumbersome portable analyzers - into every channel of an online machinery monitoring system, while enhancing the effectiveness of these systems for reliable machinery protection.

This enables the monitor to produce a steady stream of diagnostic-quality data both locally and remotely, in real time and for trending in plant historians as part of a predictive maintenance program. The features of the 3500/46M Hydro Monitor can extend your monitoring system from a device that simply tells you when to shut a machine down, to a powerful predictive maintenance tool that helps you keep your hydro turbine generating units humming smoothly.

In a future Hydro Corner article we will describe how the Multimode feature of the 3500/46M monitor can work hand-in-hand with the State-Based Analysis features of System 1* analytic software to enhance and simplify trending and diagnostics across the varying operating states of a machine.

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Instrumenting Older Reciprocating Compressors

Indicator ported valve pressure sensor installation

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CONDITION MONITORING OF RECIPROCATING COMPRESSORS REQUIRES HAVING THE APPROPRIATE MEASUREMENTS AVAILABLE.

Introduction

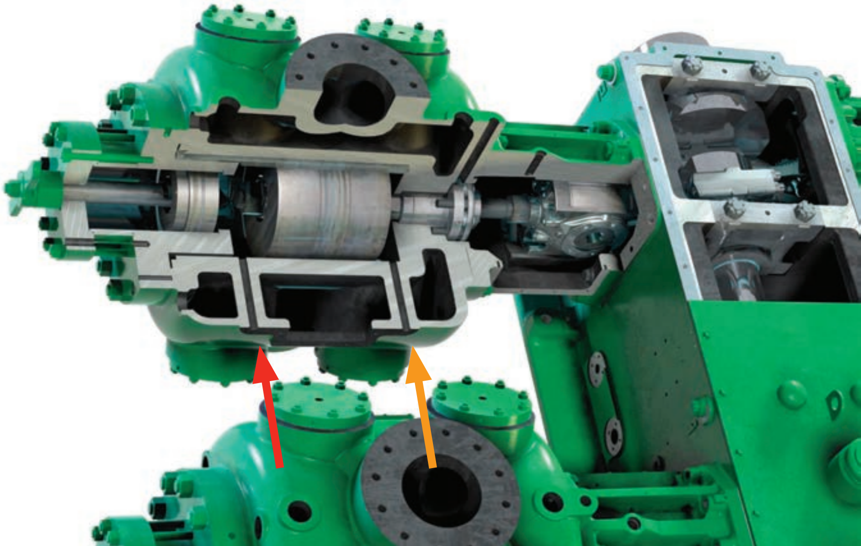
Many types of compressors are used in industrial processes. Among these, reciprocating compressors typically operate with the highest efficiency and excel in applications requiring high pressures and low to medium flows. Unfortunately, they also have the highest maintenance costs among compression equipment. In spite of this, there are applications in refining and chemical processes where the benefits of these compressors make them the best choice. There have been many articles highlighting the need for, and benefits of, condition monitoring on these machines. This article will focus on how to install pressure monitoring systems on machines that do not already have the necessary access points.

Benefits of Chamber Pressure Measurement

The majority of machines in industrial facilities function in a purely rotational manner. These include motors and centrifugal pumps and turbomachines such as axial or centrifugal compressors, gas turbines, and steam turbines. In these systems the largest forces acting on the rotor come from rotational effects such as unbalance, misalignment and rubs.

In reciprocating compressors, however, the largest forces come primarily from cylinder gas pressure and the cyclic acceleration of massive reciprocating components. Direct measurement of the pressure in the chamber and the resulting pressure and rod load waveforms provide the basis of calculating thermodynamic performance for each chamber, and for performing diagnostics for the most common malfunctions – including valve leaks, piston ring leaks, and crosshead pin failures. Without the pressure measurement the levels of forces on various components can only be estimated.

FIGURE 1: GE example. Reciprocating compressor cylinder cut away to show pressure ports in both the head-end (red arrow) and crank-end (orange arrow) chambers.



Measurements and data available with chamber pressure monitoring	
• Pressure waveform	• Gas force waveform
• Suction pressure	• Rod load waveform
• Discharge pressure	• Combined rod load
• Compression ratio	• Maximum rod tension
• Maximum pressure	• Maximum rod compression
• Minimum pressure	• Degrees of rod load reversal
Thermodynamic performance analysis	
• Discharge volumetric efficiency	• Indicated horsepower
• Suction volumetric efficiency	• Adiabatic flow balance
• Suction capacity	• Flow balance
• Discharge capacity	• Suction power loss
• Median capacity	• Discharge power loss
• Adiabatic Mean capacity	• Power to median capacity
Malfunctions	
• Suction valve leak	• Discharge valve leak
• Excessive rod load	• Piston ring leak
• Impact correlation	• Packing leak

TABLE 1: Directly measured and calculated values available when utilizing the Bently Nevada* 165855 pressure sensor, 3500 monitoring system, and System 1 software.

