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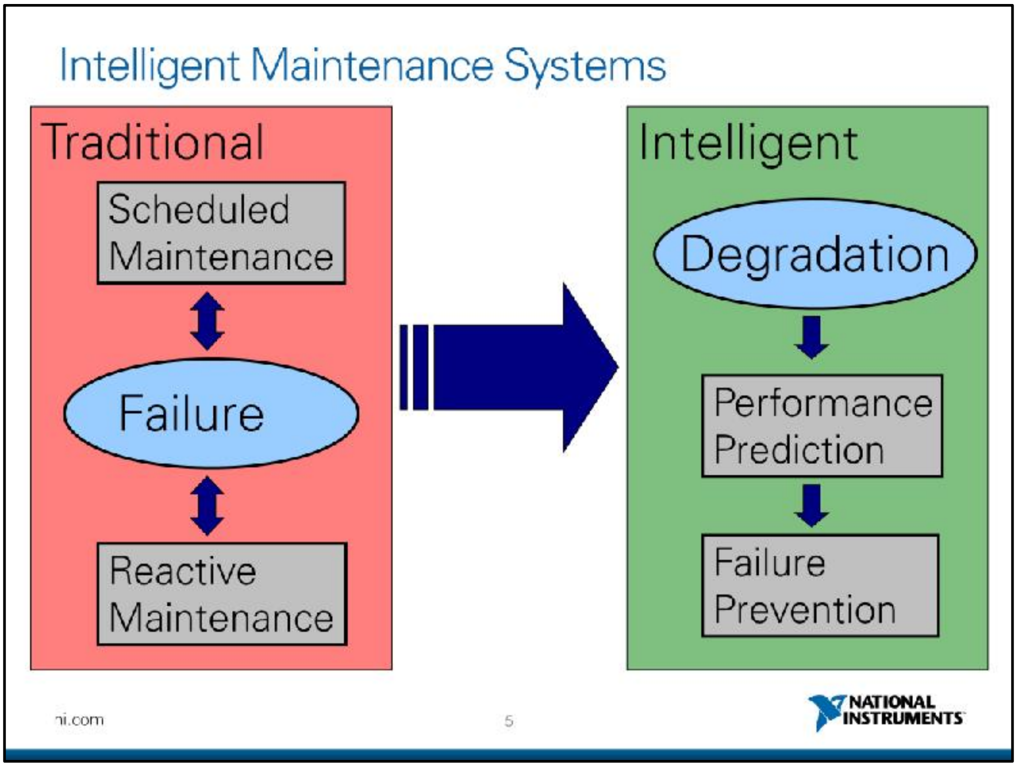
Vibration Analysis and Troubleshooting

- Objectives:
- Vibration Sources, Vibration Analysis Techniques
- Machine Failure Analysis
- Monitoring systems for vibration and temperatures of rotating equipment.
- New challenges (wireless and remote vibration systems)

