orbit

Volume 31 | Number 1 | 2011

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

A New Dawn for Asset Availability

From the Desk of **Gary B. Swift**

Editor | Orbit Magazine

A New Dawn for Asset Availability

Greetings, and welcome to my first issue of Orbit as your new editor! My goal is to publish an issue every calendar quarter, and to uphold our legacy of technical excellence, while at the same time expanding our coverage of asset condition monitoring and proactive maintenance topics.

I also look forward to making our content more available in digital formats as well as in traditional print. As an example, we are including a Quick Response (QR) code on the back cover of this issue. If you have a web-enabled smartphone with a QR code reader application, you can navigate directly to the destination webpage by "taking a picture" of the code with your phone. But if you don't have this technology – or if you simply enjoy the physical experience of reading a REAL magazine – don't worry. We will continue to publish the print version of Orbit.

As a quick housekeeping item, I have gathered timely information into the News section in the front of this issue, longer articles into the Features section in the middle, and recurring topics into the Departments section near the back of the magazine. For consistency, I plan to follow this basic arrangement with every issue from now on.

The theme for this issue emphasizes that asset availability can be improved by applying advancements in condition monitoring technology and by combining more than one technology in a collaborative environment. We have included several interesting articles that address this theme from a variety of different viewpoints. I especially enjoy the optimistic metaphor of the beautiful dawn photo that illustrates the theme!

On a personal note, the Hydro Corner piece is very nostalgic for me, and takes me right back to my first exposure to industrial power generation as a 9 or 10-year-old boy. My 4th grade class took a field trip to visit a local hydro generation facility, where I reached under the handrail and dragged my fingers on the slowly rotating inter-shaft of one of the running generators. I remember being impressed that the huge shaft did not slow down due to the force applied by my little hand…

Of course, my teacher saw what I was doing and shouted, "Get away from there! You could lose a finger!" I have been interested in power generation ever since, and went on to become a plant engineer at a large nuclear generating station. I am happy to report that I still have all of my fingers!

I look forward to sharing a journey of discovery as we explore asset condition monitoring together.

Cheers!
Gary

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Celebrating Our Experience

The Bently Nevada team is well known for providing excellent customer support. An important factor in developing and sustaining our high level of expertise is the continuity and synergy provided by hundreds of dedicated employees, who together, have provided many thousands of years of high quality service.

The Western US employees listed here are only a small fraction of our total team, yet they represent almost 1700 years of experience – just on these two pages! Our multinational team extends around the globe, where similar commitment can be found in every region. The story on Page 48 is a good example, as it mentions some of our Field Engineers from Africa, Europe, India, Latin America, Middle East, and North America regions.

40 YEARS: BEVERLY FRICKE

Bev came to us in 1970, and has had a variety of roles since then. For the past 10 years, she has been a Customer Services Representative (CSR) for Bently Nevada products. "I am thankful for the educational opportunities that I have had here," she said, "and for a job that allows me to work so closely with our customers. It's a great place to work!" Bev is a native Nevadan, and she enjoys hunting, fishing, and other outdoor activities in her spare time.

35 YEARS

Corinne Anderson, Roger Heath, Jim Flakus, Charles Morgan, and Gayle Trent. *Not Shown:* Lynda Clement

30 YEARS

Valery Adams, Robert Huber, Rusty Lane, Denise Rogers, Gordon Speltz, and Daniel Welsh.

25 YEARS

Stephen Byrne, Michael Crafton, Stephen Dexter, Corrine Goldade, Joy Jacobs, Kevin Roath, Richard Slates, Katherine Steffen, Marc Tompkins, and Brian Wheat.

20 YEARS

Christine Armenta, Andrew Cartledge, Paul Crafton, Dennis De Lange, Stephen Gaskell, Michael Merritt, Paul Richetta, Derek Rickford, and Steven Sturm. *Not Shown:* Adrian Cobb and Jozsef Patyi.

15 YEARS

Robert Allen, Darren Bradbury, Kyle Brown, Rand Croxall, Michael Grimes, Curtis Hoffman, Bryan Holzbauer, Dan Lu, Scott Martin, Jonathan Mccormick, David O'Connor, Derrick Olson, Richard Rickard, Joseph Robert, Susan Roush, Alyscn Simms, Holly Whipple, and Joseph Whiteley. *Not Shown:* Vickie Baldwin, Donald Buchanan, Jeanne Fallon-Carine, John Lenhart Cindy Peterson, Andres Ramirez, Don Stanford, and Michael Turek, and Robert Whitehead.

10 YEARS

Monica Arthurs, Ana Baldwin, Christopher Baldwin, Peter Bellis, James Dezerga, Claudia Hamilton, David Ferdon, Timothy Heng, Donald W Johnson, Bradley Jorgensen, Bradley Kelly, John Kimpel, Jeffrey Mandl, Katherine Marquardt, Alan Meredith, John Monson, Ana Pacheco, Rebecca Pappenfort, Rebecca Patterson, Violet Pete, David Spaulding, Sean Summers, Randall Tanaka, Martha Williams, Susan Young, and William Zubon. *Not Shown:* Daniel Brennan, Dan Dean, Keith Dutton, Lucy Gao, Christopher S. Hansen, Shawn Mott, Vikki Perri, Kathleen Pete, Boris Sheikman, Brent Tuohy, and Summer Woodson.

3300 Monitor System Obsolescence

Landon Boyer | Product Line Manager | landon.boyer@ge.com

Since its introduction in 1988, the Bently Nevada 3300 series monitoring system has served with distinction as a highly reliable solution for machinery protection and monitoring needs. However, as technology has advanced, it has become increasingly more difficult to find suppliers that manufacture the components on which the 3300 system relies.

Accordingly, our focus has transitioned from the ability to sell new 3300 systems indefinitely, to the ability to adequately support the large installed base of 3300 systems worldwide while providing adequate lead-time for customers to develop appropriate migration strategies.

After careful assessment, we have formalized the following support plan:

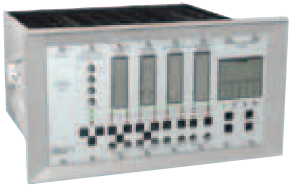
We will support the 3300 monitors in Phase 4 as long as possible given limited availability of components. In Phase 4, we support repair of products – provided that the required replacement components are still available. However, we no longer provide spare parts.

We are committed to holding this Phase until all monitors are out of their 3-year factory warranty. Current estimates are that we can continue in Phase 4 until January 2014, at which time we will move to Phase 5. In Phase 5, we can no longer support the monitors, and we do not recommend continuing to use them in in a machinery protection application.

As always, we will honor our 3-year factory warranty. We are committed to holding Phase 4 of obsolescence until all spare 3300 monitors that were purchased during Phase 3 are beyond their warranty period.

Bently Nevada Product Life Cycle Phases

- **Phase 1:** Complete systems, spares, and repairs are available. Periodic product enhancements are implemented. New custom modifications are available.
- **Phase 2:** Same support as Phase 1, except that enhancements are no longer planned, and new custom modifications are discouraged.
- **Phase 3:** Spares only. No new systems are available.
- **Phase 4:** Repair only. No spares are available.
- **Phase 5:** Product is obsolete and is no longer supported. It is not recommended for continued use in a machinery protection application



Field verification and troubleshooting services will continue to be available for 3300 monitor systems for several years after the transition to Phase 4. While we are committed to provide field service as long as practical, we cannot guarantee that problems encountered by the field service engineers will always be able to be corrected, since we will no longer be producing spare parts.

Note: This obsolescence notice does NOT affect 3300 Input/Output (I/O) Modules. 3300 I/O Modules will remain in their current status, and will continue to be available.

GE recommends that all 3300 monitoring system customers consult with their local sales professional specializing in Bently Nevada Asset Condition Monitoring to develop an appropriate migration strategy. This strategy should take into account the timelines for Phases 4 and 5 outlined above, the planned outage schedules for affected machines, and other relevant details.

We are acutely aware that migration to a newer platform must address the cost-benefit considerations of advanced functionality versus the disruption that system replacement represents. Some customers will place primary emphasis on advanced functionality, with less concern for installation convenience. Others will place primary emphasis on minimal disruption, preferring a "drop in" replacement that preserves field wiring terminations, panel cutouts, and other installation details. Our various 3300 migration options reflect these differing needs, allowing customers multiple choices.

Several migration options exist today, including the 3500 series Monitoring System. Others will be introduced over the next 3 month period. The appropriateness of a particular option will vary on a case-by-case basis for each customer depending on their existing 3300 installation, current and future functionality requirements, anticipated service life of the machine being monitored and other details. Your GE sales professional can assist you in understanding these options and evaluating their suitability for your specific situation. ■

Best Practices Awards: Reliability – Decision-Support System Lets Rules Dictate Maintenance

Reprinted with permission from Plant Services (www.plantservices.com).

Refinery uses protection systems in conjunction with condition-monitoring and decision-support software.

The Plant Services Best Practices Awards recognize management techniques, work processes, and product and service implementations that exemplify the definition of a best practice, which the Society of Maintenance and Reliability Professionals (SMRP) defines as: "a process, technique or innovative use of resources that has a proven record of success in providing significant improvement in cost, schedule, quality, performance, safety, environment or other measurable factors that impact the health of an organization."

Entries must demonstrate how to implement a best practice, show the potential payoffs in both qualitative and quantitative terms, and provide inspiration for those who must overcome cultural inertia and make effective changes. Entries may be submitted by plant personnel, vendors, engineering firms, consultants or anyone who is familiar with the application and has permission to make it public knowledge. Our 2010 categories also include Equipment, Management and Energy Efficiency, but this round's focus is on Reliability.

Every contender offered an impressive reliability practice that can increase productivity, improve efficiency or reduce costs. Judging criteria included percentage reductions or cost savings, return on investment and broadness of applicability, with recognition given for innovation and creativity.

The winning practice was submitted by Jayesh Patel, reliability manager, Valero Refinery in Paulsboro, New Jersey. By managing its equipment below the alert level, the refinery is able to be proactive in its machinery management, allowing Valero to mitigate reactive work and the associated process interruptions. The results of this shift to proactive maintenance are improved product quality, improved machinery availability and increased profits.

Condition monitoring is combined with decision-support capabilities that utilize prewritten rules, as well as additional customized rules set by Valero.

The combination allowed the refinery to schedule maintenance without the additional pressure of emergency conditions, and Valero's successful implementation won the votes of our judges to become this round's Best Practice in Reliability.

More information about this round's entries, past entries and winners, how to enter, and the Plant Services Best Practices Awards in general may be found at www.plantservices.com/bestpractices.

Winner: Decision-support system lets rules dictate maintenance

Refinery uses protection systems in conjunction with condition-monitoring and decision-support software

Valero's Paulsboro Refinery has a capacity of 195,000 barrels per day and employs nearly 550 individuals. Condition-based maintenance is used extensively and employs a mix of permanent and portable technologies, depending on asset criticality. Low-criticality assets are addressed by a portable data collection system. High- and mid-criticality assets are addressed by online systems. For its most critical assets, Paulsboro uses Bently Nevada continuous machinery protection systems in conjunction with System 1 software. These assets include gas turbines, steam-driven and motor-driven centrifugal compressors, hydrogen reciprocating compressors, utility air compressors and liquid ring compressors for flare gas recovery. Mid-criticality assets in the refinery's coker unit are addressed by the Bently Nevada Trendmaster system, a permanently wired "sensor bus" architecture that monitors conditions several times per hour. Both the continuous monitoring systems and the Trendmaster architecture are tied into System 1 software for a unified online condition-monitoring environment.

One of the keys to Paulsboro's success with condition-based maintenance is its practice of managing machinery "below the alert level." Alarms set to notify machinery specialists of impending problems allow uninterrupted operation while appropriate actions, such as scheduling maintenance, planning an outage or recommending changes to operating or process conditions, are taken. This proactive maintenance drives the Paulsboro refinery to the far left limits of the P-F curve (Figure 1), resulting in higher product quality, improved asset availability and increased operating profits.

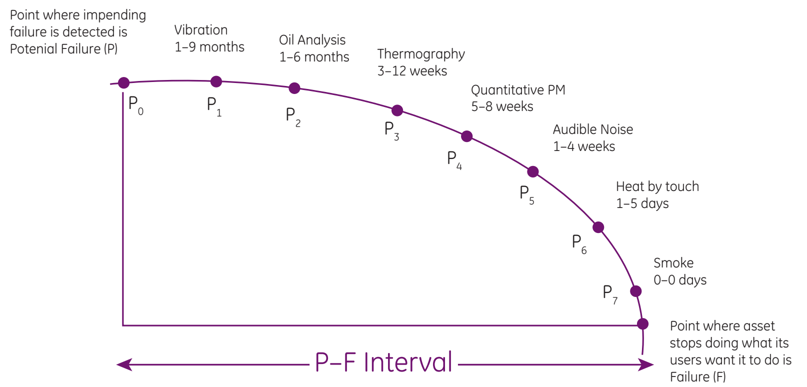


Figure 1: The P-F curve shows qualitative time relationship between potential failure (P) and functional failure (F). The further to the left (closer to P0) one can operate for any given asset, the easier it is to plan maintenance and lower the likelihood of surprise functional failures.

expertise for a particular asset or class of assets and detect asset problems automatically. While many users employ the decision-support module to detect anomalies with the rotating machinery monitored by System 1 software, what has set the Paulsboro facility apart is its use of the system on non-rotating assets, as well. By bringing process data from the plant's distributed control system (DCS), turbine control systems and process historian into the System 1 database, Paulsboro is

Managing too many alarm levels can become onerous, and a balance must be found in the quest to move farther to the left on the P-F curve. One way to achieve this is by relying not only on level-type alarms, but also on technologies that automate the data analysis and anomaly detection processes that human experts would use if manually reviewing data. Paulsboro has used the System 1 software's decision-support capabilities to embed subject-matter

able to apply the decision-support engine in analyzing and detecting anomalies on assets for which only process measurements are available, addressing applications outside of conventional condition monitoring and detecting problems in non-rotating portions of turbomachinery.

To address this mix of conventional rotating machinery, fixed equipment and process-related applications, Paulsboro uses both GE's machinery expertise in the form of preconfigured RulePaks, and their own expertise in the form of custom rules written by the resident subject-matter experts. In this way, Valero has decision-support capabilities tailored specifically to the needs of its Paulsboro operations.

"System 1 not only has predefined rules based upon Bently Nevada's 50 years of machinery diagnostics experience, but also allows us to write our own rules," says Jayesh Patel, reliability engineer at the Paulsboro facility. "These rules are what allow us to automate the diagnostic process. Further, we're able to test our rules on historical data to make sure that they fire when, and only when, we want them to."

For example, the feed filter for the naphtha hydrotreater has a direct effect on product quality and operational problems, and as such it is critical to production. Before implementation of the decision-support system, the filters were replaced every 45 days to 90 days, but more than a third (35%) were replaced under an emergency work order. In the past two years, the filters have been replaced 10 times and not one was under emergency conditions.

Also, after nine months of operation, the recycle gas compressor needed to be shut down for a water wash because of high vibration levels. Rules were developed to give advanced warning to this particular condition. Knowing that the compressor will need a wash allows it to be scheduled on Valero's time, rather than the machine's.

THE RESULTS OF THIS SHIFT TO PROACTIVE MAINTENANCE ARE IMPROVED PRODUCT QUALITY, IMPROVED MACHINERY AVAILABILITY AND INCREASED PROFITS.

The 10 burner cans on the gas turbine provided another opportunity for operating below the alarm level. One of the rules defines the maximum difference between combustion thermocouple readings. After an outage, insulation problems were diagnosed, and information from System 1 provided the confidence to operate the turbine at full load.

With the facility's asphalt heater at the decoking plant, overfiring can lead to loss of creep strength in the tubes, resulting in failure. Clogging also can limit unit performance. Rules compare tube temperature with empirically derived maximum values, and severity levels are assigned based upon temperature limits. Temperatures are compared to average temperatures from the previous week. Increases above certain limits triggers an event for a process engineer to analyze inlet conditions and feed compositions, saving both time and money.

Rupture disks protect pressure relief valves (PRVs) by separating them from corrosive process conditions. When they burst, as they're designed to do, they need to be replaced. A pressure transducer is installed in the spool piece between the rupture disk and the PRV, and when pressure is detected a work order is written to have the rupture disk replaced. Regulatory paperwork also is filled out at this time. Finally, it's important to Valero that the stack emissions analyzer results agree with those obtained when the emissions are analyzed by a lab. System 1 rules are used to make sure these reports are in agreement, thus avoiding penalties. ■

[Editor's Note: For more information, see "Using Decision Support to Reduce OpEx at Valero Paulsboro," ORBIT Volume 29, Number 1, 2009. The article can be downloaded from our online archives at www.ge-mcs.com/en/orbit-magazine.html]

Reliability Process Workshop

Lawrence Covino | Bently Nevada Product Line Manager Strategic Partnerships | GE Energy | lawrence.covino@ge.com

Bently Nevada Field Application Engineers recently practiced presenting the Reliability Process Workshop to a group of employees at the Minden, Nevada facility.

