

Cordant™ Machine Diagnostics Services: condition monitoring for rotating and reciprocating machinery





Why monitor?

The success of your plant operations is wholly dependent upon the reliable availability of the machinery you work with to get the job done. Whatever that “job” may be. Condition monitoring of your machinery involves the acquisition and processing of machine and process information and data that indicates the state of a machine or process over time. As machine states deteriorate, you lose the ability to produce product at the rate and cost needed to remain profitable and risk the health and safety of both your employees and the environment if faults or failures occur. Most malfunctions have overlapping symptoms. Because of this, a single piece of data is rarely adequate to make a clear diagnosis, and many types of data must be cross correlated. Thus, vibration analysis should be performed using data from all operating modes of the machine: steady state, transient, slow roll, and stopped.

Why Cordant™ Bently Nevada devices?


As a pioneer in machinery condition monitoring, Bently Nevada has been partnering with customers for over 60 years to help them achieve their operational goals.

- 1,250+ total number of years of MDS experience by our team
- Over 225K customer problems turned into solutions by our services teams
- Savings up to \$1M/day by avoiding lost production
- 5 to 10x cost reduction for well-planned maintenance outage versus unplanned reactive outage

Malfunction table: A comprehensive view

		Typical measurements setup						Additional measurements							
		Radial proximity probes	Casing acceleration /velocity	Keyphasor	Axial proximity probes	Bearing temperature	Trending and analysis software	Electric measured parameters (current, voltage, etc)	Structural analysis (OBS/modal analysis)	Motion amplification camera	High speed torsional kit	Lube oil analysis	Thermography	Performance	Partial discharge
API equipment	API670 5 th Edition (turbomachinery with FFB)	●		●	●										
	API670 5 th Edition (gearbox)	●	●	●	●										
	API670 5 th Edition (centrifugal comp/pump with FFB)	●			●	●									
	API670 5 th Edition (pump/motor with REB)		●												
Common rotating machinery	Unbalance (static/couple)	●	●	●			●		●						
	Misalignment	●	●	●		●	●		●						
	High runout (eccentric rotor, rotor bow)	●		●			●								
	Fluid induced instability	●	●	●			●								
	Rubs (sub-synchronous, synchronous, etc)	●	●	●		●	●				●	●			
	Rotor bow	●	●	●			●								
	Shaft crack	●	●	●			●								
	Mechanical looseness	●	●	●			●		●						
	Electrostatic discharge (ESD)	●				●	●				●				
	Compressor process instability (surge, stall, etc)	●	●	●	●		●							●	
	Pump process instability (cavitation, recirculation, etc)	●	●	●	●		●							●	
	Structural issues (mounting faults, cracks, etc)	●	●	●			●		●						
	Torsional vibration	●		●			●			●					
	REB degradation		●	●		●	●				●	●			
	Blade/vane pass	●	●	●			●				●		●		
	Gearmesh analytics		●	●			●					●			
	Bearing damage	●	●	●		●	●					●			
	Bearing wear	●	●	●		●	●					●			
Centrifugal compressor/pump	Damaged impeller	●	●	●		●					●				
	Damaged seals	●	●	●		●					●				
	Eccentric impeller	●	●	●		●					●				
	Cooling system fault						●								
	Valve fault						●		●			●			
	Compressor fouling	●	●	●			●								
	DGS faults						●			●					
Steam turbine	Damaged rotor blade	●	●	●			●								
	Damaged labyrinth	●	●	●			●								
	Unequal expansion	●	●	●			●								
Gas turbine	Air inlet blockage						●							●	
	Compressor fouling	●	●	●			●							●	
	Compressor damaged	●	●	●			●				●			●	
	Fuel Filter blockage			●			●							●	
	Combustion chamber holed			●			●							●	
	Burner blocked			●			●							●	
	Power turbine dirty	●	●	●			●							●	
	Power turbine damaged	●	●	●			●				●			●	
Combustion rumble		●	●			●									
Motor/generator	Generator/motor malfunctions (non-uniform AirGap, rotor bar cracks, etc)	●	●	●			●								
	Brush(es) fault						●								
	Insulation deterioration						●								●
	Loss of output power phase	●	●	●			●								

1. Malfunctions listed are some of the common anomalies detected; hence machinery malfunctions detected are not limited to only the listed ones in the table
2. Newer versions of the API documents may have different recommendations for measurements
3. (X) Indicates symptoms may occur or parameter may change if fault occurs



Condition monitoring and measurement

Condition monitoring—in detail

- **Steady state data** gives us information about changes in overall vibration levels, frequency content, nX amplitude and phase, position, and orbit and time-based shape during slowly changing, or static rotor dynamic and process conditions. This is an extensive amount of information, but this single operating speed provides only a narrow window of machine behaviour
- **Transient data** gives a much wider picture of the rotor dynamic behavior of the machine. It provides us information about heavy spot locations, balance resonance speeds, and how vibration, frequency content, position, and orbit shape change versus rotor speed

- **Slow roll data** allows us to identify slow roll vectors, waveforms, shaft position, and mechanical and electrical runout under cold and hot conditions. Slow roll vectors and waveforms can be used to compensate transient vector plots, orbit plots, and time-base plots. Slow roll data can also reveal a bowed shaft
- When a machine is **stopped**, the shaft centerline position can be measured. This is most useful in horizontal machines, where the shaft should rest on the bottom of the bearing in a properly aligned machine

And, that's why a **continuous monitoring system** is so important. Specifically designed to meet the unique machinery protection and condition monitoring needs of rotating machines, our solutions, which include safety integrity level (SIL) certified products can help close the gap, while simultaneously improving reliability, availability, and safety. And, with patented technology, comprehensive services, and over 60 years of experience monitoring rotating machines, no one is better equipped to help you than Bently Nevada, a Baker Hughes business.

Measurement—in detail

The process through which an analog signal is transformed into digital is usually referred to as “sampling”. Before getting into further detail, let’s look at the whole sampling process which starts with an analog signal, and ends up as a digital signal, along with one of the most common operations on the digital signal, the Fast Fourier Transform (FFT). In figure 1 below, the analog signal goes through a low pass filter, known as an “Antialiasing filter” (AAF), which attenuates frequency components above the specified frequency. Then the voltage level of the signal is “quantized” through an Analog-to-Digital converter (ADC), wherein the voltage is divided into discrete levels. After having “measured” the signal voltage, it is stored in some type of memory, at a certain rate specified in samples per second. Once the signal has been sampled, it becomes available for either direct representation or for further processing.

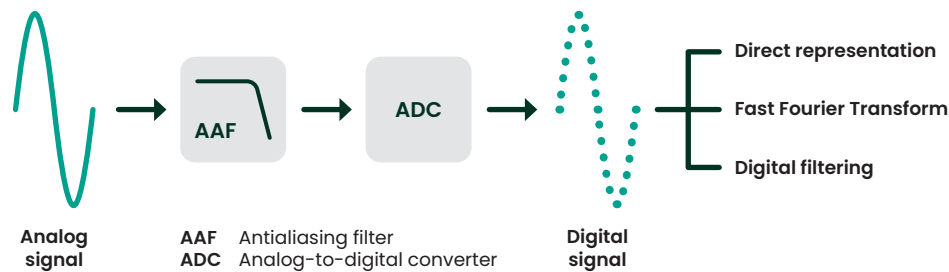
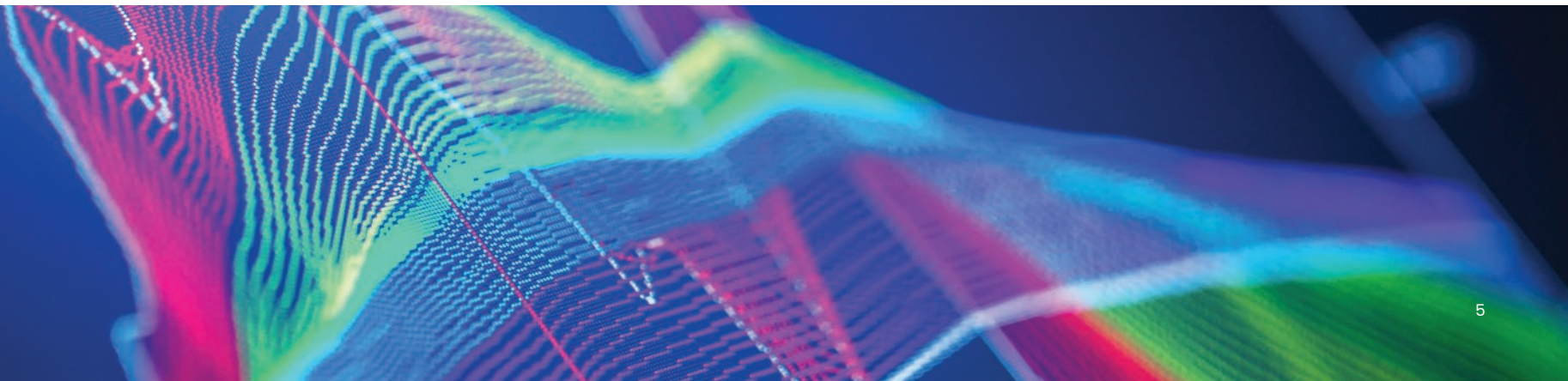


Figure 1

Even though in most cases, the time record doesn’t contain an integer number of vibration cycles, forcing us to use window functions, there are cases in which the time record does cover an integer number of these cycles. If we also consider rotating equipment in general, most of the signal frequency content is usually related to rotating speed, through some ratio (one time, two times, etc.). In cases like these, it would be useful that our sampling rate has also some type of relationship with rotation, some kind of synchronization. That type of sampling is available and is called “synchronous sampling”.