Most modern large reciprocating compressors sold today have pressure ports called indicator taps that are provided by the OEM. These ports are drilled through the cylinder walls into the chambers to allow the installation of pressure sensors (Figure 1).

A combination of the widespread availability of robust harsh environment pressure sensors and industry standards such as API 618 has led to the presence of indicator ports on many modern reciprocating machines. However, there are many compressors in use that do not have these ports due to the age of the machine or because they are not in a service that requires them.

These machines would benefit from the information provided by chamber pressure sensing combined with System 1* process calculations (Table 1), but without an indicator port it is not possible to make this measurement.

Retrofitting in-service compressors by drilling indicator ports through the cylinder walls as shown in Figure 1 is not recommended without compressor OEM review and involvement as any such operation can weaken the compressor cylinder structure with catastrophic results.

The best practice in such a case is to utilize a modified compressor valve to install the pressure sensors.

Indicator Ported Valves

These modified valves, called Indicator Ported Valves, or IPVs, directly replace an existing valve on the compressor and do not modify the pressure containment structure. Only one valve per chamber needs to be replaced with an IPV to make the pressure measurement available. Whenever possible a suction valve should be chosen as the point to install the IPV as these locations are cooler for the sensor and electronics, and at lower pressure making the installation safer and easier. In certain cases where a suction valve is not accessible to install the IPV a discharge valve can be utilized but special care should be given to the operating temperature of the location of the sensor and associated electronics to ensure a long sensor life and accurate reading.

IPVs consist of a standard valve assembly with the center bolt drilled or replaced with a hollow element that allows the connection of a port that extends out through a modified valve cover that seals around the newly added port (Figure 2).

Due to the many configurations of reciprocating compressors and variations in the processes to which they are applied, IPVs are typically provided separately from the condition monitoring system. Many replacement valve vendors as well as machine OEMs offer IPVs and can be contracted to evaluate the machine dimensions as well as the process details to provide a suitable solution. Once the IPV is installed and the port is available, the installation of the sensor follows the same best practices for integral indicator taps including an

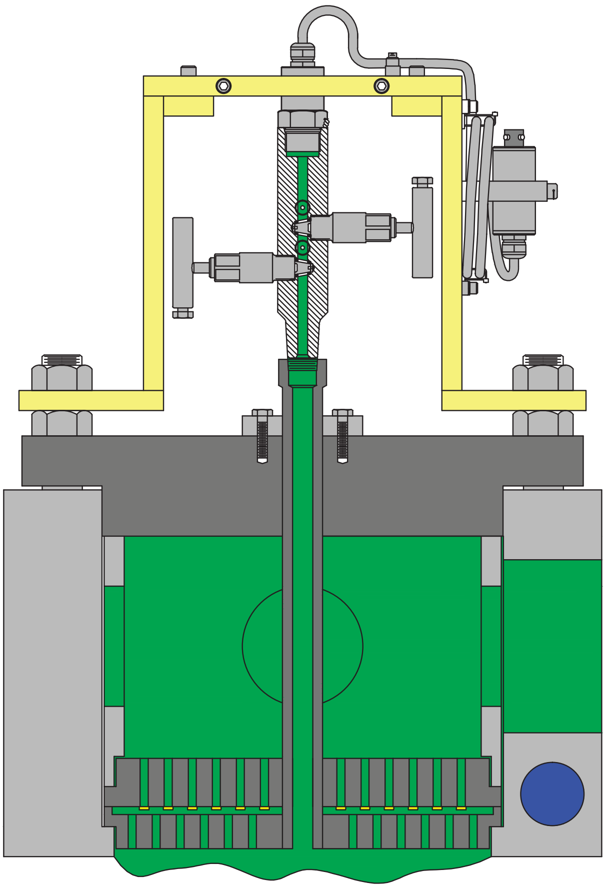


FIGURE 2: Cross section of IPV, valve housing, isolation valve, bracing (yellow shading) and pressure sensor. In this cutaway drawing of a suction valve, a double-isolation valve is shown installed in the IPV port. Green shading indicates the process gas coming into the suction valve (valve disc and seat components are at the bottom of the drawing).

appropriate isolation valve, sensor, and bracing to provide mechanical protection and avoid fatigue failure of the valve and sensor arrangement as shown in Figure 2.

Condition monitoring of reciprocating compressors requires having the appropriate measurements available. Real time monitoring of the chamber pressures on the machine is critical to understanding not just mechanical machine health such as loading and valve condition but it is the basis for making performance measurements, including actual flow rates, compression ratios, horsepower, and efficiencies.

