orbit

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

APPLICATION: One size **does not** fit all

Editor's Notepad

Editor | Orbit Magazine

Greetings, and welcome to *Orbit!*

As I think back on 2011, it's hard to believe that I have been in this assignment for a year already! During this time, I have discovered that one of the most enjoyable parts of this job is the chance to work with our Graphic Designer, Gina Alteri, who creates the artistic layout for our magazine. We had some fun coming up with the cover illustration for this issue, which illustrates that One Size Does NOT Fit All.

The three pairs of boots remind me of an old children's story called Goldilocks and the Three Bears. In the story, Goldilocks enters the Three Bears' house while they are out, and samples their food, sits in their chairs and finally, takes a nap in one of their beds. The repeating theme is that one choice is always "too much" of something (food is too hot, chair is too big, bed is too hard, etc.), while one is always too little of the same thing (too cold, too small, too soft). However, one choice is always "just right."

Similar choices need to be made when applying a limited budget to purchasing appropriate condition monitoring solutions. This issue includes several articles with examples of different types of instruments and software that are used in different kinds of applications. Some assets with long failure time cycles can be effectively monitored with periodic sampling via portable data collectors as part of a walk-around program. Other assets need to be monitored more frequently, and some need to be monitored continuously – especially if they require automatic trip functionality provided by a protection system.

Some assets that are inaccessible during operation may require permanently-installed hard-wired systems, while others may benefit from the flexibility of wireless monitors. Remote diagnostic functionality may require special communication arrangements in order to allow access while still maintaining network security. The availability of a variety of different types of data (dynamic motor current analysis, model-based anomaly detection, thermodynamic performance calculations, vibration, etc.) can enable correlation that supports more effective diagnosis of asset health. Intensive troubleshooting of a particular machine may require the power of portable diagnostic system, while specific equipment configurations (such as the slow-speed planetary gearboxes in a wind turbine) may benefit from the application of special signal processing algorithms that were designed specifically for that asset.

In his lead article, Nate Littrell explains that it is important to consider the entire system when specifying and installing a condition monitoring solution – including the needs and capabilities of the humans who are part of the system. As illustrated by the variety of factors listed above, one particular solution cannot possibly be optimal for every situation. When working together to specify a condition monitoring solution, our goal is to help you find the one that's "just right" for you.

Best wishes for an excellent 2012!

Cheers!
Gary

In this Issue

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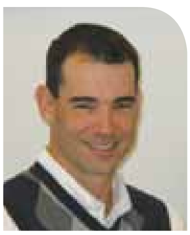
Interview with Art Eunson



Art Eunson
Bently Nevada
General Manager

As we announced in the OCT 2011 issue, our former Bently Nevada General Manager, Jeff Schnitzer, has moved to a different job in GE. Our new GM is **Art Eunson,** and I had the pleasure to interview him recently. —Editor

ORBIT: What is your previous background, Art?

ART: I'll soon be entering my 19th year with GE. My career has given me extensive experience in the Energy industry, including exposure to both the Power Gen and Oil and Gas industries. I have worked with engineering teams, and in a variety of business leadership assignments that involved leading regional, as well as project management teams. Now I am looking forward to becoming more familiar with other industries as our product line evolves to provide more complete plant-wide condition monitoring solutions.

ORBIT: Why did you decide to take this new assignment?

ART: That's an easy one, Gary. Bently Nevada has a long legacy of providing innovative, high quality products and services that our customers can trust. It's a well-known and well respected brand – further, I see exciting opportunities for us to expand what Bently Nevada can offer our customers in terms of broader asset condition monitoring solutions. So I think there's real opportunity here to grow the product line. I'm excited about the challenge, and I believe the energy industry in general is the place to be right now!

ORBIT: Has anything about the Bently Nevada team surprised you so far?

ART: I'm not sure it's a surprise, but I would say the team's loyalty to the brand and their passion to be the best has been rewarding in my first few months on the job. This team is committed to carrying on the legacy that Don Bently first developed, and are always seeking ways to innovate, expand, and develop the next solution for our customers. I am also amazed at the level of knowledge we have in this business, both here in Minden as well as globally – and I don't just mean in asset condition, or vibration monitoring. This team seems to pride itself on being rotating equipment experts first, and wanting to understand our customer's assets first. When coupled with the deep domain knowledge around the actual hardware/software/services portfolio, the knowledge level of the team is quite amazing.

ORBIT: Will your strategy be different from Jeff Schnitzer's?

ART: Jeff led this business to new heights, and the actions he set in motion for the immediate future are good ones. I'll continue to focus on those same strategies in the near term – but as always, we will continue to look for what's next – what do our customer's need, how are their operations or needs changing, and we'll look to adjust our strategy accordingly. The key here is to focus our strategy around what the customer needs. If we take that external view, that more than anything will make us successful.

ORBIT: You recently met with the developers of the AnomAlert* Motor Anomaly Detector (Artesis) in Turkey. Can you share anything that you learned on your visit?

ART: We had a fantastic review with the Artesis team, and I came away with an even better appreciation for the capabilities of this platform. I think we all realize this is a solution that needs to be better explained to our sales and region teams, as well as our customers. We intend to re-focus our efforts on how we communicate the value behind AnomAlert, double up our efforts to train and educate, and do a better job of explaining how this platform fits in with our entire line of Bently condition monitoring and protection solutions. Once we do that, I believe there is tremendous opportunity for us to better meet some of our customers' needs that were previously gaps for our product line.

ORBIT: You also visited our Commtest team in New Zealand. Can you share any future plans for these products?

ART: My visit to New Zealand to meet the Commtest team was very rewarding – this is another example of a team that is focused, motivated, and passionate about bringing great products and solutions to their customers. Although there's been a lot of focus on the portable data collector, they have a suite of other products and software that align nicely with our current product line, including a wind solution called TurningPoint*.

Our goals in the coming months are relatively straightforward. We want to market the portable device (SCOUT100) through our sales channels while having our technology teams work in parallel to integrate it with our System 1* software. We are also looking at how the TurningPoint wind solution complements our existing ADAPT* platform. Lastly, we'll be looking at the balance of the Commtest products to understand how best to bring them to our existing customer base. For some, it may make sense to keep them separate, for others, it may make sense to integrate them with their existing Bently products. We'll decide that as we go, but the goal will be the same in all cases – put the best, most comprehensive, and complementary solution together based on our customer's needs.

ORBIT: I'm sure we will be talking with you in more detail over the years. But for now, do you have any closing comments to share with our readers?

ART: I just want thank our customers, and the Bently team, for this opportunity. I'm thrilled to be in this business and am constantly reminded of the rich history that Don Bently created and developed over many years here. My goal is simple – to continue that legacy of delivering great products that help our customers operate and maintain their assets in a more effective manner – if we can do that, then we all win. Thanks, Gary, for giving me the chance to share some early perspective!

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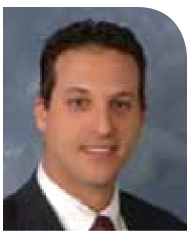
ADAPT*.wind and Turningpoint*

A Letter From Our Product Manager



Adam Weiss
Senior Product Manager
Distributed Platforms
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DEAR VALUED BENTLY NEVADA CUSTOMER,

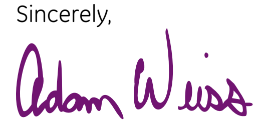
As a part of Commtest's integration with Bently Nevada, we have added Turningpoint, Commtest's wind condition monitoring solution, to our product line. Turningpoint is an excellent product that provides great value to its wind power generation customers.

We are committed to supporting the Turningpoint product as well as Turningpoint customers. The Turningpoint solution will continue to be marketed, sold, and supported. Initially, Turningpoint customers will experience no noticeable change in either products or customer support. As we continue to integrate the Commtest and Bently Nevada businesses, customers will directly benefit from the Global support and infrastructure that GE can provide.

Prior to the Commtest integration, Bently Nevada also had a wind condition monitoring solution – ADAPT. wind. This product will also continue to be marketed, sold, and supported. We have found that both products have a place in the wind generation industry, providing different features and serving different needs.

As a result of the addition of Turningpoint, customers with varied condition monitoring experience and requirements will find the solution they need within the expanded Bently product portfolio. Our team remains committed to meeting all of your machinery condition monitoring and diagnostic needs, and now has a broader range of products to meet those needs. ■

Sincerely,



Adam Weiss

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GE Product Demonstration Day in Germany

In September, 2011 the German GE team held a product demonstration day at Linde Engineering Headquarters in Pullach (close to Munich) in Germany. During this event, the German GE team showed examples from the Bently Nevada* product line, as well as other products from associated GE businesses – to a great variety of employees of Linde's Engineering and Gases Division.

The event was held at Linde's Agora facility, a new building containing the canteen and several conference rooms. The GE team used several of these conference rooms for permanent exhibition and cycling presentations of the portfolio.

The exhibition and presentations were accompanied by active discussions and helped Linde personnel to better understand our products and condition monitoring and maintenance ideas and visions. Our customers appreciated that we used a permanent exhibition so they could have the opportunity to "taste and feel" the products in reality.

Participants were Linde employees from a variety of departments, including Maintenance, Service, Sales, Reliability and Procurement. The active discussion and positive feedback that we received during several "deep dive" product presentations reinforced the importance of such a product demonstration day.

In total, more than 50 employees from Linde signed up for the individual presentations. The chance to meet and interact directly with the Linde employees has helped to strengthen our already existing business relationship.

Special thanks go to Ingo Kreh, the organizer of the event, and to the GE Germany team (Frank Braun, Guenter Klein, Thibault Straumann, Matthias Sprinz, Oliver Koch, Thorsten Dross and Thomas Kafka) for their great support during the exhibition and presentations. ■

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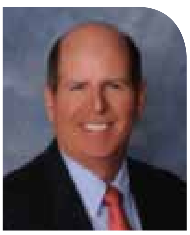
New Online Motor Stator Insulation Monitor (MSIM) for 3500 System



C. David Whitefield, P.E.
Bently Nevada Principal Engineer
dave.whitefield@ge.com

Many of our customers employ medium and large AC motors (such as the representative example in Figure 1) as prime movers for their process machinery, driving large compressors, pumps, blowers and fans. Traditionally, many of these motors have been mechanically protected and managed using Bently Nevada 3500 vibration and condition monitoring systems. The majority of motors in this class employ fluid film bearings.

FIGURE 1: GE Pegasus** MHV Medium Voltage AC Induction Motor [Reference 1]

The Problem

The 3500 System is effective for vibration monitoring of motor rotor and bearing faults, but another common problem with motors is the degradation of stator winding insulation. Stator problems, combined with bearing problems (detected by vibration), constitute over 75% of motor failures. The need to address the stator failure mode is obvious, yet there are few, if any online systems which meet that need. Existing condition monitoring techniques for this class of motors fall into one of two categories – offline or online monitoring.

Offline Monitoring

This type of testing is done with the motor shut down, cooled down, and de-terminated, using portable test equipment. Tests in this category include the following examples:

- Capacitance and dissipation factor (C & DF) testing, which are both conducted at ambient temperature.
- Megohmmeter ("megger") for Insulation Resistance (IR) and polarization Index (PI), AC and DC high-potential ("hi-pot"), Partial Discharge (PD), Power Factor or Dissipation Factor (tip-up) and other electrical tests designed to assess the condition of the stator insulation system.
- Partial Discharge Analysis: This measurement looks for indications of tiny arcs that occur within voids and gaps in the winding insulation as it deteriorates over time. Both permanently-installed and portable versions of PD instruments are used.

Other techniques can be used to complement the above tests for more effective diagnostics and health assessment.

Online Monitoring

This type of monitoring is done with the motor energized and running, usually at a significant fraction of full load. Online monitoring can be performed with permanently installed instrumentation, or with portable test equipment.

- Ground/phase fault relays: These are classic machine protection relays, which were originally electromechanical devices, and evolved into solid-state analog, then digital devices. Protective relays are permanently installed to provide real-time automatic protective measures for detected electrical faults. Modern digital relays can also provide some condition monitoring data via digital network communications.

- Partial Discharge Analysis (PDA): This measurement looks for indications of tiny arcs that occur within voids and gaps in the winding insulation as it deteriorates over time. Both permanently-installed and portable versions of PD instruments are used.

- Temperature, moisture and other parameters can also be continuously monitored.

Tradeoffs

Offline testing is time consuming, relatively expensive, and requires the process equipment to be removed from service while the tests are conducted. For these reasons, tests are performed infrequently, with inspection intervals of 3 to 6 years being common. This schedule means the inspection interval is the same order of magnitude as the failure interval. In addition, the offline tests are typically conducted at ambient temperatures, not at the operating temperature of the motor.

Protection with ground/phase fault relays is effective in shutting the machine down after a fault occurs, but does not give adequate advance warning of insulation degradation. In some instances the stator core can be damaged by an electrical fault in spite of the shutdown capabilities of protection relay systems. Core damage results in a much more expensive repair than a basic rewind, and in some cases the motor may have to be scrapped.

Partial discharge monitoring is the only currently available practical technology for online condition monitoring of stator insulation health. Feedback from our customers who have employed this technology for many years indicates that partial discharge data is difficult to interpret, and provides very little insight into, or advance warning of impending stator insulation faults.

Introducing a New Approach

Bently Nevada is introducing a new approach to online stator insulation condition monitoring. This approach is based on a new sensor developed in conjunction with GE's Global Research Center scientists. It is a complete system consisting of new transducers, a new 3500 monitor card and the services required for installation and commissioning. While it is useful as a standalone monitor, even more value can be obtained when it is connected to GE's System 1* asset management software.