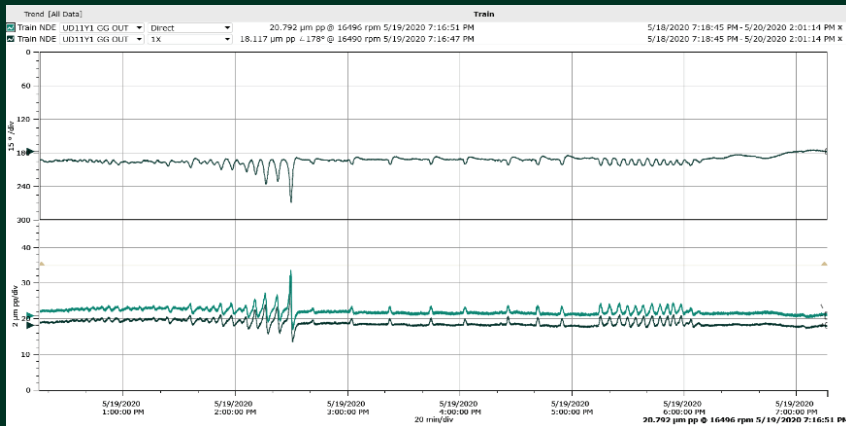
According to what we have discussed so far, it would be logical to arrive at the conclusion that if we want to get a good representation of the original analog signal, we need to make sure we select a sampling frequency high enough (assuming we have a good quality ADC). However, this is not completely true. In contrast with the typical scenario for data collection, in which the machine rotating speed is fairly constant during data acquisition (typical of small balance-of-plant machines), we are sometimes faced with the task of sampling our vibration signals during some transient event, such as a machine coast-down. Though this type of transient event might be considered uncommon, since (optimally) machines are running at normal design speed most of the time, some of the best and most useful diagnostic information is gathered during these “uncommon” state events.

It turns out that the most frequent lateral vibrations generated by rotating equipment are associated with the unbalance force. This force happens to be locked into the rotation of the shaft (the heavy spot on the rotor is located at a fixed angular location). Under these conditions, the dominant vibration occurs at one time running speed, usually referred to as $1X$, with X representing rotating speed. This also means that during machine shutdown, this $1X$ frequency component will track running speed as it decreases. Let’s suppose we want to digitize the vibration signal resulting from an unbalanced rotor, using the already discussed time-based sampling, i.e., collecting samples that are equally spaced in time, during machine shutdown.



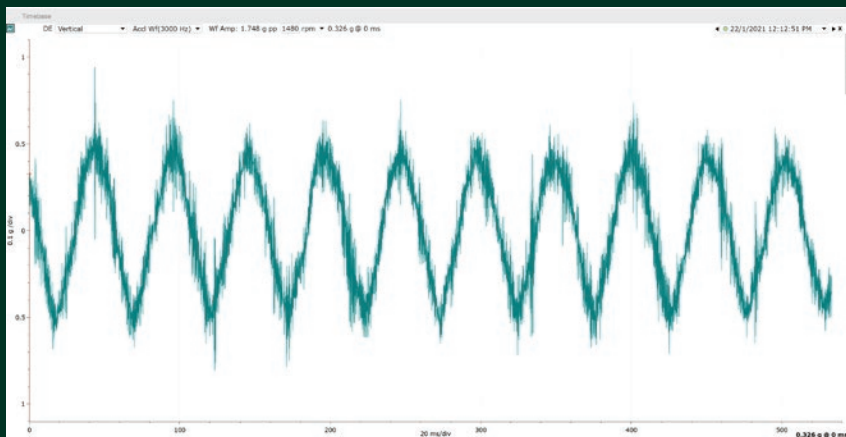
Trend

The most popular plot available is the **Trend** plot which is basically a representation of any numeric variable such as vibration amplitude, temperature, flow, etc v. time. The purpose of this plot is to show how these variables change with time, as well as how they correlate between each other.



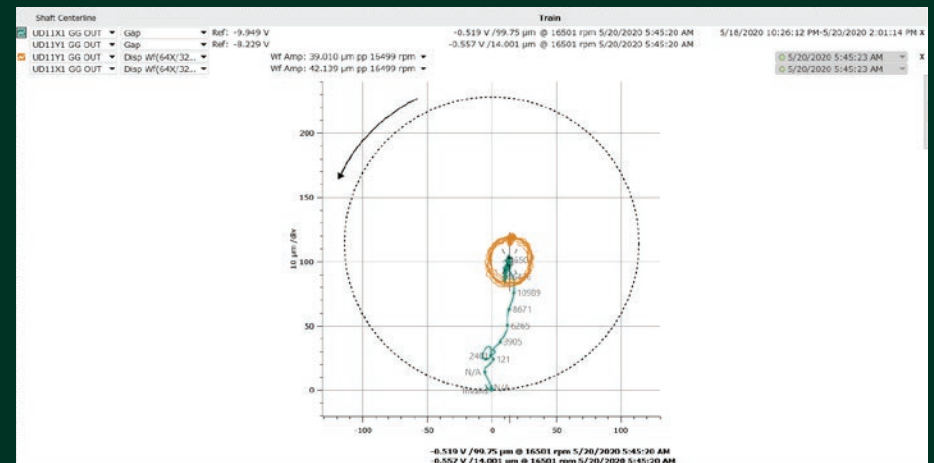
Time base

It consists of a simple representation of instantaneous signal levels versus **Time** in a similar way for to a trend plot for a static variable.



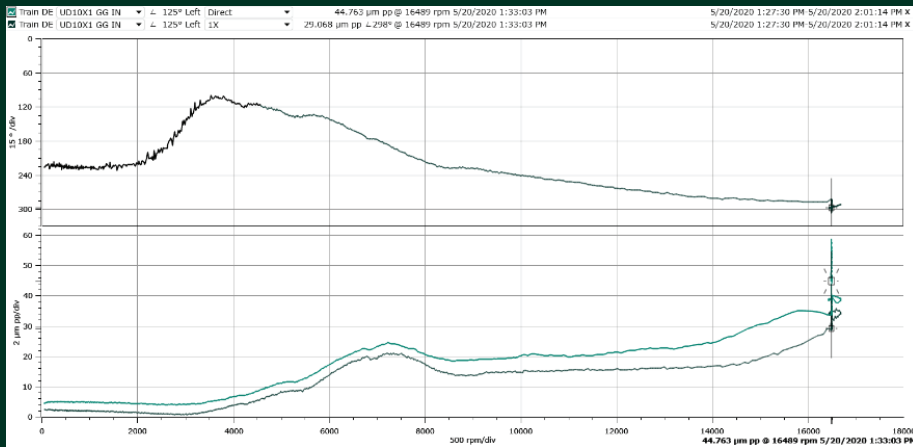
Shaft centerline

Shaft average centerline plots are plots used to observe changes in the average position of a rotor versus speed within its radial bearing clearance during startup or shutdown. It also used to display changes in shaft centerline position versus time at steady state condition. The plots are monitoring the dc gap voltage from XY proximity transducers. The circle drawn on the plot represents the diametrical clearance of the bearing. The combination of bearing clearance and the average shaft centerline allows us to visualize the average position of the shaft relative to the available clearance during startup, shutdown over time.



