orbit

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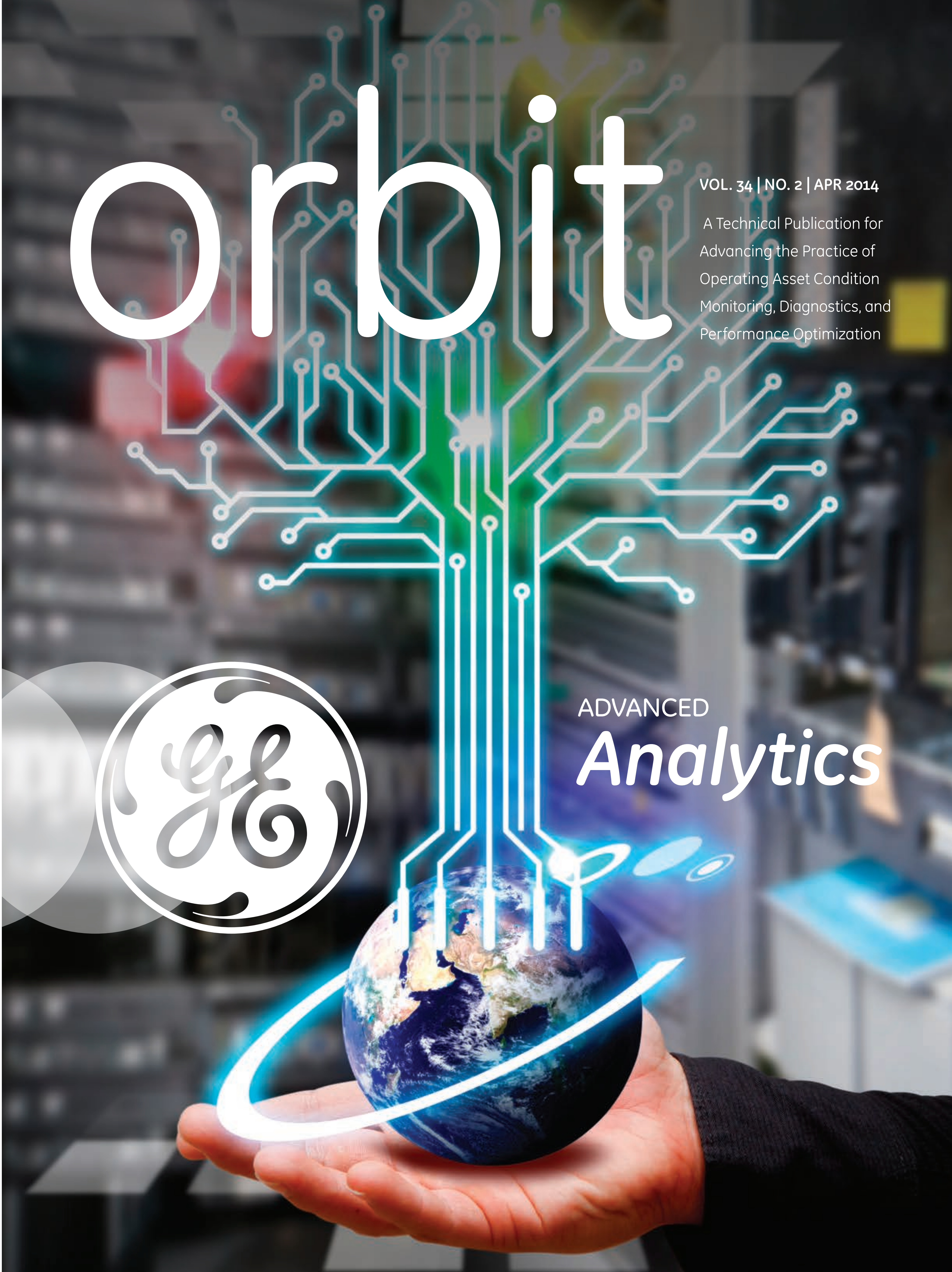
A Technical Publication for Advancing the Practice of Operating Asset Condition Monitoring, Diagnostics, and Performance Optimization



ADVANCED
Analytics

ORBIT
VOLUME 34 • NUMBER 2 • APR 2014
ADVANCED ANALYTICS

Editor's Notepad

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& *Orbit* Co-Editor

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This issue of *Orbit* Magazine is dedicated to Mr. Gary Swift, longtime *Orbit* editor. Gary we thank you for your hard work and dedication and we hope you make the most out of your retirement. Cheers!

Welcome to the first all-digital version of *Orbit* magazine!

As we advance toward an era of intelligent machines, big data and advanced analytics within the framework of the Industrial Internet, we felt it only fitting to evolve this publication. While we remain committed to providing the same value driven content you've come to expect from *Orbit*, we are also seeking to maximize the potential of this publication. We are continuing to explore the best options, so the digital version you see today may change to become a more interactive and regularly updated forum at a future date. Welcome to the digital age!

The theme of this issue explores the second piece in the stream of information flow that comprises the Industrial Internet, advanced analytics. Analytics, by definition, is the discovery and communication of meaning in big amounts of data. Through applying analytics to big data we find meaning that did not previously exist.

But, what do we mean by advanced analytics? Advanced analytics is the combination of physics-based analytics, predictive algorithms, automation and deep domain expertise, through which we can understand the data and use it to support more intelligent, proactive decisions. Our feature story this month explores advanced analytics and how it is helping revolutionize the world we live in.

Lastly, we would like to take a minute to reinforce the legacy of this publication. Don Bently wrote in the inaugural publication of *Orbit* magazine, during the spring of 1980, "We plan to greet you several times a year with news about our products, and schedules of our tradeshows and seminars. The *Orbit* staff hopes you will find the newsletter informative and enjoyable." The same holds true today, as we transition to the digital version. We hope you continue to find *Orbit* to be a valuable resource.

Respectfully,
Lindsay Sherman and Christopher Gleason
Orbit Editors

In this Issue

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

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Celebrating Our Experience

In 1973, Great Britain, Ireland, and Denmark entered the European Economic Community. Elvis Presley's Hawaiian concert was telecast worldwide, and Pink Floyd's iconic Dark Side of the Moon album was released. The Skylab space station was launched, and the basic concepts of Ethernet were developed.

American author Pearl S. Buck, Chinese-American martial arts actor Bruce Lee, and Spanish artist Pablo Picasso died, while German fashion model Heidi Klum, Swedish hockey player Peter Forsberg, and American baseball pitcher Shawn Estes (who attended Douglas High School, just a few miles from Bently Nevada headquarters) were born.

At General Electric, research scientist Ivar Giaever won the Nobel Prize in Physics for discovering superconductive tunneling. The new CFM56 project was underway, culminating in production of the world's most successful aircraft engine. Pioneering work in Computerized Tomography (CT) was started at GE's Medical Systems Division.

At Bently Nevada, production of the classic 5000 series monitor was in full swing. This old-style hand-soldered monitor used single-sided circuit boards with through-hole component mounting! The new 7200 series monitors and transducer systems were still being developed when Sherry Allred, Clark Balik, and Brooke Woellner joined the small company, which had just over 400 employees at the time.

Minden employee photos by Adrian Cobb.

40 YEARS

CLARK BALIK, SHERRY ALLRED & BROOKE WOELLNER HAVE BEEN WITH THE BENTLY NEVADA TEAM SINCE 1973!

35 YEARS

BACK ROW, LEFT TO RIGHT: Glenn Green, George Powell, Curt Hooper, Greg Marenco. Front row: Tom Pfoh, Melissa Tucker, Joe Adlao. **NOT SHOWN:** Valerie Breckenridge, Ricky Putney.

30 YEARS

BACK ROW, LEFT TO RIGHT: Tim Daly, Skip Wight. Second row: Joe Sedminik, Deb Epps. **FRONT ROW:** Patti Reynolds. **NOT SHOWN:** Dante Crippa (Italy), Peter Mol (Netherlands), Jeff White, Mike Wright.

BACK ROW: Alan Tart, Don Cosens, Ron Wilson. **NEXT ROW:** Joe Taylor, Arvin Huck, Ray Curtiss, Roy Francis. **FRONT ROW:** Belinda Moran, Raymond "Jack" Wulff, Ingrid Gilstrap, Darcy James, Althea Ruana, Danielle Futrell-Hurin. **NOT SHOWN:** Paul Cutunilli, Ha To Duong, Joe Pettit, Duane Winter, Dennis Mills, Ronald Thornton.

25 YEARS

20 YEARS

BACK ROW: Mel Maalouf, Kathy Johnson, Amy Trahan, Chuck Tuggle, Kary Grabow. **FRONT ROW:** Nate Littrell, Karen Stoffer, Saleem Ali, Carrien Isham, Joan Moore. **PICTURED BELOW:** Kim Murphy, Art Eunson **NOT SHOWN:** Erik Evens, Paul Barrowclough (UK), Erik Evans, Clair Forland, Ruhan Temeltas (Turkey), Jozef Toth (Slovakia), Jianhua Xing (China).

15 YEARS

BACK ROW: Steve Clemens, James Roylance, Andrew Hopkins, Eze Varela, Fritz Schweigert, Chris Solberg. **NEXT ROW:** Brandon Rank, David Shafer, Olga Malakhova, Trent Trahan, Mike Gonzalez. **NEXT ROW:** Nick Steinman, Ron Thayer, Nathan Weller, Gary B. Swift, Alan Frogget, Bambi Torres. **FRONT ROW:** Dan Perez, Michael Henningsen, Desiree Constable, Helen Robinson, Joyce Jones. **NOT SHOWN:** Kevin Ahearn, Sanjeev Ahuja (UAE), Mylin Aquino (Philippines), Richard Archer, Raj Arumugam, Steffie Baird (Australia), Janice Barnes, Chris Barnett, Michael Barreras, Andrew Bell, Uday Biradar (India), Arco Boeter (Netherlands), Stephen Burns, Tanya Bynum, Donald Charlton, Tim Clark, Anthony Dinunzio, Jacek Dyrda (Poland), Darren Evans, Beth Floyd, Mark Geneau, Jason Hayward (Canada), Ron Hornbrook, Matt House, Todd Kirchoff, John Kitchens, Sunil Kutty (India), Corinna Moessner (Germany), Will Nanse, Walter Piotto (Brazil), David Price, Matthew Priddy, James Reynolds, Glauco Sapia (Brazil), Pascal Sari (France), Shekhar Sashital (India), Terri Schneeberger, Edward Shek, Pascal Steeves, Craig Stephens, John Tomlinson, William Trevino, Marius van der Heiden (Netherlands), Lee Webster (UK), Oliver Wiederhold (Germany), Kenichi Yamamoto (Japan), John Yu.