System Description

As shown in Figure 2, the new stator insulation monitoring system includes the following components for each monitored motor:

- 3 each – High Sensitivity Current Transformers (HSCTs)
- 3 each – HSCT interface modules
- 2 each – Voltage dividers (for phase reference)
- 2 each – Voltage divider interface modules
- 1 to 3 each – temperature inputs (RTD's or thermocouples)
- 1 each – BN 3500 Rack and HSCT monitor card

The HSCTs, voltage dividers and all interface modules are installed in or on the motor terminal box. Field wiring directs the signals to the 3500 monitor card.

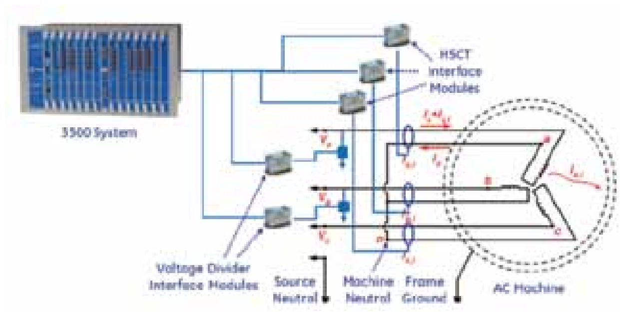


FIGURE 2: Permanently-installed online motor stator insulation health monitor.

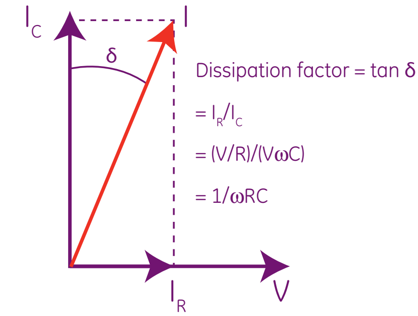


FIGURE 5: Phase angle relationship between capacitive and resistive leakage current.

FIGURE 3: The HSCT is a special current transformer that is very sensitive to small values of differential current.

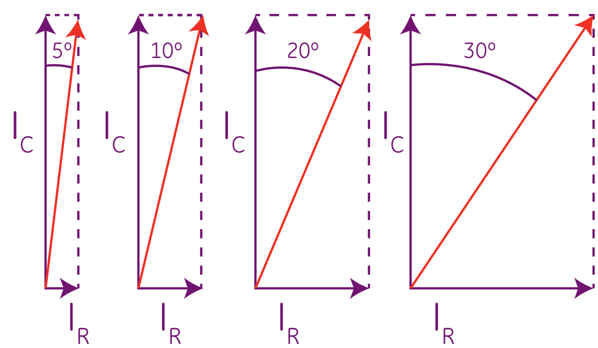


FIGURE 6: As the insulation system degrades, the change in capacitance and dissipation factor are indicated by the change in the phase angle between IC and IR. This example shows a case where capacitance remains unchanged, but aging increases the conduction through the insulation.

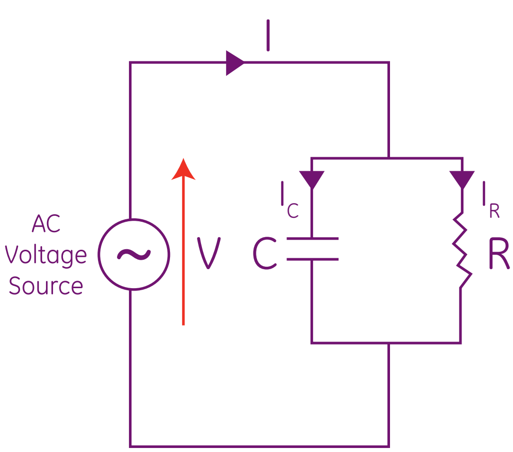


FIGURE 4: Equivalent circuit for stator winding insulation. C = capacitance, R = resistance, V = source voltage and I = source current.

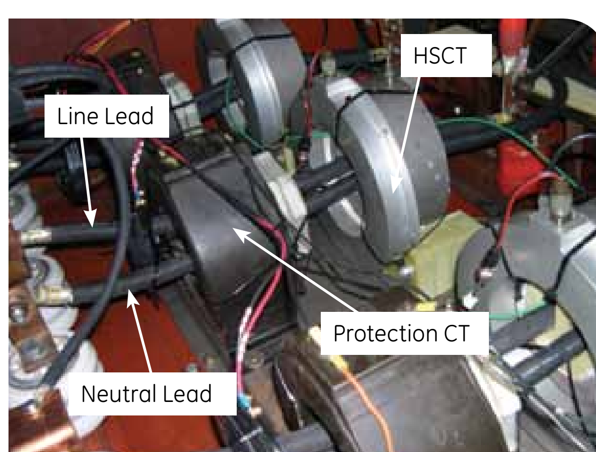


FIGURE 7: Example photo shows the inside of a 4160 V motor termination enclosure during testing of the new HSCT sensors. The large brown CTs are for normal differential protection. The HSCTs are the thinner aluminum-covered rings to the right of the protection CTs. To the right of the HSCTs are some test instrumentation CTs that were taking additional measurements as part of the test.

How does it work?

The HSCT (Figure 3) enables measurement of very low amplitude leakage current (which leaks through degraded winding insulation).

The HSCT interface module amplifies the low level signal, which is directed to the 3500 monitor card via field wiring. Voltage reference signals are similarly conditioned and directed to the 3500 monitor. Winding temperatures (from RTD's or thermocouples) are the final inputs to the monitor card. The monitoring system conditions and processes these signals, providing access, trending and alarming for values of capacitive and resistive leakage currents, Capacitance and Dissipation Factor (C & DF).

The offline C & DF test is used by many of our customers as a part of their medium and high voltage motor preventive maintenance programs. Our new monitoring system brings the benefits of that assessment tool to the online condition monitoring world.

Figure 4 illustrates the basic relationship between capacitive and resistive components of the leakage current. In a new or rewound motor, the primary leakage path is capacitive, resulting in very low levels of resistive leakage current.

Figure 5 shows how the Dissipation Factor describes the phase angle of the current through the stator insulation. If the insulation were a perfect dielectric, its resistance would be infinite, the angle, δ, would be zero, and dissipation factor would also be zero.

Insulation systems degrade over time because of electrical, thermal and mechanical and environmental stresses. As the insulation system degrades, the resistive component increases, appearing as a larger dissipation factor, as shown in Figure 6. The leakage current measurement is temperature dependent, thus the need for the temperature inputs into the monitor.

Target Machines

Our initial solution offering targets 3-phase AC induction and synchronous motors in the 1,000 to 6,000 horsepower range, operating with supply voltage in the 2.3 kV to 5 kV range. The motor must be externally wye-connected (Figure 2). We must have access to both phase and neutral leads in the terminal box, as shown in Figure 7.

Value of this method

This new technology is the first commercially available online assessment of stator insulation system health on medium and high voltage motors via leakage current sensing. This means that you no longer have to shut your motor down for offline testing to determine if it is headed for trouble. The system allows you to realize the following advantages:

- Avoid unplanned outages
- Do more effective maintenance planning
- Avoid offline monitoring downtime and associated costs
- Detect many problems that are not detected by existing technologies
- Extend time between inspections
- Reduce the cost of repair versus a protection trip, by avoiding stator core damage

System Introduction

Our current development plan calls for availability in the third quarter of 2012. Please contact your local Bently Nevada sales engineer for more information. We'll also be publishing more information on this technology in an upcoming issue of Orbit. Stay tuned for more information on motor condition monitoring! ■

References

1. GE Motors Pegasus MHV Medium Voltage AC Induction Motors brochure, GEA-12310C.

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Orbit Mobile App Available

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http://ge-mcs.com/orbitipad

The ORBIT magazine app features new issue notification, caching for offline reading, and article sharing through social media.

"ORBIT for iPad is our latest digital offering to our customers. With its loyal following, deep content, and multi-decade history, ORBIT is a natural fit for Apple's iPad," said Scott Sbihli, Digital Strategy and Marketing Leader. "We'll continue to invest in digital because our customers want to engage with GE in new, interactive ways."

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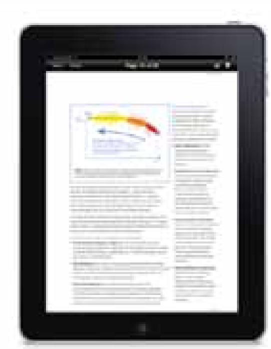

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Portable Vibration Analyzers Update

Don Marshall
Product Manager
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As we bring 2011 to a close and begin a new year, I would like to take a few minutes to recap where we have been with portables and to lay the groundwork for where we are headed in 2012.

The Past

Bently Nevada has a long history with portable vibration monitoring and analysis instruments. Our Commtest integration, which started in August, 2011, fits perfectly with our plans to expand our plant-wide monitoring capabilities. A key portion of the integration includes portable vibration monitoring instruments, which are an important anchor point to a plant-wide condition monitoring program. Our new portable vibration instrument product line is called SCOUT, and our first product to market is the SCOUT100 (Figure 1) which is joining the existing Bently Nevada product line.

We reached an important milestone when our Commtest team in Christchurch, New Zealand celebrated the manufacture of the first SCOUT100 production unit (Figure 2). To emphasize the team nature of their efforts, the group wore commemorative SCOUT100 rugby jerseys for the occasion. Visiting from the USA, Integration Leader Chris McMillen showed his support by sporting the colors of New Zealand's world champion rugby team.

FIGURE 1: Bently Nevada* SCOUT100 Portable Vibration Analyzer

FIGURE 2: Our New Zealand team pauses for a group photo. From left to right, they are: Tapiwa Ndhlala, Vincent Yang, Calvin Broadhurst, Lisa Ewan, Brian Wood, Angel Johnson, Paul Graham, Mike Kemp (holding SCOUT100 unit), Colin Chaney, Nigel Leigh, Chris McMillen, Lynden Sherriff, Kevern Rump, Brett Taylor, Allan Vergara, Brindsley Archer & Mark McPhail.

We have moved forward with the introduction of SCOUT to the Bently Nevada family of products, and to our customers.

In September, 2011, we completed the first of an ongoing series of internal training sessions for our Field Application Engineers (FAEs). This class was held at the Commtest North American Sales & Training office in Knoxville, Tennessee.

Experienced FAE, Billy Gilkerson, participated in the course. "The folks at Commtest did a great job in getting us up to speed with the SCOUT100," he said. "They gave us insight into the product and the marketplace that we have not been playing in for quite some time. Everyone in the class was very appreciative of their efforts."

In November of 2011, we shipped the first SCOUT100 to a large refinery in the southern USA. We also completed another internal training session at our Minden, Nevada facility (Figure 3).

The Present

Customer interest and inquiries are rapidly increasing as word gets out. This month (January, 2012), we are training another class of global FAEs, and we are expanding our internal training to include our Services Field Engineers. We will also begin the global launch of our SCOUT100, so watch for further announcements on this. For the initial phase of the product introduction, we will continue to offer standalone Ascent* software. Later this year, this application will be integrated with our System 1* platform.

FIGURE 3: Scott Roby and Steve Gaskell collect vibration samples with the SCOUT100.

The Future

Our Machinery Diagnostic Services (MDS) engineers will be receiving SCOUT units to use in the field, and our Technical Support technicians will be receiving SCOUT units to use for their product support activities. Our Technical Training Development group will also be creating customer training course materials to support the new portable vibration analyzers with traditional hands-on Bently Nevada training offerings.

We will market the SCOUT portable product line directly to our customers, just as we do the rest of our portfolio – with additional emphasis placed on an integrated plant-wide solution. This means that going forward, our customers will realize added benefit and value as we bring together wireless, motor monitoring, and scanning and surveillance systems with their route based walk around vibration program. We are committed to continue investing in the Commtest and Bently Nevada product lines over the long term.

For More Information

Visit our SCOUT100 Portable Vibration Analyzer webpage. The QR code is for readers with smartphones, and the URL address is for the rest of us: ***http://www.ge-mcs.com/en/bently-nevada-portable-and-diagnostic/data-collection/scout100.html*** ■