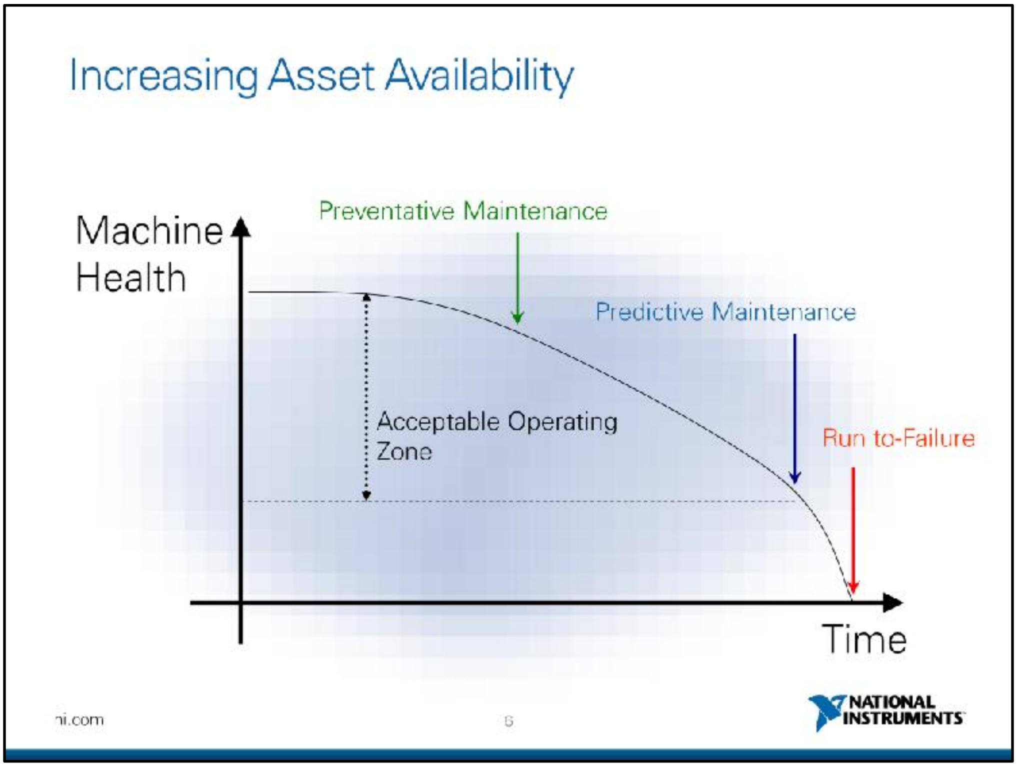
Why Monitor Vibration



Many of National Instruments Customers are working to build Asset Monitoring Systems that support the change to predictive or condition based maintenance as compared to scheduled or reactive.

These asset monitoring systems may include intelligence for automated diagnostics, and perhaps predicting the point of failure of the asset.

National Instruments is working to make the task of developing, configuring, and deploying Asset Monitoring Systems easier for our customers, from developer to OEM to End User.



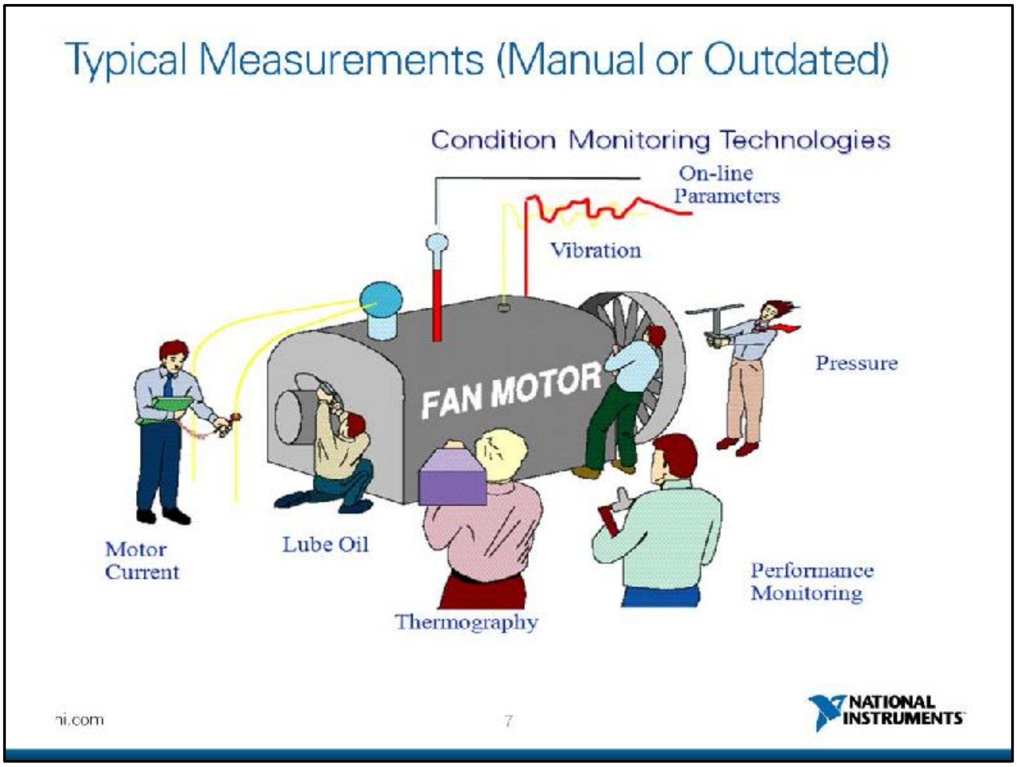
Let's take a look at how a predictive maintenance strategy, featuring condition monitoring, can help lower the cost of machine operation. There are three main types of maintenance strategies that are typically used: preventative maintenance, run to failure, and predictive maintenance, which is what we have been discussing.