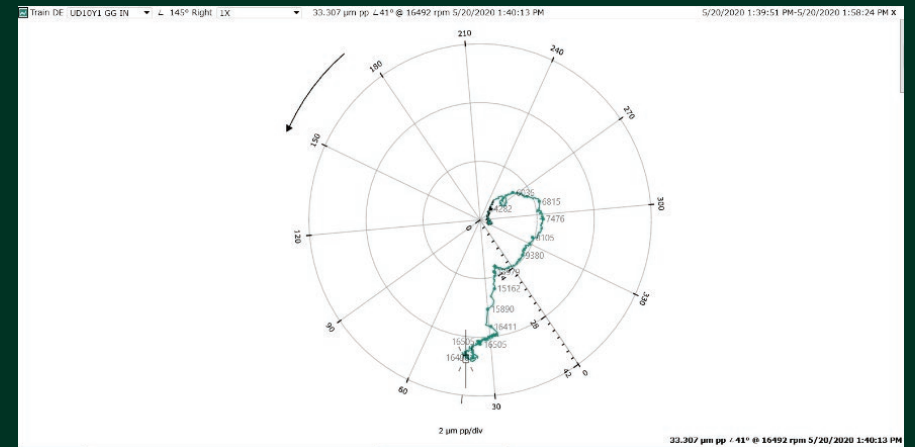
Bode

The most widely used plot format for transient conditions is the **Bode** plot. This plot displays amplitude and phase information versus rotating speed. It is actually a combination of two plots included in one single format. This plot can be used to display any nX filtered data, with “ n ” being an integer number and “ X ” running speed. However, its most common application involves $1X$ or synchronous data, which represents the rotor response to the unbalance force. In this form Bode represents unbalance or synchronous response characteristics of the system. Direct amplitude is often shown to document if there is vibration content at other, then presented vector, frequency.



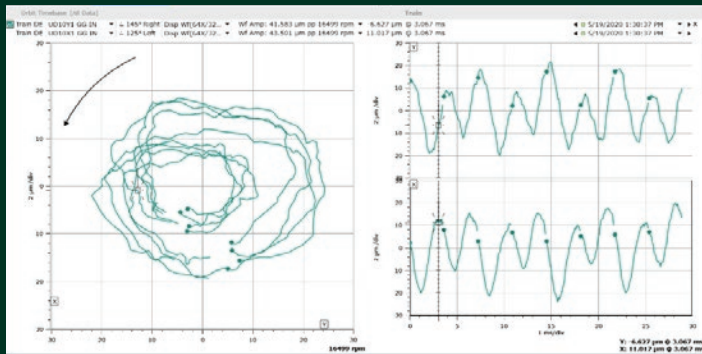
Polar

The **Polar** plot displays the same information as the Bode for amplitude and phase of filtered vibration, but in a different coordinate system. Main coordinates are “amplitude”, represented in the radial direction, and phase, which is measured circumferentially. Since those are the only traditional coordinates in this plot, the missing one, which is “rpm”, is typically included as “labels” close to each vector sample. This plot is used in both transient and steady state conditions and is useful in determining the slow roll vector, slow roll speed range, balance resonant frequencies, synchronous amplification factor, heavy spot location and rotor mode shape as well as changes of the filtered vibration against time or speed.



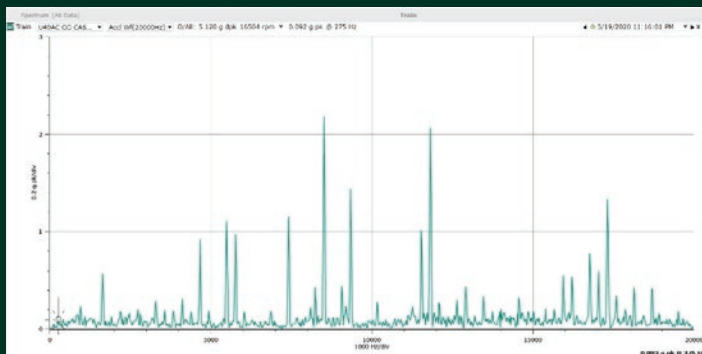
Orbit

The overall or unfiltered **Orbit** constitutes the most realistic representation of rotor vibratory motion within bearing clearance, leaving aside the runout effects. The orbit displays the instantaneous path of the rotor geometric center from two orthogonally mounted (XY configuration) vibration transducers. The Orbit plot is one of the most powerful machinery management plots, because it combines vibration amplitude, phase and frequency into a single plot that is easy to interpret.



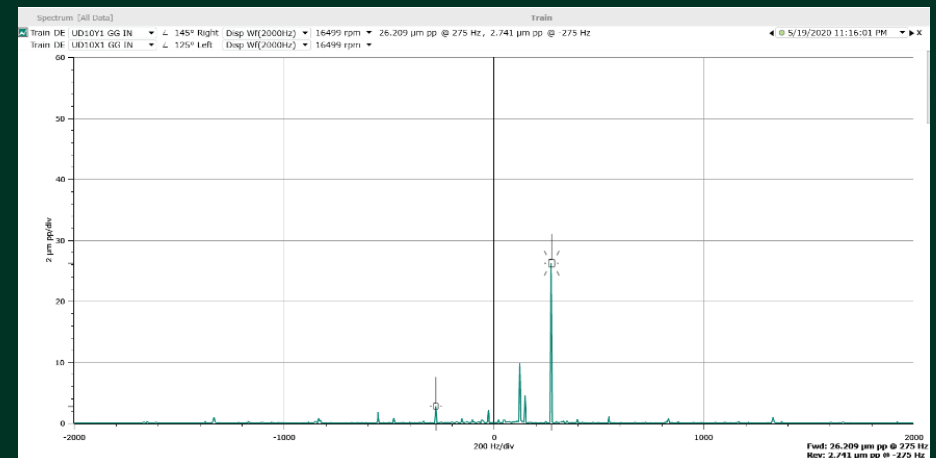
Spectrum

The **Spectrum** is a representation of the signal coming from a transducer that has been previously sampled/digitized, so that a special computational algorithm known as Fast Fourier Transform (FFT) can be applied. The main purpose of this algorithm is to find all the pure sine waves, each one with a specific amplitude, frequency, and relative phase, so that when added together, they allow reconstructing the original complex waveform. Commonly a presentation of a signal's frequency components versus amplitude.



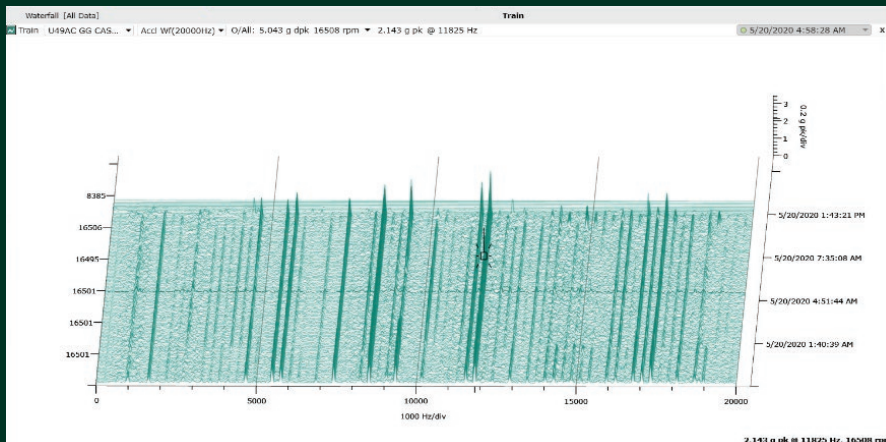
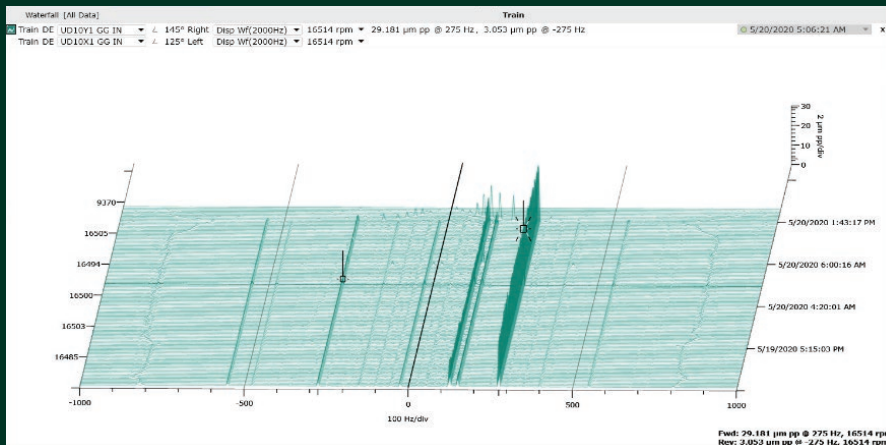
Full spectrum

It has also been called the **Spectrum** of an orbit. Similarly to the half spectrum, it gives information about the frequency content, from two vibration signals generated by two orthogonal transducers X and Y. As it derives from two orthogonal transducers, it provides information of vibration precession. The full spectrum is calculated by performing a Fast Fourier Transform on each transducer waveform. The results are then subjected to another transform that converts the data into two new spectra that represent frequencies of precession, one spectrum for X to Y precession and one for Y to X precession. Finally, information about direction of rotation is used to determine which of the spectra represents forward (orbital motion in the same direction as rotation) and which represents reverse (orbital motion opposite rotation) precession frequencies. The result is a full spectrum plot, in which the horizontal frequency axis has a positive and negative side. In this configuration, each frequency component will have a forward and reverse line. A direct consequence of the mathematical procedure used to obtain this plot is that by comparing the forward and reverse amplitudes of a given component, the shape and resulting precession of the associated orbit can be inferred.