The simulation requires four participants who assume the roles of maintenance, operations, sourcing, and finance managers.

Each round of the simulation represents a single week in the life of your plant where you must decide how many resources to deploy, how to stock your spare parts inventory, whether to push your machines harder or voluntarily take them off line to perform proactive maintenance, and whether you should pursue performance bonuses at the risk of problems later on.

Every week, you document your plant's performance and every five weeks, you roll these results up to headquarters where your performance is compared against other plants.

The Reliability Process Workshop is a tool that our global sales teams can now use to help GE customers better understand the financial benefit of proactively managing the heath of all of their assets and to assist with transitioning your organization along the Value Chain of Reactive to Proactive maintenance.

"Using the principles of reliability centered maintenance in our discovery and problem solving approaches with customers will serve to build on Bently Nevada's long-time reputation of providing industry expertise to our customers via our sales and commercial teams."

—Jerry Pritchard
Global Sales Director, Bently Nevada Asset Condition Monitoring.

"Culture change is often the least planned for but many times the largest hurdle to overcome when an organization takes on a new initiative. Moving from time-based or reactive maintenance to a condition based proactive approach requires our customers to embrace and manage change within their organizations. The Reliability Process Workshop is a tool that our global commercial teams can now use to help the customer through that change so that they can recognize the potential value of a Condition Based Maintenance approach to managing their assets."

—Jeff Schnitzer
General Manager, Bently Nevada Asset Condition Monitoring. ■

FAE Leader Don Silcock provides guidance

Four participants role-play as plant staff

"Finance Manager" calculates profits and losses

For information on participating in a Reliability Process Workshop, contact your local GE Sales representative.

In Memoriam

Koh Se Young
Country Executive
GE Energy Korea
1957–2010

It is with profound sadness that we announce Se Koh's passing on Friday, Dec. 3, 2010 in Seoul, Korea. He was the Country Executive for South Korea and was one of our newest CX's joining the Asia Pacific team in April of 2010.

Se Koh was born in Gimjae City, South Korea in August, 1957. He attended primary and secondary school in Seoul. He moved to the US where he studied engineering, completing a Bachelor's degree in mechanical engineering from the University of Massachusetts, Lowell and a Master's degree in mechanical engineering from the University of California, Berkeley. In 1985, Se was married to Yanghee Woo and together they have enjoyed three children, Catherine, Allen, and Carolyn.

Se first joined GE in 1983 as an engineer through Edison Engineering Development Program at GE's Nuclear Energy business located in San Jose, CA. Se then moved to Bently Nevada Corporation and relocated to Seoul, Korea in 1989. There, he established Bently Nevada Korea Co., where he served as managing director. He was later appointed as a general manager of Bently Nevada Asia Pacific Region operation.

Se came back to work for GE with GE's acquisition of Bently Nevada in 2002. He then relocated to Singapore and served as Asia Pacific region sales & operations director for the Optimization and Control business until his recent appointment as the Korea Country Executive in Seoul.

Se enjoyed many activities, but was especially an avid enthusiast of tennis, skiing and of course, golfing. Many of our fondest memories of Se are together with him while playing his favorite sport, golf. Our heartfelt condolences, thoughts and prayers go out to Se's family as they mourn his loss. In remembrance, a sampling below of a few of our GE leaders whom have expressed their personal notes to Se, our dear colleague.

—Kenji Uenishi
Region Executive, GE Energy, Asia Pacific

The news of Se's passing was very tough and sad for all of us to hear in the GE leadership team. He was an excellent man.

— John Krenicki
GE Vice Chairman, President and CEO, GE Energy

Se was really the heart of OC in Asia; he started Bently Nevada Korea and built it into the strongest, most customer facing business units we have around the world today, hired and mentored the future leadership of our business...But more than all that, Se was a very good friend to many of us around the world, someone whose legacy will live on with the team he built, and the family he raised...We will all miss him dearly.

— Brian Palmer
CEO, Measurement & Control Solutions

Se was the consummate professional who always wanted to excel. His passion, dedication and loyalty made a big positive impact all on those who worked with him. He will be missed.

— Magued Eldaief
Executive Director, Energy Accounts

Se was a great role model for GE leaders in terms of showing dedicated and passionate style, who always try to share his knowledge and be proactive and put all of his efforts for growth until the end. His short life is a big loss for GE.

— Soo Hwang
National Executive, Korea

I have worked with Se for a number of years and we became close friends. He was a great business partner and we worked together very well and I have enjoyed his clear-thinking, passion and guidance. He has my utmost respect and I have learned a lot from him. More than just work, we have also enjoyed playing golf together for many years. We will miss him. Se has left a legacy...Bently business in Korea and Asia would not be where it is today without him. He has left a deep positive impact to a lot of us and we are all grateful for his time and passion. I think he has lived his life well and will be fondly remembered by everyone that he has touched.

— Loh Ming Kit
Asia/China RGM, Measurement & Control Solutions

Se was a great businessman and mentor to a lot of people. He was instrumental in building a lot of the current Bently business we have today in Asia and certainly has influenced a lot of the other regions with his many best practices that he has shared. He set the benchmark on how to work with many different cultures to get them to deliver excellent results.

He was a personal friend to me and I learned a lot from his wisdom and experiences. The world has suffered a great loss and I will truly miss him.

— Jeff Schnitzer
General Manager, Bently Nevada Asset Condition Monitoring

Se Koh was a man of integrity. His word was his commitment. Se established the global footprint enjoyed by Bently Nevada (and other GE businesses) in Korea and the rest of Asia today. His visionary leadership will be missed across the entire organization.

— Jerry Pritchard
Bently Nevada Sales Leader

Condition Monitoring Partnership

GE has entered into an agreement with Artesis Teknologi Sistemleri, a predictive maintenance technology manufacturer headquartered in Istanbul, Turkey. Under this agreement, GE has acquired an equity share of the company, and Artesis® will manufacture a range of GE's intelligent condition monitoring products designed to detect anomalies on motors and generators of various sizes and loads.

Artesis will produce a new motor and generator anomaly detection solution from GE's Bently Nevada product line known as AnomAlert*. GE is committed to developing cleaner, smarter, more-efficient solutions to meet today's energy challenges, and the investment in Artesis will enable GE to serve customers more effectively with a growing family of innovative solutions.

"Our agreement with GE is further evidence of the recognition of the contribution of our technology for improving the productivity and energy efficiency of industrial facilities. We are now in a better position to serve our customers all over the world," said Ahmet Duyar, founder and CEO of Artesis.

AnomAlert products are used for monitoring and anomaly detection across multiple industries including the oil and gas, chemical and petrochemical, power generation metal processing, pulp and paper, water, cement, food and beverage, automotive, textile and maritime sectors.

For more information visit us online: http://www.ge-mcs.com/en/bently-nevada.html

AnomAlert Motor Anomaly Detector

About Artesis Technology Systems

Artesis, founded in 1999, is an innovative company, which advanced predictive maintenance technology by developing a model-based condition monitoring approach. Artesis products are used for condition monitoring of electric motors, motor driven machinery and generators. Artesis technology is commercially available through licensable applications, OEM sales and industrial products.

Artesis products received the Editor's Choice Award, 40 Best Products of 2000, *Control Engineering USA* and "Technology Innovation Award 2007" for simplifying predictive maintenance, The Institution of Engineering, United Kingdom. www.artesis.com. ■

[Reference: Press Release – GE Expands European Presence with Artesis Teknoloji Sistemleri Agreement. ISTANBUL, TURKEY—September 29, 2010]

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

TRUE
Condition Monitoring

Alan Thomson | Product Line Manager | alan.thomson@ge.com

There are over 8,000 System 1 Machinery Condition Monitoring enterprises in operation around the world today. Over the years, we have observed customers using the data and information available to proactively identify a developing problem, manage a machine through to an outage or to get to root cause of a fault. While it is comforting to know that significant problems can be detected and diagnosed, for every "true" alarm there are many more regarded as "false positive."

A "false positive" or "false alarm" is an alarm that causes work that is unnecessary. Example: an alarm that occurs during a transient state of operation, i.e., a vibration level that exceeds the operating load alert setpoint, but is due to the machine temporarily going through a critical speed. These types of alarms can be a nuisance as they create unnecessary work in acknowledging and clearing them.

A "false negative" alarm is the case where a significant event took place and there was no alarm indication of the event. For example, the house burned down and the smoke detector did not alarm.

In System 1 we have added functionality to improve alarm integrity towards "true positive" alarms. The "State Based" alarming function allows the user to qualify alarms based on being in a specific state. For example, start-up, shutdown, operational load change or temporary condition, like a turbine wash cycle. In addition to this, a collaborative environment, with data from several independent sources, can be correlated, and combined to enhance alarm integrity.

There are many System 1 case studies that show many rotor dynamic or vibration alarms correlate strongly with other independent measurements or calculations. Process data from a DCS or historian can usually be found to correlate well with rotor dynamics. Thermodynamic performance and rotor dynamics have also revealed strong correlations. In all cases a simple application of a "set of rules" using the Decision Support editor in System 1 could greatly enhance the integrity and produce truly positive alarms.

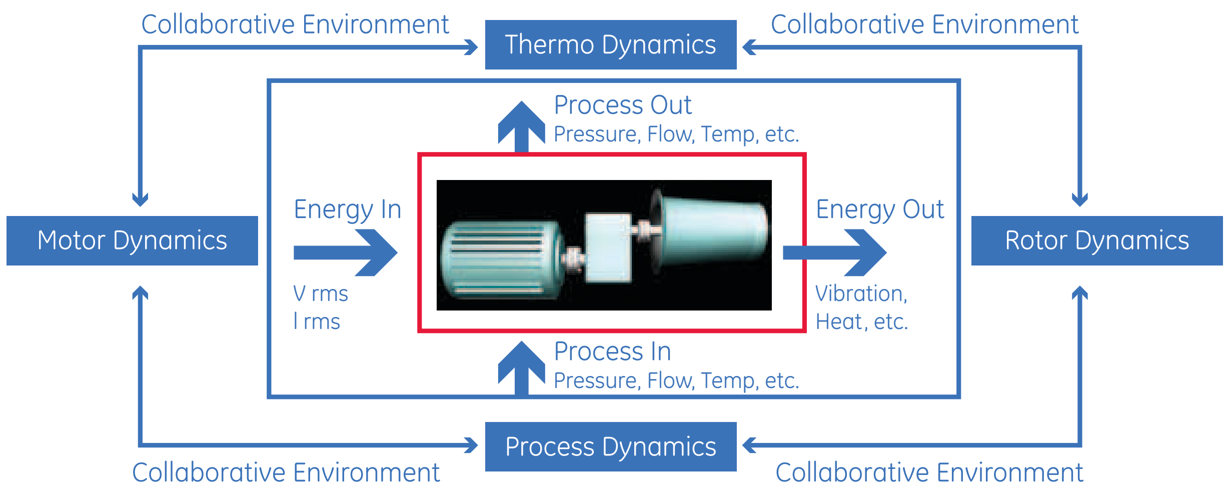
With the addition of AnomAlert to our condition monitoring portfolio we have introduced a further capability where electrical and mechanical anomalies can be detected using the AC motor as a "sensor". Again, strong correlation with vibration has been confirmed, further strengthening the alarm integrity for AC motor driven machinery.

As an example, during a series of mechanical and electrical fault tests, AnomAlert Motor Anomaly Detector was compared with ADRE (rotor dynamics) technology to study the correlation between faults known to produce vibration changes and the identification of the same fault using the motor as a sensor.

Collaborative Environment

As we continue to observe System 1 users manage their plant equipment, it becomes obvious that correlation, state based analysis, and anomaly detection systems can play a valuable collaborative role to produce "true condition monitoring" that matches the plant operator's alarm management philosophy.

Watch for our next Orbit issue where we will introduce GE's SmartSignal technology and show how it fits into a collaborative software environment, complementing System 1 Plant Asset Management. ■



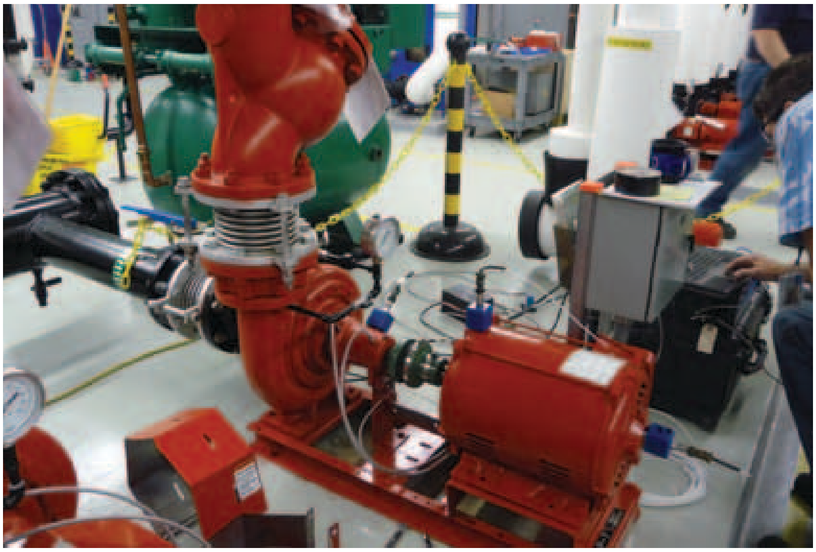


Figure 1: This photo shows the motor-driven centrifugal pump that was the subject of this investigation. [Pump 7, Condenser Water Pump]

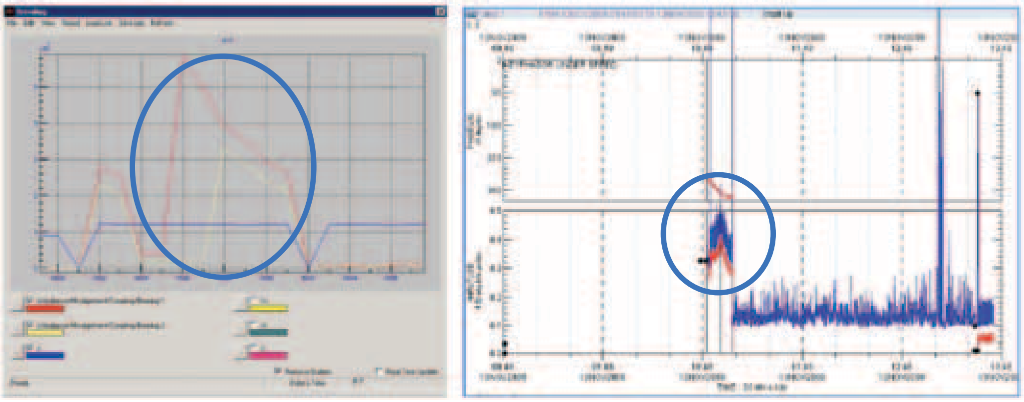


Figure 2: AnomAlert and ADRE trend plots both showed indications of misalignment.

Integrating Condition Monitoring Technologies

Drew D. Troyer, CRE, CMRP
President, Sigma Reliability Solutions | drew.troyer@sigma-reliability.com | www.sigma-reliability.com

Which Condition Monitoring (CM) technology creates more value for the organization – vibration analysis or oil analysis? The answer is, without question – BOTH! In the plant, I believe in the "Five Rights of Proactive Machine Reliability Management" – in no particular order of importance:

RIGHT ALIGNMENT

Angular or offset misalignment produces stress concentration, which leads to wear, fatigue and yield deformation.

RIGHT BALANCE

Dynamic force imbalance produces stress concentration, which leads to wear, fatigue and yield deformation.

RIGHT LUBRICATION

Wrong type, wrong amount, degraded or contaminated lubricant leads to mechanical and corrosive wear.

RIGHT FASTENING

Looseness produces stress concentration, which leads to wear, fatigue and yield deformation.

RIGHT OPERATION

Operating machines incorrectly leads to wear and failure and can be a danger to the operator and others.

How could we conceivably manage these "Rights" of machine reliability without an integrated approach to machine condition monitoring? Vibration is the lead technology for alignment, balance and fastening, while oil analysis is essential for lubrication.