-To run machines 24/7, Asset health management plays an important role. The optimal point to run a machine to is when its operation becomes too expensive, or the risk of failure rises significantly. We'll call everything above this point the Acceptable Operating Zone. There are three main types of maintenance strategies, preventative maintenance, predictive maintenance, and run-to-failure.

-A preventative maintenance strategy is completely dependent on time, not machine performance, and is usually based on manufacturer's recommended maintenance plans. This means that not only can repairs be performed when not needed, causing undue downtime, but can also can miss equipment deterioration that is happening faster than expected by the manufacturer.

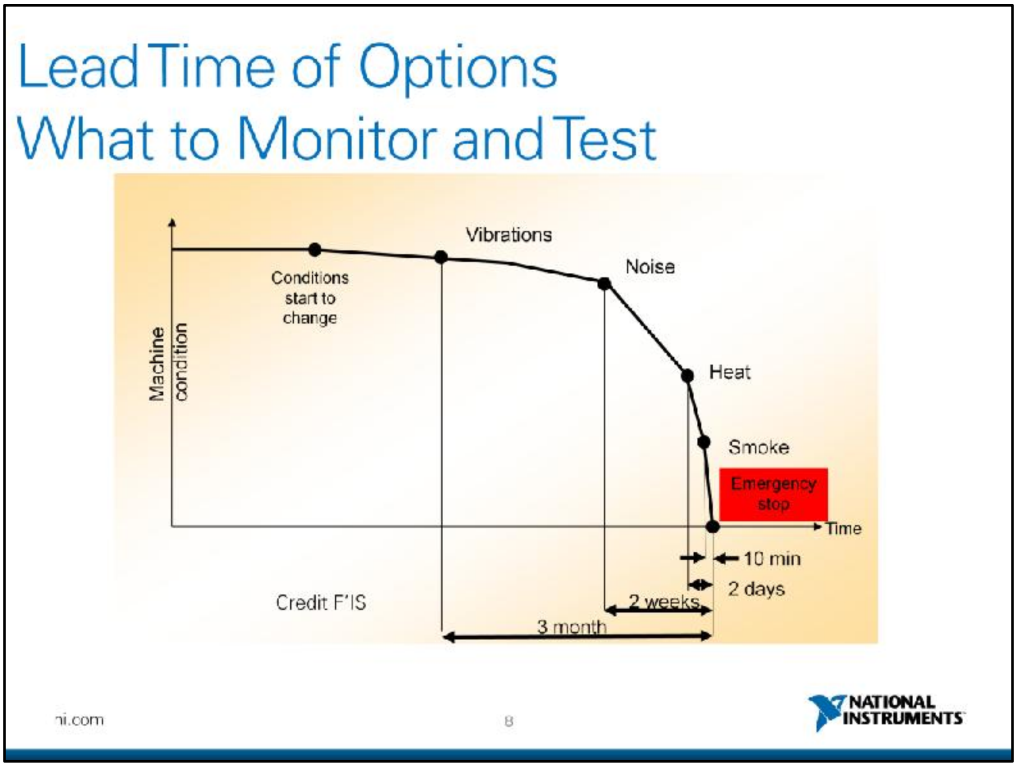
-Run to failure is a maintenance approach that is completely dependent on machine performance, only repairing when the machine fails. It extends the amount of machine uptime but drastically increases repair costs because of the increased risk of a catastrophic failure.

-Predictive maintenance, the strategy we have been discussing, attempts to extend machine uptime through acceptable performance by only performing repairs when on the cusp of dropping below acceptable operating levels.



There are many measurements that can be made to monitor the condition of the asset. These measurements, change over time as the asset degrades or wears.

For rotating machinery the most common measurement is vibration. We will spend the majority of this workshop reviewing vibration measurements and interpreting these measurements.