10 YEARS

LEFT TO RIGHT: Marissa Cullers, Scott Rokis, Karen Schanhals. **NOT SHOWN:** Samad Adam (South Africa), Stephen Coe (Canada), Gabriella Czika-Bácskay (Hungary), Kedar Desai (India), Shoaib Haleem (Canada), Sandeep Kantak (India), Parag Naik (India), Parag Jayvant (India), Gishu Pillai (India), Michael Powell, Glen McNally, Teri Paulsen, Haitao Qi (China), Abhijit Thakoor (India), Yu Zhang (Singapore), Xiyu Zhu (China).

CITYSCAPE, DUBAI

Condition Monitoring & Diagnostics Training – Middle East and Africa

Mohamed Shams
Lead Services Manager
mohamed.shams@ge.com

With more than 50 years of technical training experience, GE's Bently Nevada* has pioneered the art of long-term skill development. Our courses are presented in more than 20 languages and are available online, at your on local facility, or at GE training locations around the world. We offer technical training in topics including condition monitoring & diagnostics, inspection & measurement technologies and control systems. Our proven techniques have achieved strong regional expertise in more than 50 countries.

Machinery Vibration Analysis & Diagnostics

This series offers proven analytical techniques for solving machinery vibration problems in rotating and reciprocating machines. These courses are recommended for Condition Monitoring, Reliability and Maintenance professionals.

- Fundamentals of Vibration
- Basic – Machinery Diagnostics
- Intermediate – Machinery Fundamentals & Applied Diagnostics
- Advanced – Advanced Machinery Dynamics
- Reciprocating Compressor Condition Monitoring & Diagnostics
- Balancing Workshop

Machinery Thermodynamic Analysis & Performance

Students of this course will learn how to use Bently Performance software to calculate thermodynamic parameters for evaluating the condition of monitored assets. Basic and advanced level courses are available for the following machinery types:

- Gas Turbines
- Steam Turbines
- Centrifugal Compressors
- Centrifugal Pumps

Bently Nevada Systems Operation & Maintenance

These courses are offered to Instrumentation and Maintenance professionals responsible for operating and maintaining Bently Nevada protection and monitoring hardware and software systems.

- 3500 Operation & Maintenance
- 3500 Encore Operation & Maintenance
- ADRE* Sxp/408 DSPi
- System 1* Fundamentals
- Ascent* & SCOUT Portable Data Collector & Analyzer Training

Mobius ISO Vibration Analysis Certification

GE has partnered with the Mobius Institute to provide ISO vibration analysis certification for Categories I, II & III in specific countries of the Middle East & Africa.

Computer-Based Resources

GE is offering two computer-based resources related to vibration analysis and diagnostics:

- Data Acquisition (DAQ) Self-Study Course
- Machine Library Reference CD

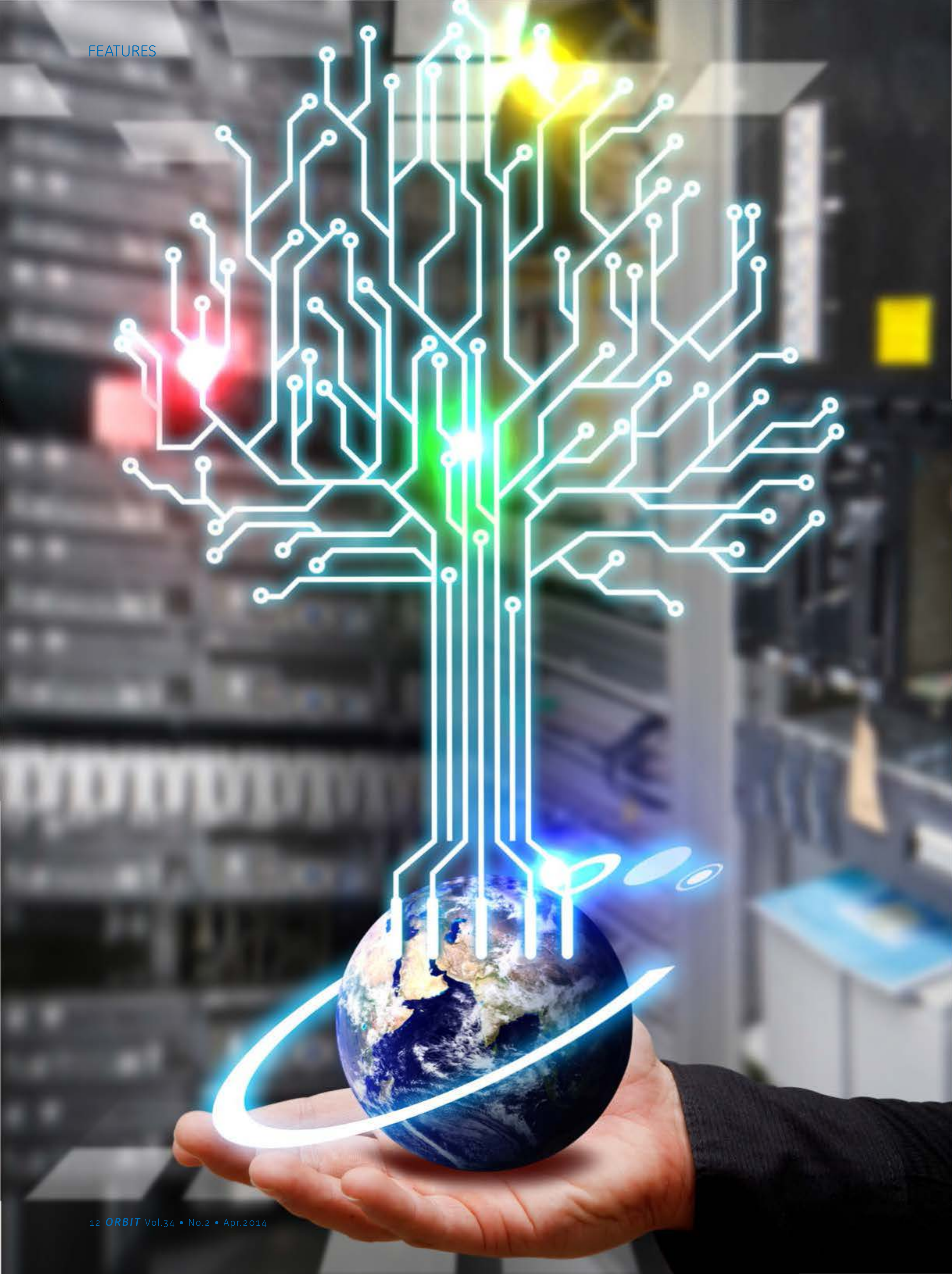
2014 Training Courses

Note: This calendar was accurate at the time of publishing, but printed materials are subject to change without notice. To ensure that you have the most accurate information, please contact your local sales office, or check our online training portal at this link:

http://ge-energy.turnstilesystems.com/ProgramHome.aspx.

Course Title	Days	Location	Start Date
Saudi Arabia			
SCOUT Portable Vibration Analyzer	2	Khobar	16-March
3500 System Operation & Maintenance & System 1 Fundamentals	5	Khobar	21-April
Machinery Diagnostics	5	Khobar	1-June
3500 System Operation & Maintenance & System 1 Fundamentals	5	Jubail	13-July
3500 System Operation & Maintenance & System 1 Fundamentals	5	Yanbu	9-September
ADRE 408 Sxp	3	Khobar	7-October
Machinery Diagnostics	5	Yanbu	2-November
Machinery Fundamentals & Applied Diagnostics	5	Khobar	9-November
United Arab Emirates			
Mobius CAT I (Course & Exam)	4	Abu Dhabi	16-March
3500 System Operation & Maintenance & System 1 Fundamentals	5	Abu Dhabi	7-April
Bently Performance	3	Dubai	20-April
Advanced Machinery Dynamics	5	Dubai	11-May
Mobius CAT II (Course & Exam)	4	Abu Dhabi	8-June
Mobius CAT I (Course & Exam)	4	Abu Dhabi	5-October
Mobius CAT III (Course & Exam)	5	Abu Dhabi	2-November
3500 System Operation & Maintenance & System 1 Fundamentals	5	Abu Dhabi	17-November
Kuwait			
3500 System Operation & Maintenance	3	Kuwait	10-February
System 1 Fundamentals	3	Kuwait	6-April
Machinery Diagnostics	5	Kuwait	7-September
3500 System Operation & Maintenance	3	Kuwait	12-October
Qatar			
System 1 Fundamentals	3	Doha	2-February
3500 System Operation & Maintenance	3	Doha	20-April
Machinery Diagnostics	5	Doha	4-May

Course Title	Days	Location	Start Date
3500 System Operation & Maintenance & System 1 Fundamentals	5	Doha	7-September
ADRE 408 Sxp	3	Doha	16-November
Oman			
Machinery Diagnostics	5	Muscat	22-June
Bahrain			
3500 System Operation & Maintenance	3	Manama	10-March
Pakistan			
Machinery Diagnostics	5	Lahore	3-March
3500 System Operation & Maintenance	3	Lahore	9-June
System 1 Fundamentals	3	Lahore	13-October
Turkey			
3500 System Operation & Maintenance	3	Istanbul	3-March
Machinery Diagnostics	5	Istanbul	9-June
System 1 Fundamentals	3	Istanbul	15-September
Algeria			
Machinery Diagnostics using System 1	5	Algier	20-April
System 1 Fundamentals	3	Algier	17-August
Machinery Diagnostics using System 1	5	Algier	19-October
Nigeria			
Machinery Diagnostics	5	Port Harcourt	15-September
3500 System Operation & Maintenance & System 1 Fundamentals	5	Port Harcourt	20-October
3500 System Operation & Maintenance	3	Port Harcourt	17-November
South Africa			
System 1 Fundamentals	3	Midrand	7-April
3500 System Operation & Maintenance	3	Midrand	14-July



ADVANCED Analytics

As an engineering company, GE has always done math, and done math well. But in many cases, there's no fixed formula for how our assets will be impacted by operational, environmental, or maintenance changes over their long lifetimes—for how an engine will behave in a patch of turbulent air, or how wind turbines will interact with each other during a storm—because the real world is full of chaos. But it's only in the real world that you can truly see what's happening.