Proactive control of reliability should be the major focus of our condition monitoring process, but we also need to effectively detect and diagnose problems when proactive control isn't enough. Again, we require an integrated approach – for several reasons.

Oil analysis tends to take the lead in detecting problems with hydraulics and reciprocating equipment, such as engines. Vibration analysis tends to take the lead with pumps, motors and other rotating equipment with rolling element bearings. They are about even when it comes to gears and equipment with plain bearing systems, such turbo-machinery. The truth is, most plants have a combination of these equipment types and, as such, a combined approach is required.

In a study of 750 failures at a large power generation facility, engineers found that oil analysis provided the earliest indication in about one third of the failure events, vibration analysis lead the way in another third of the events, and both technologies provided simultaneous warning in the last third.

Why is it important to get the earliest warning possible? In addition to proactive management of machine health, we monitor the condition of our machines to detect impending problems before they affect the machine's function, so we can avoid equipment downtime, minimize collateral damage and support effective planning and scheduling of maintenance. In some instances, we can detect problems early enough to identify and eliminate the forcing function, avoiding failure altogether. In other instances, we must detect problems early enough to accomplish the following maintenance planning and scheduling goals:

- Schedule repair during a normal production outage, avoiding downtime.
- Arrange for the delivery of required parts that aren't kept on hand.
- Gain access to special tools required to complete the job.
- Organize for special skills or labor to complete the job.
- Assemble work plans and instructions.

By planning ahead, we reduce the failure's impact on the organization and increase the efficiency with which we carry out maintenance. To plan effectively, we must diagnose problems effectively. Diagnostically, vibration analysis is excellent at localizing machine faults and the amplitude and nature of the vibration signal provides information about the failure and its severity. The shape, size and concentration of wear particles in the oil is a tell-tale of the wear mechanism, its root cause and the severity of the event.

For most problems, we benefit from having oil analysis and vibration analysis data combined to answer the following questions about the failure event - what, where, why and how bad is it? Isn't that the essence of why we monitor the condition of our machines in the first place? Additionally, we always proceed with a greater degree of confidence when two (or more) CM technologies reveal the same problem, which was the case in a third of the 750 failures that were evaluated in the study mentioned earlier.

Integrated Condition Monitoring Examples			
Root Cause Condition	Failure Mechanism	Incipient Fault Indicators	Advanced Fault Indicators
Lube oil oxidation in a rolling element bearing application	Degradation of the lubricating oil film leads to increased contact fatigue wear of the rolling elements and raceways and corrosion and cutting wear of the brass bearing cage.	• Early indicators of oxidation • Increased concentration of iron and copper particulate • Increased amplitude of high -frequency vibration due to the loss of the lubricant film	• Advanced stage indicators of oxidation • Increasing oil viscosity • Oil becoming dark and pungent smelling • Increased concentration of wear particles • Increased size of wear particles • Increased amplitude of vibration in the bearing fault frequencies • Sensory indicators in latest stages of failure
Misalignment in a rolling element bearing application	Misalignment produces increased stress concentration, leading to wear, degradation and seizure.	• Increased amplitude of vibration at one times the running speed. • Increased concentration of iron particulate.	• Increasing amplitude of vibration at bearing fault frequencies, indicating the nature of the bearing failure • Increasing size and concentration of iron particles • Increased production of copper particles • Thermal degradation of the oil • Sensory indicators in the latest stages of failure.

Figure 1: This table illustrates the power of integrated condition monitoring to better control and respond to the root causes of machine failure.

Organizing for Integrated Condition Monitoring

Unfortunately, vibration analysis and oil analysis are typically carried out by different groups within the organization. Vibration analysis activities typically reside in the condition monitoring or vibration monitoring group, while oil analysis usually resides with the lubrication team. Making matters worse, the oil analysis program usually consists of submitting occasional samples to a laboratory in exchange for results that frequently look more like chemistry than machine condition monitoring. And, too often, oil analysis is used to schedule oil changes while equipment condition assessments are left primarily to vibration analysis. As the engineers in the study discovered, integrating oil analysis and vibration analysis into a common organization produced cross-pollination in the troubleshooting process, creating a synergistic effect – oil analysis was strengthened by vibration analysis and vice versa. We can take additional steps to strengthen the organization bond between these two natural allies.

First, we can cross-train our technicians. It's common for oil analysts and vibration analysts to specialize in their respective technologies. In order to communicate effectively to solve machinery condition problems, oil analysts must understand vibration analysis and vibration analysts must understand oil analysis. So, our oil analysts should be trained and certified, at least to Level I, in vibration analysis and our vibration analysts must be trained and Level I certified in oil analysis.

Further, we need to combine the data into a common platform. By pulling the machine condition data together into a System 1 platform, the analysts are working from the same basis and the combined information is available for cross-technology trending and analysis. For instance, we may want to correlate the increase in wear particle concentration of iron in parts per million to the amplitude of vibration at a particular frequency in mm/s as a function of time. Combining information into a common platform enables this higher level analysis.

Integrating our condition monitoring data onto a common platform greatly improves our diagnostic power. However, there may be an even more important benefit to this process. Integrating condition monitoring data onto a common platform also breaks down the traditional organizational barriers that have kept us focused on our respective technologies.

Having trained thousands of condition monitoring technicians I can say without hesitation that – while they are in the classroom – vibration analysis technicians see the value of oil analysis and vice versa. However, back in the plant, it's too easy to fall back into our routine of focusing on our respective technologies – rendering the cross training to a quickly forgotten intellectual exercise. To make beautiful music, we need to get the entire choir singing from the same page in the song book – that's how organizations work.

For condition monitoring, System 1 software is our song book. Sharing this common platform facilitates a team approach to problem solving. Yes, we may each continue to specialize in our respective technologies, but we "act locally, while thinking globally." It makes a big difference.

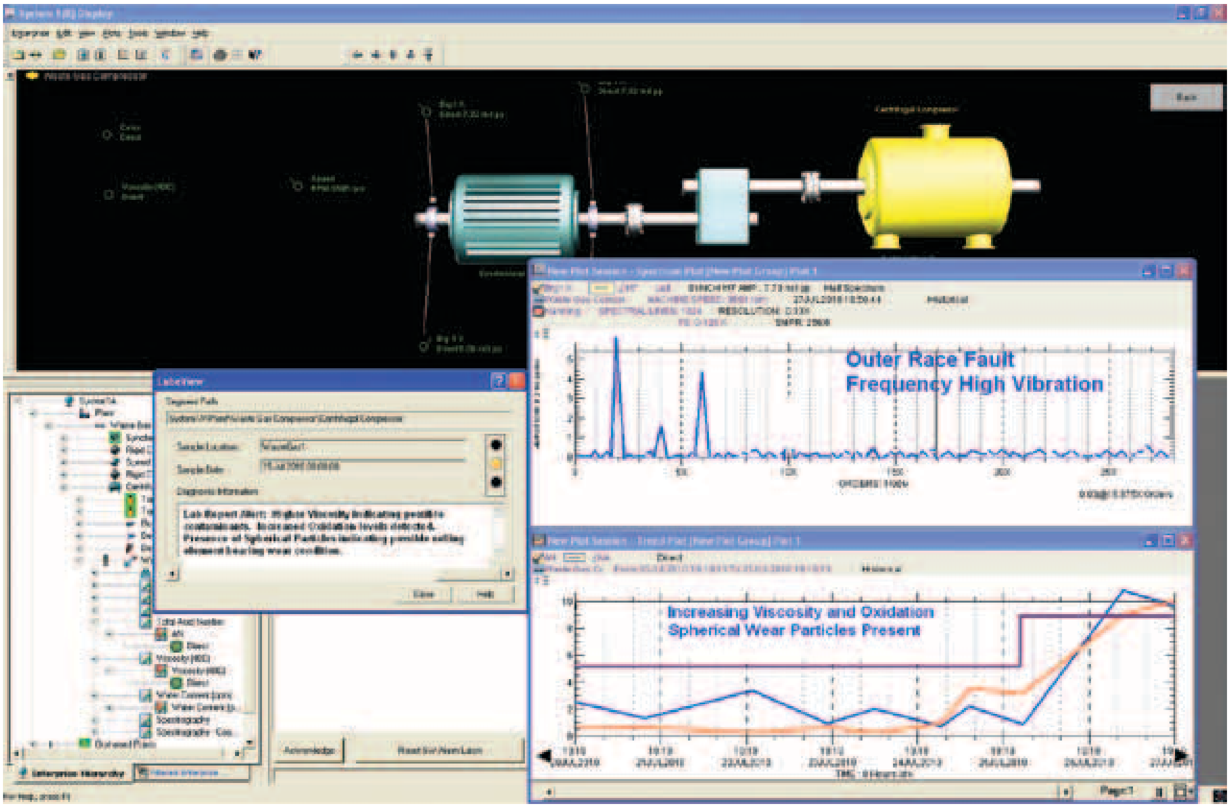


Figure 2: System 1 software allows us to view and correlate condition monitoring data from various sources in a single tool. Using a single software package improves diagnostic power and breaks down organizational barriers. Our example plot shows an increase in Rolling Element Bearing Outer Race Fault Frequency vibration, coupled with an increase in Lubrication Viscosity, Oxidation and the presence of newly detected Spherical Wear Particles. This correlated information increases our certainty that the monitored bearing is degrading.

Conclusion

Oil analysis and vibration analysis are natural allies in achieving machine reliability. They offer complementary strengths in controlling the root causes of machine failure and in identifying and understanding the nature of abnormal conditions. Success depends on making changes in the organization to foster the development of condition monitoring and machine diagnostic generalists in lieu of technology specialists.

A carpenter goes to the site with all the tools necessary to complete the job. While it may be possible to cut a board with the claw of a hammer, the carpenter is more likely to draw his saw, which is a more effective tool for the task. We in condition monitoring must view technologies as enabling tools. Just like the carpenter, we also need the right tools in our bag to complete the job of ensuring machine reliability.

LNG Carrier Seawater Pump Condition Monitoring

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Artesis has recently completed a successful installation trial of its Motor Condition Monitor (MCM®/ AnomAlert* Motor Anomaly Detector[1] technology for the global shipping organization of an important GE customer – one of the world's largest energy companies. The goal of this installation was to validate the effectiveness of the Artesis condition monitoring technology in a variety of applications. This case history describes the results of AnomAlert units that were fitted to two seawater pumps aboard a Liquefied Natural Gas (LNG) carrier.

The shipping organization has more than 50 ships in its worldwide fleet, and is already very much aware of the benefits of Condition Monitoring (CM) – running a successful global initiative to adopt CM technologies and programs throughout the fleet. AnomAlert provides the opportunity to monitor equipment that is currently outside of the existing CM program, where the equipment may be inaccessible or in a location that is hazardous to personnel.

For its wide range of ships – including crude and product carriers, shuttle tankers, Liquefied Petroleum Gas (LPG), LNG and hydrocarbon carriers, lubricant oil barges and offshore support vessels – the shipping organization applies an assortment of tools for identifying, prioritizing, benchmarking, quantifying, mapping and controlling risks – which include the risk of asset failure and costly downtime.

[1]Motor Condition Monitor (MCM) and AnomAlert are both names for the same monitor. For simplicity, we will use the term "AnomAlert" throughout this article.

The Project

The Engineering Superintendent for the shipping organization was first introduced to Artesis through an internal recommendation. Then, following his subsequent reading of articles in the engineering press and meeting the team at an industry event, he became interested in exploring the capabilities of the AnomAlert system for himself.

…OVER THE NEXT FEW MONTHS THE ARTESIS TEAM PROVIDED EXCELLENT SUPPORT, PARTICULARLY DURING THE COMMISSIONING PHASE WHERE VARIOUS SOFTWARE COMMUNICATION ISSUES WERE ENCOUNTERED.

"As with all new technology in the marketplace, there is a degree of skepticism when embarking on an initial R&D and trial period," he said. "To prove a useful and worthwhile tool we needed to determine whether the AnomAlert unit could accurately detect a fault prior to catastrophic failure and ultimately, provide us with a non-intrusive monitoring process with cost saving benefits."

"Having met with Artesis, it was agreed that our validation trial would run up to the point where a specific failure was predicted and maintenance recommended, so that the prediction could be compared with the subsequent maintenance report. The units were then installed by the ship power specialist," he continued. "Over the next few months the Artesis team provided excellent support, particularly during the commissioning phase where various software communication issues were encountered."

The two motor-driven seawater pumps that were selected for monitoring are vertical, double-suction centrifugal pumps in the Main Cooling system (Figure 1).

Machine Condition Assessment

Artesis carried out initial assessments with early reports indicating that both monitored seawater pumps were experiencing rubs, misalignment, a vane pass anomaly, and a reduction in pumping efficiency that suggested that early misalignment had contributed to impeller damage. Successive reports increased the indications of progressive erosion or corrosion of the pump internals, with a gradual decrease in power consumption as the pump was able to do less useful work. The monitoring specialists predicted that pump performance would continue to decrease as erosion advanced. This analysis process also allowed the team to use power factor and electrical load (kW) as a simple indicator of the pumping performance and the condition of the parts that are susceptible to erosion.

The initial information presented by the software is in the form of "traffic lights" (red, yellow and green colors) in a diagnostic window (Figure 2). Red lights indicate a problem that needs attention, and simple guidance is provided on the urgency associated with the problem, and the work that is required to address it.

Additional information on these problems is available through trend curves that show how monitored parameters have changed over time (Figure 3).

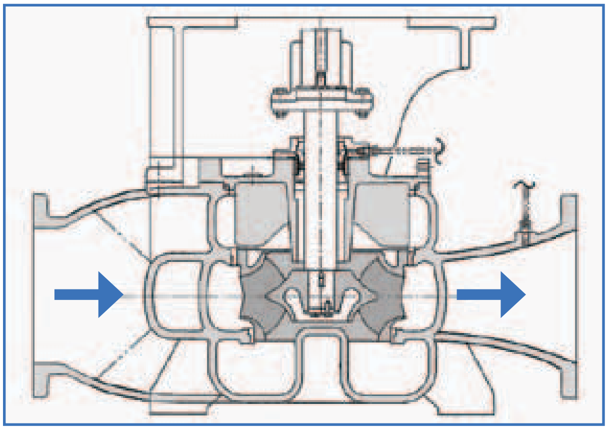

Figure 1: Cross-sectional view of seawater pump, showing the shrouded double-suction, six-vane impeller. The directly-coupled drive motor is not shown in this drawing.

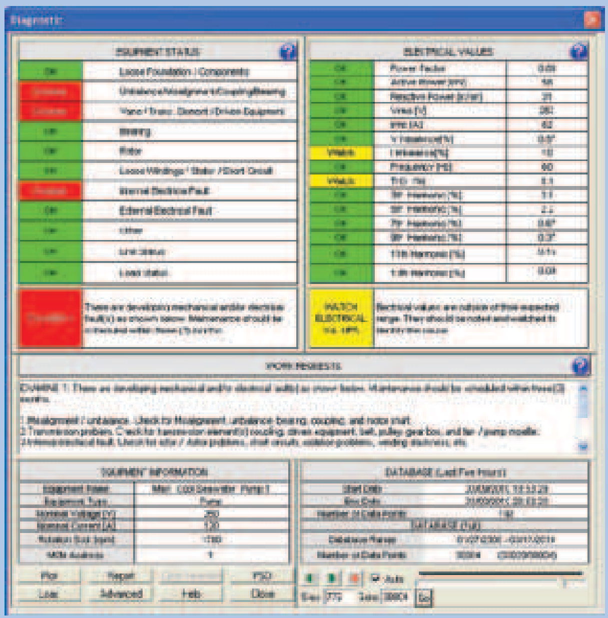

Figure 2: This diagnostic window shows the situation that existed about 6 months into the monitoring process, with level 1 alarms for Misalignment and Rotor Problems, as well as internal and external electrical faults that may be indicating stator deterioration as a result of misalignment. Current imbalance alarms have shown that this has increased to more than 10%, tending to confirm stator damage.