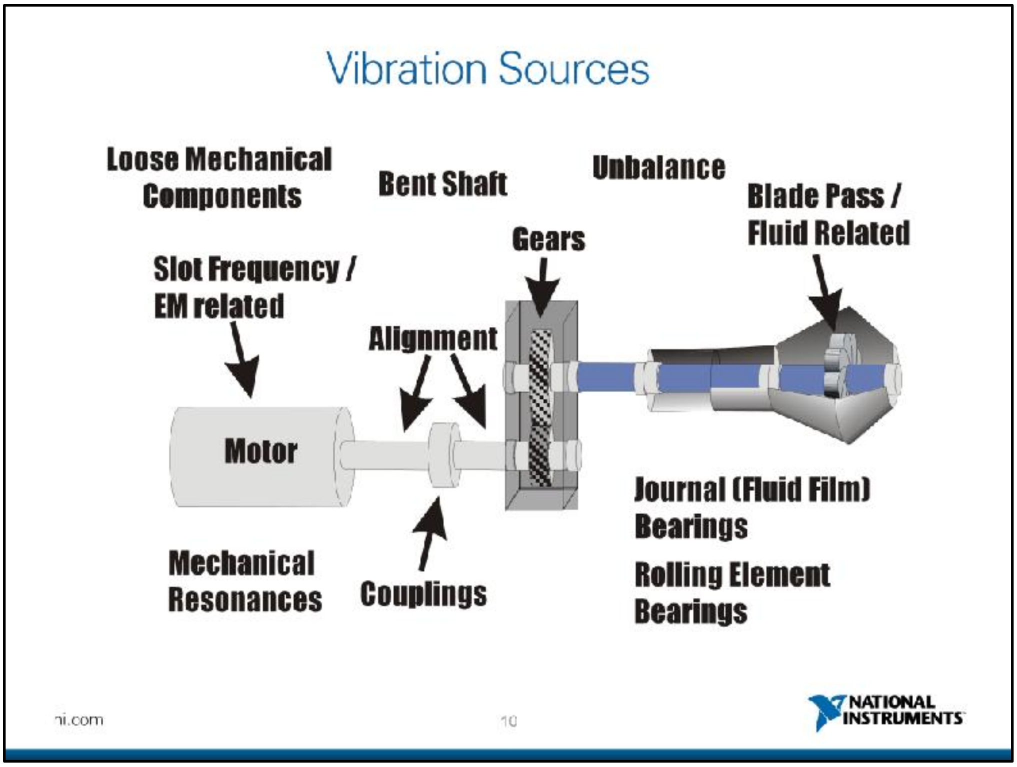


As we look at condition monitoring, and even at factory acceptance or design verification testing we see several sensory measurements which provide a view of the health of the machine. National Instruments offers a platform which incorporates hardware to make direct measurements from analog and digital sensors, as well as communicates with control systems to simultaneously note the operational state of the machine being monitored or tested.

There are several sensory measurements to be made in Asset Health Monitoring. Vibrations are the most common, and offer the most information about the health of machine components.