Analytics are a way of seeing. They give us the ability to find patterns amidst chaos. They allow us to understand what's happened in the past, forecast what's to come in the future, and make informed decisions that bring about the changes we desire. And change, dramatic change, is at the heart of industry today.

John Perry
Marketing Content Strategist

Industry is transforming due to the big data and mobile technology revolutions that have happened in the consumer world. The Industrial Internet is a new vision for industry, where data-generating smart machines outfitted with sensors, software, and wireless communication converge with advanced analytics to give people meaningful insight into industry's most intractable challenges and cutting-edge opportunities.

Data is the light source of this vision, and GE is bearing the torch by not only designing and manufacturing smart, data-centric machines, but also by bringing together the best and brightest minds in software development to turn data into actionable information. GE Software, founded in 2011 with a one billion dollar investment, is developing a robust platform for the Industrial Internet called Predix as well as advanced analytics solutions in areas such as energy and transportation.

"The gap that we're trying to fill, and really complement the engineering side of GE, is understanding, through data-driven analytics, the chaos of the world that our equipment operates in," says Anil Varma, data science leader for GE Software. "The question becomes, how do you do analytics on the operational data that comes off of our equipment, taking into account all the data about the environment and the way the customer operates the equipment over decades of life?"

To better understand how advanced analytics help us see and gain insight, it helps to know what we are looking for.

Most frequently, industrial analytics have been used to monitor asset health and identify problems. As with Bently Nevada's expertise in vibration monitoring and diagnostics, many analytics target the health of individual assets, not only for safety reasons in cases such as jet engines, but also because asset failure directly relates to inefficiency, lower production, revenue loss, and maintenance expense. The types of analytics developed early on for this purpose were of two classes, descriptive analytics and predictive analytics.

Descriptive analytics essentially summarize raw data. Take a complex device like GE Aviation's GEnx engine. You could, in theory, take each stream of vibration sensor data and analyze it individually. This approach would be incredibly inefficient though, because you'd need as many people as sensors to do it, since there's only so much information a single person can process. Descriptive analytics aggregate all that sensor data to provide a general picture of, for instance, the vibrational dynamics of the engine.

Predictive analytics take this information one step further, applying statistics, modeling, and machine learning to forecast potential future states of a device and predict problems well in advance of failure. Predictive analytics are the staple of the Industrial Internet and are at the heart of GE's Predictivity solutions.

And yet, prediction alone doesn't completely fulfill the promise of the Industrial Internet. Information has little power unless it can influence decision making. And this is where GE's approach to advanced analytics comes in.

If you compare GEnx, first produced in 2006, to GE90, the world's largest turbofan engine introduced in 1995, GEnx is designed to output much more data than GE90. Applying analytics to that additional data can happen in a few different ways.

"You have two choices. You could use the same measurements that you had previously, but maybe the resolution is higher, but you're basically back to where you were," says Dustin Ross Garvey, lead machine learning researcher at GE Software. "Or you can see how new sensors combine with things we've measured historically to make better decisions. As you add more and more signal, you're getting more and more observability."

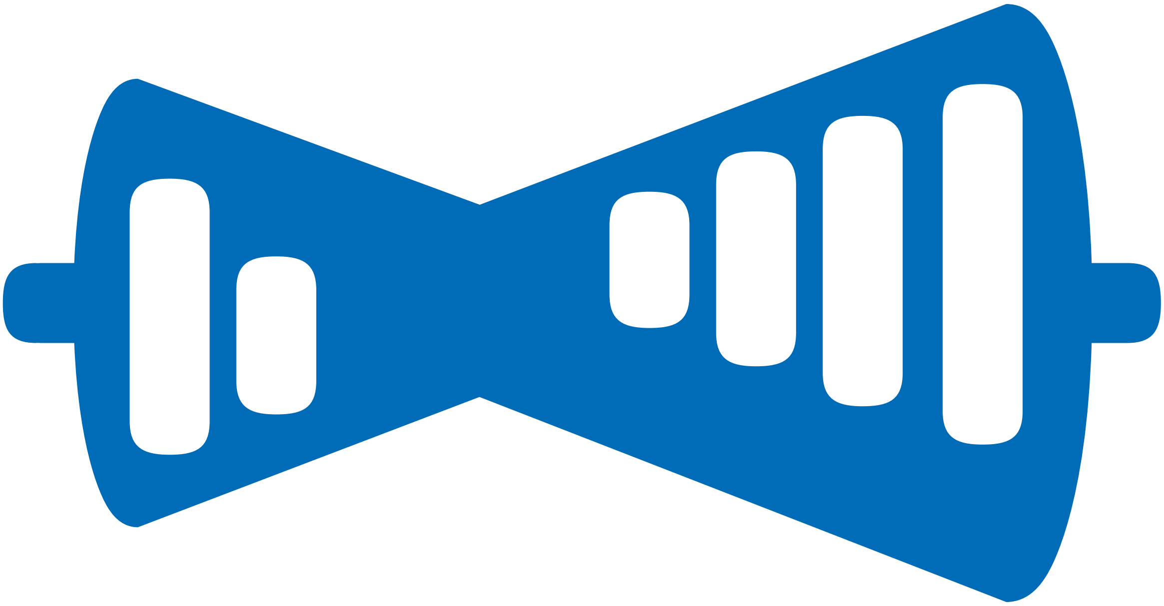
Having greater, more varied, and better data opens up the possibility of answering a much wider and more interesting range of questions that directly impact productivity. Instead of focusing exclusively on failure prevention, there's an opportunity to focus on performance and actively make decisions to improve production based on data.

GE Oil & Gas's hydraulic pumping systems, for instance, are outfitted with sensors that can measure the efficiency and flow rate of the pumps. Knowing whether or not a pump is operating inefficiently or is about to fail is important, but advanced analytics can be developed to answer questions in a more positive direction, analyzing efficiency on a field level, identifying which wells are the most productive, assessing the water cut of particular wells, and recommending decisions that can improve production for the entire field.

When analytics are applied to recommend courses of action to decision makers, they are known as prescriptive analytics. If predictive analytics are the Industrial Internet's staple, prescriptive analytics are its endgame. All the efforts of smart machines and big data are designed to ultimately influence and improve decision-making by harnessing the power of ubiquitous data.

GE is at a stage where operationalizing big data to reduce failure and increase uptime is a standard part of our approach to advancing the Industrial Internet, whether in aviation, energy, healthcare, or transportation. Now, with advanced analytics, the focus is shifting toward answering value-driven questions. How do customers increase overall production? How can various assets work together to make a process more efficient? How can a customer choose the asset least likely to fail among the fleet for a high priority task? What new opportunities can we generate by combining multiple structured, unstructured, asset, system, and environmental data?

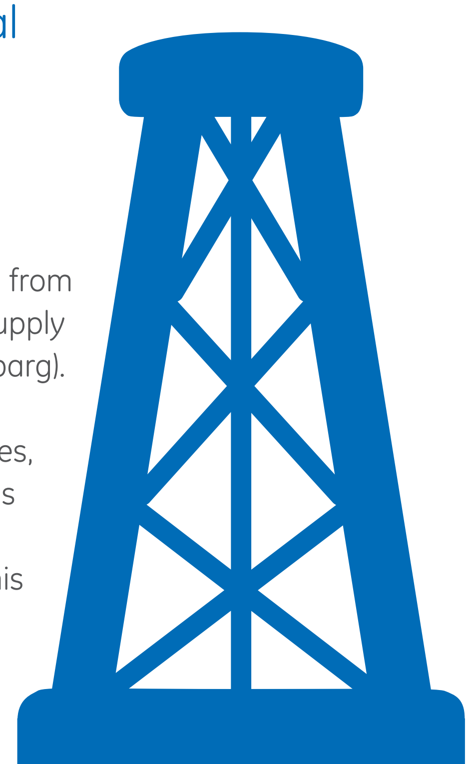
Answering these kinds of questions requires scaling up from the level of individual assets to looking at entire fleets and systems, and growing analytics from predicting outcomes to prescribing solutions. The world may be chaotic, and there might not be a single formula to describe how an engine will behave in the real world, but with the rise of advanced analytics the real world is getting a lot more knowable.



SEA DEBRIS

Detected in the Lube Oil Cooling System of a Combustion Turbine on an Oil and Gas Offshore Platform

Customer Success Story from GE's Industrial Performance & Reliability Center



What did GE's Analytics Software Find?

In August 2013, shortly after startup, the lube oil supply temperature on a bearing on a combustion turbine increased from 150°F to 175°F (65°C to 80°C). At the same time, the lube oil supply pressure dropped from 78.3 psig to 72.5 psig (5.4 barg to 5.0 barg). Also, the scavenge temperatures began to return higher than expected values. The platform was not aware of these changes, as no alarms had triggered in the control room. Experts in GE's Industrial Performance & Reliability Center (Industrial PRC) notified the customer of these changes and began to track this potential problem on their regular weekly call.

What was the Underlying Cause?