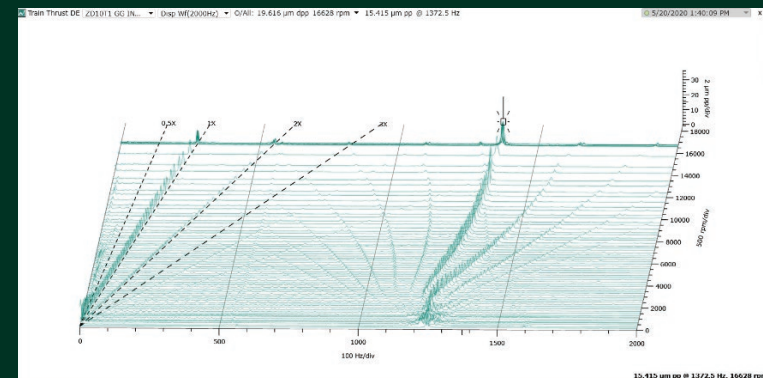
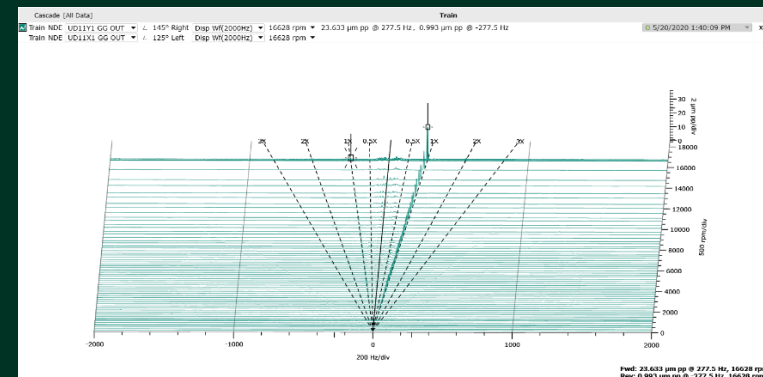
Waterfall

The **Waterfall** plot is basically a trend of the frequency content of the complex vibration signal. This plot type allows determining how the frequency content of a signal changes with time. It has three axis or coordinates: frequency in the horizontal axis, time on the left hand vertical axis, and amplitude on the right hand vertical axis. As time is represented on one of the axis, the main use of this plot is related to steady state data, i.e. when the machine operates at constant speed. The main use of this type of plot is to evaluate the frequency components present in the vibration signal over time, as well as the appearance or disappearance of any abnormal frequency component. Both the full and half spectrum can be displayed as a waterfall plot format.



Cascade

The **Cascade** plot is similar to the waterfall already discussed, in the sense that it shows a group of spectrums at the same time, but instead of displaying them versus time, the cascade shows several spectrums that are generated for different rotating speeds. It has three axis or coordinates: frequency in the horizontal axis, speed of the machine on the left hand vertical axis, and amplitude on the right hand vertical axis. One of the most important advantages of this plot format is that it can show a great deal of information on a single plot. As speed is represented on one of the axis, the main use of this plot is related to transient data, i.e. machine startup or shutdown events. Another important benefit of this graphic tool is that when properly configured, it clearly indicates whether a particular frequency component is speed dependent or not, allowing the diagnostician to identify different malfunctions. Both the full and half spectrum can be displayed as a cascade plot format.



Integrated services, machinery protection, and machinery management systems

9+ million sensors deployed globally

300K+ installed monitoring devices

600+ technology patents

1,800+ employees worldwide

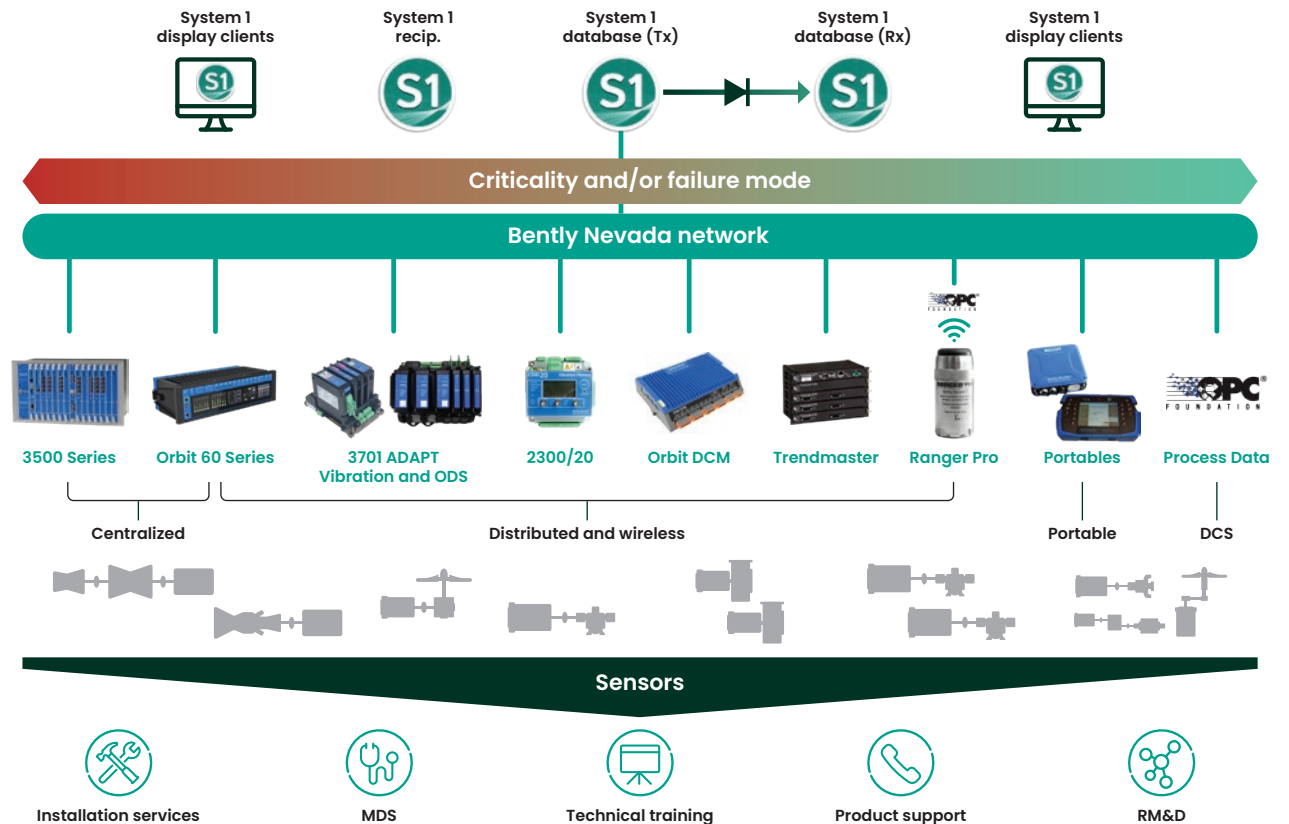
2,000+ worldwide System 1 users

Bently Nevada, a Baker Hughes business, not only provides industry leading machinery diagnostics services, but also manufactures all the hardware needed for a complete machinery protection and condition monitoring solution. As manufacturers of an extensive line of wired and wireless sensors, portable data collection systems, and both distributed and rack-based monitors, it is only natural we should be interested in the reliable detection of misalignment from the sensors we have installed in plants around the world. Bently Nevada offers more than promises of a plantwide solution for our customers, we bring your complete solution together from one vendor.

No other company has the portfolio of products and services that Bently Nevada does.

Typically, Bently Nevada's machinery sensor installations are more comprehensive than that of many other protection and condition monitoring companies making for an optimal scenario for machine fault diagnosis. However, our machinery diagnostics team can provide diagnostic analysis and recommendations for asset improvement strategies even when non-Bently Nevada systems are deployed. The caveat to this is that the sensor data coming off the machines must be sufficiently granular to support diagnosis of machine fault root causes.