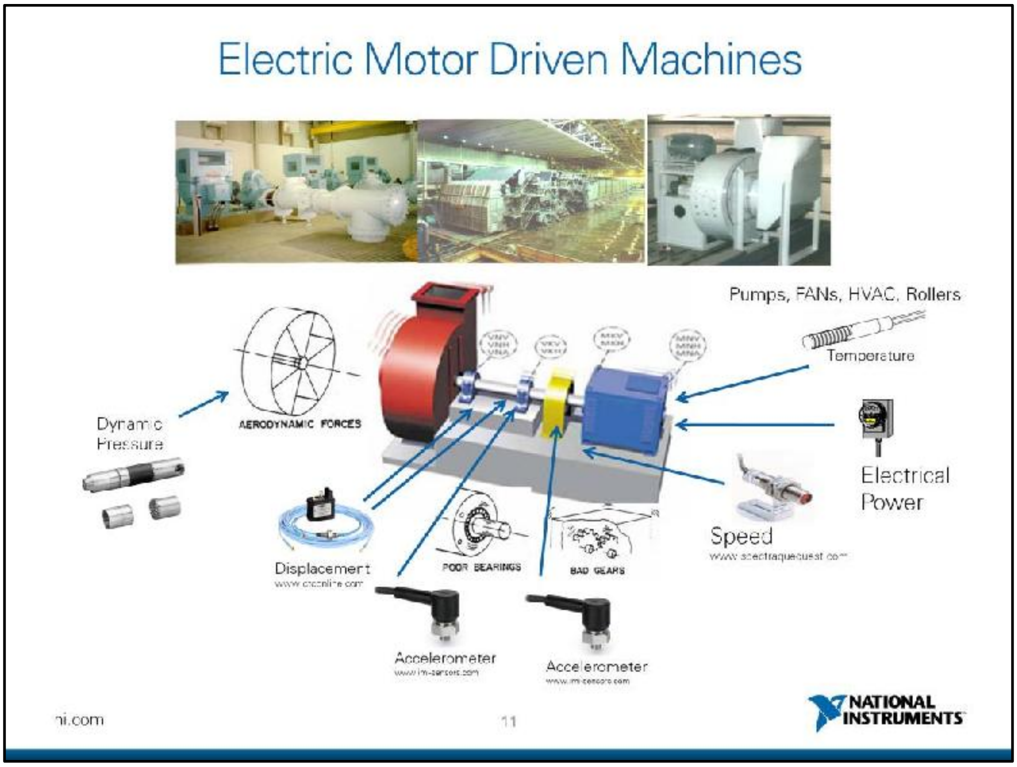
A multi-month prediction based on changing vibration levels at the specific frequencies of bearing, gearbox and other mechanical component provides ample time to schedule production, maintenance staff, and the availability of spare parts. In turn, the time to repair is reduced since everything is in place for the repair.

Lets first take a look at vibration sources.



While the computer-based machinery monitoring system is capable of monitoring many sensors and signals, we will focus on vibration for the majority of this presentation.

Let's consider some vibration sources of a generic operating machine. Some vibration sources are due to machine design: slot frequency/EM related, gears, coupling, mechanical resonance, and bearings are some examples. Other sources result from potential problems: mechanical looseness, unbalance, and alignment. All these vibration sources combine to create a measurable vibration signal. The vibration sensor (accelerometer, proximity probe, velocity probe, etc.) produces a multi-tone signature where each tone represents the vibration from a specific mechanical source.



Many machines are driven by electric motors.

Electric motor driven machines include pumps, fans, Heating and Ventilation or (HVAC) blowers and many other machines. This class of machines is the most commonly used machine in the world. Did you know there are more induction motors on planet earth than there are people?

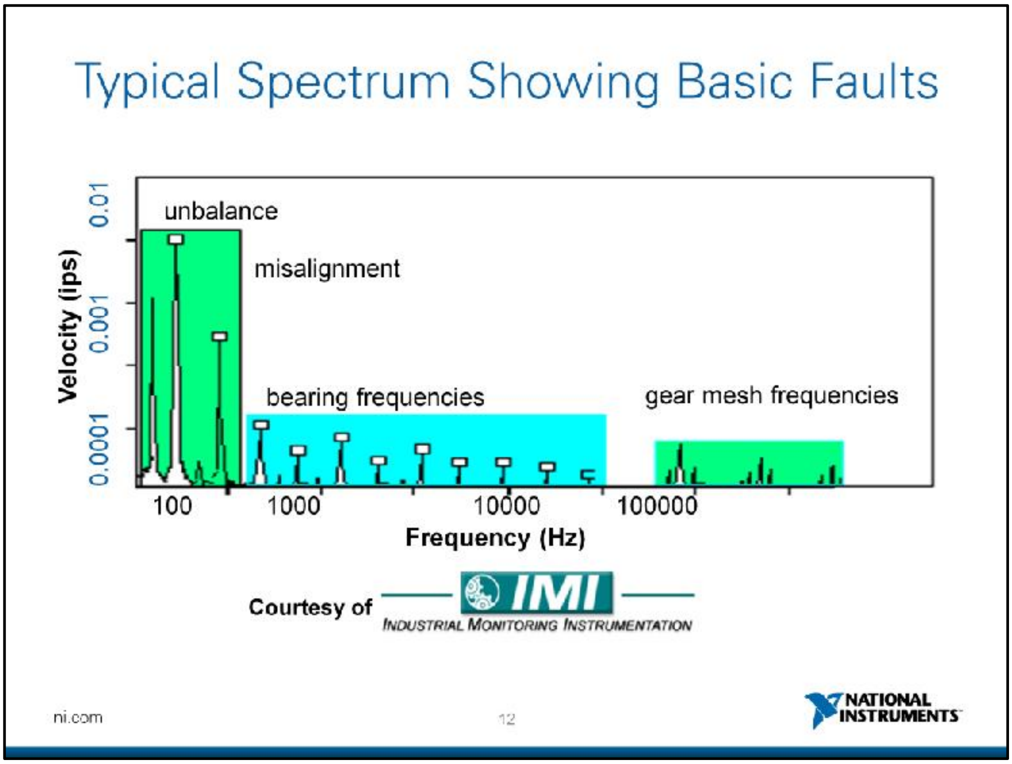
Electrical motor machines are often driven by induction motors. Their rotating shafts are supported by roller element bearings. Gearboxes provide speed changing mechanics to adapt the speed of the shaft for the driven component such as the pump or the fan. Fans and pumps have vanes and blades.