Operators on site examined the situation and learned that, during the time the turbine was down, debris from the sea was able to collect in the lube cooling system. After startup, the debris reduced cooling water flow and didn't allow for proper cooling of the oil. This caused the temperatures to increase and the pressure to drop.

What was the Value to the Customer?

The notification of the issue from the Industrial PRC allowed the platform to take preventive action to clean the system and remove the debris before the temperatures increased further. The temperatures returned to model predictions after maintenance was performed. If this preventive measure had not been taken, temperatures could have continued to increase, resulting in a need to shut down the turbine, causing a loss of production.

What They Saw

The screenshot shows a steady increase in the lube oil temperatures with a drop in the supply pressure, deviating from model predictions. The temperatures and pressure returned to predicted levels after maintenance was performed.

GE's Industrial Performance & Reliability Center, using Proficy SmartSignal software, provides comprehensive predictive monitoring across all critical rotating and non-rotating equipment plus key balance-of-plant equipment. The Catch of the Week highlights some of the critical catches detected every day.

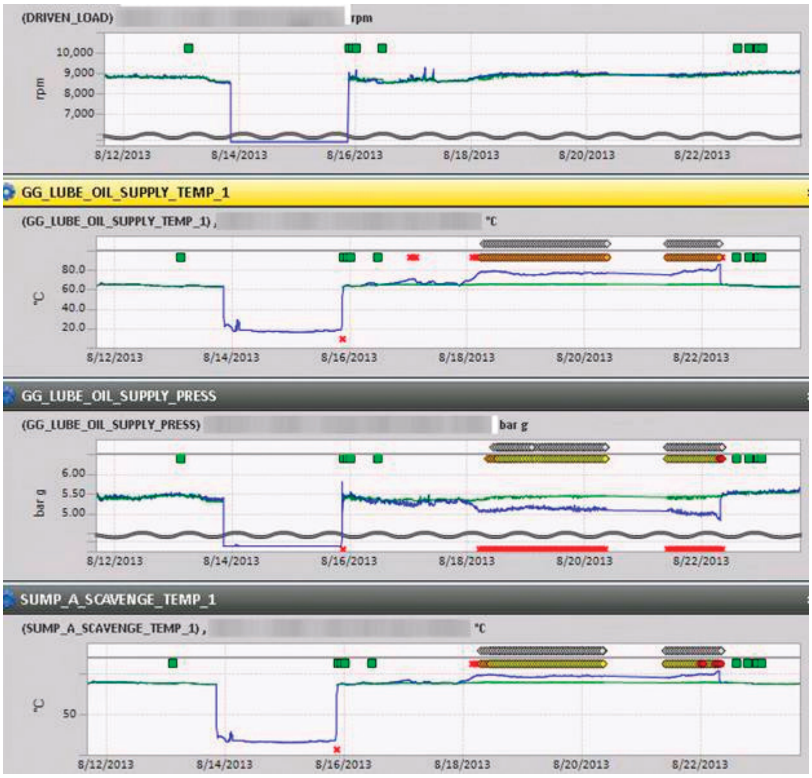
Real customers, real stories. What if you have small, undetected issues that might lead to big problems? We can help you find out.

Meet GE's Experts

Thomas Lowisz
Customer Reliability Engineer

Alex Jenkins
Customer Reliability Engineer

Mike Roe
Customer Reliability Manager



System 1* *for Portables*

NEW TOOLS TO IMPROVE DIAGNOSTIC ANALYSIS

In the last issue of Orbit we discussed how System 1 for Portables simplified the database configuration process by implementing new features and embedding decades of vibration expertise directly into the software. In following the unifying theme of this issue, Advanced Analytics, we will discuss ways the next evolution of System 1 builds on legacy products to offer more effective diagnostic capabilities.

System 1 for Portables offers new tools and incorporates Bently Nevada* and Commtest* expertise on machines and machine faults to create a software environment conducive to running an effective condition monitoring program. New features like predefined default Smart Plots, fault frequency overlays, other plot tools and reporting options will help in identifying and diagnosing machine faults more quickly and effectively than ever.

Nick Aboumrad
Bently Nevada Systems Engineer
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Smart Plots

After uploading collected data and identifying machines of interest, the next logical step is to review relevant data that was collected on each machine. By using the Smart Plots feature in System 1 for Portables you can quickly view predefined default plots that display the information that is most important for your current point of interest. These plots are built to display data that is important for diagnostics and will vary depending on which component you currently have selected. The default plot definitions are built and displayed differently depending on the asset/component type that is selected, the data collection method, and common fault types.

For example, if you are focused on a particular bearing and switch to the Smart Plots view, depending on your measurement configuration, you may see four plots that include a velocity spectrum, acceleration waveform, demodulated ("enveloped") spectrum, and a stacked trend plot with the associated measured variables (Figure 1). In comparison, if you had displayed smart plots from a selected machine train, the smart plots would have displayed stacked trends ordered driver to driven, showing the overall vibration levels for the horizontal, vertical, and axial measurements for that entire train.

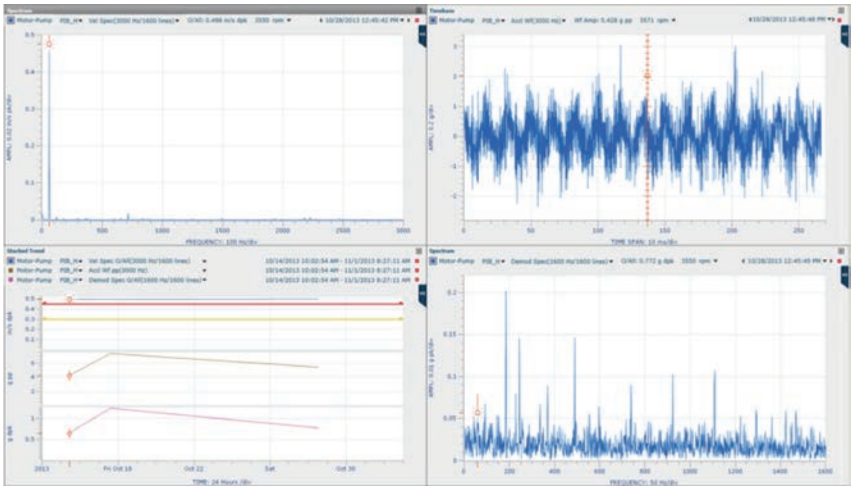


FIGURE 1: An example of a Smart Plot for a particular bearing. The display includes a traditional velocity spectrum (upper left), timebase waveform (upper right), stacked trend (lower left) and demodulated spectrum (lower right).

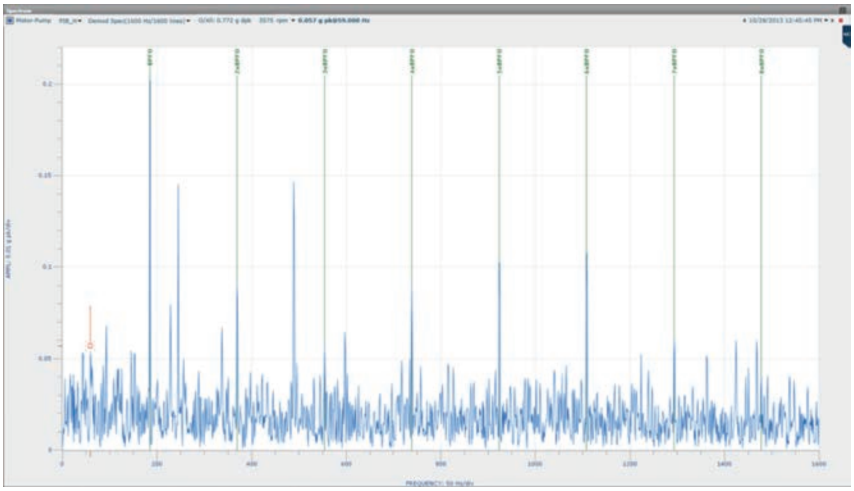


FIGURE 2: BPFO (Ball Pass Frequency for the Outer race) overlays are observed to line up with vibration peaks in a demodulated spectrum.

Fault Frequency Overlays

Another feature that has been introduced as part of System 1 for Portables is the ability to overlay fault frequency markers onto a spectrum plot in order to identify specific components of interest. These fault frequencies are machine specific and dependent on properties that are established during the database configuration process. The overlays can include the fundamental frequency as well as a number of harmonics.

These overlays can help you to diagnose why there are peaks of high vibration at particular frequencies.

Example: When you evaluate a demodulated vibration spectrum taken on a rolling element bearing, these overlays will help show if peaks line up with known bearing fault frequencies (Figure 2). In addition to bearing-related frequencies, frequencies associated with machine running speed, power supply line

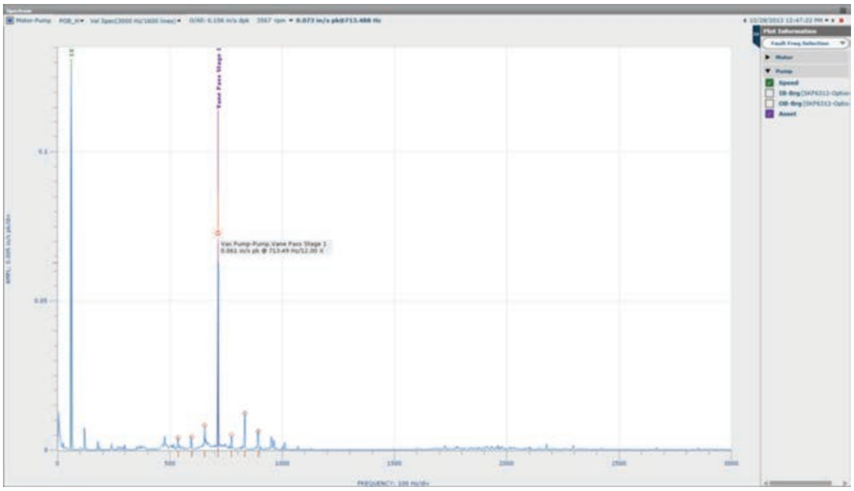


FIGURE 3: This example shows vibration peaks associated with running speed (1X) and vane pass frequency overlaid on a velocity spectrum based on data collected from a pump, with the fault frequency list shown in the right column.