Indicator ported valves provide an industry accepted and safe method of installing pressure sensors on virtually any reciprocating compressor. In future Orbit issues, we will describe how to install sensors in confined areas and accurately measure crank angle during compressor operation, in order to accommodate Pressure vs. Crank Angle (P-⊕and Pressure vs. Volume (P-V) analysis.

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Measurement Consistency with Your SCOUT Portable Vibration Monitoring Instrumentation

Sensor Positioning - Part 1 of a 2 Part Series

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The most successful vibration based condition monitoring and evaluation programs begin with a thorough understanding of the machinery in terms of how it's built, its internal component parts and how it is supposed to operate. This information is crucial when determining sensor mounting and data collection parameters. A thorough understanding of the machine's internals and how they interact leads directly to understanding how the machine can be expected to fail in service. Once failure mechanisms have been recognized, sensor placements and data collection parameters can be assigned that target their specific manifestations. The goal of vibration based condition monitoring and evaluation is to identify when those failure mechanisms are in play and enable proper decisions to be made to implement the appropriate corrective action in a timely manner.

Consistency is the Key

Machinery condition monitoring and evaluation is an exercise in change analysis with regard to failure mechanism manifestations. The question we are expected to answer is: "What's different today compared to the last time I took data on this machine, and does it give me an indication of a developing problem?" Getting the correct answer to this question requires that sensors are applied consistently from one data collection activity to the next, and that the measurement parameters are appropriate for the machine's failure mechanisms. This article focuses on sensor placement quality and consistency.

One advantage that permanently installed online continuous or scanning monitoring systems have over portable data collection systems is the fact that the measurement-to-measurement sensor consistency is guaranteed because they are permanently affixed to the machine. Ideally, machinery monitored by portable instruments would also have permanently installed sensors, but the financial reality is that machines monitored by portable instruments rarely have permanently installed sensors; the main exceptions being machinery in difficult to access, unsafe to access or hazardous areas.

The clear majority of measurements made with portable vibration data collectors use magnetic based accelerometers. Most 100 mv/g industrial accelerometers, such as the ACCL0333 and AS3100S2-Z2 that are delivered with the SCOUT100 and SCOUT140 instrument kits, are very robust and provide the consistency and repeatability required. The variable element that challenges the necessary repeatability is the magnetic sensor mounting. Once sensor measurement locations are established, accelerometer placement consistency becomes the single practice that has the greatest impact on overall program success or failure.

Sensor Location Considerations

Much has been written about proper sensor mounting locations on industrial machinery. The single most important consideration for determining appropriate sensor locations is the need for a relatively unobstructed "view" from the sensor mounting surface straight through the machine to the rotating elements. The ideal locations are those that are as close as possible to the bearings that hold the internal rotating components in place. Particular care must be taken to ensure that a solid structural pathway exists between the externally mounted sensor and the internal bearing, as close as possible to the plane of the bearing, with as few interfaces or discontinuities between parts as possible.

The most common error made when placing magnetic based accelerometers on the non-drive, or outboard, end of electric motors, is placing the sensor on the end-bell that doubles as a ventilation duct for cooling air flow. A good, solid, direct connection from the accelerometer, through the magnetic base, through the end-bell to the motor case and eventually to the bearing itself is extremely rare in the radial plane of the bearing. Although an argument can be made that a solid, contiguous connection is made from the accelerometer to the bearing, it is much too indirect and crosses too many interface boundaries to be of much value. By the time any indication of bearing distress is recognized in the data, it has usually progressed to the point where functional failure is imminent.

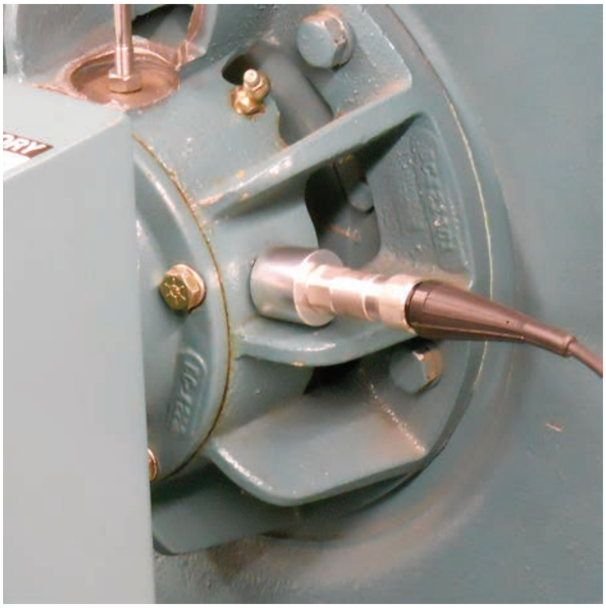

FIGURE 1: Horizontal accelerometer attachment on the Drive End (DE) bearing of a multi-stage centrifugal air compressor. This location is on the bearing housing, which allows a direct vibration transmission path. However, the paint had not yet been removed at the mounting surface, as this photo was taken during initial characterization while a new vibration condition monitoring program was being established. Observe the uncapped grease fitting, which could allow dirt to enter the bearing when adding lubricant.