The complete solution



The basic requirements of an integrated system

- Continuous monitoring system
- Keyphasor
- XY for relative in all main bearings
- Reliable probe installation allowing to measure radial position
- XY or VH for absolute in all main bearings
- Thrust position
- Other mechanical positions (CE, DE, ECC as needed)
- Bearing metal temperatures
- Process (load) parameters
- Auxiliaries systems data

The advantages of Bently Nevada systems



Orbit 60 is not just the result of 60 years of know-how. It's the result of more than 200 focused customer engagements where we asked you directly what you needed in a new platform. You told us clearly your three biggest requirements:

- A cybersecure solution for both machinery protection and condition monitoring. A solution that satisfied the needs of not just machinery engineers, but the OT and IT worlds in which data must move
- A reduction in installation costs by using less space for the same channel count, by allowing more flexibility in where the system was located, and by reducing the length and number of wiring runs
- An easier and more cost-effective way to integrate process data into the machinery monitoring ecosystem while delivering machinery data to the process control and monitoring ecosystem



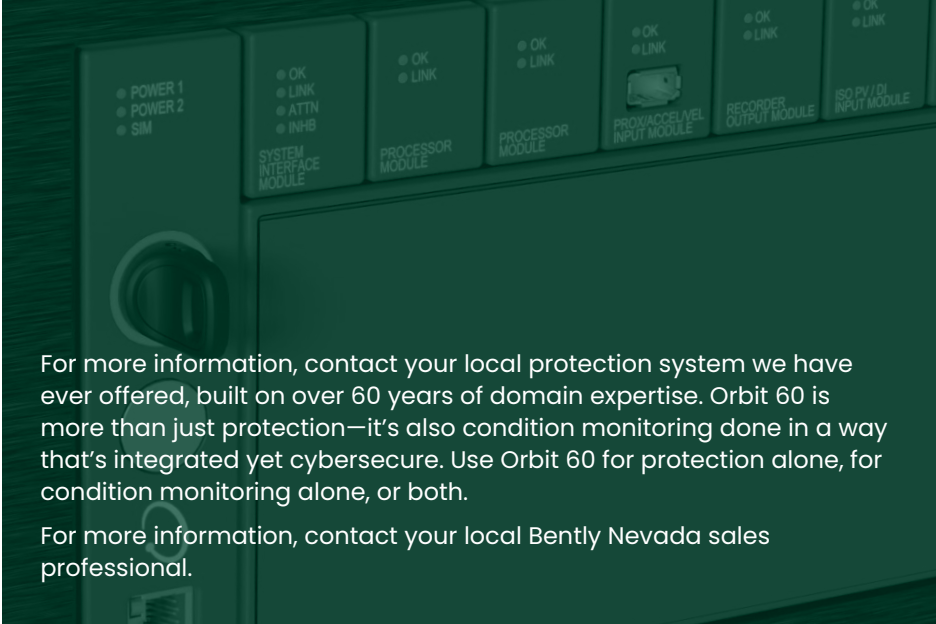
Our powerful 3500/22M TDI rack interface module eliminates the need for bulky external data acquisition on the hardware or special interface modules between the monitor rack and software. Simply plug an Ethernet cable into the 3500/22M rack and you're ready to communicate with our powerful System 1 software for advanced diagnostics, condition monitoring, and other plant asset management functionality, without interrupting or interfering with machine protection. The result is a zero-footprint solution that simplifies System 1 connectivity for existing machinery protection systems. And the enhanced data collection technology of our 3500/22M TDI rack allows earlier and improved diagnosis of previously difficult-to-recognize intermittent events.



Machinery diagnostic services tools

Our global team of experienced field engineers provides a comprehensive range of machinery diagnostic services (MDS) for rotating and reciprocating machinery—regardless of original equipment manufacturer.

For more than 60 years, we have been the technical leader in advanced machinery analytics and diagnostics. Our hardware, software, and services provide customers with unmatched solutions for creating a safe, reliable, and productive plant environment regardless of industry. Nowhere is that machinery expertise more on display than with our machinery diagnostics service (MDS) team. Our MDS services team is comprised of over 150 globally dispersed technicians who undergo the industry's most rigorous training. With an average of over nine years of experience working on various machine classes, they can get to machinery malfunction root causes quickly and recommend solutions to get your operations up and running reliably before downtime becomes a big hit to your bottom line.



For more information, contact your local protection system we have ever offered, built on over 60 years of domain expertise. Orbit 60 is more than just protection—it's also condition monitoring done in a way that's integrated yet cybersecure. Use Orbit 60 for protection alone, for condition monitoring alone, or both.

For more information, contact your local Bently Nevada sales professional.

Data collection tools

ADRE

In 1980, we had a revolutionary idea. What if the methods for collecting machinery and process data on tape and then tediously turning it into plots could be automated? It would mean a dramatic reduction in the time needed to diagnose machinery conditions, allowing engineers to spend less time reducing data and more time interpreting it. We called it the ADRE® System—Automated Diagnostics for Rotating Equipment—and it truly revolutionized the industry.

More than 40 years and five successful product generations later, the ADRE system remains globally recognized as the tool of choice for professionals tasked with assessing machinery conditions in the field and on the test stand. It has become the standard against which all others are measured when it comes to on-demand, flexible, field-rugged multi-channel machinery data acquisition.

Our latest generation of the ADRE system is everything you've come to expect from the world's premier data acquisition system while exponentially boosting its power, performance, and ease of use.



SCOUT

Most people know Bently Nevada for the online condition monitoring and protection of the world's most critical rotating assets. Fewer know that Bently Nevada, together with their 2011 acquisition of Commtest Instruments, have a combined experience exceeding 30 years in portable vibration data collectors and analyzers. And some aren't aware that Bently Nevada's flagship condition monitoring software, System 1, supports not only our critical machinery protection systems but the full portfolio, including portables.

Over the years we've received a lot of feedback from portable users, about how they'd really like their devices and software to behave. Here's a distillation of those requests, along with how we've been addressing them. They're grouped into three types, those related to:

- The data collector/analyzer
- Setting up a database and routes
- Analysis and reporting, back in the software

SCOUT200 represents the new evolution in portable instruments. It de-couples data acquisition and display, freeing you to use the industrial handheld of your choice, providing the best options for screen size, portability, connectivity, flexibility, while maintaining industrial strength and extreme hazardous area ratings.



All of these instruments work seamlessly with Bently Nevada's best-in-class System 1 machine condition monitoring software. Use it to prepare routes, analyze data, detect long-term trends, set and detect alarms. This is the



same powerful software that drives the complete range of Bently Nevada monitors. So, you'll have one source of the truth, easy to use and plantwide.

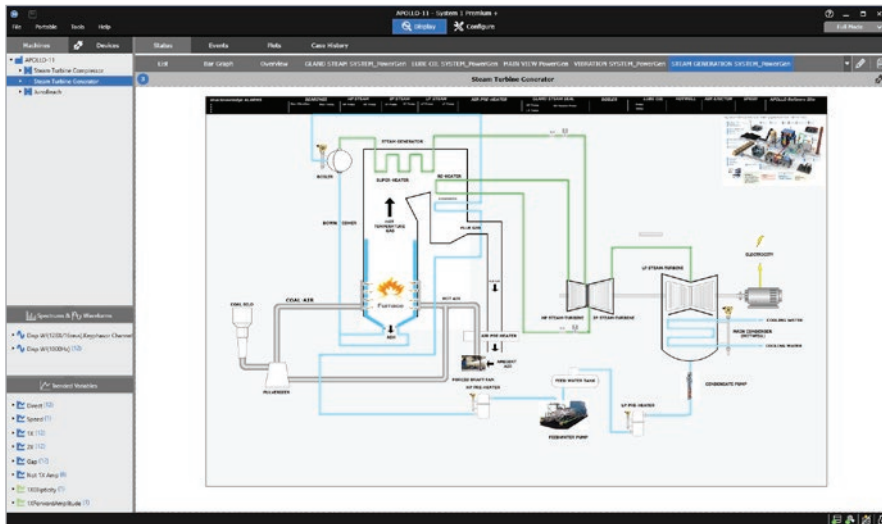
System 1



The success of any process-intensive industry relies heavily on the proper care and management of the machinery powering the work. Unplanned outages or inefficient maintenance routines can reduce productivity and eat away at your profits.

At Bently Nevada, we understand the challenges our customers face. Our System 1 condition monitoring software has been designed as an all-in-one answer to even your most difficult machine asset management and health monitoring challenges. Building on the strategic pillars of connectivity, analytics, and visualization the System 1 platform provides the plantwide critical asset monitoring data and analytics solutions you need to keep your plant running smoothly and avoid unwanted downtime.