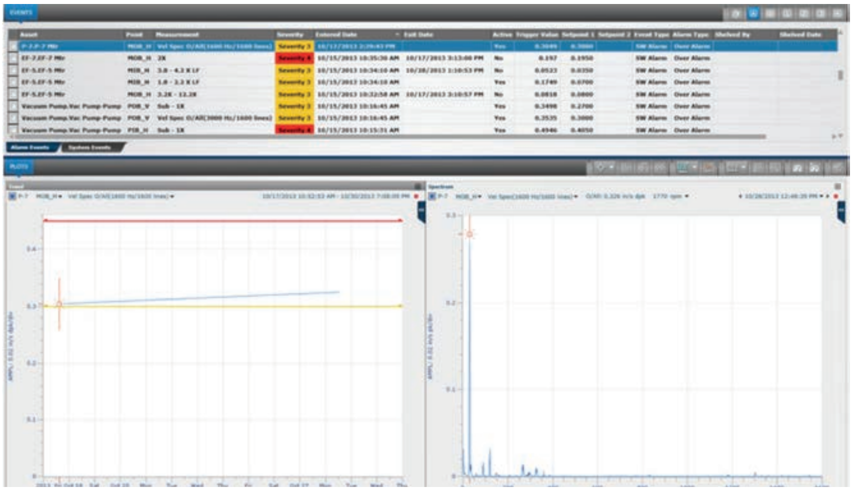
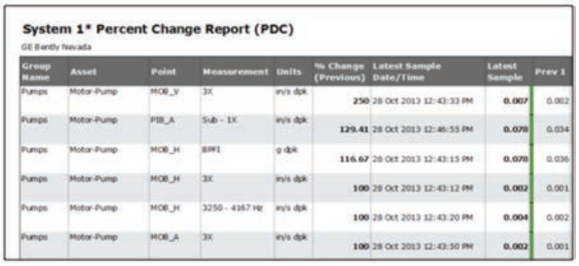


FIGURE 4: Example showing trend and spectrum Alarm Plots for a selected alarm event.



System 1* Percent Change Report (PDC)

GE Bently Nevada

Group Name	Asset	Point	Measurement	Units	% Change (Previous)	Latest Sample Date/Time	Latest Sample	Prev 1
Pumps	Motor-Pump	MOB_V	3X	in/s dpk	250	28 Oct 2013 12:43:33 PM	0.007	0.002
Pumps	Motor-Pump	PIB_A	Sub - 1X	in/s dpk	129.41	28 Oct 2013 12:46:55 PM	0.078	0.034
Pumps	Motor-Pump	MOB_H	BPFI	g dpk	116.67	28 Oct 2013 12:43:15 PM	0.078	0.036
Pumps	Motor-Pump	MOB_H	3X	in/s dpk	100	28 Oct 2013 12:43:12 PM	0.002	0.001
Pumps	Motor-Pump	MOB_H	3250 - 4167 Hz	in/s dpk	100	28 Oct 2013 12:43:20 PM	0.004	0.002
Pumps	Motor-Pump	MOB_A	3X	in/s dpk	100	28 Oct 2013 12:43:50 PM	0.002	0.001

FIGURE 5: Quick Reports configuration dialog and sample report output.

frequency, rotor bar and vane pass events, and other asset specific faults can be overlaid on the plot. By using the fault frequency list provided in the plot, you can display multiple fault frequencies on the same plot at the same time to identify different regions (Figure 3).

Other Plotting Features

System 1 for Portables also offers a number of additional features that assist analysts who are performing advanced diagnostics on monitored machines.

Based on the existing data collection and signal processing settings, the resulting spectral resolution limits may make the exact frequency of a vibration peak somewhat unclear. By using the peak interpolation tool included in the software, you can calculate a very close approximation of what that frequency actually is. This can provide valuable information such machine running speed in situations where it is not being measured directly by a tachometer instrument.

Two additional software features are Quick Plots and Alarm Plots. Quick Plots allow you to establish plots with parameters that are of particular interest to you and see them instantly. These plots remain open and update automatically with new data as you focus on other points or machines. This offers a huge time savings compared to other condition monitoring software because instead of having to recreate the same plots every time a new machine is selected, the plots you already created are automatically updated with the information applicable to each new selection.

Alarm Plots allow you to quickly view the data that is associated with any selected alarm event. Typically the plots will include a trend of the measurement that went into alarm, along with its associated spectrum or waveform plot (Figure 4). When you select a different alarm event the predefined default Alarm Plots are automatically updated with the appropriate supporting evidence.

Reporting Options

System 1 for Portables also includes options for creating reports that will help present your diagnostic analysis. The Percent Change Report can be used to show change in measured variables that occurred between data collection cycles. This report can be created to include all measured variables for a particular selection, or you can use the filtering options to only include those measurements that have a significant change or are above a certain threshold (Figure 5).

Another available report is the Diagnostic Report. This report will export machine and event information, along with the plots that have been created, and put it in a template that is ready for a vibration analyst to enter detailed diagnostic findings and recommendations for the necessary actions that need to be taken.

Conclusion

The features that are offered in Systems 1 for Portables today, as well as those that will be added over time, will assist vibration analysts in completing their diagnostic analysis and in maintaining an effective condition monitoring program. The tools not only embed decades of knowledge into the software, but are also designed to help analysts focus in on problem areas and make an accurate diagnosis more effectively than ever before.

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

Visua

Anomalies with the Wrapped Timebase Plot in ADRE* Sxp 3.0 Software

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RELEASED IN JANUARY 2014, ADRE Sxp 3.0 contains a new Wrapped Timebase plot feature. This new view of the timebase waveform is useful for visualizing how periodic anomalies as seen from a single vibration probe relate to the angular position of the rotor during its rotation. These circular waveform plots make repeatable anomalies show up more clearly when using synchronous sampling. Examples include a damaged tooth (or teeth) on a gear and wear in a fixed outer bearing race (especially if it is located in the load zone.)

Recall: A timebase plot is a presentation of the instantaneous amplitude of a signal as a function of time. When the instantaneous digital values are connected, the recreated waveform corresponds to a classic oscilloscope trace of the signal as seen in the time domain. Timebase plots are very commonly used to display vibration data in software such as ADRE Sxp and System 1*.

An example timebase plot is shown in Figure 1. In this example, synchronous data collection settings were established to create waveform records based on collecting 1024 instantaneous samples per revolution for a total of two revolutions in each record. 50 such waveform records were collected, and averaged together to create this TSA timebase plot.

A "wrapped timebase" plot in Sxp software displays the waveform data in a circular format, rather than an x-y plot. Figure 2 shows an example where this same waveform record (from 17JAN14, 10:00:32:857) is shown as a "wrapped" timebase. Each revolution of the monitored rotor is represented by a full circle. The full scale range of the vibration signal (0.28 g) is represented graphically by the distance between the inner and outer circles. The accelerometer signal is shown as "+" (toward the sensor) and "-" (away from the sensor) about the dashed circle that represents the "0" value.

Note: One way to visualize why the angular values increase in the direction opposite to shaft rotation is to imagine the plot axes being printed on a piece of paper, which represents the rotor divided up into 360 degrees. As the shaft rotates, the probe stays in its fixed location – in this case at the true vertical orientation on top of the machine casing. In this example, the shaft (represented by the paper plot) turns clockwise. So relative to the vertical probe, the measured angle starts with 0 degrees, and counts upwards through 90, 180, 270, and then 360/0 degrees for each rotation of the shaft.

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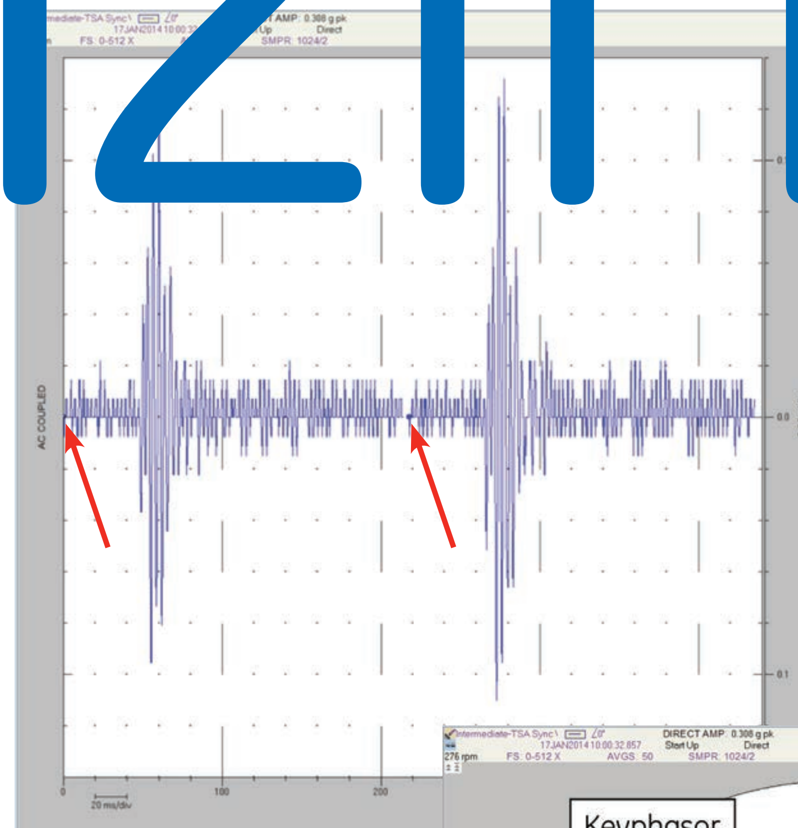

FIGURE 1: This example shows a Time Synchronous Averaged (TSA) vibration waveform record captured from an accelerometer on a wind turbine gearbox. The total time period shown on the x-axis is just under half a second which corresponds to the time required for the rotor to make two complete rotations. This familiar horizontal format mimics the traditional CRT trace on an analog oscilloscope. Red arrows indicate location of the Keyphasor* marks.