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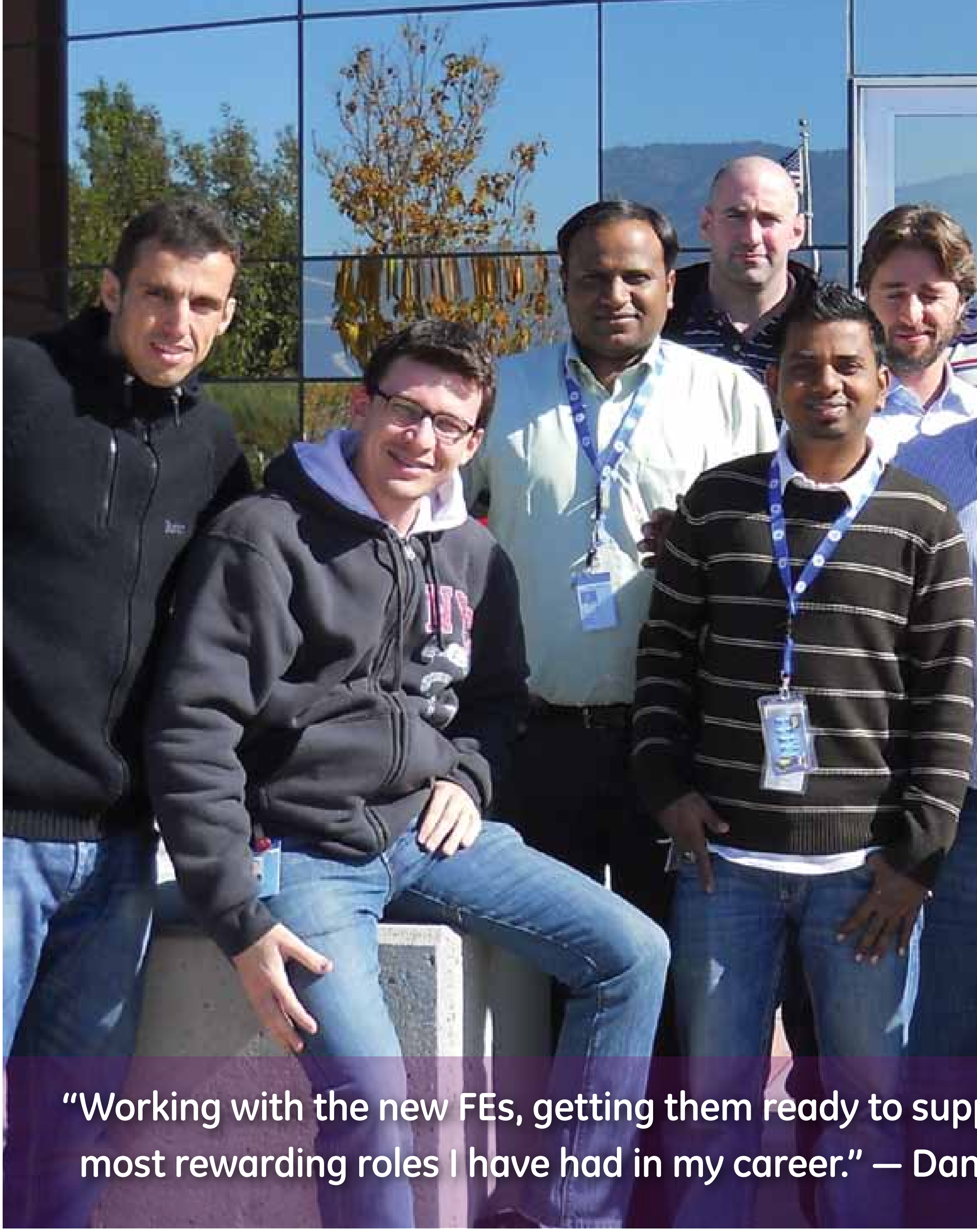

Services Update – Field Engineer Program (FEP)

ABOVE: Field Engineers take a short break between training exercises to step outside for a class photo. From left to right, they are: *Back Row:* Angel Palomo cono, Shailendra Singh, Michael Meyerhoff, Juliano Viana, Jon-olav Hjelmtveit, John Fairfield, Sindre Bloch osborg, Colin Morrison, Shaun Tycer, Chris Zinn, and Bibek Biswal. *Middle Row:* Marcos Florencio (seated), Siva Rajagopal, Frank Luis Rodriguez, Juan Diego Munoz, Fahrurrazi Raimi, Rika Kartorahardjo (seated) and Dan Walmsley (instructor). *Front Row:* Charles Grislin (kneeling).

INSET: Marcos, Rika, and Bibek practice their skills with a hands-on workshop exercise.

port our customers in the field, is one of the
Walmsley, Services Lead Training Instructor

Another class of Bently Nevada FEP delegates graduated recently after four weeks of Systems Engineer training at our Minden facility. These Field Engineers returned to their home regions for mentored On the Job Training (OJT) as they continue to gain experience. A few of the students, who are entering Machinery Diagnostic Services (MDS) assignments, completed an additional two weeks of MDS-specific training before heading home.

This particular class is typical of our international workforce, with students from Argentina, Australia, Brazil, England, France, India, Malaysia, Norway, Spain, and USA. If you live in any of these regions, don't be surprised if you see one these Field Engineers performing Bently Nevada services at your own site!

Bently Nevada Systems Engineers perform a variety of onsite services, including installation, troubleshoot-ing, and repair of our condition monitoring products (transducers, monitor systems and software). MDS Engineers specialize in machinery diagnostics, both remotely and onsite, using a combination of permanently-installed and temporary condition monitoring equipment and diagnostic software. ■

the KEY to Successful Applications: *Consider the System…*

Nate Littrell, P.E.
Bently Nevada Systems
Application Leader
nate.littrell@ge.com

System boundaries and emergent capabilities are foreign terms to many engineers – yet they use these concepts all the time. A system can be as simple as a motor and pump or as complex as an entire refinery. The system boundary concept is useful because it provides a framework for the inputs, outputs and core functions for the 'System of interest' which can now be considered as a 'black box'.

In these examples, a motor-driven pump is a system that consumes energy and moves fluids. On a grander scale, a refinery is a system that consumes crude oil and energy in order to output processed petroleum.

Any time one considers launching a new condition monitoring or machinery protection initiative, it is important to step back and consciously consider the boundaries for the system in question. System Boundary selection is critical to overall success of the project because it exposes interactions with system components that may not be obvious. A common example of this is not considering the local communications network of a facility as part of the system when adding condition monitoring or controls upgrades. The added traffic on the network and criticality of the information will rapidly show that the network is within the system boundary.

The system boundary is determined by the intended capability of the system. In Systems Engineering, this is called an emergent property. A classic example is an airplane. The components of an airplane do not, by themselves, possess the ability to fly. However, when assembled, an amazing thing happens and there is a system (airplane) that possesses the emergent property of flight! Similarly, a sensor does not have the ability to make an assessment of machine condition by itself. It is a component that must be considered in the context of a larger system.

The Bently Nevada* product line includes systems that can deliver various emergent properties. At the most granular level, there is machine protection. This is the core ability for a machine to protect itself by shutting down through continuous monitoring of machine parameters such as vibration, temperature, pressure, etc. The system boundary for machine protection is the machine itself, the controls, sensors and monitoring equipment used to initiate an automated shutdown. The trip functions are locally embodied by design for fast, robust operation.

At the next level, we have machine condition monitoring, which expands the system to include networks and computers for remote monitoring (Figure 1). Most importantly, a human being becomes part of the loop for condition monitoring. The skills and behaviors of the person involved in the system become a key part of realizing the value from the condition monitoring system.

At the highest level, Bently Nevada offers systems and services to optimize the overall performance of the plant. Products such as Bently Performance* and EfficiencyMap* are advanced physics based analytical platforms that pull data from all systems in a plant to drive informed operational decisions that ultimately affect the profitability of the venture (Figure 2). GE's Proficy** SmartSignal** is another software offering that uses adaptive, empirically based optimization algorithms to provide a robust and fault tolerant solution for systems whose behavior may be too complex or insufficiently observable for physics based modeling.

The Bently Nevada team is committed to understanding the operational methodology at your facility. It is the goal of our business to partner with you and your team to discover the best possible solution and engineer a smooth deployment of the system that best suits your unique needs. ■

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**Proficy is a trademark of GE Intelligent Platforms, Inc. SmartSignal is a trademark of SmartSignal Corporation, a wholly owned subsidiary of GE Intelligent Platforms, Inc.

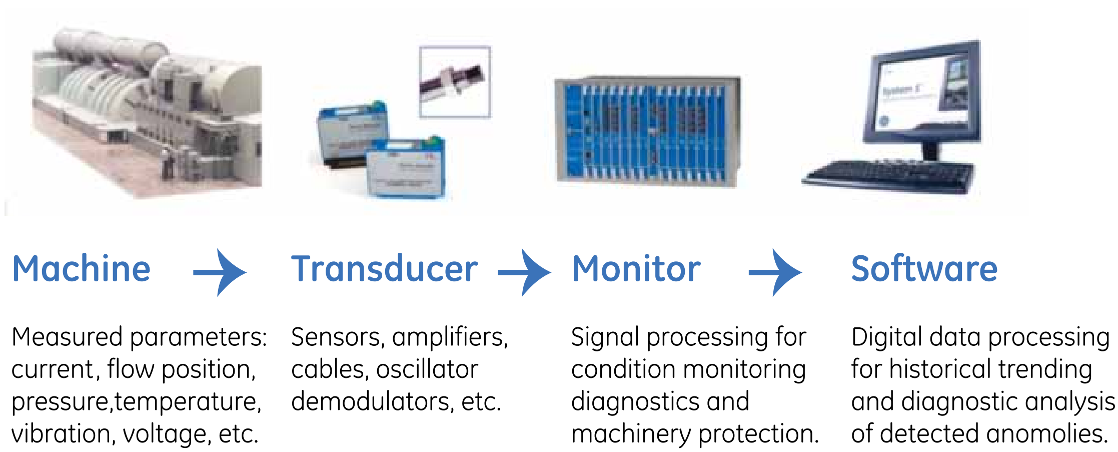

FIGURE 1: Simple illustration showing the main components of a machine protection and condition monitoring system.

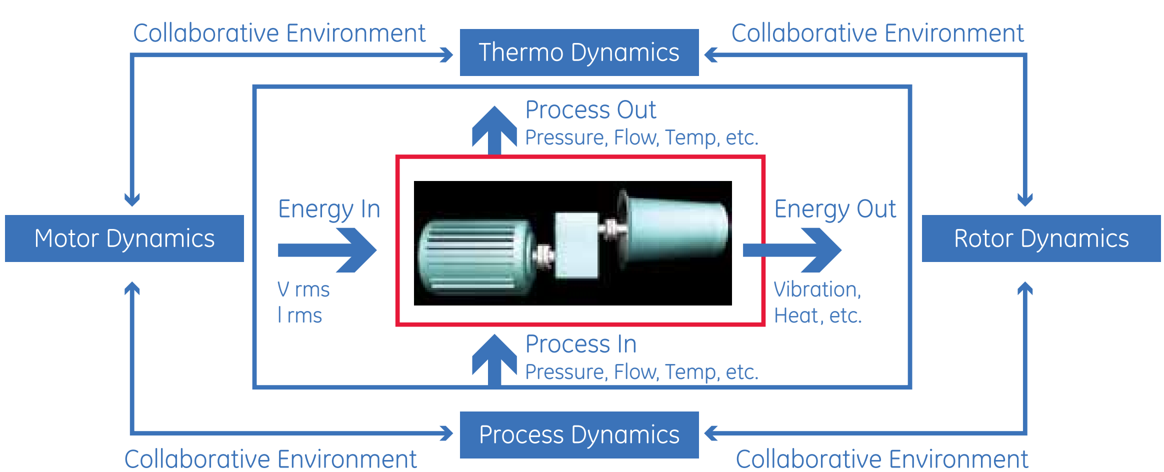

FIGURE 2: This example shows a system boundary around a motor-driven compressor. Mass and energy calculations can be used to determine the thermodynamic efficiency of the machine.

FIGURE 1: Mitsui Chemical's Osaka facility

AnomAlert* Application Trial

Mitsui Chemical Osaka Facility

Shinji Hiragakiuchi | Mechanical Engineer – Rotating Equipment Team Leader
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Introduction

This brief story describes a successful application trial of an AnomAlert Motor Anomaly Detector system that was installed at Mitsui Chemical Corporation's Osaka Works (Figure 1). The site is located at the center of the Sakai-Senboku coastal industry district approximately 11 miles away from the city of Osaka, Japan. Almost 1,200 employees (including contractors) currently work at this facility, which includes several different plants that process the several important products (Table 1). The facility has a large jetty that can accommodate a 100,000-ton class vessel for shipping the products.

Phenol, Bisphenol A
Polypropylene
Ammonia, Urea
Silane Gas

TABLE 1: Major products of the Osaka Works.

Application Trial

For this evaluation trial, an AnomAlert monitor was installed on the three phase induction motor that drove two screw-type air compressors through a speed-increasing gear train. This machine is one of four identical compressor units that provide air to deliver production materials to the next stage of the system for further processing.

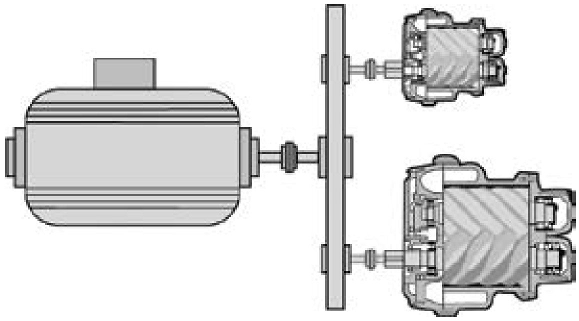

FIGURE 2: Simplified diagram shows the monitored machine train. The drive motor is visible on the left side of the bull gear, and the low-pressure and high-pressure screw compressors are on the right side – with the bull gear driving their individual pinion gears.

Drive Motor Description

- Design: 3-phase, 4-pole, air-cooled, AC induction motor
- Rated Power: 6.6 kV at 73 A
- Maximum Operating Speed: 1750 rpm
- Fixed speed at 60 Hz
- Rolling Element Bearings

Screw Compressor Description

- Design: Screw type
- Special Features: Seal leakage recovery system
- Discharge Pressure: 0.60 MPa
- Capacity: 116.6 m^3/min

Application Trial Details

At the beginning of November, 2010, just three months after the scheduled plant turnaround, the operations staff noticed significant fluctuation in motor current on one of four identical screw type air compressor units (named A, B, C and D in this article). The other machines were running smoothly with no fluctuations, just as they were supposed to be.

The fluctuation in motor current was observed in the control room on the current indicator for the B machine only. The amount of the fluctuation was measured at about 2 to 3 Amperes and its frequency was very low. The operations team immediately decided to remove the B machine from service and contacted the mechanical team to request troubleshooting the cause of the observed fluctuation in motor current on the B machine motor.

During normal operation, the compressor loading is fairly stable and motor current is accordingly steady. Depending on production demand, it is occasionally required to run all four machines at the same time. The machines are not equipped permanently-installed condition monitoring instruments, such as vibration monitoring system. However, current transformers and power transformers are mounted on two of three power lines for protection against electrical faults.