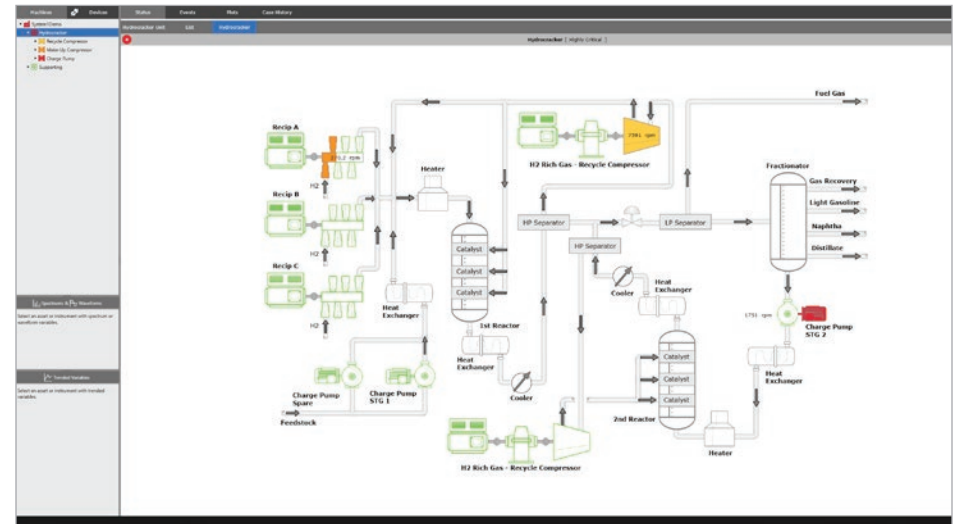
System 1's connected platform gathers and stores important machine health data across your entire enterprise in one central location, for real-time analysis, diagnosis, and preventative condition-based maintenance planning. Make data-informed decisions and achieve true operational intelligence with System 1.



System 1 Decision Support

Decision Support contains a collection of proven Bently Nevada machine condition monitoring analytics engineered to provide early detection of mechanical, process, auxiliary, and instrumentation events. Configured property rules can be adapted to suit the unique operational application of a machine or asset. You can apply Bently Nevada's Analytics, which has been engineered to automate failure mode detection for a wide variety of machines.

In addition to packaged algorithms, Decisions Support allows users to create and deploy custom rules that help you capture, disseminate, and leverage knowledge of your equipment, processes, and business solutions. Custom rules preserve operational knowledge in a usable format that can be broadly applied in an easily repeatable and manageable way.



Condition monitoring solutions for reciprocating compressors

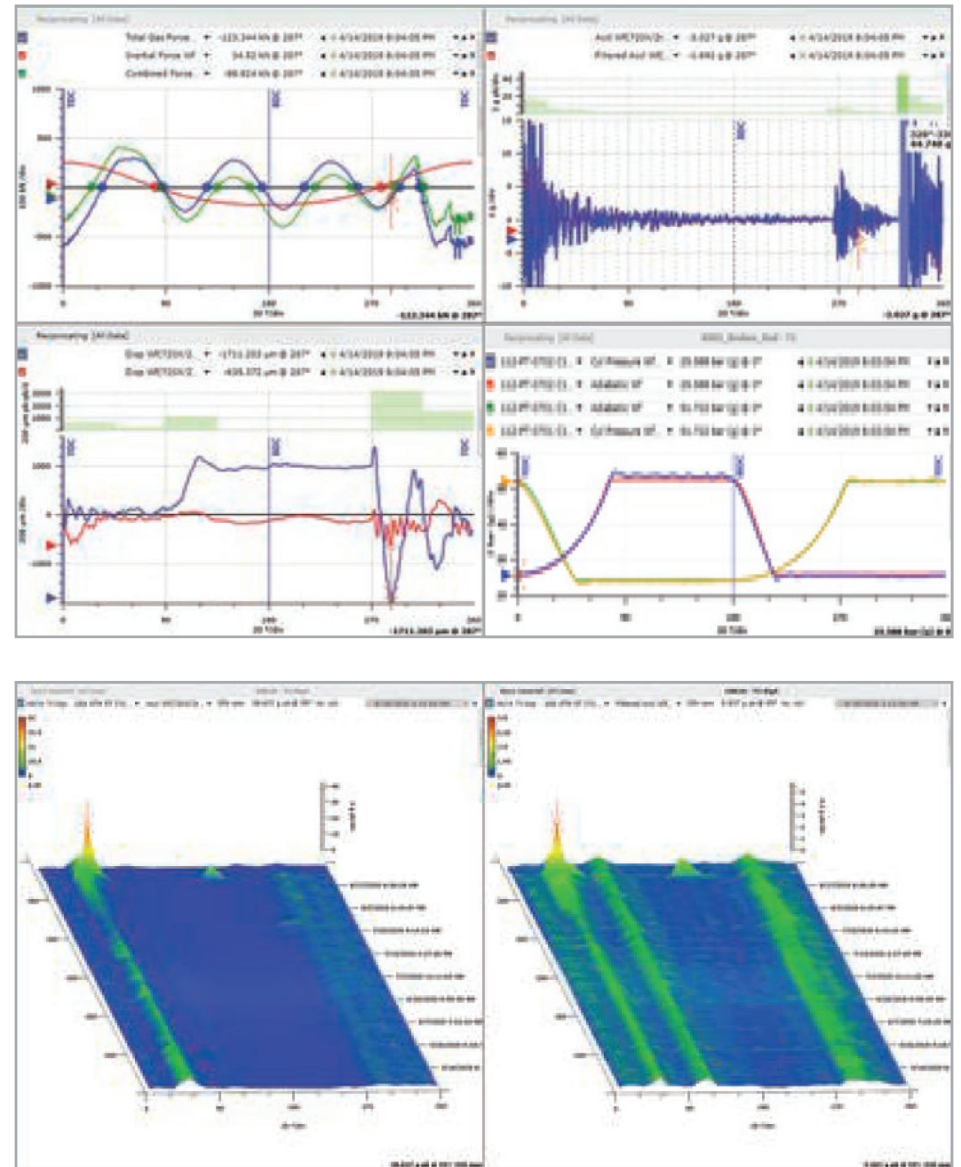


Do more than just protect your recips, proactively manage them with the enhanced condition monitoring and Decision Support capabilities of System 1, our most advanced software ever.

System 1 streamlines decision-making processes by bringing machine data into a single platform, providing clarity and context to your operations and enterprise. Its connectivity, analytics, and visualization capabilities combine to specifically address the unique needs of reciprocating compressors.

The result is a total reciprocating compressor solution, capable of providing:

- Discharge pressure
- Suction pressure
- Minimum/maximum pressure for each crankshaft revolution
- Compression ratio
- Peak rod load for both compression and tension
- Number of degrees of rod reversal
- Suction volumetric efficiency
- Discharge volumetric efficiency
- Indicated horsepower
- Capacity at suction conditions
- Capacity at discharge conditions
- Suction power losses
- Discharge power losses
- Indicated clearance volume
- Flow balance of suction capacity to discharge capacity
- Adiabatic median capacity between suction and discharge capacity
- Adiabatic flow balance of theoretical suction to theoretical discharge capacity
- Power to median capacity ratio
- Adiabatic discharge temperature
- Crosshead impact knock analysis
- Cylinder impact knock analysis
- Piston rod vibration analysis including rider band wear
- Cylinder trim analysis:
 - Leaking discharge valve
 - Leaking suction valve
 - Leaking piston rings
 - Leaking pressure packing
 - Frame loading
 - Crosshead pin loading



MDS in-house applications

Bently BALANCE

Bently BALANCE software is a multi-plane machinery balancing product that saves plants money by providing sophisticated, user-friendly tools to more efficiently balance their machinery. Since imbalance is the single most common machinery malfunction, a way to quickly balance even the most complex machines is critical. Bently BALANCE has proven extremely valuable to our customers and our own machinery diagnostics engineers by giving them a simple way to balance even the most complex multi-plane problems,



decreasing the outage time and number of shutdowns often required to manually balance a machine. Bently BALANCE is a System Extender for System 1, with the ability to bring in machinery data from the System 1 Classic database, further speeding up the balancing process across a wide range of machines and enabling comparison between machines.

Torsion



Torsional vibration excitation in rotating machinery can cause system reliability issues or even catastrophic failures. All rotating machineries undergo some fraction of degrees of torsional vibration during operations. The torsional vibration is not as easily identified as translational vibrations, due to the lack of simple and direct measurement devices.

However, if left uninspected, torsional vibrations can do as much damage as that from translational vibrations. Typical damages developed under excessive torsional vibrations include shaft cracks, coupler cracks, gear wear, gear tooth failures, key failures, shrink fit slippage, etc. Therefore, torsional vibration detection and monitoring is an important step in rotating machinery condition monitoring, especially for those machines driven by a variable frequency drive (VFD), a pulse width modulation motor (PWM), or a synchronous motor (SM), etc.