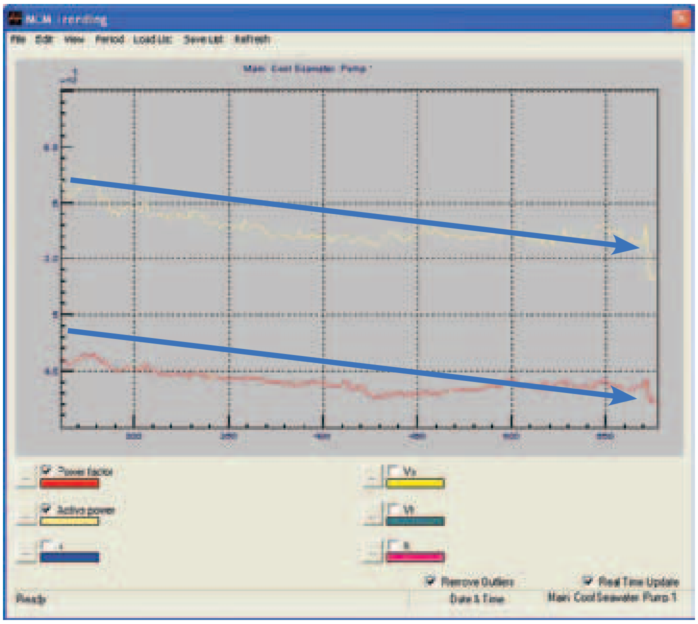

Figure 3: Trend plot showing a gradual progressive decrease in both active power and power factor parameters for Main Cooling Seawater Pump Number 1.

Figure 4: Pump internals after removal for inspection. Observe the significant loss of metal from the tips of the casing flow vanes (fins). Approximately 19 mm of metal was lost in two places. Fin thickness was also reduced from the original dimension of 7 mm to 4.5 mm. It turned out that the Vane Pass anomaly was produced by this damage, rather than by deterioration of the impeller.

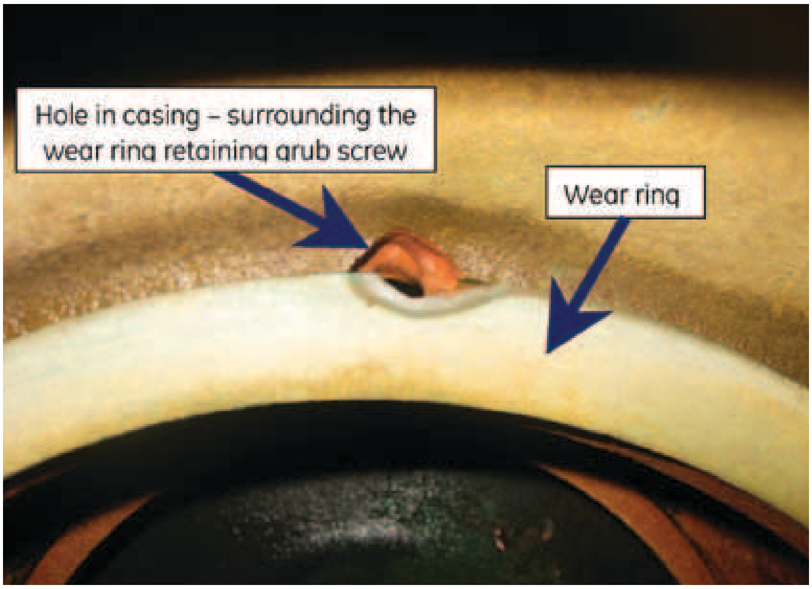

Figure 5: Upon disassembly, it was discovered that erosion had produced a hole in the pump casing, at the point where a wear ring retaining screw caused a localized flow disturbance.

Trend curves can be displayed for all the measured and derived parameters. In most cases, the trend curves are automatically labeled with the parameter causing them. However, in some cases, an unusual problem may not be automatically classified by the equipment, and requires expert interpretation. The expert can analyze the power spectral density (PSD) curve and other parameters – that are beyond the scope of this article – to identify the nature of the underlying problem. In this case it was possible to identify that there was an anomaly corresponding to the vane pass frequency, confirming the diagnosis that something inside the pump was interfering with the normal smooth flow of water.

Interestingly, as time progressed, the power continued to decrease, but some of the indications of rubs and motor stator issues decreased, consistent with internal misalignment loads decreasing as internal wear took place inside the pump. This was followed by a decrease in the intensity of the vane pass frequency signals, indicating a loss of effectiveness of the impeller suggesting it been strongly impacted by erosion or other damage.

Inspection Results

Once the power factor fell below a pre-determined threshold, maintenance was scheduled to disassemble the motor and pump to compare the as-found conditions with the assessments provided by the AnomAlert unit. When the upper casing cover was removed, it was very apparent that the flow vanes (fins) had suffered significant metal loss due to erosion (Figure 4). The impeller had light fouling, and the wear rings had eroded, causing a reduction in performance by allowing recirculation flow. A small hole had also eroded in the pump casing where a flow disturbance was produced by a wear ring retaining screw (Figure 5).

Pump Repairs

- The impeller was in good condition, so it was simply cleaned and reused (Figures 6 & 7).
- The eroded wear rings were replaced, restoring normal clearances and pump efficiency.
- The hole in the pump casing was repaired using cold resin techniques, preventing further deterioration of the casing at that location.
- Although the casing fins were heavily eroded, they were not significantly impacting performance, so the casing cover was reused without repairing the fins.
- Cost of repairs was approximately 10% of the "normal" cost of pump replacement associated with the previous Run-To-Failure (RTF) regime.

Figure 6: Impeller after cleaning. Axial view into one of the impeller eyes (suction).

Figure 7: Impeller after cleaning. Radial view of the impeller vane tips (discharge).

Summary

Delivering a succinct and informative maintenance report at the end of the trial, Artesis stated that there were signs of wear ring damage and a loss of performance consistent with a hole in the pump casing (Figure 8). The subsequent replacement of wear rings and repair of the casing hole helped return the efficiency of the pump to normal. It was also reported that fixing the hole in the casing where the retaining grub screw for the wear ring is located saved the pump casing from further deterioration. Although the pump casing fins suffered a heavy loss of material during the trial, and it was advised that these should be repaired, this was not essential for pump operation. No damage was recorded to either the rotor or stator of the drive motor and none was suggested from the trial data

At the successful completion of the trial, the Engineering Superintendent concluded: "The online system monitoring was the most beneficial part of the trial process. Using a simple traffic light system to identify that a fault exists, when and where appropriate, allowed for intrusive investigations and repair before failure. This remote on-line indication has enabled a reduction in maintenance man-hours and downtime. The AnomAlert units have the potential to save on spares and we are continuing to evaluate the functionality of Artesis in various applications within our fleet."

The application of AnomAlert technology facilitated the implementation of a proactive approach to pump maintenance, which resulted in a 90% cost saving over the older method of replacing the entire pump after it failed. ■

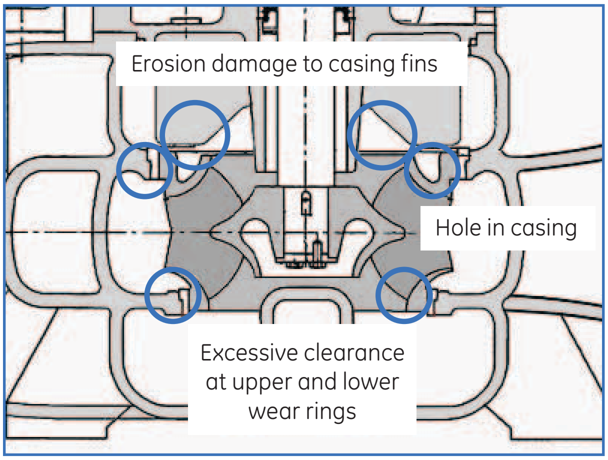

Figure 8: Identified sites of pump condition degradation.

Online Condition Monitoring Reaps Benefits for Borealis Porvoo

Bengt Bergman | Inspection Technician | Borealis Polymers Oy
Petri Nohynek | Sales Application Engineer – Bently Nevada* Asset Condition Monitoring | GE Energy

Figure 1: Overhead view of seawater pump, one of four used in Borealis' ethylene plant

Introduction

This article describes the condition monitoring (CM) approach employed by the Borealis Porvoo petrochemical complex in Finland. Central to their approach is the use of the complex's Metso Distributed Control System (DCS) and ABB® process historian (PMS), as the environment from which all online condition data from various assets is viewed as well.

All of the assets in the complex are included in a condition monitoring program utilizing a route-based portable data collector (PDC). Data is collected at monthly intervals, including not just overall static measurements but also dynamic data (i.e. waveform and spectrum).

The most critical assets in the complex are addressed with machinery protection systems that continuously sample and process vibration and other machine measurements. The parameters measured by these systems are connected to the DCS for easy viewing by operators as well as trending in PMS. As with other assets, monthly PDC routes are performed on these machines for condition monitoring purposes.

The complex also contains certain so-called "essential" assets that do not necessarily require continuous machinery protection, but do require more frequent data than is available via a strictly manual data collection regime. These assets, like all others, are addressed by monthly rounds with a portable data collection instrument, but are augmented by an innovative that will be described below. As with the machinery protection systems deployed on the complex's critical assets, the online system for addressing "essential" assets provides relevant condition data directly to the DCS.

By using special-purpose online condition monitoring hardware to sample and process the necessary vibration and condition data, more information is available than when treating vibration as just another process point such as via 4-20 mA vibration transmitters. This provides operators with a routine data set sent to their DCS and PMS screens that is much richer than just overall vibration amplitudes, allowing more timely and informed intervention when asset problems occur. This richer data set is available from the systems used to monitor Borealis' critical assets as well as their "essential" assets. When in-depth diagnostics are required, the plant's portable data collection instrument can be used to capture additional dynamic data, while the online system provides a steady stream of rich static data that indicates developing problems between manual data collection intervals. As mentioned, an important component of Borealis' strategy is that rather than using separate condition monitoring software for their online systems, they transmit the condition data from these systems to their DCS, allowing operators are able to see both asset condition information and process information within a single HMI (Human Machine Interface) environment. This eliminates the need for operators to learn an entirely different system and ensures that condition data and process data are available simultaneously on the process control system – the preferred environment for operators and the environment with which they are most familiar. This, in turn, helps ensure that asset conditions receive as much attention as process conditions.

About Borealis Porvoo

Borealis in Finland is a fully integrated petrochemical complex employing 850 people. It is comprised of five separate plants as summarized in Table 1:

Product	Number of Plants	Sub-products	Capacity (KT/year)
Olefins	1	Ethylene	390
		Propylene	220
		Butadiene	25
Phenol and Aromatics	1	Phenol	185
		Acetone	
		Benzene	
		Cumene	
Polyethylene (PE)	2		390
Polypropylene (PP)	1		220

Table 1: Overview of Plants, Products, and Capacities for Borealis Porvoo

Feedstock for the PE and PP plants is produced by the olefins cracker, which started-up in 1971. The cracker derives its feedstock from the nearby Neste Oil refinery. In operating the plants, economy and efficiency come through the centralized purchase of steam, electricity, and other infrastructure services from within the Porvoo industrial area.

Identifying a Need for Periodic Online Condition Monitoring

As discussed in the introduction to this article, the condition monitoring approach throughout Borealis has been built around the use of the DCS and PMS as the primary portal for online data, augmented by monthly and as-needed data from their portable data collector (PDC) regime. The so-called "critical" assets (such as turbomachinery and screw compressors) are addressed with GE's Bently Nevada 3500 Series continuous machinery protection systems, connected to the DCS and PMS.

All machines, whether critical or not, are also included in the PDC collection route, allowing periodic samples of dynamic (waveform) data with a collection interval of roughly once per month.

A third category beyond just "critical" and "non-critical" was identified by Borealis' in the Summer of 2008 when they upgraded four seawater pumps and recognized that PDC routes alone were inadequate. Online monitoring would be required, particularly during startups, and would need to provide special signal processing functionality, such as acceleration enveloping, normally associated with the monitoring of rolling element bearings.

Borealis consequently identified the following requirements for an online system for these newly identified "essential" assets (i.e, their four seawater pumps – see Figure 1) that were somewhere in the middle of continuum between critical and non-critical assets:

- The pump trains consist of an electric motor, a gearbox, and the driven machine (seawater pump), all using rolling element bearings. The online system must be capable of detecting fault development in these machines at an early stage.
- Each machine uses different bearings and runs at different rotational speeds due to the intermediate gearbox. Thus, it must be possible for the signal conditioning (such as filtering) for each measurement point and its derived parameters to be set independently of any others. In other words, a "shared" filtering and signal-processing scheme whereby all channels used the same settings would not meet their requirements.
- The online system must allow a direct interface to the DCS.
- The online system must use the DCS as the primary display environment rather than requiring separate, special-purpose condition monitoring software.
- The online system must provide buffered outputs, allowing a route-based PDC to be easily. connected for collection of dynamic signals as needed and during monthly routine routes.
- The online system should provide at least one direct amplitude value from each pump to track condition in real time during startups.
- Direct overall amplitude alone is insufficient for condition monitoring purposes – the online system must therefore be able to provide a richer data set than just overall amplitude, without the need to rely on the PDC.

Borealis approached GE's Bently Nevada team with these requirements and after careful review of the requirements, the following solution was proposed:

- Each pump would be monitored via eight (8) accelerometers: 2 on each motor, 4 on each gearbox and 2 on each pump
- One accelerometer from each pump would be connected to a Bently Nevada 1900/65A monitoring system (Figure 2), a multi-channel stand-alone system capable of accepting up to 4 vibration inputs and 4 temperature inputs. Signal processing can be applied to each vibration input, allowing a single input to generate up to four different measured parameters

Figure 2: A Bently Nevada 1900/65A Monitor.

Figure 3: A Bently Nevada Trendmaster Dynamic Scanning Module (DSM).

such as direct amplitude, enveloped acceleration, integrated acceleration (i.e., velocity), and others. Because the 1900/65A is a continuous monitoring system, at least one channel on each pump train is continuously monitored and trended, allowing real time data display during pump startups.

- The 1900/65A would be connected to the Metso DCS via Modbus® protocol.
- The other 7 accelerometers from each pump train would be routed to a junction box that splits the signals between a Bently Nevada "scanning" (rather than continuous) online system and a buffered output connector. A selector switch would allow the user to route the desired signal to the buffered output connector for connection to a PDC, but would not affect whether the signal was routed to the "scanning" system.
- The "scanning" system would employ the Bently Nevada Trendmaster* Dynamic Scanning Module (DSM). A DSM (Figure 3) can accept several thousand sensor inputs (vibration, temperature, pressure, etc. and sequentially scan each of its sensor inputs in a polling fashion. It is a cost-effective approach for online monitoring points that do not require continuous machinery protection.
- The DSM would communicate its intermittently measured values to the Metso DCS via Modbus protocol.
- The ABB PMS would thus provide a unified display environment for the online data from the 3500 series continuous monitoring systems, the 1900/65A systems for one accelerometer on each seawater pump, and the DSM hardware for the intermittently sampled data from the other 7 accelerometers on each seawater pump.

From 1900/65A:	From DSM:
Direct amplitude (RMS) Units: RMS velocity (mm/s) Purpose: general machine condition **Enveloped amplitude** Units: peak acceleration (m/s^2) Purpose: bearing condition **High-frequency acceleration** Units: peak acceleration (m/s^2) Purpose: gear teeth condition	**Direct amplitude (RMS)** Units: RMS velocity (mm/s) | Purpose: general machine condition **Direct amplitude (0-pk)** Units: Velocity (mm/s) | Purpose: general machine condition **Enveloped amplitude (RMS)** Units: RMS acceleration (m/s^2) | Purpose: bearing condition **Enveloped amplitude (0-pk)** Units: peak acceleration (m/s^2) | Purpose: bearing condition **High-frequency acceleration** Units: peak acceleration (m/s^2) | Purpose: gear teeth condition **Filtered Velocity – Rotor Region** Units: Peak velocity (mm/s) | Purpose: unbalance, misalignment, looseness, and other malfunctions that occur predominantly near the machine's rotative speed (1X) **Filtered Velocity – Prime Spike** Units: Peak velocity (mm/s) | Purpose: well-developed bearing problems that occur at frequencies well above shaft rotative speed (1X)

Table 2: Summary of static data values supplied from online condition monitoring hardware to DCS.

Figure 4: PMS screen showing trends of gearbox high-speed shaft upper and lower bearing vibration, filtered to various frequencies and with various signal conditioning applied.

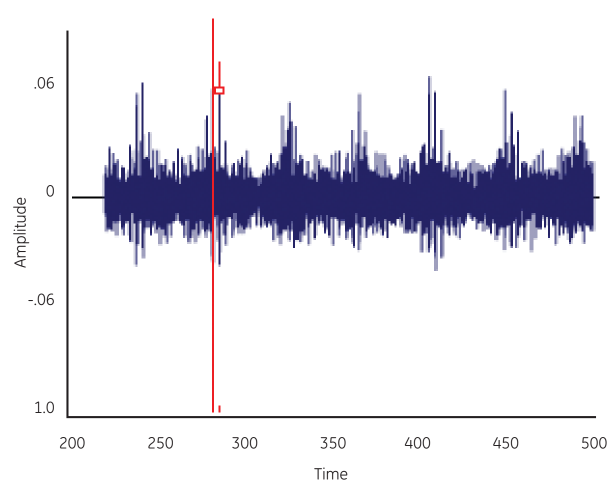

Figure 5: Timebase from PDC showing impacts occurring at inner ring fault frequency.