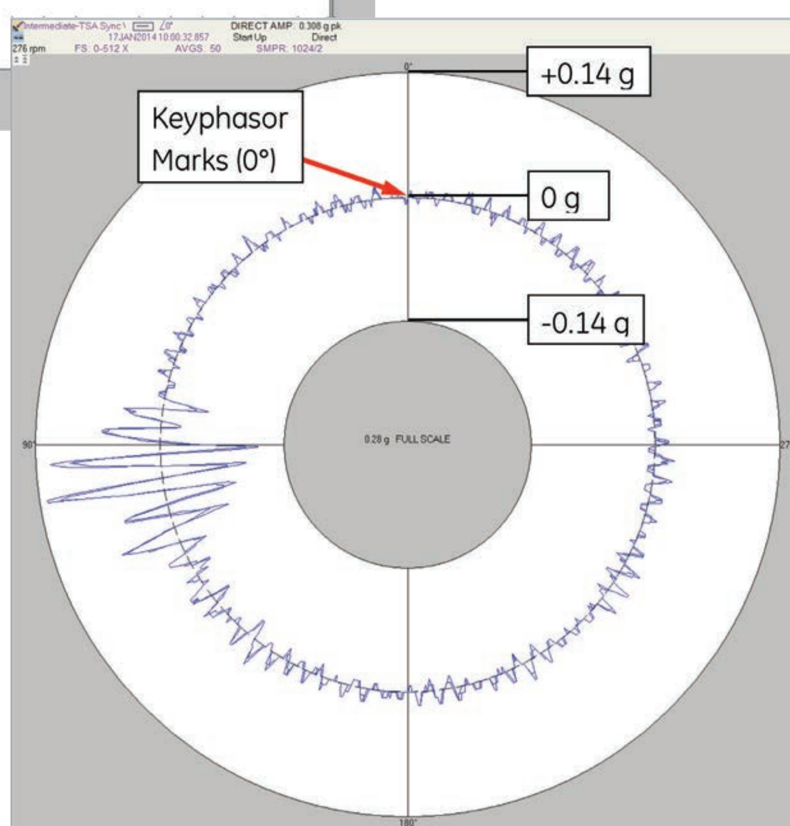

FIGURE 2: In this example, the same data from Figure 1 is shown in a wrapped timebase plot. The accelerometer is mounted vertically on the top of the monitored gearbox, where the 0 degree reference mark is shown on the plot. Rotation is clockwise, so, starting with the Keyphasor event, time increases (degrees of shaft rotation increase) in the counterclockwise direction around the outer circle of the plot. With machine speed of 276 rpm, each complete revolution takes about 0.217 seconds.

The data shown in Figures 1 and 2 is from a wind turbine gearbox shaft that carries an 82 tooth gear. The higher frequency oscillation at 82 times the shaft rotation frequency is caused by this gear. Viewing it in the wrapped timebase plot, we can see how the vibration relates to the shaft rotation angle. In this case we can see that there is an anomaly related to broken gear teeth at about 90 to 95 degrees phase lag from the Keyphasor triggering feature.

The data shown in Figures 1 and 2 is collected with Time Synchronous Averaging (TSA). TSA can filter out non-synchronous vibration from the waveform, leaving only vibration information that is synchronous with shaft rotation. Since the wrapped timebase shows vibration as it relates to the revolution of a shaft, it is useful to filter out non-synchronous vibration, and only show synchronous vibration. When TSA is used, a single revolution shown on the plot represents many actual revolutions of the shaft averaged together.

Configure a timebase plot as a wrapped timebase in the timebase plot group configuration by selecting the Wrapped Timebase option as shown in Figure 3.

Note: The Wrapped Timebase Plot only applies to synchronous waveforms. Asynchronous waveforms in a plot group configured for wrapped timebase will simply be shown as traditional timebase plots.

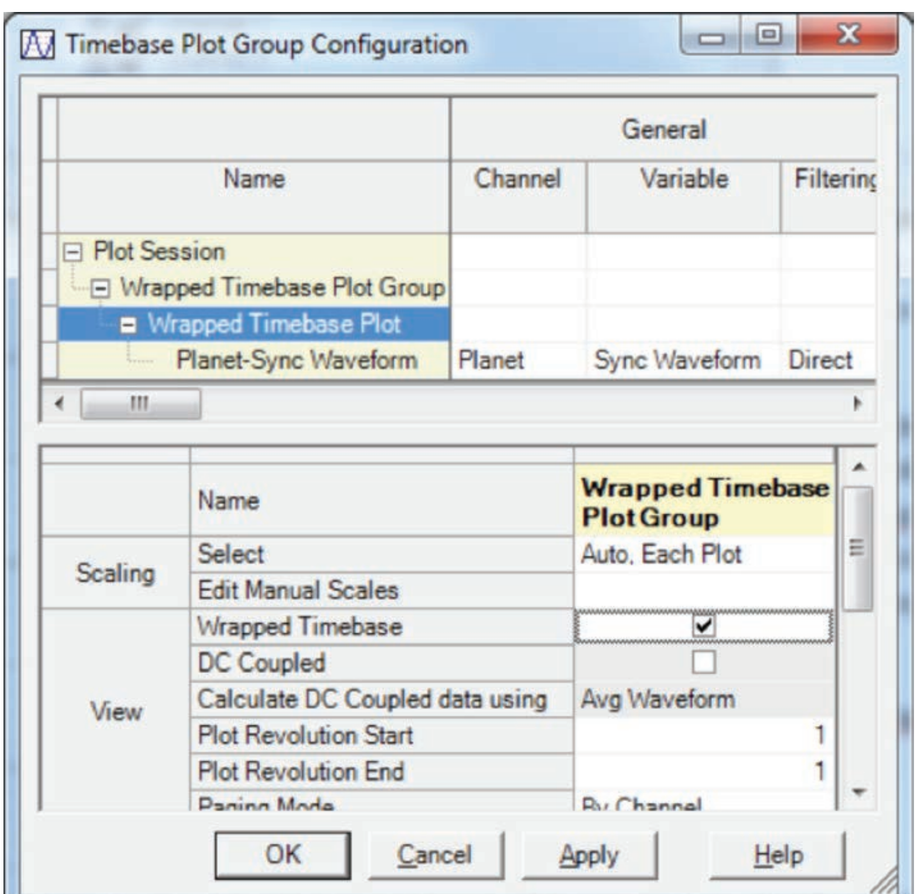

FIGURE 3: Configuring the wrapped timebase plot in ADRE SXP 3.0 software.

Multi State Analysis in Condition Monitoring Systems (CMS)

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In condition monitoring and protection systems, it is often possible to establish two separate alarm levels for each measured parameter. In Bently Nevada* systems, for example, the lower severity alarm is called the "Alert," while the higher severity alarm is called the "Danger" alarm. Crossing these alarm thresholds provides information about a minor deviation of the measurement from normal conditions (Alert), and a more serious deviation (Danger).

The Danger alarm usually indicates that a significant change in physical condition of the monitored asset has occurred. When the monitoring system is configured to interact with a protection system, the Danger setpoint is normally selected to actuate protective trip logic, which shuts down the protected machine without human intervention. Of course, such a protective trip impacts the production process, but this outcome is preferable to allowing the machine to be damaged by continued operation.

With diagnostic systems that do not provide automatic protective functions, it is often possible to use more than two thresholds for each measurement. Consequently, the diagnostic system can distinguish between more subtle changes in physical condition of the monitored assets. In this Hydro Corner article, we will describe typical measurements (and symptoms) that are used specifically for evaluation of physical condition of hydro turbine-generator machines. However, the approach presented here can be used for any other assets covered by a diagnostic system as well.

Operating Conditions

Ideally, observed symptoms should only depend on actual condition of the monitored asset, and unambiguously describe failure modes. However, in the real world, production assets can operate in various challenging environments with different operating conditions. Observed symptoms can be significantly affected by these factors, rather than indicating the true physical condition. Many observed symptoms are functions of not only the physical condition of the asset, but also of the following variable factors:

- Process Variables, and
- Environmental Variables

Process Variable Dependence

In this example, a 220 MW generator was instrumented with a 3500 monitoring and protection system. Generator shaft vibration Danger alarms were established with setpoints of 140 µm. During normal unit operation, operations personnel noted significant variation of shaft vibration levels. The vibration values at the generator bearings ranged from approximately 50 µm up to almost the alarm setpoint of 140 µm.

Based on vibration data collected from XY displacement transducers for various operating conditions, it was observed that the varying levels of rotor vibration depended significantly on generator load. An example of such correlation analysis for a chosen transducer is shown in Figure 1. This vibration data was collected during one week of typical unit operation, and based on the experience of station personnel, it shows a representative relationship between vibration and load for their generator when it was in good (normal) physical condition.

Note: This x-y plot tool is a standard feature of Bently Nevada System 1* software. It is very useful for correlation analysis, to observe relationships between vibration from various transducers dedicated to condition measurement and the selected process or environmental variable.

Observe that the normal range for load regulation for this generator is between 140 and 220 MW. Interestingly, vibration levels initially drop as load is raised above 140 MW, falling to a minimum at about 155 MW, then rising and peaking at about 200 MW before again falling as load is raised to maximum.

The range of vibration levels for the analyzed measurement point (bearing #2 – transducer Y) is from around of 60 µm up to 130 µm. The black line represents empirical correlation between the measured Symptom (rotor vibration) and the Process Variable (generator load).

Suppose the plant operators observe vibration levels around of 80 to 85 µm (approximately 60% of the Danger setpoint of 140 µm). Does this mean that the generator physical condition is normal? Maybe – but maybe not – depending on actual generator load at the time of the vibration measurement.