To detect the torsional vibration of the rotating machinery, several methods have been developed and/or improved. Commonly used methods include Strain Gauge-based methods, Torsion graphs, tachometer frequency modulation-based methods, laser vibrometer based methods, and Zero-crossing detection-based methods. Onsite, traditionally, the torsional vibration is detected by a phase demodulation process to the signals generated by tooth wheels or optical encoders. This demodulation-based method has a few unfavorable issues: the installation of the tooth wheels needs to interrupt the machinery's normal operation; the installation of the optical barcode is easier; however, it suffers from short term survivability in harsh industrial environments. The geometric irregularities in the tooth wheel and the end discontinuity in the optical encoder will sometimes introduce overwhelming contaminations from shaft order response and its harmonics. In addition, the Hilbert Transform based phase demodulation technique has inevitable errors caused by the edge effect in FFT and IFFT analyses.

ADRE has been able to use its raw data and a Matlab executable application for diagnostic purposes for some time. However, we now have a new non-contact technology developed within Bently Nevada that does not need a toothed wheel or striped tape.

Vorso **torsional vibration solution** is a new sensor and approach from Baker Hughes Cordant™. Operating by measuring the shaft torsional stress with two non-contact transducers. The Cordant™ Vorso torsional vibration sensor is the next chapter in non-contact dynamic measurements from Bently Nevada.

Vorso torsional measurement

This new technology allows for measurement of torsional dynamics and torsional condition.

The Vorso system works by using **Eddy Current Stress Instruments**. Many materials exhibit changes in magnetic and conductive properties with stress. These changes can be detected using eddy current techniques.

System

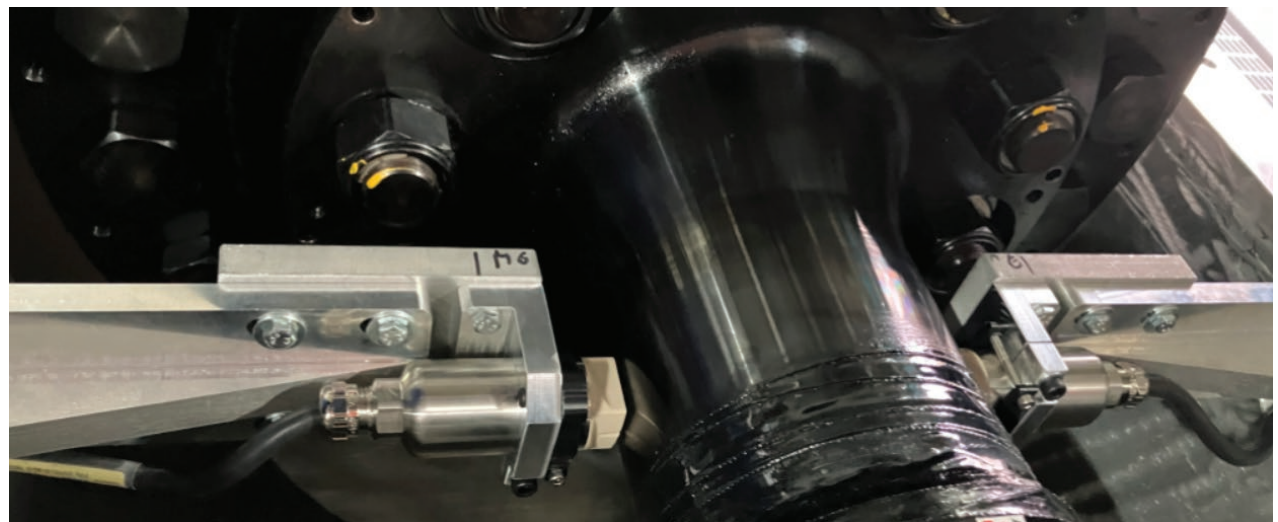
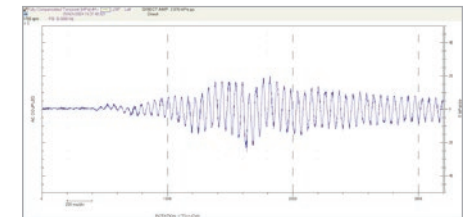
- Stress range: 0-300 MPa (0-43.5 ksi)
- Accuracy: 0.1 Hz
- Stress Scale Factor: $\pm 10\%$
- Amplitude response: $\pm 3\text{dB}$, 1-1000Hz
- Phase response: $\pm 20\text{deg}$, 1 – 1000Hz
- Min shaft diameter: 76mm (3 inches)
- Shaft material: 4140, 4340, others upon request
- Shaft speed: 60 – 10 000 rpm

Non-contacting sensors



Data acquisition options

Torsional analytics & diagnostic services



Simple installation

Non-contacting sensors and no shaft preparation

Verify machine behavior

Validate design models

Torsional condition

Monitor for changes in torsional behavior, cracks

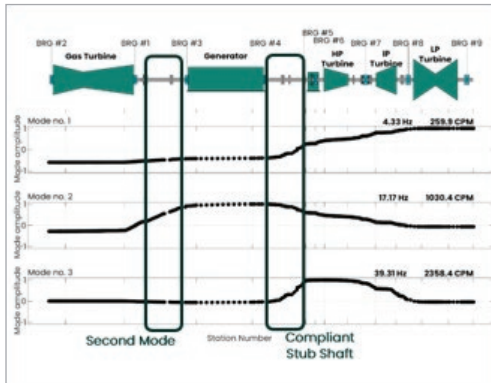
Fatigue life

Test and evaluate stress in typical operational events

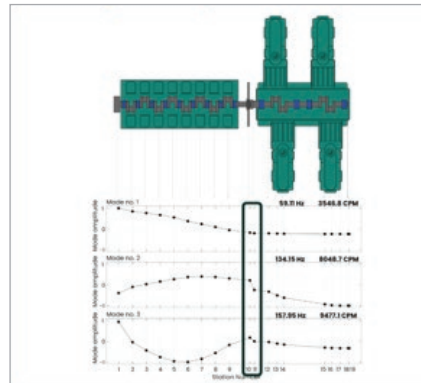
Services with Vorso

Measurement location

Firstly, some information will be required about the machine to correctly identify a measurement location. The measurement locations must be selected based on the rotordynamic model and account for the mode shape of your machine. Usually, the resulting locations will be close to the couplings.

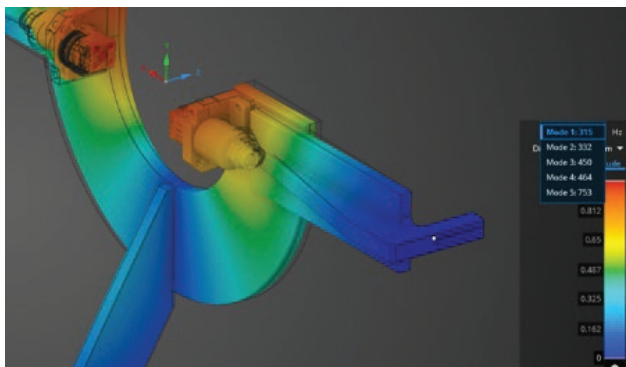


GT-Gen-ST mode shapes



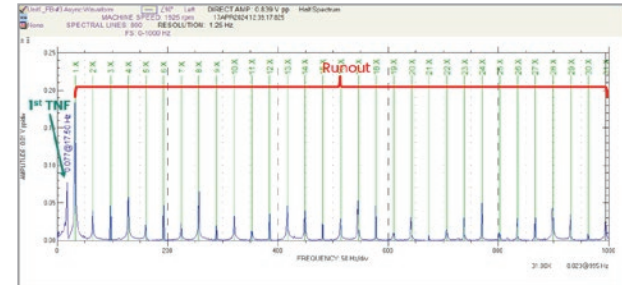
Engine-recip. mode shapes

To allow for correct and accurate measurement additional bracketry will normally be required for a Vorso installation. This is a process our team can help with. Designing, testing, and commissioning custom brackets needed for your machine.

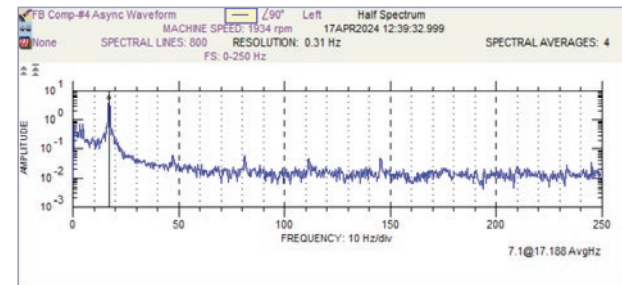


Identifying the first torsional natural frequency

Following on from commissioning Vorso a key behavior in the pursuit of evaluating the torsional condition of the machine is in identifying the first observed natural frequency. This can then be compared to expected rotodynamic models for the machine to flag any change. Or it can be tracked by periodic measurements to observe shaft behavior and possible changes in shaft stiffness.