This system allows the condition monitoring data summarized in Table 2 to be sent to DCS.

A very important feature of the resulting system is that it not only provides these additional static values to the DCS beyond just simple overall values, but also that the filtering frequencies for each of the static values in Table 2 can be configured individually for each measurement point, thus enabling clear and precise analysis tools to be developed for various purposes.

Results

Case History #1 : Gearbox Bearing Problem

1 Very soon after the system had been commissioned, operators noticed high-frequency vibration trends starting to increase on all measurement points for the gearbox on one of the pumps. Overall velocity trends did not show any changes until several months later. Figure 4 shows the relatively stable trend of the overall velocity levels while the high-frequency acceleration levels show a clear upward trend.

Armed with this early warning information from the online system, PDC data was gathered showing impacting occurring at a frequency corresponding to the inner ring. Normally, this would suggest the bearing was worn out and result in routine maintenance to replace the high-speed shaft's upper bearing. However, because the gearbox was brand new, the gear OEM was consulted for their opinion; additionally, on 28 January 2009, a vibration survey and an endoscope inspection took place. The vibration survey (Figure 5) showed impacting occurring at a frequency corresponding to the bearing's inner ring. The endoscope inspection (Figure 6) showed damage to the rolling elements themselves. Based on the results, it was agreed that the upper bearing was faulty and the pump was subsequently scheduled to be removed from service.

Figure 6: Photo showing damaged inner ring (on the left) surface on the high-speed shaft.

Case History #2: Snow Induced Resonance

2 The evening of 24 November 2008 brought a severe storm with large accumulations of very wet snow. The control room operators noticed that overall RMS velocity started to increase on the non-drive end of one of the pumps, but all other vibration values were stable (Figure 7).

By 7 am the following day, the trip level was reached, but it was agreed to wait until a CM technician could perform a closer analysis with a PDC, particularly because only a single variable was showing this dramatic increase.

First, the system was checked to rule out an instrument fault as the cause of the high reading, and it was confirmed that there were no instrument faults. Spectrums collected by the PDC (Figure 8) showed high amplitude at only 1X (rotative speed) without corresponding increases at other bearing-related frequencies, indicating vibration primarily in the rotor region, consistent with the trends from the online system.

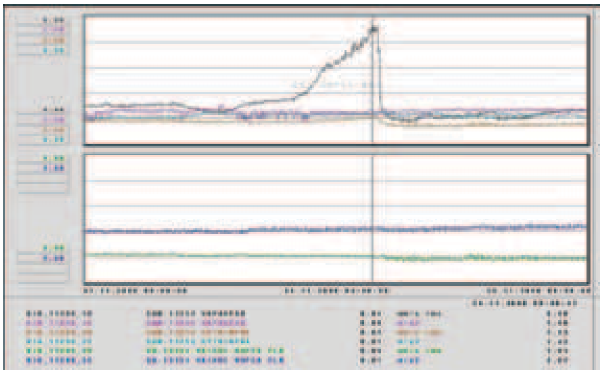

Figure 7: PMS screen showing trends of pump NDE bearing where overall RMS velocity increases markedly, but all other parameters from this bearing remain relatively stable.

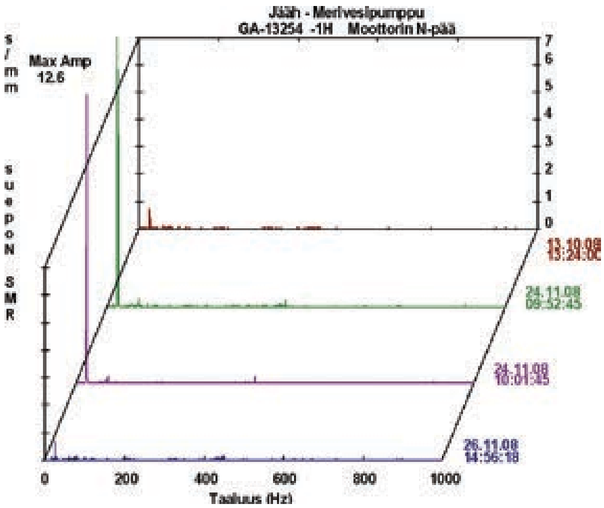

Figure 8: Spectrum trend from PDC showing elevated 1X vibration but normal bearing-related frequencies (note that readings were taken with a magnetic-mount temporary sensor).

Figure 9: Seawater pump showing snow build-up on motor shield.

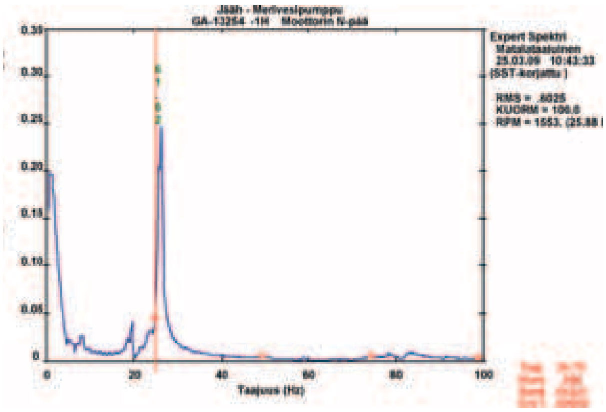

Figure 10: Seawater pump resonance frequency measured with an impact test.

BECAUSE THIS INCIDENT MADE PLANT PERSONNEL AWARE OF THE CLOSE PROXIMITY BETWEEN THE STRUCTURAL RESONANCE AND THE RUNNING SPEED OF THE MOTOR, THEY WILL BE ABLE TO PROACTIVELY INTERVENE IN THE FUTURE WHEN SNOW IS PRESENT.

While technicians were looking at the pump (Figure 9), they noticed that there was heavy show on top of the motor shield and – for no particular reason – began to remove it. They were immediately informed by control room operators that the vibration levels were decreasing. The technicians proceeded to remove all of the snow, resulting in a return of vibration levels to normal.

Afterwards, it was verified by an impact test that the motor runs slightly below a structural resonance, Figure 10. It was further reasoned that the addition of mass to the system (in form of wet snow) had effectively reduced the frequency of this resonance to coincide with the excitation provided by the running speed (1X) of the motor. The result was significantly elevated levels of 1X structural vibration, exactly as observed.

Mathematically, this effect can be seen from Equation 1.

$$\omega = \sqrt{\frac{k}{m}} \quad [1]$$

Where $\boldsymbol{\omega}$ is the resonant frequency, *k* is system stiffness, and *m* is system mass.

It can be clearly seen that adding mass (i.e., increasing *m*) while holding the stiffness *k* constant has the effect of reducing the system's resonant frequency.

Conclusion

Both case histories highlighted in this article illustrate the value of Borealis' online system for their seawater pumps. In the first instance, a bearing problem that would normally have gone unnoticed for at least a month between PDC rounds was spotted very early, allowing a defective bearing to be identified on a new gearbox and consultation with the OEM to occur in a proactive manner. Had the bearing problem progressed unnoticed, severe and more expensive damage may have ensued, as bearing flaws can progress quite rapidly once they reach a certain stage of degradation. In the second instance, operators were immediately alerted to a potentially damaging structural resonance and were able to correct it, albeit somewhat fortuitously. Because this incident made plant personnel aware of the close proximity between the structural resonance and the running speed of the motor, they will be able to proactively intervene in the future when snow is present.

The online systems installed by Borealis work together to address their critical and essential assets, supplemented by a portable data collection regime. There are three significant factors that have helped Borealis in their success thus far:

1. Borealis uses their DCS and PMS as the primary user interface for vibration readings and process readings, helping to ensure that asset conditions are given as much attention as process conditions and that online condition monitoring systems are providing data to operations personnel in real time.
2. Borealis relies on a rich data set of static vibration data, not just overall amplitude values; additionally, they have access to dynamic data, which is absolutely vital in the ability to diagnose root cause.
3. Borealis has an experience machinery diagnostic engineer on-site, capable of interpreting dynamic data and correlating it with the static data available in the DCS.

In the future, Borealis realizes that they can receive even more value on their critical and essential assets by supplementing their system with online dynamic data delivered directly to their CM technician, reducing the need to rely upon manually collected data from a PDC. This system can co-exist with the data currently delivered to their DCS and PMS, providing a simplified view of asset conditions for operators while simultaneously providing a more detailed view of asset conditions for machinery specialists. ■

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

Simplifying

Predictive Maintenance

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Although the benefits of predictive maintenance are widely accepted, the proportion of companies taking full advantage of the approach remains relatively small. For many potential users, the complexity and cost of traditional condition monitoring systems remains a significant obstacle.

When the Artesis team was first challenged to find a way of solving this problem, customers said that it would require an innovative approach to avoid the shortcomings of traditional systems. So the solution had to be very simple and inexpensive, easy to install, and able to provide flexible links to existing systems. And importantly, it had to avoid putting a heavy setup and analysis burden on busy maintenance staff.

Artesis responded by focusing an intense development effort on the most common form of machine – the whole range of equipment driven by three-phase electric motors. The resulting product is AnomAlert, a device that combines inward sophistication with outward ease of use. It brings the benefits of predictive maintenance to the widest possible range of users.

The "model-based fault detection" approach used by AnomAlert is not only innovative, but unique in its field. This approach was originally developed and used for applications in the aerospace industry [References 1, 2, 3 & 4]. The advanced algorithms used in the product are the subject of careful patent protection. Developing this mathematical process into a practical tool required a considerable effort, which included tests on several million electric motors to ensure the accuracy and repeatability of the diagnostics.

Artesis has succeeded in harnessing an innovative advanced technology to provide a simpler, more effective, and more affordable condition monitoring solution that has sparked a predictive maintenance revolution [Reference 5]. It is a fitting addition that complements the suite of Bently Nevada Asset Condition Monitoring products.

Overview

Traditional techniques for predictive maintenance have relied on observing trends in the levels of a number of key measurements over time. By carefully selecting the range of measurements, a skilled analyst was able to spot significant changes and to develop an idea of the fault that might be causing them. However, the analyst was often confused when the measurements were altered as a result of operational changes, such as speed or load changes, rather than by a developing fault. Setup and analysis costs have typically pushed such systems beyond the reach of many potential users.

AnomAlert takes a completely different approach, based on the use of mathematical models of the equipment being monitored. It uses measurements of voltage and current signals only, allowing it to be installed in the motor control cabinet without long cable runs. Once installed, it automatically initiates a self-learning phase during which it builds up a reference mathematical model. This model includes information about all electrical and mechanical characteristics of the motor and its driven system. This learning process requires no input from the operator, and includes all operating states experienced during training, such as different speeds and loads.

When the reference model is complete, AnomAlert switches to a monitoring mode in which a new model of the system is created every 90 seconds. This new model is compared statistically with the reference model, and potential faults are identified and characterized. The system is then able to assess the severity of the problem and produce a series of local indications to suggest what is wrong, what action should be taken and how soon it should be done. Diagnostic information is also sent to a connected computer where detailed information is presented to the maintenance group – including the specific fault, the recommended action, and an estimate of time to failure. Electrical and mechanical problems are diagnosed, including common faults like insulation breakdown, damaged rotor bars, imbalance, and bearing defects.

Key to the successful development of AnomAlert was to ensure that the advanced technology being used was invisible to the user. In fact, once the system has been installed the user has very little to do other than respond to information being provided to him by the system. Such information can be communicated as local traffic lights, control system inputs, computer displays, or e-mail messages, accommodating virtually any physical location.

So successful has AnomAlert proved at monitoring motor-driven systems, that the core technology has now been extended to provide equivalent cover for generators and alternators through the introduction of the AnomAlert for Generators solution.

Challenge

In today's competitive business environment, manufacturers are faced with growing production demands while at the same time cutting the cost of manufacturing. One pervasive cost that drags down productivity is low asset effectiveness resulting from breakdowns and unnecessary maintenance interventions. In the US alone, the combined cost of excess maintenance and lost productivity has been estimated at $740B, so the potential justification for implementing better approaches is huge.

The predictive maintenance approach has long been recognized as being capable of reducing such costs, and a wide range of condition monitoring technologies have developed to allow it to be implemented in industrial environments. Such technologies work by analyzing data gathered from the equipment in order to recognize fault characteristics sufficiently early to minimize both failures and unscheduled interruptions in production.

Vibration analysis is the most common method of condition monitoring, representing 85% of all systems sold. Other technologies include infrared (IR) thermography used to detect temperature changes in bearings and shafts; tribology or lubricating oil analysis; motor current signature analysis for electric motors; and ultrasonic analysis of bearing wear.

These traditional approaches have been deployed successfully in a number of key industries. However, they suffer from important limitations that have made them inaccessible to the great majority of the organizations that should be able to achieve the benefits of predictive maintenance. In fact, industry estimates suggest that somewhere between one in a hundred and one in a thousand potential users have been able to effectively deploy condition monitoring up to this time. So why, despite the universally acknowledged benefits of predictive maintenance, have so few companies achieved successful deployment?

Firstly, the diversity of condition monitoring components has made it very difficult for most people to configure monitoring systems. Correct selection of different types of sensor, cabling, data acquisition and processing equipment, and software has been a complex and daunting process even when only one vendor is involved. With multiple vendors, this task requires an effort level that few companies are willing or able to address.

Secondly, the implementation of such systems is far from straightforward. Online systems require sensor installation, significant cabling often involving long cable runs, and complex integration of data processing systems. Even portable systems typically require the installation of many transducer mounting points to be effective. Setting up the condition monitoring software system is also a cumbersome activity. It often requires long manual entry of asset, sensor, and data processing information and the establishment of "baseline" levels that can be taken to represent normal behavior for the equipment being monitored. This then allows alarm levels to be painstakingly set up for each measurement. This largely manual process becomes even more burdensome when baselines and alarms must be configured for a range of different speeds, loads, or operating conditions – a situation encountered in most installations.

Thirdly, even when all these tasks have been completed, the system requires considerable time and effort to deliver results. The required outputs are quite simple from the user's standpoint: a clear indication of which items of equipment are developing faults, the type of fault, the action that should be taken, and the timescale for that action. However, obtaining these outputs requires time for rising trends to be detected and considerable analysis and interpretation by the user. The skills and person-hours needed to do all this are often not available to a typical maintenance organization.

System costs have typically been unacceptably high. Portable systems have been relatively inexpensive to buy, but prohibitively expensive to operate. Online systems have avoided the high personnel costs of portable systems, but are very expensive to buy and install. Automated, "intelligent" systems have sought to reduce the analysis burden, but have been extremely expensive and difficult to set up.

As a result of these problems, there has been an increasing demand for simple, effective, and inexpensive condition monitoring systems that allow the great majority of organizations to benefit from the adoption of predictive maintenance without sacrificing diagnostic capability. Satisfying this requirement has been the cornerstone of the development of the Artesis system.

Response

AnomAlert was developed to meet a market requirement for a condition monitoring product that can provide simple and accurate maintenance scheduling information, without the need for interpretation by highly trained personnel. It aims to be very simple to install, set up, and operate, and to require little or no user intervention until an equipment fault is detected.

The benefits of the Artesis approach can best be summarized by taking a look at the contrast with conventional technology in each of the three problem areas previously described.

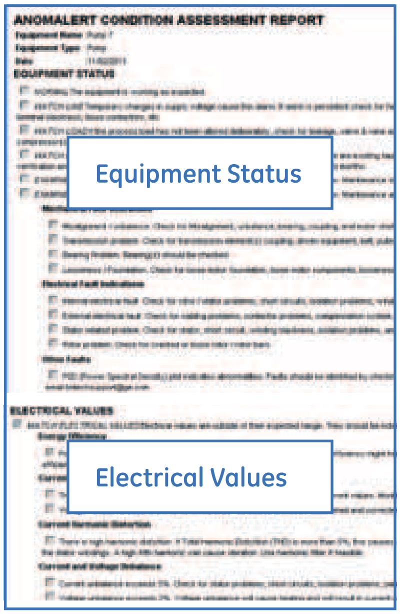
Firstly, the AnomAlert system is extremely simple to configure. AnomAlert monitor units are available for fixed or variable speed drives, and for high or low voltage power. For low voltage installations, only current transformers or transducers are required, while for high voltage systems, suitable voltage transformers are added. A suitable standard adaptor is then selected to link each unit to the software package, typically using network or wireless devices.