One way that maintenance specialists can assess generator condition is to determine the normal variation of measured vibration with load, and establish the empirical correlation curve as a baseline during normal operation. If the observed vibration ever deviates significantly from the established curve, it is indication of an anomaly that may reflect a change in physical condition of the asset.

Operating States

Defining several different operating zones as "states" allows us to more easily establish alarm settings that indicate normal vs. abnormal conditions. As an example, Figure 2 shows the same data from Figure 1, only with six different states defined by various ranges of generator load. For each state, we have indicated normal conditions (green), slightly abnormal (yellow), and highly abnormal (red). Establishing these states makes it easier for maintenance personnel to recognize whether or not the 80 to 85 µm vibration level is normal at any given generator load. As shown in Figure 2, this vibration would be:

- Completely normal for states #2 and #4,
- Somewhat abnormal for the state #3,
- Significantly abnormal for states #5 and #6.

Note: We have no sense for normal vibration during state #1, because this particular generator only operates at these low loads very briefly during loading and unloading.

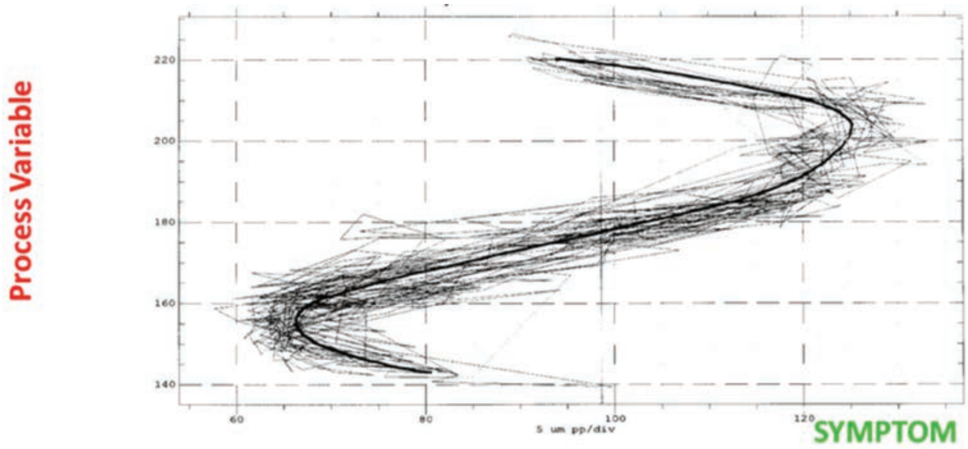

FIGURE 1: This System 1 x-y plot shows how generator vibration in μm (labeled "SYMPTOM" on the x-axis) varies with load in MW (labeled "Process Variable" on the y-axis)

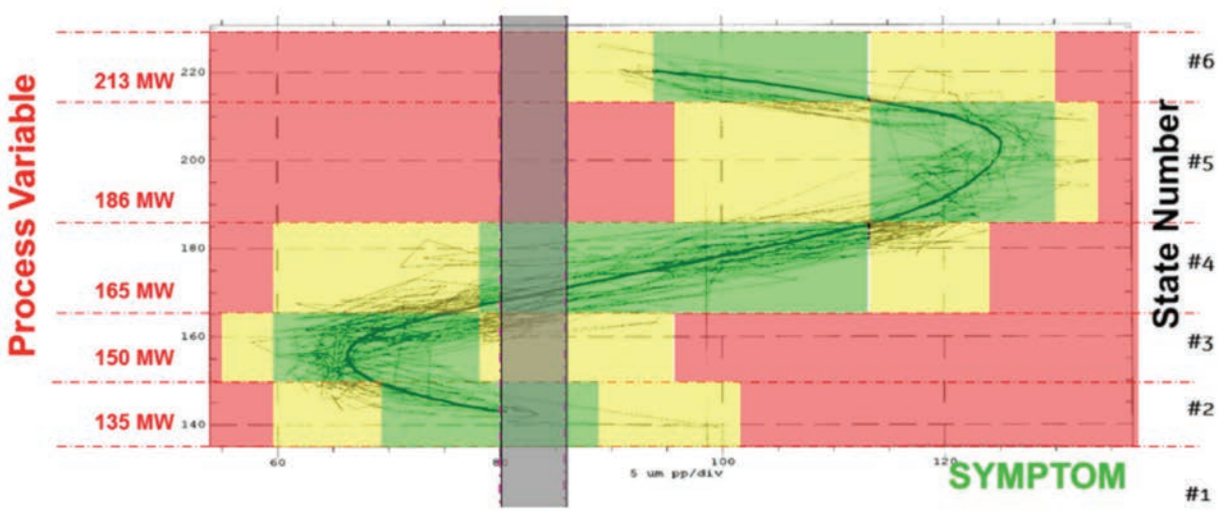

FIGURE 2: The vertical gray band represents the discussed example with measured vibration levels between 80 and 85 μm. Each of the "states" has been established with a region of normal vibration shown in green, and slightly abnormal vibration shown in yellow. The red zones indicate highly abnormal vibration data.

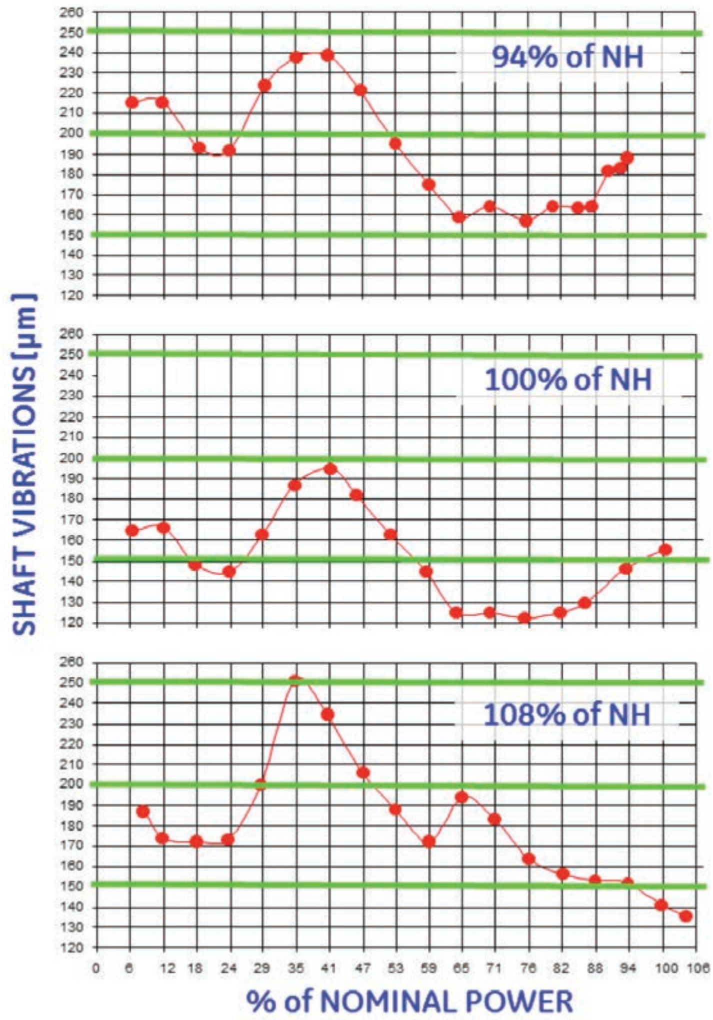

FIGURE 3: Change of shaft vibration at the TGB during vs. changing generator load for three different values of head. "NH" indicates Nominal Head – in other words, the exact hydraulic conditions under which the unit was designed to operate.

Logic Rules

Now that we have developed this set of empirical relationships describing the expected vibration for various power ranges, it is easy to convert them into a set of logic rules for use in System 1 Decision Support tools (Figure 6). These logic rules can be created in Rule Desk tools, or installed as pre-configured HydroX™ RulePaks (Reference 1) that will detect when abnormal conditions (anomalies) are identified:

- for particular machine bearings,
- for particular transducers or measurements,
- for particular states such as the example in Figure 2

Environmental Variable Dependence

ISO Standard 7919 (Reference 2) includes guidelines for evaluating shaft vibration for Hydro-Turbine-Generator (HTG) machines during normal operation. The vibration values presented in the guidelines are described as being independent of "time, head and power." For very basic plant maintenance programs that have not evolved past Predictive Maintenance (PM) methodologies, these guidelines can be appropriate for determining setpoints for monitoring and protection systems.

However, for more advanced programs that use Condition Based Maintenance (CBM) or Predictive Maintenance (PdM) techniques, it is necessary to have a monitoring system that is capable of performing more advanced diagnostics. These systems fall into two general categories:

- Expert Systems: Represented by the HydroX™ RulePaks, and
- Anomaly Detection Systems: Represented by the AnomAlert monitor, Proficy* SmartSignal software, etc.

It is important to realize that various environmental variables – including head – can influence vibration levels of a HTG. Although head is one of the most important environmental variables, others can also influence the vibration readings. These include water temperature, when the range is significant. With some plants, the annual change of water temperature may be as small as 2 °C, with negligible influence on vibration. Other sites may have changes in water temperature of up to 20 °C, in which case the water temperature influence on vibration is usually quite visible.

For a turbine at a different power plant, shaft vibration was observed to vary with significant changes in head (Figure 3). These three plots each show the relationship between shaft vibration and generator load for the Turbine Guide Bearing (TGB) over the normal range of operating load. For this machine, it is clear that the lowest vibration levels occur when head is nominal. When the head deviates from nominal (either higher or lower) by several percent, observed vibration values increase significantly – in some cases by as much as 50%!

CMS Hardware

As we described in the previous issue of Orbit, the Bently Nevada 3500/46 Hydro Monitor incorporates a unique "Multimode" feature (Reference 3). This allows you to establish up to eight distinct machine modes, each with its own unique set of alarm parameters, including Alert and Danger thresholds.

It also allows a control system to automatically tell the monitor which mode exists at any particular time so the correct alarm settings will be used automatically. The selection of various operation modes is executed by three contacts located in the Input/Output (I/O) module of the monitor (labeled IN-1, IN-2, and IN-3 in Figure 4).