The above shows a spectrum of **raw data** from a Vorso measurement however using our own post processing tools our team is able to produce clear and accurate plots representing torsional stress in physical units (MPa or ksi).



These services and measurements are conducted by our team using Vorso field measurement kits and an ADRE® System.



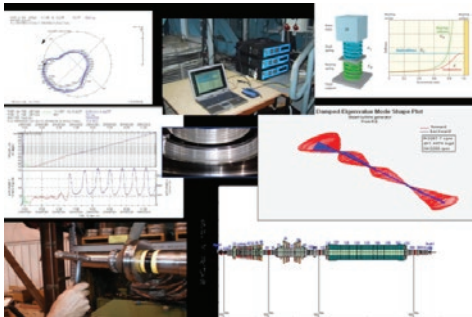
Other services

Rotordynamic modeling

Our capabilities include sophisticated rotor modeling tools that allow us to understand your machinery more fully and document its predicted and actual behavior. This modeling can be useful when contemplating design or operating changes, or simply documenting an existing configuration. Customers often use these services to help analyze new seal or bearing modifications they may be contemplating, or changes to the rotating assembly such as couplings or impellers.

Structural analysis (modal impact and operation deflection shape)

Most machine problems are not solely rotating equipment issues, but rather a complex interaction of rotating and structural issues. Structural analysis is deployed when other corrective actions, such as correcting machine imbalance and alignment have been exhausted, and the machine is still experiencing premature failure, excessive noise/vibration, cracking, etc. To address the structural side of the equation, Bently Nevada offers structural analysis tools such as modal impact testing and operation deflection shape (ODS) analysis.



Modal impact testing is performed while the machine is not operating to determine a structure's resonant frequencies and mode shapes.

ODS is performed while the machine is operating to define the actual movement of a structure based on the forces acting on the system, which may or may not be resonant vibration. We have specialized for years in rotating equipment diagnostics and are better equipped to understand all aspects of the rotating and structural equation to solve complex machine problems.

Oil analysis

Oil analysis is a laboratory-based evaluation of lubricant properties, suspended contaminants, and wear debris. Its purpose is to assess the condition of the oil and to identify incipient and progressing defects in the equipment in which the lubricant is used.

The analysis is performed either on a periodic basis or as an unscheduled (diagnostic) activity. By monitoring oil sample results throughout the service life of a specific machine, it is possible to identify trends that help prevent unexpected failures and avoid costly repairs.

We additionally perform comprehensive analysis and interpretation of oil condition data to support accurate diagnostic conclusions regarding the health of machinery and assemblies and provide training programs focused on lubricant analysis and condition monitoring techniques.



Motion amplification

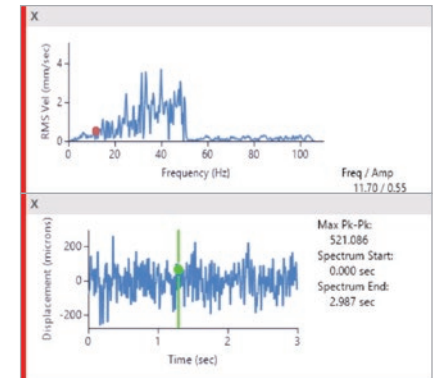
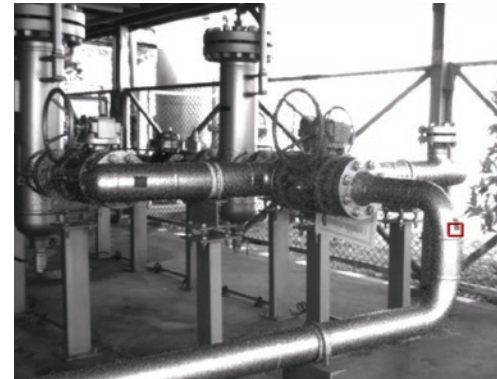
We have recently expanded our service capabilities to include motion amplification (MA) which helps our engineers further diagnose machinery and structural related vibration issues.

MA is a relatively new technology that allows the analyst to easily visualize minute amounts of movement that are ordinarily invisible to the naked eye.

Through the use of a specialist high-speed camera, the software can effectively convert each pixel into a video image that represents vibration and motion and can measure displacement down to 0.1 mil-pp (2.5 μm -pp) at 3.3 feet.

- Provides quick survey of machine case or structural displacement
- A good option for conducting a survey on equipment where access is a challenge
- Immediate animation available upon recording allows more rapid evaluation of vibration conditions
- Suitable to assess piping and structural vibration within the specified frequency ranges
- Effective up to 650 Hz (at reduced resolution) but most effective up to 120 Hz which makes vibration assessment on power generation units most conducive
- New features also allow shaft and coupling inspection capabilities while the shaft is rotating
- Spectrum, waveform, and orbit analysis with export capability
- Measurement of displacement values

With Motion Amplification, data from each pixel in the image can be used as a vibration measurement location, which allows the user to generate a vibration waveform and spectrum for a selected area of interest (see on the right) or create an overview of the shape of the registered motion using preconfigured filters.



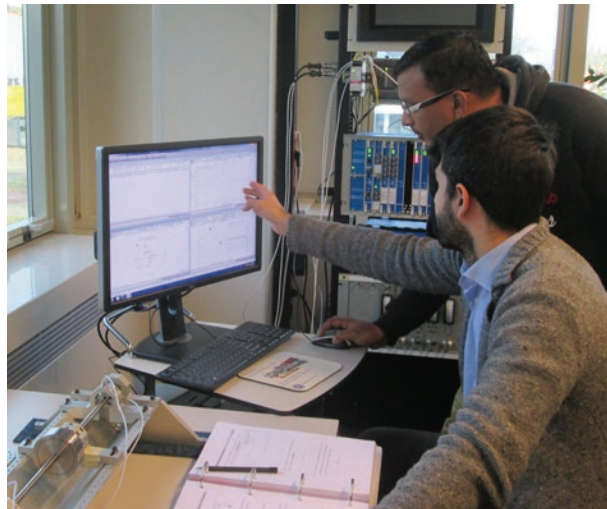
Example of soft foot detected on a reciprocating compressor

Machinery diagnostics training

We are pleased to offer standard training that impart the same machinery diagnostic methodologies to our customers as are employed by our own MDS engineers. Courses are available for basic and advanced machinery diagnostic topics, rotor balancing, machinery alignment, and getting the most from machinery diagnostic tools such as our ADRE portable data acquisition system and System 1 software.

With over 50 years of technical training experience Baker Hughes Industrial Solutions (IS) has an unbeatable track record empowering customers through technical courses. Digital Solutions offers a wide range of technical training courses ranging from condition monitoring and diagnostics, inspection technologies and measurement technologies, as well as control systems. Our techniques have received great recognitions from major clients in over 70 countries with more than 10 languages for training activities conducted onsite, at Baker Hughes training locations or online. With Baker Hughes Industrial Solutions, clients are confident their teams are staying up to-date with the latest technologies.

Our technical training programs provide you and your team the knowledge and skills required to protect and control your machinery and to optimize the performance of your machinery. Bently Nevada work with you to build a training plan that is best adapted to your needs. Overall, it will maximize your return on investment by ensuring machinery availability and reliability, by avoiding unplanned events and limiting disruption risks and costs.



A comprehensive suite of service offerings from Cordant™

Hosted Services

Hosted Services is an all-in-one monthly subscription for hosted infrastructure, software, and asset health management services as the outcome. This allows asset owners to benefit from our decades of domain expertise embedded in System 1 and delivered through our remote monitoring and diagnostics (RM&D) service centers to realize the full value of asset condition monitoring programs without CAPEX investment.

Supporting service agreements (SSAs)

To help you get the most from our installed condition monitoring solution, we back it up with a full array of support services. Our total solution packages can boost the reliability and efficiency of your reciprocating machinery—and help you make informed maintenance decisions.

Maintenance and support agreements (M&S)

A Bently Nevada maintenance and support (M&S) agreement is a comprehensive plan which provides customers the necessary support and knowledge needed to improve uptime and product quality, reduce unplanned outages and limit unscheduled repairs. Included in your M&S agreement is access to our technical support team for help with issue resolution, software upgrades, and cybersecurity updates.

Customized human machine interfaces (HMIs)

We can create fully customized diagnostic HMIs for individual assets or even your entire plant. These HMIs allow operators and others to quickly drill down to specific assets and subsystems to understand the nature and severity of problems and the precise actions to take for mitigation.

And more...

- Installation and configuration
- System tuning and optimization
- Cybersecurity services

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