Secondly, during installation each AnomAlert unit only requires connection to the motor supply cables and so does not have to be positioned close to the equipment being monitored, which might be in a hazardous or remote location. This provides all the benefits of having an online system without the cost and complexity of extensive cabling. The AnomAlert units are typically installed in the motor control center by means of a square cutout in the front panel, following which connections are made to sensors, power supply, and communication devices. A relay output is also available to control visual or audible alarm equipment, or to provide a simple input to a plant data acquisition system.

Once the AnomAlert unit is switched on, it requires minimal user configuration before entering an automated "learn" mode during which the complete normal operating condition of the connected system is established. This process accommodates the full range of speeds and loads that are experienced by the system, and accommodates electrical, mechanical, and operational characteristics of the motor, coupling, and any type of driven equipment (typically including pumps, fans, compressors, and conveyors).

When the learning period is complete after a few days, the Artesis system creates a complete Condition Assessment Report for the connected equipment. This report identifies any existing mechanical, electrical, or operational problems and recommends corrective actions and how soon such actions should be carried out. Unlike conventional systems, this information is provided to the user immediately without having to wait for data trends to be collected and analyzed over an extended period. From this point on, the AnomAlert system provides automated condition monitoring cover for the connected equipment.

Thirdly, the Artesis system is almost entirely automatic in normal operation. Every 90 seconds it compares the current operating condition of the equipment with the normal condition established during the learn mode. If a problem is detected, "traffic lights" on the front panel of the AnomAlert monitor unit change color to indicate the type and severity of the fault. More detailed information is presented by the AnomAlert stand-alone software package which provides the user with a concise, accurate description of any developing faults, recommendations for maintenance actions, time to failure, and a wide range of electrical characteristics.



Artesis has succeeded in harnessing an innovative advanced technology to provide a simpler, more effective, and more affordable condition monitoring solution that has sparked a predictive maintenance revolution. It is a fitting addition that complements the suite of Bently Nevada Asset Condition Monitoring products.

Condition Assessment Report

ANOMALERT CONDITION ASSESSMENT REPORT

Equipment Name :Pump 7

Equipment Type :Pump

Date :11/02/2011

EQUIPMENT STATUS

☐ *NORMAL* The equipment is working as expected.

☐ *WATCH LINE* Temporary changes in supply voltage cause this alarm. If alarm is persistent check for har terminal slackness, loose contactors, etc.

☑ *WATCH LOAD* If the process load has not been altered deliberately, check for leakage, valve & vane ad compressors). If the process is altered deliberately, AnomAlert should be updated.

☐ *WATCH EXISTING FAULTS* The operation of the equipment is NORMAL although there are existing fault verification and corrective action at the next scheduled maintenance but no later than six (6) months.

☐ *EXAMINE 1* There are developing mechanical and/or electrical fault(s) as shown below. Maintenance sh

☐ *EXAMINE 2* There are developing mechanical and/or electrical fault(s) as shown below. Maintenance an

Mechanical Fault Indications

☐ Misalignment / unbalance. Check for Misalignment, unbalance, bearing, coupling, and motor shaft

☐ Transmission problem. Check for transmission element(s) coupling, driven equipment, belt, pulley

☐ Bearing Problem. Bearing(s) should be checked.

☐ Looseness / Foundation. Check for loose motor foundation, loose motor components, looseness

Electrical Fault Indications

☐ Internal electrical fault. Check for rotor / stator problems, short circuits, isolation problems, windir

☐ External electrical fault. Check for cabling problems, contactor problems, compensation system,

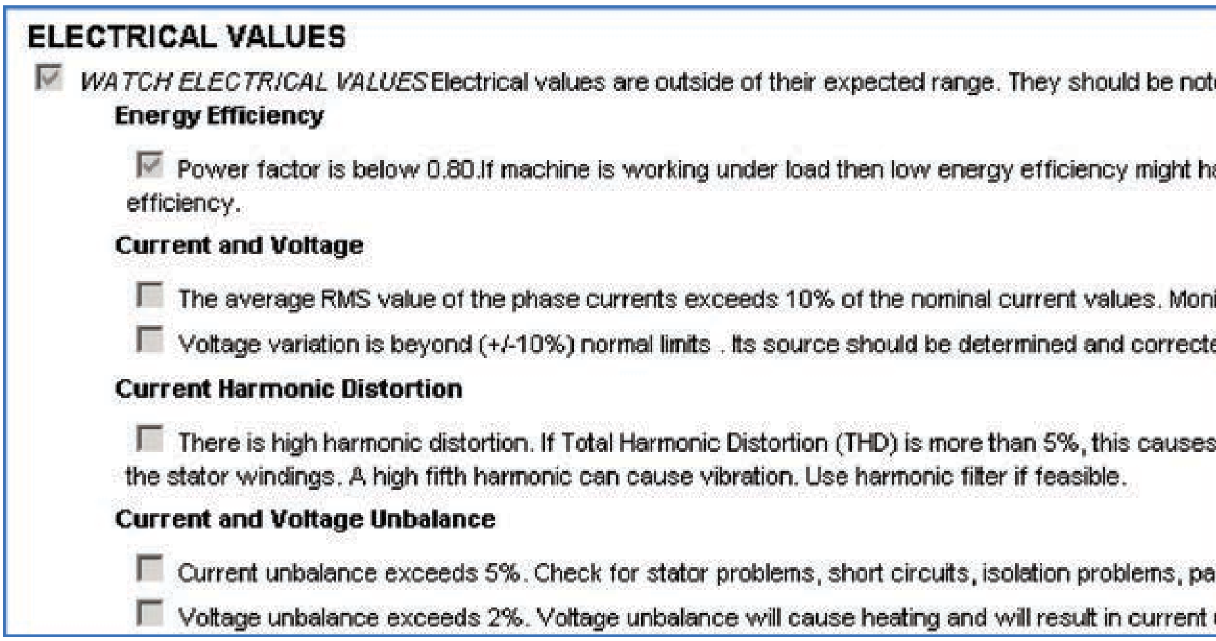
☐ Stator related problem. Check for stator, short circuit, winding slackness, isolation problems, anc

☐ Rotor problem. Check for cracked or loose rotor / rotor bars.

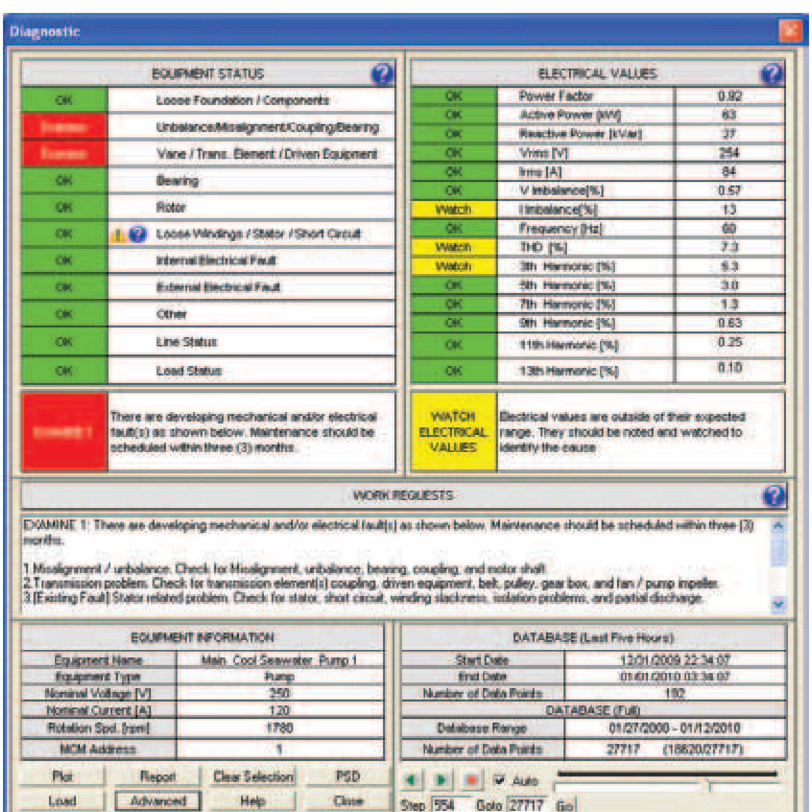
Other Faults

☐ PSD (Power Spectral Density) plot indicates abnormalities. Faults should be identified by checkin email bntechsupport@ge.com

The Equipment Status section includes indications of mechanical, electrical and other faults.



The Electrical Values section includes indications of various electrical problems.



Diagnostic Display

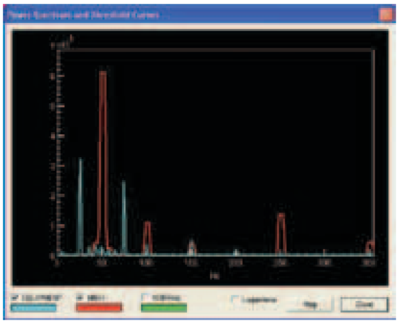
This diagnostic display gives also maintenance planning information with timing based on the severity level assessed by the system as *"within 6 months"*, *"within 3 months"* and *"as soon as possible"*. Such recommendations are based on the results of many similar assessments in the field and represent an average behavior for similar types of equipment.

Many users of the AnomAlert system spend much of their time in the field, away from their office workstations. To keep them up to date with the condition of their equipment, AnomAlert for System 1 can send email messages when a new fault is detected. These messages contain a summary condition report, prompting the user to check details in the software.

Although AnomAlert for System 1 excels at providing the user with actionable information in a concise, practical form, some advanced users choose to make use of the more complex displays that it can also provide. Trend plots can be used to show how faults have been developing over time for example, and Power Spectral Density (PSD) displays indicate the way the system has used information about the frequency content of the measured signals.

Power Spectral Density (PSD)

In this example, sidebands around the power supply line frequency (50 Hz) are shown in the figure, below. These ± 25 Hz sidebands represent modulation at shaft rotation speed (1X frequency for a 4-pole motor) and typically indicate machine unbalance or misalignment.



Power Spectral Density (PSD) display.

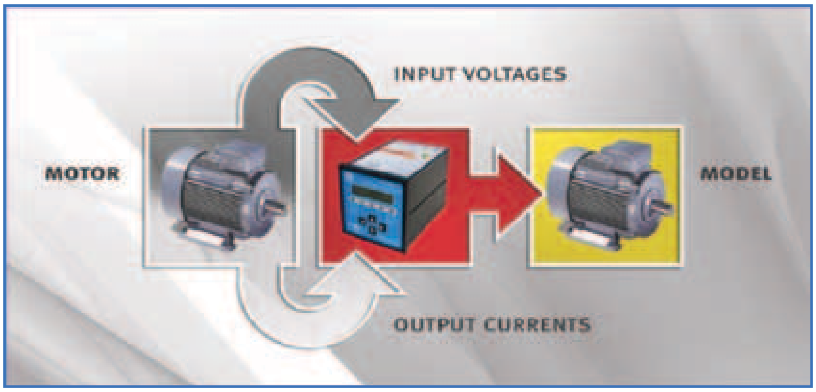
Technology

Although the AnomAlert system is simple to implement and operate, the technology behind it is both sophisticated and unique. By combining advanced model-based fault detection and intelligent diagnostics, the system is able to deliver outstanding results with minimal user intervention.

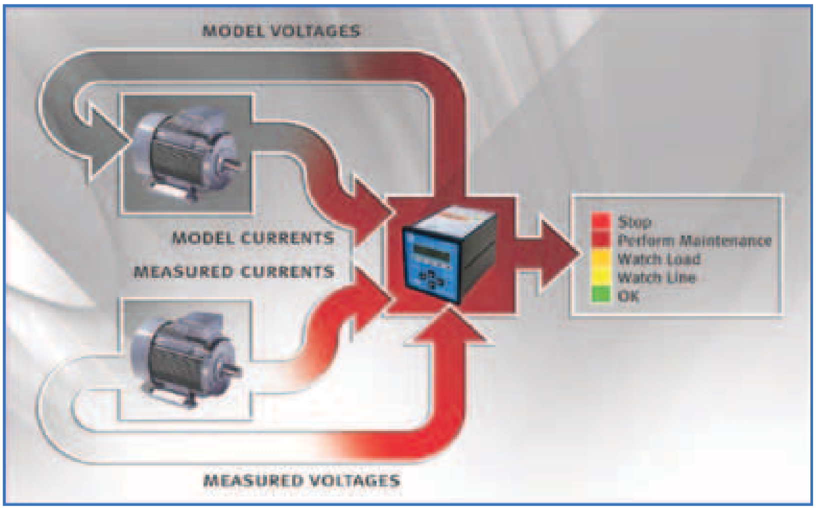
The principle of the AnomAlert approach is to build a mathematical model of the motor driven system that it is connected to, and then to compare the dynamic behavior of that model with the actual, measured dynamic behavior. The model consists of a set of differential equations, which describe the electromechanical behavior of the motor driven system, including the full range of mechanical, electrical, and operational characteristics.

During learn mode, AnomAlert acquires real-time data from the physical equipment before applying advanced system identification algorithms to calculate a set of model parameters. The mathematical model takes into account all speed and load variations experienced during the learn mode, eliminating the need for manual set up of multivariate alarms. When completed, this model represents the normal operating condition of the connected equipment. In normal operation, AnomAlert produces a series of new mathematical model of the system and by comparing the parameters in this new model with those in the reference model, developing faults can be accurately detected and diagnosed. This model-based approach effectively allows the motor itself to act as an advanced condition monitoring sensor, and is not confused by preexisting faults in the equipment.

AnomAlert monitors and compares 22 different model parameters, which are represent a wide range of electrical, mechanical, and operational faults. In addition to recognizing problems with the electrical supply, internal electrical problems like insulation breakdown are monitored. Mechanical faults identified by the system include foundation and coupling looseness,



Learning Phase



Operating Phase

imbalance and misalignment, and bearing deterioration. Operational problems leading to changes in load or electrical characteristics are also recognized. The model-based approach has proved very sensitive to early-stage faults, while at the same time being immune to false alerts.

In addition to its diagnostic capabilities, AnomAlert also provides the user with a wide range of electrical parameter measurements – including real and reactive power – which allow the system to be used for energy consumption assessments. Other parameters, such as total harmonic distortion, supply harmonic content, and voltage imbalance, also provide a valuable power quality analysis capability.

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[5] Innovation Award for "Simplifying Predictive Maintenance", The Institute of Engineering and Technology, United Kingdom, Dec 2007.

System 1* Condition Monitoring Platform Pays Off for SADAF

Munir A. Qureshi | Lead Machinery Diagnostics Engineer | munir.qureshi@ge.com

SADAF (an affiliate of Saudi Basic Industries Corporation, SABIC) is a conglomerate of petrochemical plants located in Jubail Industrial City, Saudi Arabia. In 2006 the SADAF Rotating Equipment group, in collaboration with their GE sales representative, developed a plan to upgrade six plants over a span of five years. Each upgrade would include the installation of a Bently Nevada 3300/3500 Machinery Protection System, and the System 1 Optimization and Diagnostic platform.

The Problem

The Ethylene Plant, which earns more than 10 million Saudi Riyal (~3 million US dollars) per day, is one of four plants successfully upgraded as of early 2010. During this upgrade, several attempts to start the 11KT/K3 Propylene Compressor Train resulted in high vibration trips at driver steam turbine Idle-2 speed. In need of assistance, the SADAF Rotating Equipment Specialist contacted their GE Machinery Diagnostics Services (MDS) engineers and requested an emergency site visit.

The Solution

An MDS engineer was onsite and on-the-job in 12 hours. Within one hour of analyzing data plots captured by System 1 software, the MDS engineer was able to identify the root cause as a combination of shaft surface imperfections and turbine case thermal warping, the latter being a result of inadequate heat soak time at Idle-1 conditions. As the unit was restarted, close monitoring of live System 1 data enabled the successful approach to full speed under manual turbine control.

However, as the plant was brought to maximum capacity over the next 24 hours, all startup attempts of the tail gas High-Speed Turbo Expander units' 11K4 and 11K5 resulted in trips at <15% rated speed resulting in loss of full production capability.

Again, using System 1 data plots, another MDS engineer was able to diagnose fluid-induced instability at the compressor bearings of each sister unit. A subsequent root cause analysis enabled the SADAF Rotating Equipment

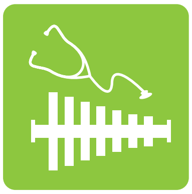
Engineers and OEM (GE Oil & Gas) to fine tune the lube oil and seal gas systems resulting in a successful run to rated operation and full production capability. In both cases, a detailed diagnostic report was submitted with long-term recommendations to identify and mitigate similar problems.