The monitor can be used for HTG machines that have strong correlations of vibration to process or environmental variables. It can be programed specifically to accommodate the most important variables that accompany operation in situations such as: various load ranges, generation versus pumping mode (for pumped-storage units), synchronous condenser mode, and so on.

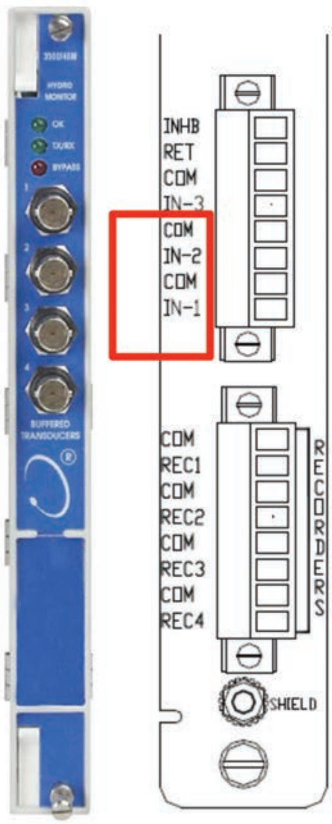

FIGURE 4: Front view of 3500/46 monitor (left) and partial view of its I/O module, showing the three inputs for selection of operating mode (in red rectangle).

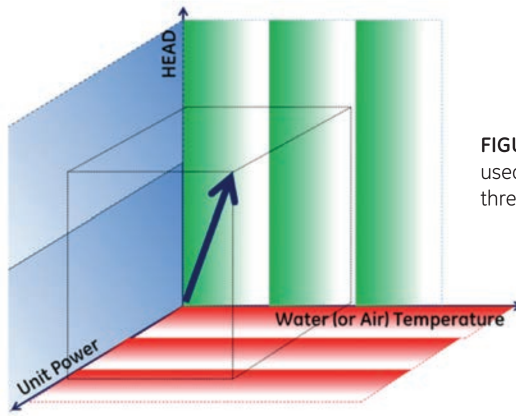

FIGURE 5: An example of 3-D space used for state based analysis with three input parameters.

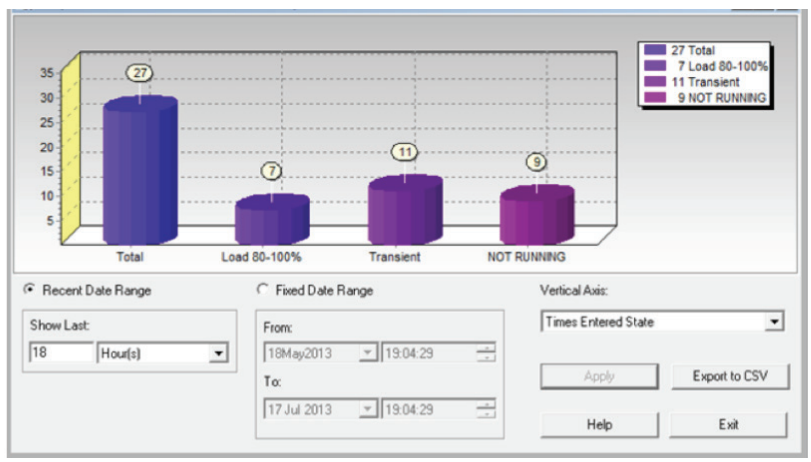

FIGURE 6: An example of State Histogram build by State Based Analysis Tool

FIGURE 7A: These toolbars show the functions that are available for creating logic rules in System 1 Decision Support tools.

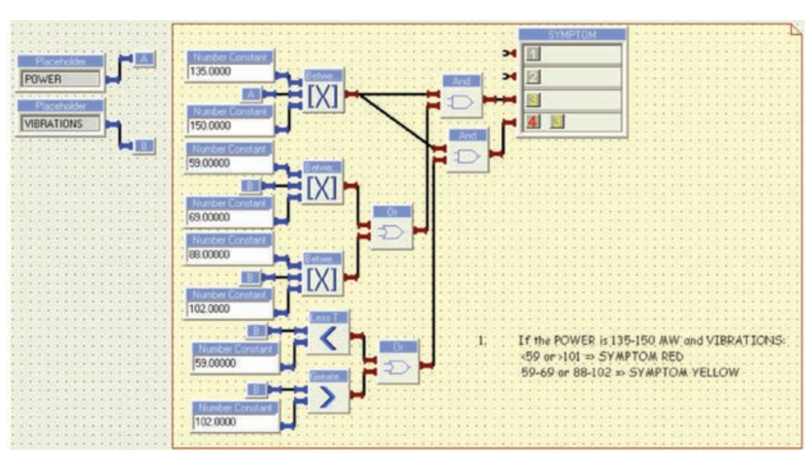

FIGURE 7B: Rule Desk tool used for construction of a specific rule to evaluate generator vibration during operating in State #2.

It is sometimes possible that seemingly obscure environmental variables may not be recognized as important factors that can impact generator rotor dynamics In one example of a run-of-river hydro power plant with vertical Kaplan turbines, it was observed that the vibration level actually depended on direction of the wind!

For some wind directions (coming from one side of the river or the other), the difference in head from one end of the dam to the other was more than 0.5 m (1.6 ft), which was enough to introduce significant errors to the average head measurement – with puzzling impact on rotor vibration. Once the plant staff recognized this effect, they implemented individual head measurement systems for each unit. With more accurate head measurements available, it became possible to increase the sensitivity of the Alert threshold. When this was accomplished, an accurate correlation curve was created to compare Rotor Vibration (Symptom) with Head (Environmental Variable) – similar to the Rotor Vibration vs. Load correlation curve that was created at the plant in the earlier example.

CMS Software

Bently Nevada System 1 software offers a unique System Extender application called State-Based Analysis, which is dedicated to monitoring of assets with more than one mode of operation. This application allows you to define any requested number of dimensions of the analysis, and for each dimension, establish a designated number of ranges.

The first example in this article used 1-Dimensional (1-D) analysis. The dimension was that of generator load, which was divided into six separate ranges. Now, we will go a little bit deeper using the advanced analytics features of System 1 software, and define a 3-Dimensional (3-D) case for a hydro turbine generator. This space is described by the following parameters (Figure 5):

- Generator load (3 ranges, shown with red shading),
- Head (2 ranges, shown with blue shading), and
- Temperature (3 ranges shown with green shading).

Now, when the "symptom" data (such as vibration) is collected in the System 1 database, it can be correlated to these three parameters, by indexing it to the 18 different subspaces that we have defined. The State-Based Analysis system extender has no limitations on either the number of dimensions that can be used to define states or on the number of sub-ranges that can be defined for each dimension.

The State Based Analysis tool allows building of State Histograms which can be observed and reported whenever State Indicators have been configured. Figure 6 presents as an example such histogram build for 4 states.

Note: One hydro-turbine OEM used a software package that allowed them to define approximately 150 different variables for correlation of measured parameters! System 1 software is even more flexible, allowing you to evaluate a practically unlimited number of symptoms, and to define an unlimited number of variables.

Advanced Analytic Software for Predictive Maintenance

The valuable information determined by advanced analytic software can help with more effective implementation of Predictive Maintenance (PdM) programs. Reference 4 describes some of these software tools that can be very useful for improving maintenance in hydroelectric power plants. In addition to System 1 software, these tools include the HydroX™ RulePak that can be used for some specific hydro-turbine-generators, and Proficy SmartSignal that can be used without any limitations for any hydroelectric power plant asset.

Many standard System 1 RulePaks are available for various assets. The standard RulePaks can be extended by creating additional custom rules that facilitate automatic recognition of changes to machine condition. The new rules can be created easily by using System 1 RuleDesk tools. The new custom rules can be useful for evaluating the condition of monitored assets for which you have established multi-mode correlations with process or environmental variables.

Figure 7A shows the RuleDesk logical functions, while Figure 6B shows part of a screen during the process of building of an expert rule. This particular rule will automatically evaluate generator vibration levels for State #2 (135 to 150 MW), as defined in Figure 2.

Note: The available logic tools can perform numerical operations, as well as specialized functions for processing dynamic "waveform" data. This data includes mechanical vibration, fluctuating water pressure pulsations, and proportional voltage or current signals that come from sensor systems measuring a wide variety of environmental and process parameters.

Conclusions

The hardware and software tools described in this article accommodate more precise condition monitoring and protection operation, and more accurate diagnostics than older systems could handle. System 1 software can use MultiMode states from hardware (such as defined in the 3500/46M monitor) or as defined by maintenance specialists in the software itself. Different alarm setpoints can be used - not only for direct vibration, but also for other measurements and analysis (for instance, specific alarms for amplitude vs. phase "acceptance regions" that can vary with changes of selected process variables).

At the expert level of diagnostic software, specific rules can also be created to reduce the "noise" in symptoms that can be caused by the influences of process and environmental variables – thus facilitating more accurate detection and diagnosis of actual changes in asset condition. The custom rules dedicated for each state result in a more efficient PdM approach. Even in an organization that hasn't advanced beyond a traditional Preventive Maintenance (PM) program, System 1 software can provide more accurate diagnostic information, allowing users to detect (and act earlier on) anomalies recognized through the use of state-based analysis techniques.

If an organization recognizes the importance of considering the influence of process or environmental variables but does not have the required expertise, the Bently Nevada team can help. Our specialists can assist with creating appropriate Decision Support rules to perform the needed correlation analysis. In addition to creating custom rules with an optimal number of states in a multidimensional space, our team can help with validity checking and implementation or "commissioning," of the rules in your facility (Reference 5).

References

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For More Information

The Bently Nevada Hydro Turbine/Generator Condition Monitoring and Diagnostics Application Package brochure (GEA-13902) is available at this link: **http://www.ge-mcs.com/download/bently-nevada-software/gea_13902.pdf**