Mechanical Troubleshooting

The mechanical team started an investigation into the cause of the fluctuation in motor current of the B compressor unit. The team conducted a vibration analysis by using a portable analyzer, and reviewing process parameters such as output pressure. Although a slow audible beating sound was heard at about 0.35 Hz, no significant evidence of mechanical malfunction was identified. The mechanical team consulted with the compressor manufacturer about any possible causes of the observed symptom. The compressor manufacturer agreed with the results of the investigation done by the mechanical team and advised them to investigate for any possible electrical faults on the motor. It was suspected that the slow beating sound may have been a symptom of a broken rotor bar in the motor.

Electrical Troubleshooting

The on-site electrical team was involved in the further investigation to be carried out. During this investigation, the B motor was started solo (without being coupled to the gearbox and compressor). The fluctuation in motor current was not observed during the low-current regime with solo operation of the motor. However, the audible beating sound was still heard near the B motor. It seemed that the frequency of the audible noise matched the frequency of the fluctuation in motor current that had been observed earlier on the motor control panel, which was about 0.35Hz. Indications were insufficient to point directly to a root cause, which would have facilitated making a decision to either return the motor to normal service or schedule a complete overhaul.

Motor Swap

As a final troubleshooting step, it was decided to swap the B motor with the motor of the D compressor unit, which had been observed to be running fine. After the B motor was swapped with the D motor and coupled with the D compressor, the D compressor (now being driven by the B motor) was started up. The fluctuation in motor current was again observed on the B motor. Therefore it was concluded that the B motor itself – and not the B compressor or gearbox – was somehow causing the fluctuation in motor current. However, it was still unknown what the root cause of this symptom was, and whether or not the motor needed to be overhauled again after only three months of operation.

FIGURE 3: Motor Current Trend Plot of the B Motor. Observe that the frequency of the current fluctuation is approximately 0.35 Hz (3.5 cycles/10 seconds).

This plot was created from online measurements made by the portable test device during electrical troubleshooting before the AnomAlert monitor was installed. The portable device does not have a spectrum analysis function, so Mitsui could not perform the frequency analysis needed to identify the source of the observed current fluctuation

After the internal discussions it was decided to plan a complete overhaul for the B motor and send it to the manufacturer's designated repair shop, even though it had only been in service for about three months following the most recent overhaul.

About two months later, GE introduced AnomAlert to Mitusi Chemical Osaka Works and offered an on-site trial. Since the cause of the motor current fluctuation on motor B was still unknown, the AnomAlert trial was expected to provide a good solution to diagnose the root cause of the observed symptom prior to sending the motor back to the manufacturer's repair shop. Both Mitsui Chemical Osaka and GE agreed to conduct the on-site trial, using AnomAlert to monitor the B motor.

GE provided a laptop computer for use by the AnomAlert SCADA software. All wiring, including installation of Potential Transformers (PTs) and Current Transformers (CTs) was performed by Mitsui Chemical. AnomAlert was set up with the motor specifications. Since the cause of the symptom was still undetermined, running hours for the trial were limited in order to prevent the machine from experiencing further degradation or subsequent failure if the existing fault were to become worse during the trial. It was agreed to run the machine for only a few hours to collect data and allow the AnomAlert monitor to "learn" the relationships of the measured parameters to the modeled values.

The machine was started and AnomAlert automatically initiated the Learn mode and then successfully shifted to the monitoring mode. When the machine load reached the point where current was 73A, the fluctuation in motor current appeared. The AnomAlert software main screen remained with all states in green – suggesting that all the parameters measured & calculated by AnomAlert were below the calculated anomaly criteria (Figure 4).

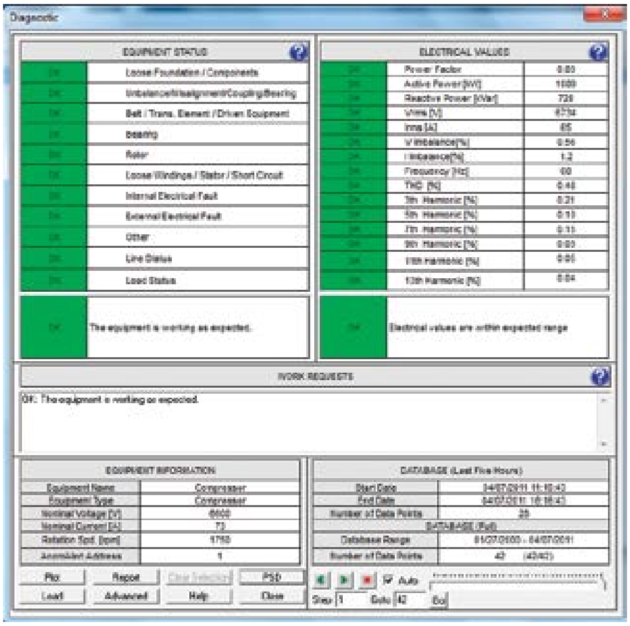

FIGURE 4: AnomAlert software Main Screen. The green color indicates that machine operation is normal.

Although the motor current showed significant fluctuation, the AnomAlert algorithms (which were developed from extensive data collected from real motors) judged that the B motor could be run for normal service.

While the machine was running, AnomAlert expert, Dr. Izzet Onel, remotely accessed the AnomAlert monitor from the Artesis office in Turkey – connecting to the laptop computer through the mobile modem where the AnomAlert software was running. Initiating remote diagnostics on the live data being captured by AnomAlert, Dr. Onel quickly identified the sideband frequency components that were associated with the pole pass frequency in the Power Spectral Density (PSD) plot (Figures 5 and 6).

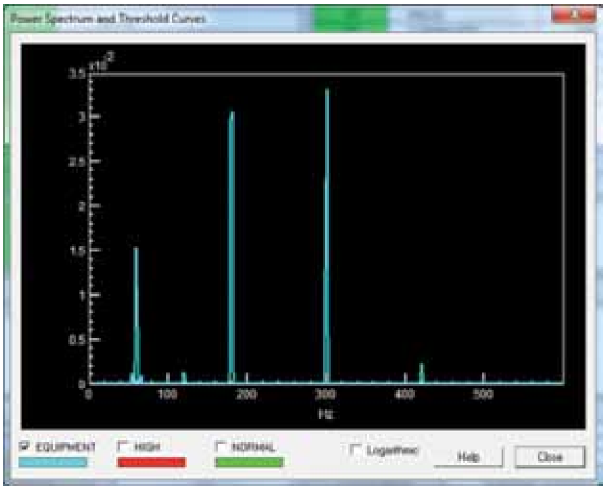

FIGURE 5: PSD plot showing significant peaks at 60 Hz (motor supply frequency), 180 Hz (third harmonic) and 300 Hz (fifth harmonic).

The PSD curve is calculated as an average of several PSDs that were collected during the learning period. The default number of learning iterations is 4000, which can take more than a week to complete. So in this specific case, the number of learning iterations was set to a smaller number (60) so that the learning period could be completed more quickly.

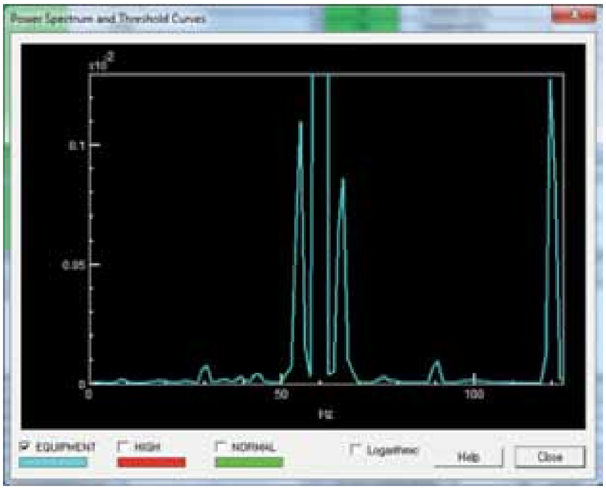

FIGURE 6: PSD plot zoomed around pole pass frequency.

This spectrum shows us that the 3rd and 5th harmonics of supply frequency are excessive. Such harmonics cause torque pulsations. Since it was already known that power supply harmonics were very low, the existence of harmonics on the PSD curve indicates the possibility of a developing electrical fault.

Note: Since AnomAlert measures voltage and current of the monitored equipment, its PSD frequency spectrum is different from a mechanical vibration spectrum. For example, with a vibration spectrum, motor unbalance would manifest as 1X (synchronous) frequency. But in AnomAlert, it would show up as supply frequency ± motor rotating frequency. A more detailed discussion of PSD analysis is beyond the scope of this summary, but will be included in future ORBIT issues.

The large peak at 60 Hz is the motor supply frequency. Motor unbalance manifests itself as sidebands at ±-1X frequency (motor rotative speed) around the supply frequency. Since motor speed is about 1750 rpm, (29.2 Hz), mechanical unbalance is observed at 60 ± 29.2 Hz. There are two symmetrical peaks at those frequencies, although their magnitudes are very low. This means that the B compressor motor has a minor unbalance problem.

Rotor bars or end ring problems manifest themselves around the supply frequency based on motor slip and number of poles. For the B compressor, this was calculated as 60 ± 5.3 Hz. When the PSD curve was zoomed during subsequent evaluation, it was very obvious that there were two symmetrical peaks on 65.3 and 54.7 Hz. These peaks correspond to rotor bar or end ring problems.

Dr. Onel concluded that the data indicated a possible rotor bar fault, which is most likely due to cracking. He verified that the B motor could still be run with this level of the fluctuation in motor current – just as was indicated by the green status colors in Figure 4. The result of the remote diagnostic findings were reported to Mitsui Chemical Osaka and the machine was shut down after enough data samples were captured to enable further analysis. This only required a few additional hours of machine operation. After the compressor was shut down, the AnomAlert database was sent to Dr. Onel. His subsequent evaluation validated the findings described above.

Based on the remote diagnostic report, Mitsui Chemical Osaka decided to skip the scheduled repair at the manufacturer's repair shop, which had been scheduled to occur in a few weeks. This decision allowed the plant staff to save the time that would have been needed for the repair at the workshop, as well as all costs relevant the repair and any production loss that would have resulted from having one of the four compressors out of service.

Trial Results Summary

- AnomAlert quickly captured enough data to diagnose the cause of an actual failure after only a few hours of operation. The cost of installation was fairly minimal when compared with the value of the diagnostic data that was obtained.

- The AnomAlert monitor clearly indicated that the machine could remain in service although the observed fluctuation in motor current was very visible. This helped Mitsui Chemical make the decision to continue running the B compressor.

- Based on the diagnostic information provided by the AnomAlert monitor and the expert evaluation that Dr. Izzet Onel was able to perform remotely, the Osaka Works staff was able to confidently postpone sending the motor back to a manufacturer's facility for complete overhaul. Continued use of the AnomAlert helped the operations team to watch for trends and maintain their confidence level to run the motor.

- Mitsui Chemical Osaka is now considering the installation of additional AnomAlert units on other critical machine trains. ■

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Detection of Wind Turbine Gear Tooth Defects

*Using Sideband Energy Ratio**

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Gear tooth defect detection is an important capability of any wind turbine condition monitoring system. The Bently Nevada ADAPT*.wind monitoring system has been designed specifically to monitor gear tooth condition and bearing health of wind turbine generators. The focus of this article is the theory and application of gear defect detection using machine casing vibration. Sideband Energy Ratio (SER), a patent pending algorithm utilized in the Bently Nevada ADAPT.wind monitoring system, has been developed specifically to aid in the detection of gear tooth damage.

SER calculates the ratio of side band energy to gear mesh center frequency energy and has demonstrated high sensitivity to gear damage in several cases. We will discuss the theory behind SER and share a case history showing successful gear tooth defect detection on parallel stage gear meshes of two wind turbine gearboxes. These gearboxes were inspected, and specific gear damage was documented prior to sensor installation and data collection. The gear defects are clearly visible in the data when analyzed utilizing the Bently Nevada ADAPT.wind monitoring system and the SER algorithm.

HISTORICALLY,

gear defects within a wind turbine gearbox have been difficult to diagnose at an early enough stage such that maintenance and repairs for these defects can be scheduled in advance.

Most wind turbine gearboxes have several speed increasing stages which each produce a different gear mesh frequency. The gearboxes also transfer a very large torque from the main rotor to the generator through these gear meshes resulting in relatively high energy gear mesh frequencies when compared to the energy level of signals produced by a small gear defect. Because of the overpowering gear mesh frequencies, gear defect signatures can often be obscured in the overall vibration signal and difficult to diagnose. Recently a new algorithm, SER, has been developed specifically to automatically detect and distinguish gear defect signatures within an overall vibration signal and provide an early detection warning of developing gear damage.

Amplitude Modulation

To understand SER, we first need to understand sidebands. Sidebands appear in a spectrum around a center frequency and generally occur as a result of an amplitude modulation of a signal at that center frequency. Amplitude modulation has a familiar use in AM radio in which it is used as a technique for transmitting information via a radio carrier wave. In a typical amplitude modulation example, the carrier signal is a single (sinusoidal) tone with amplitude based on frequency, f_c , as described in Equation (1).

$$A_m = A(t)\cos(2\pi f_c t) \quad (1)$$

The amplitude, A, of the carrier signal is modulated by a lower frequency modulation signal (this is the message signal for communications), m(t).

$$A(t) = A_0[1 + m(t)] \quad (2)$$

For illustration, we can assume that the modulation signal is a single frequency tone with frequency, f_m. Substituting this in for m(t) in Equation (2) gives the following.

$$A_m = A_0\,[1 + \beta\cos(2\pi f_m t)]\cos(2\pi f_c t) \quad (3)$$

Where β is known as the modulation index. It must be less than 1 in radio communication for less distortion and better signal recovery. Expanding Equation (3), we have

$$A_m = A_0\cos(2\pi f_c\, t) + \frac{A_0\beta}{2}\cos[2\pi(f_c + f_m t] + \frac{A_0\beta}{2}\cos[2\pi(f_c - f_m)t] \quad (4)$$

As a result, this amplitude modulation produces multiple frequency components, i.e., the carrier frequency, f_c, and side bands, $f_c - f_m$, and, $f_c + f_m$, which are slightly above and below the carrier frequency. The amplitude of the carrier frequency depends on the value of the modulation index, β, as seen in Figure 1 (for modulation index less than 1) and Figure 2 (for modulation index greater than 1). This type of amplitude modulation that results in two sidebands and a carrier is often called double sideband amplitude modulation (DSB-AM).