Measurement locations, once determined, must be clearly marked. If triaxial accelerometers are used, the marking must include an indication for proper sensor orientation. Markings can be as formal as epoxied embossed metal tags or as simple as indelible marker or paint stick. Regardless of which method is used, the markings must be easy to find, identify and interpret. They must be consistent to enable many different SCOUT instrument users to be able to properly place and orient the sensor every time data is collected.

Sensor Mounting Considerations

Proper surface preparation and care placing the sensor on the machine is critical to a program's success. Once the measurement locations have been determined, they must be properly prepared to enable the most solid connection possible.

The surface on the machine that the magnet attaches to must not be painted (Figure 1). Paint is an excellent attenuator of the high frequency vibration signals that provide early indications of rolling element bearing distress. These are the signals that often indicate that the bearing's lubricant has been compromised and needs to be refreshed to provide the opportunity to prevent the start of internal damage in the very near term. Given the number of rolling element bearing manufacturer failure analysis studies that have conclusively shown that more bearings fail because of issues related to compromised lubrication – the inability of the lubricant to fulfill its primary function of carrying the load and separating surfaces with relative motion with respect to each other at the microscopic level – than all other causes combined, the best method for identifying lubricant compromise at the earliest possible opportunity should not be inhibited by a couple of layers of paint.

The surface that the magnetic base attaches to on the machine must be flat, smooth and clean. The magnet is sufficiently flat and smooth when it is delivered as part of a SCOUT data collector kit, but it must be verified to be clean before it is affixed to a machine to take measurements. Small ferrous metal filings, shavings or chips as well as grime, grit or just plain dirt between the

FIGURE 2: SCOUT's sensor keeper is a convenient place to carry the accelerometer, keeping it clean and providing a ferrous "keeper" for the magnetic circuit of the mounting base.

magnet and the mounting surface on the machine will also result in inaccurate and unrepeatable measurements. Plan on cleaning the mounting surfaces on the machine and the magnetic base by wiping them every time data is collected. The easiest way to keep machinery mounting surfaces clean is to cover them completely when data is not being collected. Depending on the shape or profile of the surface plastic caps can be affixed or simple covers can be made from flexible magnetic sheets – the kind that can be purchased at arts & crafts or office supply stores.

When the magnetic based accelerometer is not in actual use, the magnet should always be affixed to the sensor keeper on the SCOUT instrument's shoulder strap (Figure 2) or it should be attached to a ferrous disk or plate. Keeping magnets affixed to something is always good practice. Loose magnets that are not attached to some ferrous plate or disk when not in actual use, thus keeping the "magnetic circuit" open, tend to lose their holding strength fairly quickly.

Machine Surface Preparation

Proper flat, smooth mounting surfaces can be prepared or attached to any machine. The following methods are all very effective, but they are listed in decreasing order of preference.

- Machine a smooth, flat surface on the casing itself (Reference 1). This can be easily accomplished with a drill and a flat spot-face tool whose size is only slightly larger than the major diameter of the magnet's poles. No paint should be visible on the mounting surface. If the location is to be used for a triaxial accelerometer, be sure to mark the orientation.
- Drill, tap and countersink a hole whose dimensions match a dedicated accelerometer magnetic base mounting pad. The pad's threads should be lightly painted with a thin locking compound and then threaded into the hole and tightened per the manufacturer's recommendation. Orientation marks should be added, if appropriate.
- Epoxy a mounting disk to the machine surface, being sure that no paint is between the metal mounting disk and the machine's bare metal surface.

Note that on some machines, finding a flat surface on a round machine case is nearly impossible. The beveled surfaces on the magnetic bases are designed to accommodate this situation. The magnet's pole bars are to be placed along the same (longitudinal) axis as the center of the curvature of the case. The exact locations locations where the magnet will contact the machine must follow the same rules as previously described. The linear surfaces where the magnet contacts the machine must be linearly flat, smooth, clean and well-marked.

Concluding Remarks

Repeatability is critical when performing condition monitoring and evaluation measurements using portable vibration instruments. Without it, one cannot properly interpret changes in the data from one reading to the next, thus rendering the program ineffective. Our goal is always to be in the best position to provide timely and accurate assessments of machinery functional health and one of the best ways to ensure that we are able to meet our objectives is to begin the process where the sensor attaches to the machine.

Part 2 of this series will address the vibration data collection parameters themselves and how best to identify and interpret changes that indicate operating health degradation at its earliest opportunity.

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