The Payback

The foresight of SADAF Engineers to invest in System 1 software provided a healthy return on that investment from the day that the platform was commissioned. Without the vital data captured by System 1 software and the expert analysis by the GE MDS engineers, SADAF engineers would have resorted to reopening machine casings for physical inspection, causing a minimum of four days production loss in each case.

"In behalf of SADAF, we would like to appreciate your team, mainly Elie Saba and Munir Qureshi [Machinery Diagnostic Services], and Samih Khalifah [Site Project Manager], particularly for their support during restart of our Ethylene plant. Proving the benefits of having System 1 again, for the professionalism demonstrated from both Elie and Munir for providing accurate diagnostics related to vibration problems encountered on our machines here at SADAF. Their support and ability to pinpoint the issues enabled us to restart in a more controlled mode. Again our thanks to GE for being there with us when we needed help..." —Mr. Toufic Aboudaoud, SADAF Senior Rotating Equipment Specialist

Keys to Success



- Trained and experienced specialists were able to isolate the root cause of the problem quickly and accurately.
- Global presence and rapid response saved precious time and reduced production losses.
- Continuous online monitoring using System 1 software captured vital information that may have otherwise been missed. The available data accommodated rapid determination of the root cause, which avoided the possibility of further machine damage and production losses.

Reference: Customer Success Story, GEA18458 (12/2010)

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

Field Engineer Program

Peter Park | Strategic Initiatives, Training & Development | peter.park@ge.com

The Measurement & Control Solutions Field Engineer Program (FEP) is building our pipeline of qualified Bently Nevada Field Engineers, who can offer our expertise and tradition of service excellence to our customers. Turning out more than twenty graduates this past January, the program is well on its way to achieving its goals to train and certify more than forty field engineers in 2011.

The Field Engineers who completed classroom training in January have since returned to their normal assignments, where they will continue building their expertise by completing identified On-the-Job Training (OJT) requirements as part of our FE Certification process. During the classroom sessions, three of our Services Team/Technical Lead Engineers also worked toward becoming Certified FEP Instructors.

"The FEP training has provided me with the fundamental knowledge and practical skills to become a better Machinery Diagnostic Services (MDS) Field Engineer. The training has improved my technical competence which will help me to communicate better with customers and troubleshoot issues pertaining to the core monitoring systems."

— Frank McNellis, MDS Engineer FEP Graduate, January, 2011

In addition to the great turnout, the program also saw its first cross-training experience in January. Three Latin-American graduates from the Control Solutions technicians program attended the Bently Nevada Systems Engineer program in Sugar Land. They left Texas with a new skill set, equipped to provide more value for their customers back home. This experience is an example of how our team is always looking for ways to enhance the synergy between our field services organizations.

Sugar Land FEP: Back Row (left to right): Peter Park, Jesus Andres Rodriguez, Matus Kolarcik, Fernando Faciini, Carlos Gomez, Don Jimison. Front Row (left to right): Frank McNellis, Adolfo Cantillo, Jesus Quevedo Gamez, Sebastian Gregoroff, Dmitry Storozhev, Courtney Brown.

Bahrain FEP: Back Row (left to right): Tom Dixon, Ramanathan Peruvemba, Magnus Olsson, Muthana Aljundi, Jeremias Vakuendisa, Ivan Belousov. Middle Row (left to right): Jad Taleb, Ghassan Linjawi, Esam Al-Ghamdi, Preetam Gaikwad, Esimhesor Ewesor, Javed Saifi, Ahmed Samir. Front Row (left to right): Peter Park, Mohamed Shams, Daniel Walmsley.

Supporting Service Agreements

David McNeilly | SSA Product Line Manager | david.mcneilly@ge.com

Supporting Service Agreements (SSAs) are designed to help our customers implement Asset Condition Monitoring effectively using the System 1 platform.

In the current economic climate, we recognize that our customers do not always have the available resources to manage an effective Asset Condition Monitoring program with their own staff. Our global service organization can provide the missing pieces to help our customers realize the value from their investment in System 1, combining the technology with products and machinery knowledge and implementing processes that can help deliver results.

Currently, we have over 100 active agreements with customers all over the world. The scope of these agreements can vary widely – matching the unique needs of each customer. We manage the Bently Nevada Asset Condition Monitoring System with remote system health and machinery health monitoring.

We also provide our customers with proactive actionable information to help them avoid unplanned downtime. For some customers we simply schedule regular visits to site, show them new functionality and help them to apply the tools for their own specific application.

No matter the size or scope, each Agreement is managed by a "local" SSA Site Lead tasked to focus on Value delivery.

Asset Condition Monitoring Program Requirements

Clearly, an effective Asset Condition Monitoring program does not happen by itself. There are several necessary elements beyond the technology itself that must be addressed in the overall program:

- Monitoring system setup, developing the initial data collection rates and types (static, dynamic, transient, filtered frequency bands etc.), documenting machine mechanical and electrical characteristics and operating design parameters.
- Viewing System 1 Event Manager, notification of alarms and initiation of action.
- System optimization, adjusting trending parameters and pre-alarms. Configuration change management to ensure that changes are approved and documented.
- Data management to avoid data loss in the event of computer malfunction or trend file overflow.

- Machine baseline and periodic audits comparing changes over time to investigate early signs of deterioration in condition and to document how the machine responds to changes in operating condition.
- Instrument installation and maintenance.
- Server performance management.
- Developing event notification to inform Operations of specific action required.
- Results record keeping.

SSA Web Portal

Collecting all of the relevant information in a single location with standard formats enables quick assessment and response to important information. An SSA Web Portal (Figure 1) can accommodate the following functions:

- Display an updated list of customer and GE contact Information and procedures.
- Post a schedule of upcoming events (audits, conference calls, outages, site visits, etc.).
- Serve as a searchable repository for reports and other documents.
- Provide a list of current Machinery Diagnostic Services (MDS) action items
- Display real-time Alarm and Event Management (if included in contract)
- Display real-time contract performance dashboards.

SSA Remote Alarm and Event Management

Alarm and event management is focused on using software alarms to provide early warning of anomalies in machine behavior. Using E-mail notifications via the customers' SMTP server, the alarms are received into the Web portal and the attending engineer will review, investigate and disposition them according to an established process (Figure 3).

Figure 1: Each SSA Web Portal is customized to meet the needs of the specific customer.

The E-mail notification opens a Workflow in the Web Portal. These Workflows will trigger documented action and provide visibility over the period of the agreement. They will be used to document root cause problem solving. Pushing alarm notifications enables the remote monitoring personnel to begin investigation of problems even before the customer is aware of any anomaly.

This process focuses on identifying problems early, assessing and communicating in order to jointly develop an Action Plan, and to track the status of reported alarms through to resolution.

Early Warning

By constantly monitoring the software alarms and events that occur on monitored assets, our SSA staff provides early notification of impending machinery problems BEFORE they reach the point of functional failure.

Machine-specific exception reports are produced as part of the alarm assessment process and are provided to the customer within a few hours of alarm assessment. All Exception Reports are stored in the Web Portal. All Exception, Baseline and Optimization reports can be found quickly for each machine in the site's Report Manager to provide a complete machine health history.

Figure 2: Remote Monitoring Center, Minden, Nevada, USA.

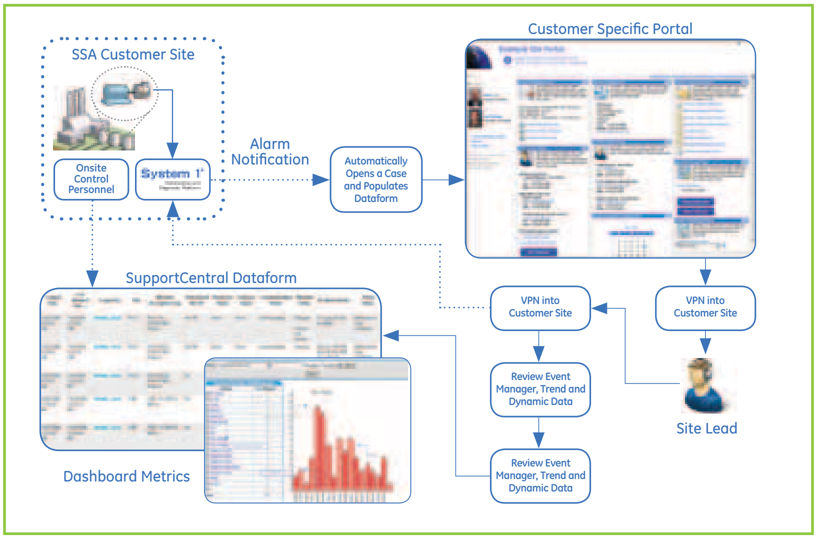


Figure 3: Remote Alarm and Event Management Workflow Process.

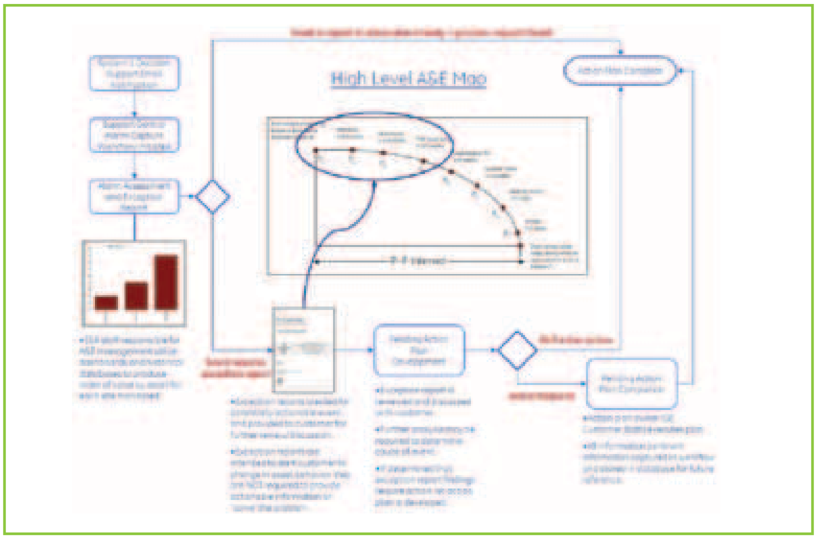


Figure 4: How Alarm and Event Management fits the P-F Curve

Invitation

If you are a System 1 owner, and want to find out how to use your platform more effectively, please give us a call. We will come to see you – and, using a Value Analysis approach – discover your needs and offer potential support solutions. Give us a call, we probably can offer you more than you realize. For further general information on Bently Nevada Supporting Service Agreements, visit us online:

http://www.ge-mcs.com/en/bently-nevada-services-and-support/services-and-support/service-agreements.html

If you have a web-enabled smartphone with a Quick Response (QR) Code reader application, simply take a "picture" of this graphic to navigate directly to our webpage.

Thrust Bearing Position Monitoring

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Editor's Note: Our Hydro Corner department will include an ongoing series of articles about condition monitoring and protection topics specifically for hydro turbine generator machines. The previous issue of ORBIT (Volume 30 Number 1, December 2010) launched the series with an article on XY radial position and vibration monitoring. This installment concentrates on axial thrust position monitoring. —GBS

Hydro Turbine Generators with vertical shafts have significant axial loads due to the large mass of the rotating machine components (generator rotor, shaft, and turbine runner), as well as any downward hydraulic thrust produced by the turbine. The axial loads are supported by very heavy-duty thrust bearings. Machines generating more than about 1 MW usually use fluid type thrust bearings where the axial thrust is supported on a thin layer of pressurized oil.

While the machine is running, the faces of the bearing pads are separated from the shaft collar by a thin oil film which provides a hydrodynamic buffer between the two surfaces to prevent metal-to-metal contact. The allowable hydraulic thrust load that can be accommodated by standard machine design is satisfactory for Francis or Pelton runners. However, Kaplan ("variable-pitch propeller") runners require provisions for higher than normal thrust loads due to the added downward loads produced by this type of runner.

Thrust Bearing Design

There are typically three types of thrust bearings used in hydroelectric units: the adjustable shoe, the spring loaded bearing, and the self-equalizing bearing.

With all of these designs, the bearing components are typically immersed in a reservoir of lubricating oil that incorporates a cooling system. The load is carried by a wedge-shaped oil film formed between the shaft thrust collar and a series of segmented stationary support pads or shoes. The stationary shoes are usually coated with babbitt (a soft "white metal" very commonly used in bearings), or a tough, low-friction plastic such as poly-tetra-fluoro-ethylene (PTFE). This results in an extremely low coefficient of friction and negligible bearing wear with hydro generators in satisfactory condition.

Continuous monitoring of oil and pad material temperatures usually provides enough time so that the hydro generator can be shut down before any damage to the main components occurs in the event of elevated temperatures during normal operation. During machine startup, an oil-lift system is often employed to provide separation between the pads and the thrust collar during the period of time before relative motion between these components allows a hydrodynamic wedge of oil to form. The oil-lift system prevents the relatively weak babbitt material from being damaged or "wiped" by insufficient lubrication during startup.

Transient operating conditions (such as rapid changes in speed or load) are becoming more commonplace in hydro-turbine applications – especially in pumped storage hydro stations – which are mostly used to meet peak power demand at very short notice. These machines may also be operated as "synchronous condensers" (with the turbine drained and the generator motorized) for reactive power compensation on the transmission grid.

Thrust Position Changes

Because of the importance of the thrust bearing for hydro generator operation, thrust bearing position monitoring is a vital component for machine condition monitoring as well as for automatic protection trips. Changes in measured thrust position can be the result of static or dynamic influences such as the following examples:

- Position of the shaft thrust collar can fluctuate as result of variable oil film thickness between the bearing pads and the shaft collar, which may indicate changes in lubricant supply pressure.
- Position of the shaft collar can change as a result of abrasion wear of the bearing pads.
- Position of the thrust collar can change with changing properties of the lubricating oil – such as viscosity changes caused by temperature changes or the substitution of a different type of oil.
- Position of the shaft can change significantly for various malfunctions of the thrust pad support system.
- In some operating conditions, fluctuating axial load can cause relative movement between the thrust collar and other components of the thrust bearing.

Transducer Installation Considerations

Because of the reasons listed above, there are various types of transducer installation that will provide the most effective monitoring for any specific machine. Also, unit construction and operating modes can influence the selection of a suitable transducer installation. Some of the transducer installation considerations are listed below:

- How many axial position transducers are needed? This number often ranges from 1 to 4 transducers. Usually, the number of transducers correlates with the output (and physical size) of hydro-generators. Larger machines can benefit from more measurements to monitor rotor system alignment. Also, additional transducers are easier to justify financially when they are applied on a high-output machine.

- What is the required linear range of transducer operation? This usually varies between about 2 and 10 mm of displacement.
- What is the best location for attaching transducers?
- Which type of non-contacting transducer is most appropriate? These usually employ either eddy-current or capacitive type sensors.

Required Measurement Range

A typical approach for thrust bearing monitoring is to use non-contacting transducers of the type normally used for radial monitoring of shaft position in guide bearings (Reference 1). The axial rotor position change in normal conditions is usually not significant, so application of transducers with linear measurement range of only a few millimeters can often be acceptable. However, during a thrust bearing malfunction, the axial movement of the shaft can be significantly higher than under normal conditions.

The malfunction example described below is for a design where each bearing shoe is supported by an individual oil-filled bellows assembly.

In this design, a series of individual bellows assemblies are filled with pressurized oil. They are connected together with oil lines, which ensure that every bellows assembly will have equal pressure. This way, each bellows assembly generates an equal force under each shoe, maintaining the shaft in a consistent vertical position.

With normal flexing of the bellows assemblies over time, it is possible that metal fatigue can eventually produce cracks (Figure 1). When the oil leaks out of the cracked assembly, it also leaks out of ALL of the assemblies, since they are cross-connected. Such oil loss can significantly change the axial position of the rotor. Vertical movement of up to 10 mm is not unusual for such bearing support system malfunctions.

This bearing support failure mode example points out some important considerations that should be made when establishing the design of any specific transducer installation:

- What are the anticipated ranges of movement (left-right for horizontal machines and up-down for vertical machines) under normal operating conditions?
- What would be the biggest expected axial movement of the rotor system during serious thrust bearing malfunctions, and in which direction would the rotor be expected to move?

Suitable Target

The next step in designing the installation is finding a suitable surface or "target," that can operate with the non-contacting transducer, while accommodating the required measurement range. For machines that only require a relatively small range of axial measurements, this is usually not a difficult task. However, it can be more difficult to find a suitable surface for a machine that requires a measurement range of more than 4 mm, due to the need for a larger target surface for the long-range transducer to measure.[1,2]

Transducer Installation – Upper Rotor End

With vertical Francis turbines, it is a common practice to install the transducers at the uppermost end of the rotor assembly. Figures 3A and 3B show such a transducer installation that is providing speed-sensing and axial thrust position measurements by observing a toothed wheel at the top of the generator.