In many real applications, the modulation is not just a single tone but consists of multiple frequencies. Multiple frequencies in the modulation function cause multiple sidebands to appear in the spectrum as seen in Figure 3.A damaged gear tooth within a gearbox can cause this phenomenon. The damaged tooth will produce an amplitude modulation of its associated gear mesh frequency each time it passes through the mesh. That amplitude modulation occurs once per revolution of the shaft that the damaged gear is mounted on. When viewed in a spectrum, this amplitude modulation shows up as a series of spectral lines at evenly spaced frequencies on either side of the central gear mesh frequency.

These sidebands occur at frequencies of $\omega_{GM} \pm n(\omega_S)$, where ω_{GM} is the associated gear mesh frequency, n is an integer of 1 or higher (although we typically use n = 1–6 in the SER calculation based upon our experience with this measurement), and ω_S is the rotational

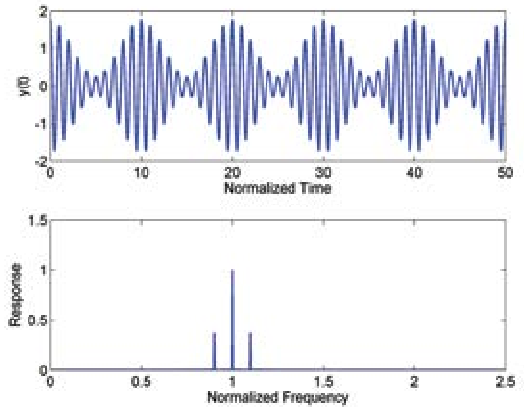


FIGURE 1: Timebase waveform and spectrum plots for amplitude-modulated carrier wave with β less than 1.

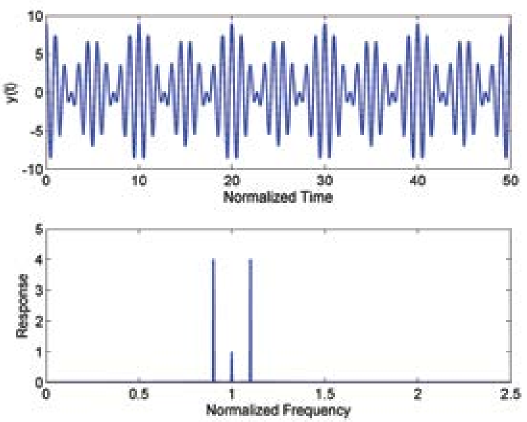


FIGURE 2: Timebase waveform and spectrum plots for amplitude-modulated carrier wave with β greater than 1.

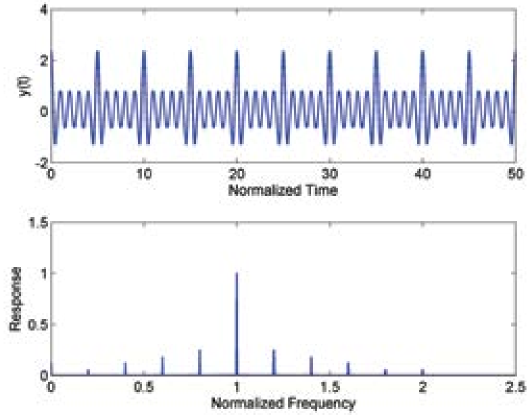


FIGURE 3: Timebase waveform and spectrum plots for a carrier wave modulated by a function having more than one frequency component.

frequency of the shaft with the damaged gear. Additional harmonics of gear mesh frequencies with sideband families of their own are also generally present in the spectrum because the waveform generated by the gear mesh is usually not a pure sine wave. This case history presents several examples of this behavior.

Sideband Energy Ratio

SER is calculated from high resolution spectrum data. Each spectrum is created from timebase waveform data generated by an accelerometer sensor and collected by the monitoring system. Several accelerometers are mounted in strategic locations on the wind turbine gearbox to monitor each gear mesh. The waveform signals from each sensor are synchronously sampled so that the sampling frequency tracks changes in speed.

This sampling technique produces narrow spectral lines of speed dependent frequencies – such as gear mesh frequencies and associated sidebands – for variable speed machines, and is essential to accurately calculate SER. Once the spectrum is generated, the SER algorithm sums the amplitudes of the first n sideband peaks on each side of the center mesh frequency and divides by the amplitude of the center mesh frequency.

$$\textbf{SER} = \frac{\sum_{i=1}^{n} \text{Sideband Amplitude}_i}{\text{Center mesh frequency amplitude}} \qquad (5)$$

SER is sensitive to the sideband amplitudes relative to the center mesh frequency. For a healthy gear mesh, any sidebands will have small (sometimes non-existent) amplitudes compared to the center mesh frequency, resulting in a low value for SER. The SER value is typically less than 1 for a healthy gear mesh.

As damage develops on a gear tooth that passes through the gear mesh, the sidebands will increase in amplitude as well as number resulting in a larger SER value. In ADAPT.wind, the SER value is calculated for the first 3 harmonics of each fundamental gear mesh frequency.

Case Histories

Several cases of gear damage were documented by borescope inspections on 1.5MW-class wind turbine generator gearboxes (Figure 4). During the inspections, damage to gear teeth on the high speed intermediate stage shaft (HSIS) pinion was discovered and photographed. The gearboxes with this documented damage were then outfitted with accelerometers and data was collected and analyzed using the Bently Nevada ADAPT.wind monitoring system. The two case studies that follow illustrate successful detection of the known gear damage by the SER algorithm.

FIGURE 4: Wind turbine planetary gearbox design

Case 1: Broken HSIS Pinion Tooth

Figure 5 shows a photo of the damaged HSIS pinion tooth discovered during a borescope inspection of the gearbox. Figures 6 and 7 display the high resolution spectrum of the acceleration data and the acceleration timebase waveform used to generate the spectrum. All plots were generated by the ADAPT.wind software.

Note: 1X, 2X and 3X labels are traditionally reserved for indicating the frequency associated with shaft rotative speed (1X in Hz = speed in RPM divided by 60). However, in ADAPT.wind SER spectrum plots, these labels are used as shorthand for Fundamental or first harmonic (1X), second harmonic (2X), and third harmonic (3X), of gearmesh frequency.

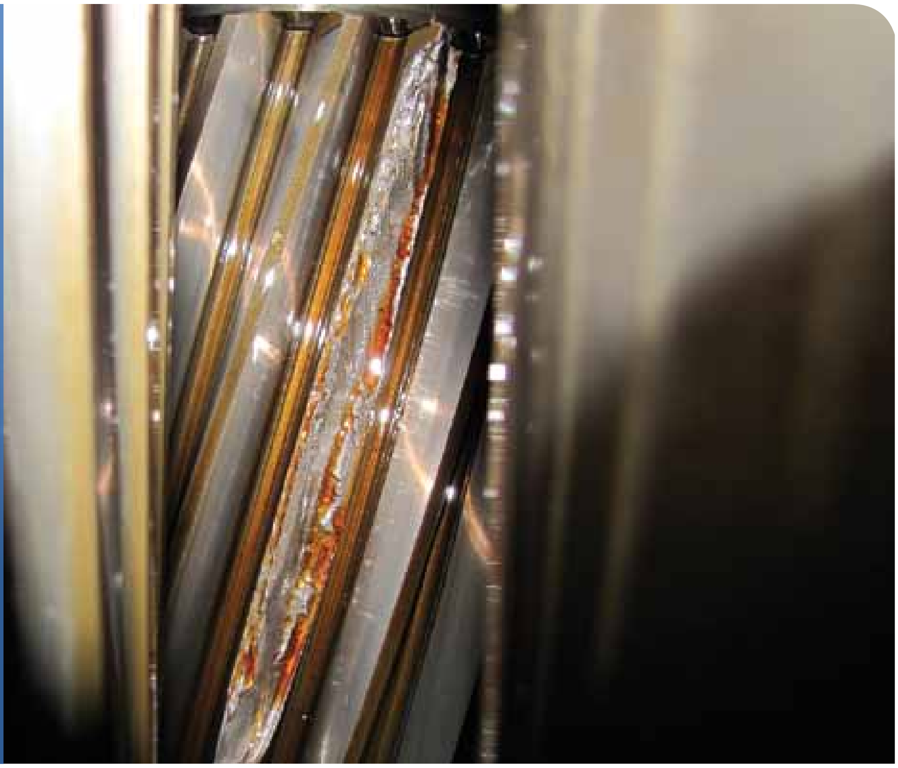
The dashed lines appearing in the spectrum plot represent the expected location of the first six sidebands on each side of the gear mesh 1X, 2X, and 3X center frequencies that would be associated with amplitude modulation occurring once per turn of the HSIS shaft. The dashed lines align perfectly with amplitude peaks in the data and in fact many more than six sidebands are present on either side of each center mesh frequency.

The SER values for the 1X, 2X, and 3X center mesh frequencies for this gear mesh and sideband spacing are 1.1, 3.9, and 5.6 respectively. Typically SER values are less than 1.0 for healthy gear meshes so the SER values seen here indicate a defect on the HSIS pinion which corresponds with the damage depicted in Figure 5.

The presence and spacing of these sidebands in the spectrum indicates that the center mesh frequency is being amplitude modulated at the frequency of the HSIS shaft rotative speed. Furthermore, the gear mesh center frequency harmonics that the sidebands surround denote which gear mesh the damaged gear is passing through.

Taken together, these two pieces of information indicate that the damaged component is passing through the intermediate stage gear mesh (the 1X, 2X, and 3X center mesh frequency lines in the spectrum belong to the intermediate stage gear mesh) and is mounted on the HSIS shaft (the sidebands have a spacing of HSIS shaft rotational speed). This diagnosis is also supported by the timebase waveform plot of Figure 7 which shows amplitude modulation occurring once per revolution of the HSIS shaft.

FIGURE 5: HSIS pinion broken tooth



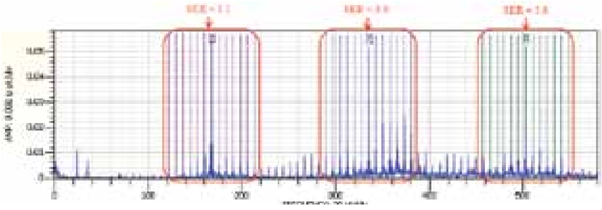


FIGURE 6: Spectrum showing center frequencies at intermediate gear mesh frequency (labeled as 1X) and second and third harmonics of gearmesh frequency (labeled as 2X and 3X). These center frequencies are surrounded by sidebands spaced at HSIS shaft speed, indicating HSIS pinion damage.

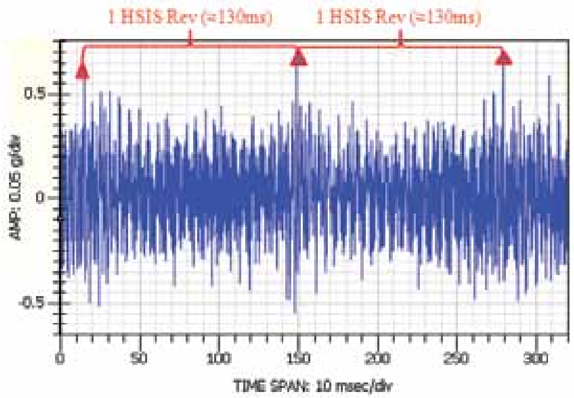
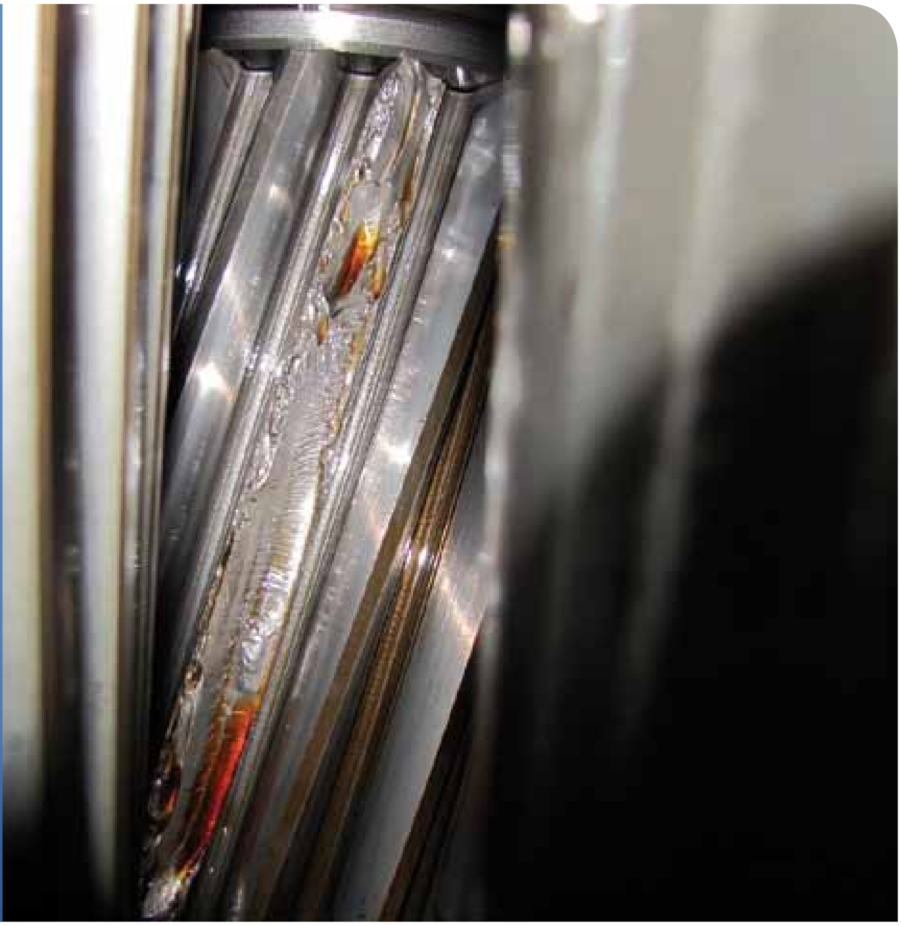


FIGURE 7: Timebase waveform showing amplitude spikes once per revolution of HSIS shaft.

FIGURE 8: HSIS pinion broken tooth



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TO UNDERSTAND SER, WE FIRST NEED TO UNDERSTAND SIDEBANDS. Sidebands appear in a spectrum around a center frequency and generally occur as a result of an amplitude modulation of a signal at that center frequency.”

Case 2: Broken HSIS Pinion Tooth

This is another example of detection of an HSIS pinion defect inside a wind turbine gearbox. Figure 8 shows a photo of the damage present on the HSIS pinion tooth – which is very similar to the previous case. The timebase waveform and spectrum plots of acceleration data for this wind turbine gearbox are given in Figures 9 and 10.

The 1X, 2X and 3X intermediate stage gear mesh center frequency harmonics with sidebands corresponding to amplitude modulation at HSIS shaft speed are clearly visible in the spectrum (Figure 10). The amplitude modulation can also be seen in the timebase waveform occurring once per turn of the HSIS shaft. As with the previous case, the presence and spacing of the sidebands in the spectrum indicate that modulation of the center mesh frequency is occurring once per turn of the HSIS shaft.

Also, the fact that the 1X, 2X and 3X center mesh frequencies belong to the intermediate stage gear mesh indicates that the damage causing the modulation passes through that mesh. From this information, we can diagnose that there is damage to the HSIS pinion in this gearbox. In this case the 1X, 2X, and 3X SER levels are 3.2, 3.5, and 6.6 respectively. These values are all well above what is typical of an undamaged gearbox, indicating that there is an HSIS pinion defect within this gearbox.

Summary and Conclusions

The SER algorithm, recently integrated into the ADAPT.wind monitoring system, is designed to target the detection of gear related defects within a wind turbine gearbox. This is accomplished by comparing the amplitude of sidebands to that of gear mesh center frequencies in conventional spectra. The two case studies described above provided an excellent test of the SER algorithm.

In both cases the SER algorithm was successful in demonstrating not only that gear damage was present within the gearbox but also exactly which gear contained the damage. The diagnosis of HSIS pinion damage predicted by high SER values and backed up by analysis of the timebase waveform, is confirmed by bore scope pictures of the damage in both case studies. Timely detection and diagnosis of developing gear defects within a gearbox is an essential part of minimizing unplanned down time of wind turbine generators.

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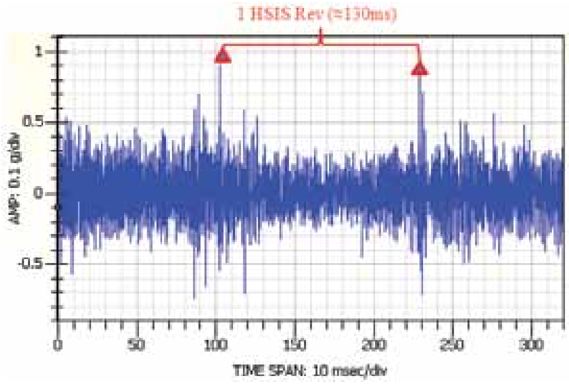

FIGURE 9: Timebase waveform showing amplitude spikes once per revolution of HSIS shaft.

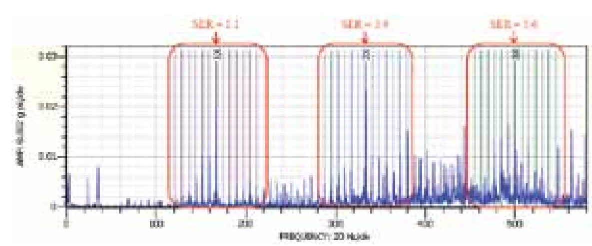

FIGURE 10: Spectrum showing 1X, 2X, and 3X intermediate gear mesh frequency harmonics with sidebands spaced at HSIS shaft speed – indicating HSIS pinion damage.

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Introduction to CYBER SECURITY

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What is it you visualize, or what is the first thought that comes to your mind when you hear the words Cyber Security?

Is it Internet Security? Sure. Is it Network Security? Very likely. Is it Product Security? Maybe. Is it physical security? Possibly yes. Is it compliance to security standards and regulations? Definitely yes. Not surprisingly, there are various ways to look at a problem, and everyone can be "right" in what they are thinking constitutes security.

While there is no perfect solution to any problem, including security, this article aims to shed light on the subject of Cyber Security with our Bently Nevada* products in the context of securing the products and the operational environment of your condition monitoring world.

Compliance to standards and regulations is at the top of many minds. There are many standards and regulations we need to be cognizant of. Some of the key ones for Cyber Security in the USA are NERC CIP *(http://www.nerc.com/)*, NIST SP800-53 and SP800-82 *(http://www.nist.gov)*, NRC RG 5.71(http://www.nrc.gov/), and NEI 08-09 *(http://www.nei.org/)*. Some other global common standards include IEC 27001 and 62443-2-4 Draft *(http://www.iec.ch/)*, ISA 99 *(http://www.isa.org/)*, and WIB M2784 *(http://www.wib.nl/)*. Your requirements will be driven by regulatory compliance, industry, and your unique needs for your business. It is outside the scope of this article to talk in depth about any of the standards, but the goal of compliance to Cyber Security standards is to ensure security of the whole operation, production system, and delivery of the services.

Risk Management and Defense-in-Depth

Risk management is an essential strategy for any organization. The risks related to product security and its working environment is usually a part of the integrated risk management approach laid out by the individual organizations. NIST SP800-37 is a good reference for applying a framework for information system security risks. Refer to chapter two on categorizing the risks in terms of severity and how to manage them.

When we talk of securing the hardware & software, the systems, the assets, and the operational environment itself, there are many approaches to take and many strategies will be deployed. One that stands out is the concept of defense in depth. The idea is simple - make it as difficult as possible for those seeking harm to exploit security vulnerabilities. As NIST 800-30 states (page 28), "the adverse impact of a security event can be described in terms of loss or degradation of any, or a combination of any, of the following three security goals: Integrity, Availability, and Confidentiality.

So, how is a defense in depth strategy implemented? Defenses can be established and deployed in multiple layers. For example, network defense, host computer defense and application defense are some of the layers where defensive techniques are deployed to detect, monitor, and protect the assets from malfunctioning. For our Bently Nevada engineering and product development teams, application security is seen today as a vital ingredient of quality deliverables. Being secure is no longer an option. It's mandatory.

Identifying & Mitigating Risks

When we talk about using condition monitoring products in many critical industries like power generation & distribution, chemical processing, petroleum refining, etc., it is important to evaluate the overall risk and form a mitigation strategy in collaboration with your suppliers and customers. Risk areas include, but are not limited to, application risk (such as known and unknown vulnerabilities in the product), deployment related risks (such as allowing remote connections to the application and the host system), and compliance risk (such as not meeting standards such as NERC CIP regulations).

Application risks can be addressed by using various techniques in the product development stage. Generating use case, misuse case and abuse case scenarios, identifying the product security requirements, designing for security, implementing or coding securely, performing manual or automated secure code reviews, and performing risk based security testing (includes techniques like fuzz testing or application penetration testing) are some activities usually undertaken in the product development stage.

Deployment risks can be mitigated by appropriate hardening of the host system, and identifying the unique requirements of the operational environment for each site etc.

Mitigating **Compliance** risk is a continuous process, and consists of two components. A) Staying up-to-date on the latest standards and regulations and 2) Mapping requirements to product features to analyze the impact, if any.

What are we doing to address these concerns?

The first thing we need to tell you is we are taking cyber security – including product security – very seriously. For our software product teams, we have begun by evaluating our security posture with the use of widely accepted and popular Building Security in Maturity Model (BSIMM) (pronounced "bee simm").

Building Security In Maturity Model

BSIMM *(http://bsimm.com)* is an industry working group consisting of approximately 30+members (visit the site for latest count on members) that share their internal security best practices. This is not a regulatory standard but is a set of recommended practices we have adopted and embraced.

At a high level, BSIMM helps teams and organizations identify their current best practices in various stages of the secure development life cycle, and use the results to set goals and objectives for improving the maturity of the digital products they develop.

The BSSIM methodology includes a set of "yes or no" questions to be answered by the teams in each of the four broad categories of governance, intelligence, secure development life cycle touch points, and deployment (Table 1). The scores are averaged for each category, and a final score ranging between zero to three is derived from this.

Governance	Strategy and Metrics
	Compliance and Policy
	Training
Intelligence	Attack Models
	Security Features and Design
	Standards and Requirements
SSDL Touch points	Architecture Analysis
	Code Reviews
	Security Testing
Deployment	Penetration Testing
	Software Environment
	Configuration and Vulnerability Management

TABLE 1: Each of the four BSSIM measurement categories includes three sub-categories.

By answering questions in these areas as part of a self-assessment (Figure 1), we have been able to better identify gaps and tighten our work procedures to ensure we develop and deploy secure products.

> "We see product security as a proactive attribute of product quality versus reactive." —**MICHAEL WHALEY**

With the backing of senior management, we have kicked off an extensive Cyber Security vision consisting of governance, training, design, and tools in our software development teams. Early in 2011, we began with an intensive training program. The training is customized for all roles in the product development lifecycle and will be an on-going process with annual reviews.

We have also initiated an internal GE certification program with the objective of developing secure products as early as possible in the product development lifecycle. Using these criteria, we have completed internal certification on many of our key products and are on course to ensure the practices are embraced in all of our agile development teams. Two of the many valuable activities we have performed include threat modeling of our product design and using integrated tools to focus, identify and fix security vulnerabilities early in the development cycle.

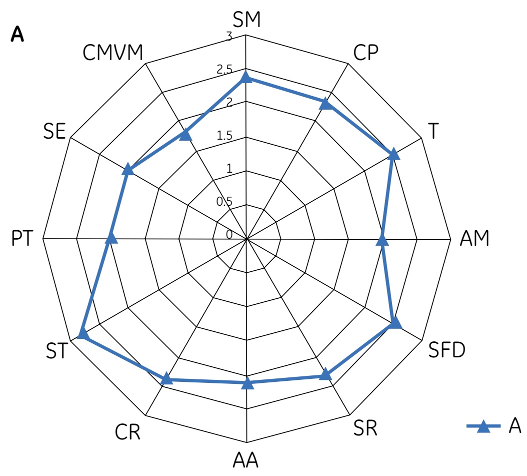


FIGURE 1: Representative BSIMM scores in all 12 sub-categories of security practices

There are many more additional initiatives planned for secure product development in the near future. For example, in the OCT 2011 Orbit issue, you may have read about the Wurldtech Achilles certification for our 3500 product. You will also hear more in the coming days as we roll out our Cyber Security offerings to meet the needs of your business.

In addition to measuring where we are and how to plan for further improvements, we have strong internal GE focus groups on security which we leverage for sharing of best practices. We want to help you become more secure and compliant, and to meet your own security objectives using our products and services. Please send us your questions, comments, and suggestions related to product cyber security by taking a small survey at the link provided below. Together, we can meet your goals. ■

https://www.surveymonkey.com/s/BN_CYBER_SECURITY

*Denotes a trademark of Bently Nevada, Inc., a wholly owned subsidiary of General Electric Company.

Using Your **ADRE*** in Remote Locations

— *OR* —

"What is that I.P. Address Again?"

John W. Kingham
Field Application Engineer
john.kingham@ge.com

One of the great benefits of the 408 is its network communications capability.

Connecting wirelessly allows you to put your 408 out near the machine, while you work comfortably in the control room. Connecting over your LAN allows you to work at your desk while the 408 is out in your plant, while connecting over the WAN expands this to any of your plants that are on your corporate network. As you can imagine, connecting over the Internet gives you virtually unlimited possibilities.

The 408 instrument has two, 1 GB, CAT 5 connectors (Figure 1). These use TCP/IP with either DHCP or Fixed IP addressing, and are LAN/WAN compatible. One of the nice things is that you can connect up directly to one port with your laptop, and then connect to your LAN with the other port. One point of caution, you can't connect directly with two laptops; one has to go through a switch/hub.

FIGURE 1: ADRE 408 communication ports.

With the information in this article, you should be able to accomplish the following tasks:

- Connect to the 408 directly
- Connect to the 408 wirelessly
- Connect to the 408 over your corporate LAN/WAN
- Connect to the 408 over the Internet

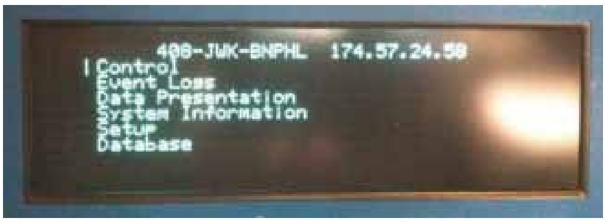


FIGURE 2: 408 display screen showing the IP Address (174.57.24.58, in this example).