Figure 1: Examples of two metallic bellows assemblies that support bearing pads of a vertical hydro-generator. The left bellows is in sound physical condition, while the right bellows has suffered a circumferential fatigue crack just above the upper convolution.

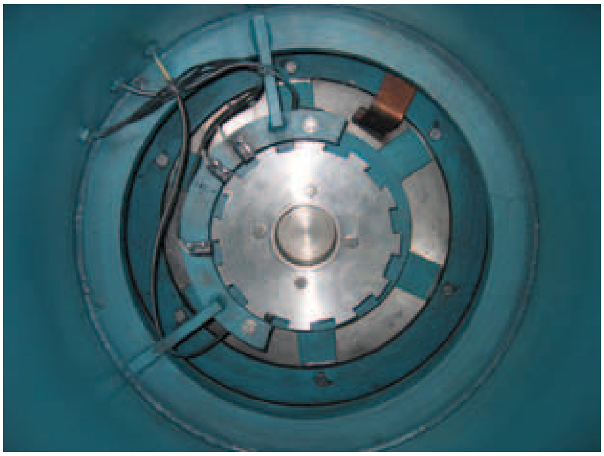

Figure 3A: This photo shows a top view of the toothed wheel that is used for speed measurements on a non-reversible unit of about 50 MW capacity. The three radial transducers provide speed signals to the control system in a "2-out-of-3" mode.

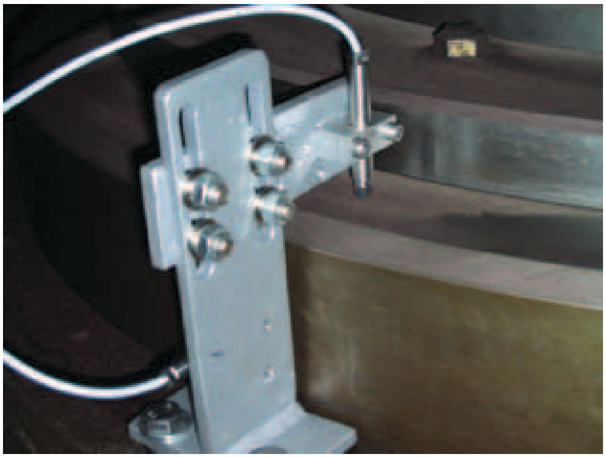

Figure 2: This photo shows the installation of a single axial thrust position transducer on a non-reversible unit of about 100 MW capacity. This example shows a typical 8mm eddy-current displacement probe installed close to the thrust bearing[3]. Observe that the bracket was made to facilitate gap adjustment of the probe during system installation and verification.

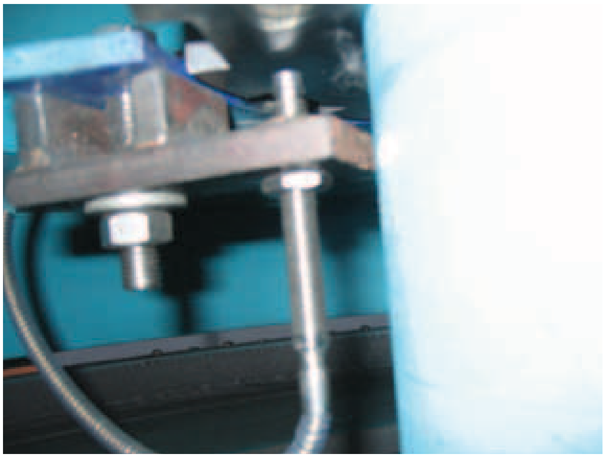

Figure 3B: This photo shows one of the dual transducers installed for axial thrust position bearing monitoring on the same machine shown in Figure 3A. These probes are observing the lower surface of the toothed wheel, and they provide signals to the monitoring system in a "1-out-of-2" mode.

[1]Example: For Bently Nevada 3300XL displacement transducers, the recommended minimum target sizes for 8mm, 11mm, and 25mm transducers are 15.2mm, 31mm, and 61mm, respectively. These minimum target sizes are required in order to accommodate the full design range of linear measurement of up to 2mm, 4mm, and ~13mm.

[2]Transducers produced by various companies operating in a similar measurement range may have different requirements for minimum target size.

[3]When monitoring thrust position for steam turbine applications, it is very important that the transducer probe be installed within about 30 cm (~12 in) from the thrust collar. This is because the rotor experiences significant changes in length due to changing thermal conditions. If the probe were installed at a significant distance from the thrust bearing, thermal expansion of the shaft could either shear off the sensor, or cause it to go out of range, depending on which direction the probe was installed relative to the surface being observed. Since hydro generator rotor temperatures do not change much with operating conditions, the restriction for the sensor to be installed close to the thrust collar does not apply to hydro machines.

Transducer Installation – Inside Thrust Bearing Oil Reservoir

With Kaplan turbines it can be more difficult to find an accessible rotor surface that can be used for thrust position monitoring. However, both "propeller" and Kaplan (variable pitch propeller) designs generate very significant axial thrust loads due to runner design. Also, these designs tend to encounter more dynamic water pulsation forces than Francis designs, which can generate axial vibration in addition to high axial loads. Therefore, thrust position measurements can provide significant value for condition monitoring of these machines.

Because the upper end of the shaft is often not accessible in Kaplan turbines, the thrust collar can be observed directly. For this type of installation, the transducers are mounted inside the thrust bearing reservoir, and are submerged in the lubricating oil (Figure 4).

Note: Capacitive sensors are very susceptible to calibration errors introduced by changes in the dielectric between the sensor and the measured target. Air, oil, steam, water, etc., all have different dielectric constants, which may require special modifications to make the capacitive sensors work correctly. However, eddy current transducers are immune to changes in the dielectric between them and the observed target and can be used in a variety of environments without the need for any special modifications.

Transducer Installation – Inter-Shaft Coupling

Some users of vertical hydro generators try to avoid installing axial thrust position transducers inside of the thrust bearing oil reservoir. Instead, they look for another, more accessible surface of the generator shaft that is suitable for measurement. One possibility to consider is the surface of a coupling between the generator shaft and the inter-shaft that connects to the turbine (Figure 5).

In this particular example, the half-coupling at the upper end of the inter-shaft was chosen as the target, as it was more easily accessible than the half-coupling at the bottom of the generator shaft. Such a transducer installation is somewhat less direct than observing the thrust collar itself. However, it can provide the additional capability of monitoring for potential problems with the coupling.

Thrust Bearing Lubrication

In order to attain proper hydrodynamic lubrication, the tilting thrust pad must orient itself at a slight angle to the moving thrust collar, so that a converging wedge of lubricating oil is formed. The tangential flow constriction formed by the narrow gap at the trailing edge of the pad acts as a "bottleneck" that forces some of the oil out radially, effectively slowing down the flow rate across the pad from the leading edge towards the trailing edge. The gradually reducing available oil volume in the gap leads to a pressure build-up in the oil film giving rise to a force that lifts the shaft (thrust collar) over bearing pads.

The axial position transducers shown in Figure 4 are fixed to a stationary point in the oil reservoir, so they can measure only the distance between probe tip and the bottom of the thrust collar – without providing any information about the thickness of the lubrication layer.

For detection of some thrust bearing operation malfunctions – such as recognition of the lubrication change from normal full-film lubrication to mixed lubrication or even boundary lubrication (Reference 2) it is more appropriate to measure the actual thickness of the oil film between the thrust collar and a thrust bearing pad (Figure 6).

This type of monitoring allows us to determine whether the surfaces of the pad and the collar are completely separated by the lubricant. For oil film thickness monitoring, the non-contacting transducers have to be connected not to a fixed point of the oil reservoir, but to a side surface of the thrust-bearing pads (for one or for several pads).

There are several reasons that the thickness of the lubrication layer varies over the surface of a thrust bearing pad. These are summarized in the list below:

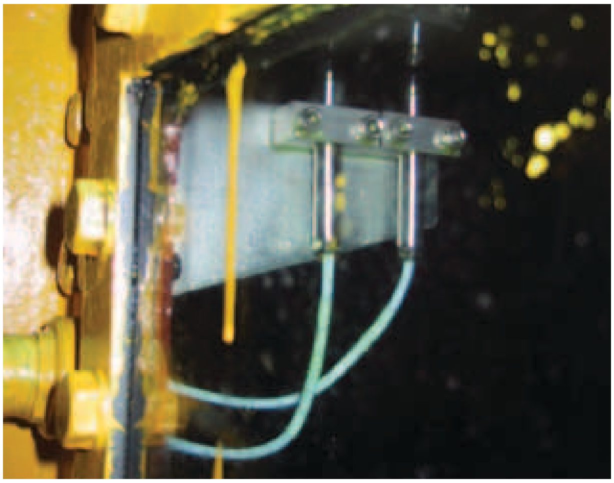

Figure 4: This photo shows dual axial thrust position transducers installed inside the oil reservoir and observing the lower surface of the thrust collar.

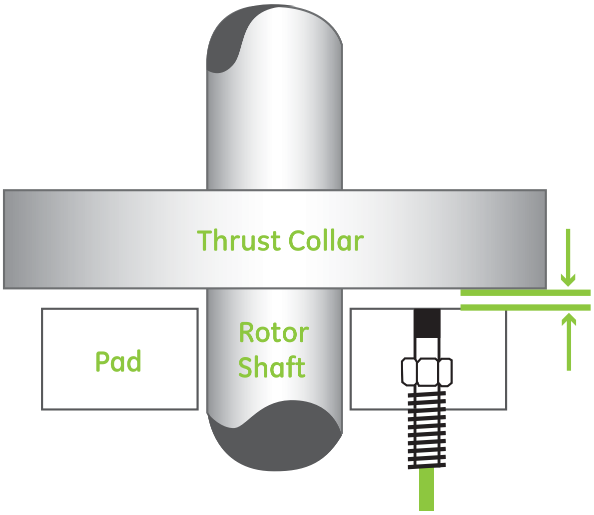

Figure 6: This simplified drawing shows an eddy-current transducer mounted to one of the thrust pads and observing the thrust collar, so that it can measure the thickness of the lubricating oil film between them.

Figure 5: This example shows a single axial thrust position transducer installed to observe the lower surface of the upper half-coupling of the inter-shaft (which connects the turbine to the generator).

Because of the importance of the thrust bearing for hydro generator operation, thrust bearing position monitoring is a vital component for machine condition monitoring as well as for automatic protection trips.

- To attain full-film hydrodynamic lubrication[4] (caused by the relative motion between the collar and the pad), the pad must be oriented at a slight angle to the collar.
- Radial flow causes some of the oil to leave the surface of the pad (Figure 7A). This radial flow depends on factors such as pad stiffness, type of pad support, etc.
- Non-uniform temperature of the bearing pads: Temperature of the oil increases from the leading edge to the trailing edge of the pad. This causes its density and viscosity to be lower at the trailing edge.

Because of these factors, the thickness of the oil film at the trailing edge of the pad is much smaller than it is at the leading edge of the pad (Figure 7B), (Reference 3).

Since the lubrication layer thickness is much smaller at the trailing edge of the pad than it is at the leading edge, it is more conservative to mount oil thickness measuring transducers to the trailing edge of a bearing pad, rather than to the leading edge. However, with reversible (pumped storage) hydro turbines, the "trailing edge" can be at either end of the pad – depending on which direction the machine is turning at any time. For these machines, it may be appropriate to install transducers on both ends of the pad.

Experimental measurements have been made of thrust bearing oil film thickness on a large bi-directional machine at a pumped storage unit (Figure 8). These experimental results clearly show the variations in measured oil film thickness across the surface of the thrust bearing pad (Reference 4).

Thrust position monitoring is usually limited to static (DC) measurements. However, it can sometimes be useful to also monitor the dynamic (AC) component of the measured signal. Due to specifics of their construction details, some units exhibit axial vibration due to operation with various structural resonances. In such a case, the dynamic signal component can be significant (Reference 5).

Structural Resonance

Resonance can result from a poor initial design, or from long-term effects of the unit aging over time. As concrete creeps, foundations shift, and reservoir levels (and associated horizontal loading of the structure) change, the stiffness of the structures can change in unexpected ways.

When stiffness changes, the natural vibration frequency of the structures also changes. If the shifted natural frequency corresponds closely to a forcing frequency caused by normal machine operation, it can result in damaging structural resonance. In some cases of structural resonance (Figure 9), it has been possible to increase the natural frequency of supporting structures away from the forcing frequencies caused by normal operation and reduce or eliminate the structural resonance condition.

Conclusion

Position measurements of the shaft in the thrust bearing and the thickness of the oil between the thrust collar and thrust bearing pads are very important for machine protection and condition monitoring of vertical hydro turbine generators. However, other types of thrust bearing monitoring (such as oil and bearing temperature and oil pressure monitoring) are also very important. These other types of thrust bearing monitoring will be discussed in future Hydro Corner articles. ■

[4] Creation of a proper lubricating oil film depends on the surface finish of the thrust bearing operating surfaces. The minimum allowable film thickness at the thinnest part of the oil wedge typically ranges from about 2.5 to 50 microns. These general oil film thickness numbers are simply provided for guidance to avoid metal-to-metal contact under clean oil conditions with no misalignment (Reference 2). Manufacturer-specific guidance should always be used when it is available for a particular machine.

References

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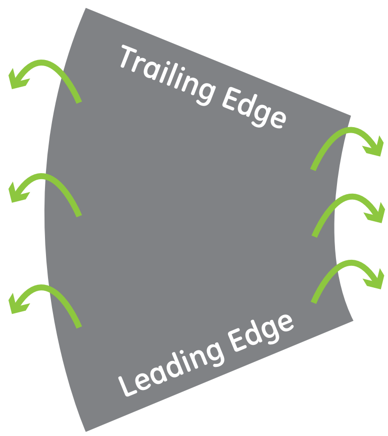

Figure 7A: This diagram has arrows that show the direction of lubricating oil flow from the operating surface of a thrust bearing pad. Observe that the oil flows radially both outwards (away from the rotor shaft), and inwards (toward the shaft).

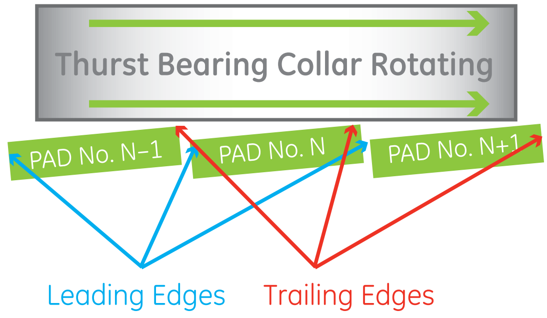

Figure 7B: This diagram shows the mutual positioning of thrust bearing pads relative to the supported thrust collar. Note: The angle of the thrust pads is highly exaggerated for clarity.

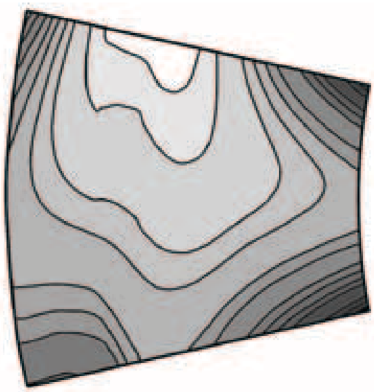

Figure 8: This plot shows variations in measured oil film thickness across the surface of a thrust bearing pad in a running machine. Darker shading represents largest film thickness, while lighter shading represents smallest thickness. The smallest measured film thickness value in this experiment was 30 microns (at the middle of the trailing edge), while the highest values were between 120 and 200 microns – measured at the pad corners.

Figure 9: This photo shows a supplemental support that was installed to increase the structural stiffness of the thrust bearing oil reservoir. This photo shows just one of the "pockets" of the bearing support structure. Similar supports were also added to all of the other pockets of the structure. This modification increased structural stiffness adequately to move the natural frequency above the forcing frequencies caused by normal operation, and to reduce the structural resonance.

Recommended non-contacting transducers for axial thrust position measurements on hydro-generators. This list shows the linear range of operation for Bently Nevada 3300 XL series proximity transducers that are suitable for thrust bearing monitoring:

- 8mm transducers: 0.25 mm to 2.5 mm
- 11mm transducers: 0.5 mm to 4.7 mm
- 25mm transducers: 0.63 mm to 13.33 mm (total linear range, 12.7 mm)

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