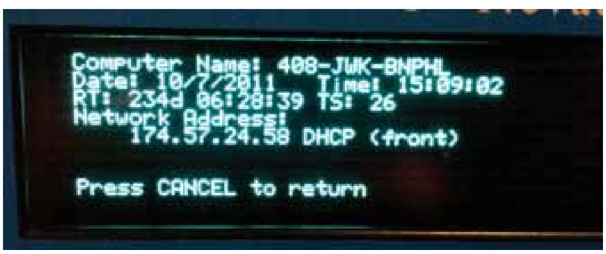


FIGURE 3: System Information screen also shows the IP address.

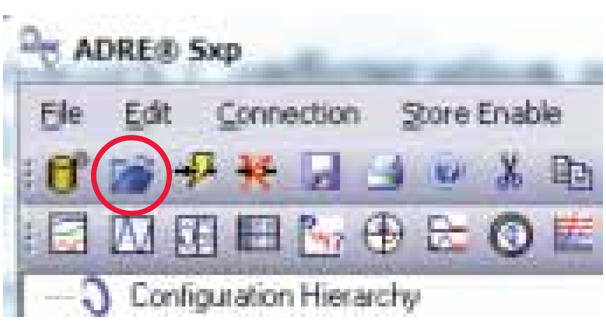


FIGURE 4: Click the Folder icon to open the Database Manager.

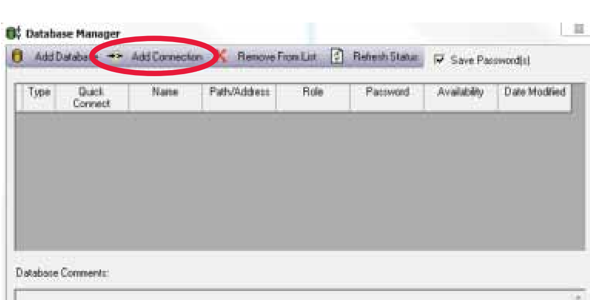


FIGURE 5: Database Manager.

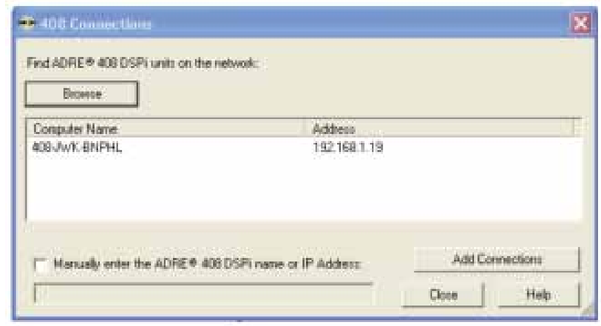


FIGURE 6: 408 Connections dialog.

FIGURE 7: Entering IP address manually.

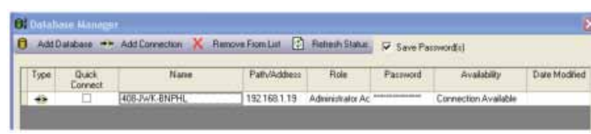


FIGURE 8: Example computer Name, IP (Path/Address), Role and Password columns.

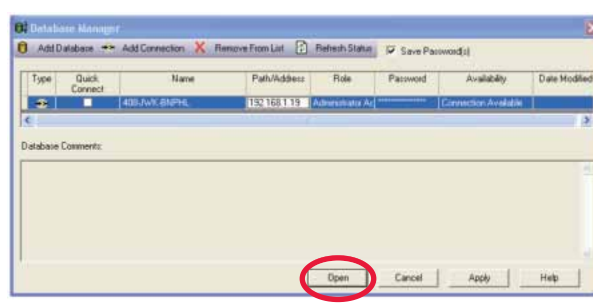


FIGURE 9: The 408 has been selected (row is highlighted in blue. The Open button is circled.

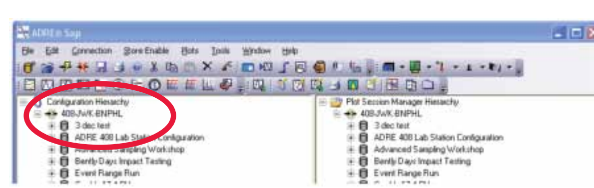


FIGURE 10: Main Sxp display screen shows connected 408 unit.

Finding your 408's IP Address

Since finding your 408's IP address figures into just about all of the directions, we are going to start here. If you don't need this step, feel free to forge on ahead.

Note: The IP address is not needed for direct (wired) connection or wireless connection (assuming there is no firewall in the way).

Once you have plugged your Ethernet cable into both the 408 and your LAN, WAN, Switch or Wireless Router, the 408 will generate its own IP address, if it has DHCP enabled, which is the default setting. To find the IP Address, go to the front panel of the 408 and click **Cancel** repeatedly until you reach the following screen (Figure 2):

As you can see, the IP address is listed to the right of the 408's name at the top of the screen. You can also select "System Information" to display a screen as shown in Figure 3.

In this example, I have my Ethernet cable plugged into the front port. If I had another connection in the back port, it would identify its IP address as well, calling it out as "back."

Direct Connection

This is probably the most common method of connecting to the 408. Simply use a CAT 5 Ethernet cable and connect one end to your laptop, and the other to either port on the 408. You can use a straight CAT 5 cable or a Crossover cable – it doesn't matter, as the 408 adapts to either. Once connected, open ADRE Sxp Software and go to the Folder Icon (circled in Figure 4). Click this icon once, and you will bring up the Database Manager (Figure 5). The database manager, as its name implies, is where you can connect to the instrument, but also where you can open local (on your computer or LAN) databases as well.

Once in Database Manager, click **Add Connectio**n to connect to your 408. Provided you don't have firewall software, the ADRE connection should pop up in the new window (Figure 6). This list only shows the connections that are on the same subnet as the ADRE Sxp client computer. Note: In some cases, you may have to click **Browse** to find your connection. If you do have a firewall, or if the ADRE Sxp client computer is on a different subnet than the 408, you will have to get the IP address from the 408 and enter it directly in to the IP address box. First, check the box for "Manually enter the ADRE 408 DSPi name or Address:" and then enter the IP address as shown in Figure 7.

In either case, after your 408 has been selected, click Add Connections in the 408 Connections dialog.

After selecting Administrator or Read-Only in the Role column, enter the password, if applicable (Figure 8). This will populate your database manager with your 408's information, and allow it to be selected. In Sxp version 2.7, it will also connect to the 408. Once you are finished adding connections, close the 408 Connections dialog.

If you are not already connected, highlight your 408 by clicking on it in the Database Manager dialog (the entire line should turn blue). Then click **Open** (Figure 9). This will close the dialog boxes, and in the main Sxp program your 408 should appear in the hierarchy (Figure 10). You are now connected to your 408.

Wireless Connection

I bought a wireless hub for about $50 USD and I use it to connect to my 408. It is awesome! I can have my laptop in the front of a demonstration room and the instrument in the back, and still communicate nicely. Think about this the next time you have your 408 on a turbine deck in the winter (or summer, or its rainy, etc. – you get the picture) and there is a nice comfortable control room nearby.

You may even consider this to be a SAFETY issue. If the parts of that large rotating machine go flying, you don't want to be anywhere near it! Note that my $50 wireless hub is not an "industrial" solution. But for my purposes it works very well. If an industrial solution is required, let me know, and I can connect you with a GE contact who recently set me up with a wireless bridge that I'm using at a plant for a DSM (Trendmaster*) application. It can transmit up to 20 miles, and does it with security and without licenses.

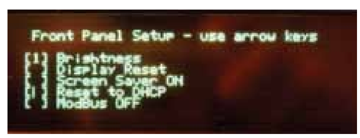
The 408 instrument can be set to have a static (unchanging) IP Address. This is done through the Sxp software. Setting a static IP may be a requirement for some LANs, and you may also find that it results in faster direct connections.

What do you do, however, if you find that the ADRE you are trying to connect to has had a static IP address configured for a different network? With the latest version of firmware, AB, it is possible to set the IP address back to DCHP using the front panel.

RESETTING TO DHCP

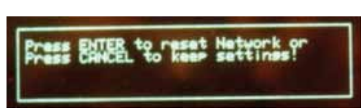
First scroll down to "Setup," and select it, as shown here:

From the Setup list, select "Reset to DHCP" and press **Enter:**

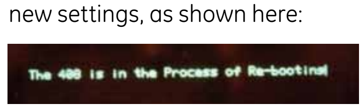


Now, select whether you want DHCP on a single port or on both ports:

Once you have made your selection, press **Enter** to reset, or **Cancel** to keep your last settings:



If you press Enter, the 408 will reboot in order to apply the new settings, as shown here:



In order to prevent any unauthorized access to the corporate LAN that could possibly occur through the wireless bridge, it is recommended that you enable the security features of the bridge (check with your IT folks to see if they have a spec for this), and disconnect from your corporate LAN any time that you are using the bridge.

We are going to use the same basic technique here as with the direct connection. The difference is that we are going to need to manually enter the IP address of the 408. So go back and follow the directions for Direct Connection with the exception of using the Browse button to find the 408. Other than that difference, the processes are the same. Just to clarify, I have included a screen shot showing how to insert the IP address in the 408 Connections dialog (Figure 11).

Corporate LAN Connection

Directions here are exactly the same as those for connecting wirelessly, except that you may have to have someone tell you what the IP address for the unit is once it is connected.

Another caveat is that you will very likely encounter security firewalls within your corporate system. If this is the case, contact your IT lead and ask them to open all communications traffic through port 3007. If you are using our new Modbus export feature, port 502 will also need to be opened for all traffic. The Modbus export feature became available with 408 firmware version AB, which corresponds to Sxp version 2.7.

Internet Connection

Since I am developing my tips from my home based "laboratory," I find that my Internet Service Provider (ISP) only allows my system to have one IP address that is visible to the Internet. Without doing some complicated configuration to my router, my option was to connect my 408 directly to my cable modem, bypassing my router. After doing this, I checked the 408 for the IP address (Figures 2 & 3), and moved my portable lab to a local café for free wireless internet access and a refreshing beverage (Figure 12).

FIGURE 11: Entering the 408 IP address manually.

FIGURE 12: Your author (right) is connecting to his ADRE 408 over the Internet from a convenient café, while his friend, Rick, looks on and provides encouragement.

From the Internet café, I manually entered my IP address as shown in Figure 11. When I clicked Add Connections, the database manager showed my connection (Figure 13):

When I clicked Open in the Database Manager, the main Sxp display showed that I had successfully connected to my 408 remotely (Figure 14). Pretty neat!

My next goal was to be able to have my 408 connected to my home network, and still be able to see the instrument on the Internet. Your system will most likely be different from my home router, and these configuration changes should probably only be attempted by an I.T. professional. In this example, I logged in to my router and select the WAN Setup option in the "Advanced" menu (Figure 15).

From here, I defined the "Default DMZ Server" as the I.P. address of my 408 when it was located on my network (Figure 16).

I have been advised NOT to select "Respond to Ping on Internet Port" unless it is needed to troubleshoot your connection. Marking this check box may allow hackers to find your 408. And even though the 408 is a "hardened" network device, it is a good idea to avoid possible trouble.

With my WAN set up in this manner (on the east coast of the USA), one of our Engineers in Minden – almost 3000 miles (~4800 km) to the west – connected to my 408 via the Internet. Meanwhile, the rest of my home network still functioned normally.

As you can imagine, these connectivity tips can make your ADRE system a much more versatile device, not just as a data collector, but as a productivity tool as well. This is another example of bringing our mantra of "Move Data, Not People" to reality.

Catch you on the next Orbit, see you the next time the Keyphasor comes around — John

*Denotes a trademark of Bently Nevada, Inc., a wholly owned subsidiary of General Electric Company.

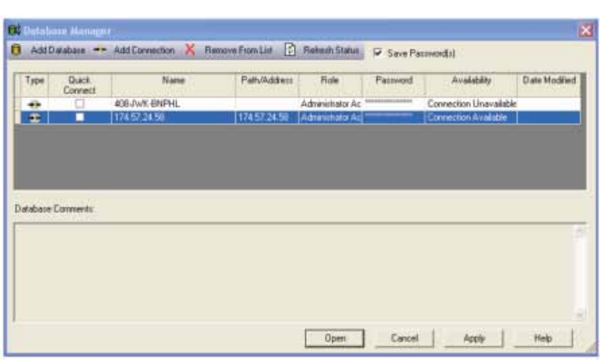


FIGURE 13: Database Manager example for Internet connection.

FIGURE 15: Example router configuration option list (your options may be different).

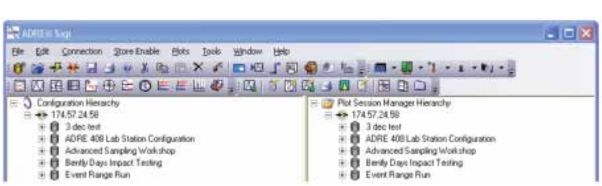


FIGURE 14: Main Sxp display showing remote Internet connection to 408 unit.

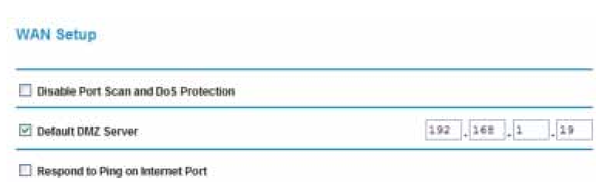


FIGURE 16: Example router configuration WAN options (your options may be different).

Main Oil Line Motor-Pump Trip

Caused by a Seal Rub

Charles Spencer | Nexen Petroleum UK | Mechanical Engineer
Martyn Campbell | Nexen Petroleum UK | Onshore Operations Superintendent
Mark Craig | Bently Nevada Field Engineer | mark1.craig@ge.com

The event investigation described here occurred during a Supporting Service Agreement (SSA) activity between Nexen Petroleum UK and General Electric (GE) Energy. The case refers to the production capabilities of an offshore platform which at full rates has the capacity to produce around 220,000 barrels of oil per day. This production is accommodated by three Main Oil Line (MOL) motor-pump assemblies, known as units A, B and C, which each have the capacity for the transfer rate of 700 m^3/h of liquid hydrocarbons.

The normal management strategy for these machines is to operate two of them, with the third remaining on stand-by status. However, at this time of this event, unit C was out of service due to ongoing repairs. In addition, unit B was off-line for the installation of new seals at both the motor drive end (DE) and non-drive end (NDE). When the B unit was restarted following replacement of seals, a high vibration trip condition was observed at the motor DE.

As a consequence, the production capabilities of the site were compromised by around 110,000 barrels of oil per day. This translates to approximately 10 million British Pounds of lost revenue daily. Therefore, the main priority for the platform was to provide a swift resolution that allowed for the safe and continued operation of MOL pump B for production purposes.

The following analysis was provided by the remote GE Machinery Diagnostic Services (MDS) team (Europe), and supported by the Nexen on-shore/off-shore Mechanical/Reliability departments. Due to the significance of the production set-back, an additional GE MDS engineer and specialist machine vendor were mobilized off-shore to ensure an immediate resolution to the case.

Analysis

Figure 1 shows a machine train diagram of MOL pump B, highlighting the vibration and temperature measurement points as configured in System 1* software. Radial measurements are taken by XY proximity probe pairs and a thermocouple, located at the DE and NDE bearings of both the motor and pump. Axial measurements are taken by a pair of proximity probes and thermocouples in the thrust position of the pump. A Keyphasor* transducer on the motor is employed as a speed reference and the process is monitored by the Bently Performance* package.

Figure 2 shows a trend of the "direct" (unfiltered) displacement amplitudes observed at the motor DE Y probe during numerous start-ups, taken from the start of the year.

Historically, when the machine attains steady-state conditions, the signal amplitude is around 53 μm (microns). However, on the most recent start-up, the machine observed a trip condition when the severity 4 over alarm was exceeded. The over alarm configurations consist of severity 1, 2, 3 (software) and 4 (hardware trip) set-points of 65, 75, 100 and 125 microns, respectively.

Figure 3 shows the direct displacement trend at the DE Y probe, during the most recent start-up of MOL pump B following the seal installation. The motor DE Y signature shows an increasing trend for 17 minutes after full speed and steady-state conditions were attained. The trend plot of the direct vibration displacement signal provides initial evidence of a continually changing machine condition, until the trip was confirmed at the 125 micron setpoint.

Figure 4 shows a waterfall plot, which confirms that that the dominant spectral activity is synchronous to motor running speed (60 Hz). The increasing 1X amplitude during steady-state operation shows that the vibration relates to changes in the rotor condition.

The uncompensated Bode plot is shown in Figure 5, indicating that the direct and 1X amplitude during start-up is different when compared to the shut-down characteristics. The plot further validates the increasing direct and 1X amplitudes at steady-state operating conditions. The plot provides additional evidence that the changing machine condition at constant full speed operation relates to recent modifications.

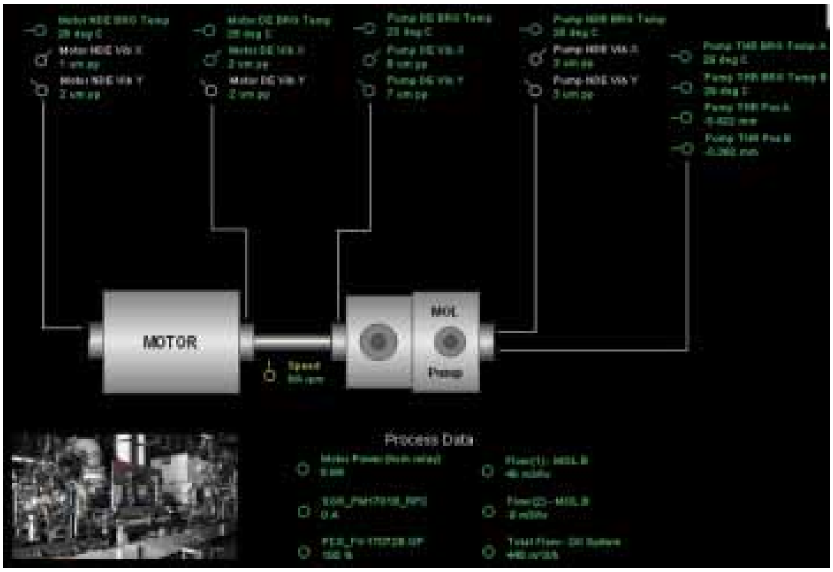


FIGURE 1: Architecture of the vibration and measurement points on the MOL unit.

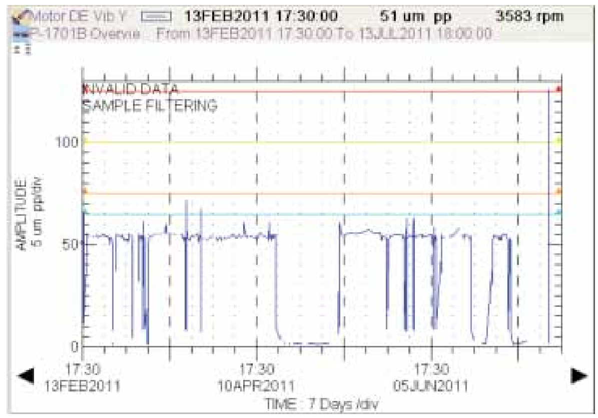


FIGURE 2: Historical trend of direct displacement values observed at the DE Y probe.

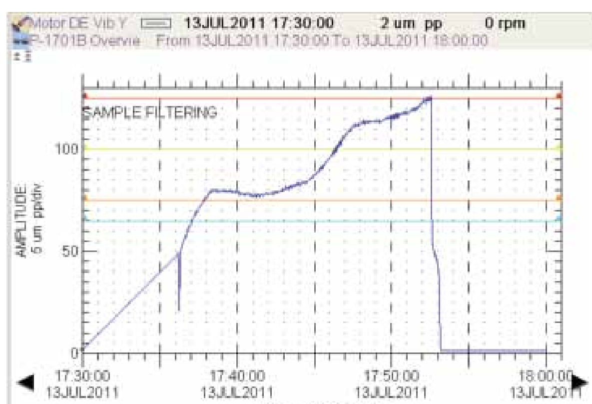


FIGURE 3: Most recent start-up and trip condition of MOL pump B, showing the trip that occurred with vibration amplitude reached the trip setpoint of 125 microns.

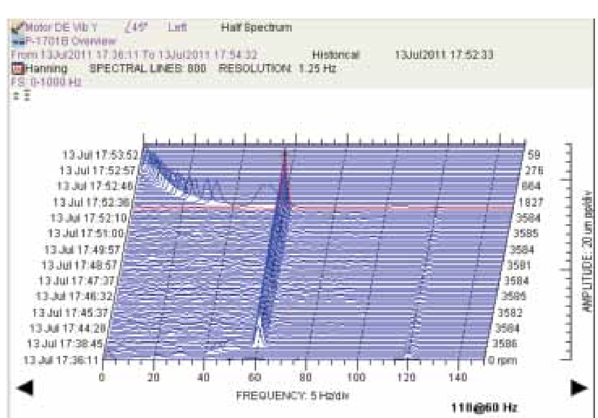


FIGURE 4: Waterfall plot observed at the motor DE Y probe.

THE INSPECTION REVEALED THAT THE MOTOR DE INNERMOST SEAL HAD RUN DRY WITH VISIBLE SIGNS OF RUBBING.

THIS PROVIDED EVIDENCE OF SEAL MISALIGNMENT DURING INSTALLATION, CAUSING THE ROTOR RUB."

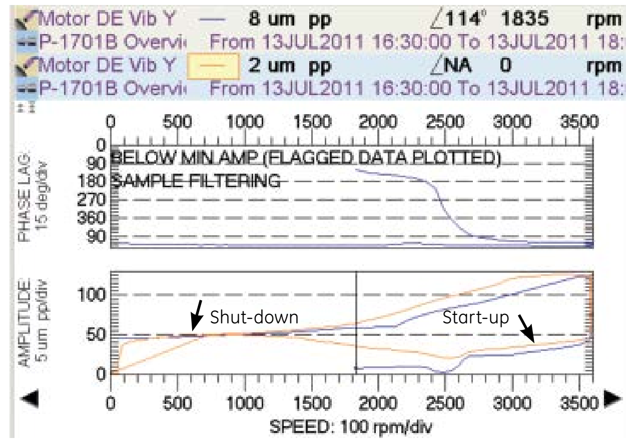


FIGURE 5: Bode plot during the period of machine operation.

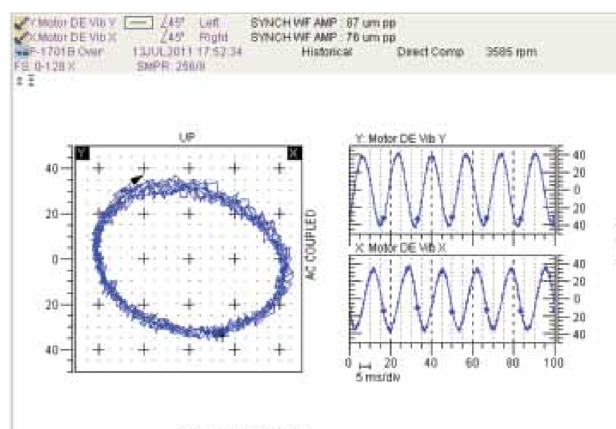


FIGURE 6: Orbit observed at the motor DE prior to machine trip.

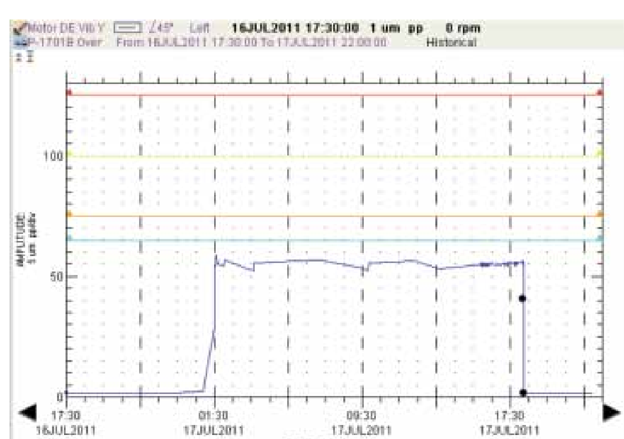


FIGURE 7: Normal vibration amplitudes observed at the DE Y probe after remedial work.

The data shown in Figures 1 through 5 provides evidence of a changing rotor at steady-state operating conditions. Such a changing rotor state can be the initiated by thermal excitation. One typical cause of thermal excitation is by frictional heating during interfacial contact between opposing surfaces. Potential areas of contact occur at the interface between components that have tight clearances. These surfaces include the contact area between mechanical seals and rotating shafts.

Initial contact occurs at the asperity peaks of the surface roughness. This light rub causes a hot-spot, which changes the mode shape and 1X amplitudes of the rotor. Changes to the mode shape of the shaft, provides greater Hertzian contact pressures at the rotor-seal interface. This provides a positive feedback mechanism that provides additional shaft heating, and drives the continued elevation of the 1X amplitude signature. These characteristics are consistent with the vibration signatures shown above and correlate to components that were changed during the maintenance action.

Signal analysis that is traditionally sought when rubs are observed includes use of the orbit plot. A rub is usually identified by deformation in orbit shape from the circular geometry. Figure 6 shows the orbit observed at the motor DE of MOL pump B, prior to when the machine tripped. The orbit is compensated to slow roll speed, which negates the contribution of mechanical and electrical run-out errors. The orbit shows an almost circular profile, providing no evidence of a radial pre-load condition, which would present further validation of a rotor-seal rub. However, as with a light rub, deformation to the circular geometry may not be observed.

Corrective Actions

Based on the analysis described above, it was decided to dismantle the motor so that an inspection of the components could be carried out by the specialist vendor. The inspection revealed that the motor DE innermost seal had run dry with visible signs of rubbing. This provided evidence of seal misalignment during installation, causing the rotor rub. The remedial work then consisted of correctly reseating the seal according to the pump manufacturer specification. Figure 7 shows the start-up and steady state vibration characteristics observed at the DE Y probe following the replacement of the seal. The direct amplitude shows values around 53 μm, which are typical of the expected signal levels for this location of the machine.

Conclusions

MOL pumps are critical machines that determine the production capabilities of the platform. Therefore, when they are not available for production purposes, it is vital that they are returned to service at the earliest opportunity. In order to achieve this, it is imperative that the correct diagnostic equipment and signatures are used. System 1 plant management software provided the correct tools for confirming the precise locality of the machine distress. Significant features of the data set showed an increasing 1X signature at the DE Y probe during steady-state operation. The amplitude was significantly greater during shut-down, when compared to the start-up. The diagnosis was of a rotor-seal rub at the DE of the motor, which caused a thermal bow.

When the above analysis was combined with historical information of the machine that was gained from on-shore support, a decision was able to be made about where future remedial actions should be focused. This led the machine specialist to an inspection of the seals, where a rub was confirmed, and appropriate remedial actions taken.

This case history shows the importance of the interaction between the relevant on-shore and off-shore personnel. It highlights some of the ongoing efforts between Nexen Petroleum and GE Energy in coming to a prompt resolution in diagnosing the root cause of machinery problems. ■

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