To test or monitor an electrical machine, we may use several sensors. These include accelerometers for vibration, tachometers or eddy current probes for speed, pressure and cavitations sensors for blade or vane monitoring, and even electrical power sensors to monitor the motor itself.

Software that analyzes the data will show Vibration levels at specific fault frequencies measured with a Sound and Vibration tailored FFT or spectrum. Integration from acceleration to velocity is often used prior to data logging and trending. As with any machine monitoring or test application, data logging at specific times or events creates a series of data files for off-line analysis.

With proper labeling of sensory data recordings, we can even conduct analysis across multiple files.

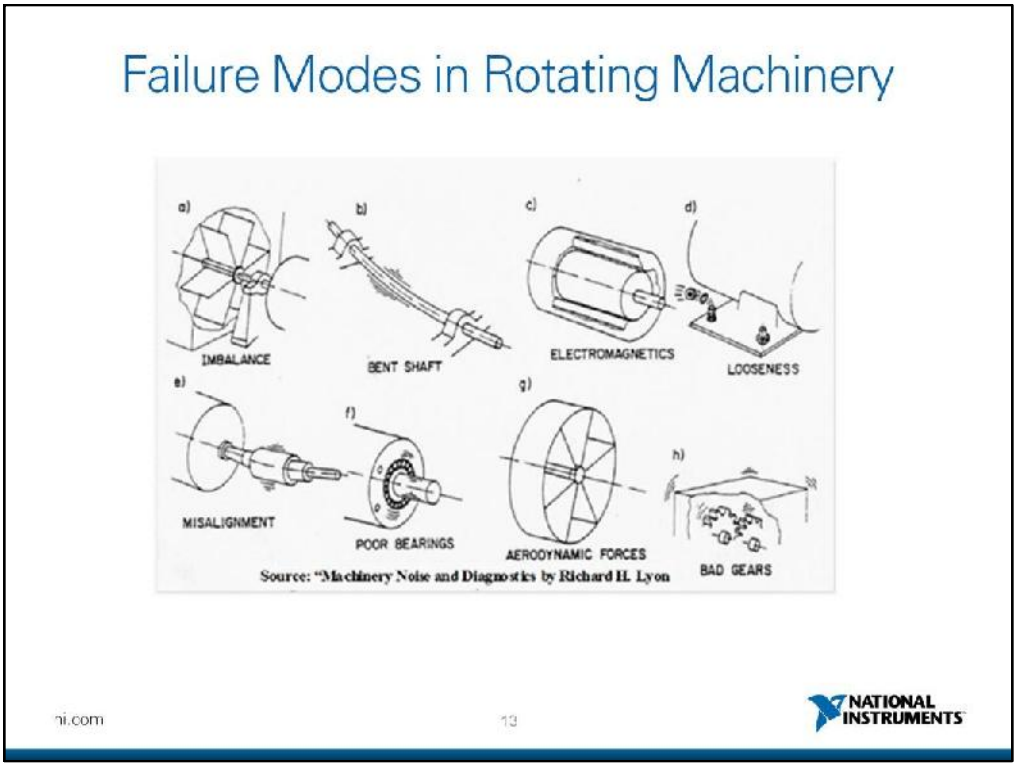
In most cases, dynamic signal acquisition hardware with 24bit resolution, simultaneous sampling, power for sensors, and anti-aliasing filters are desired.



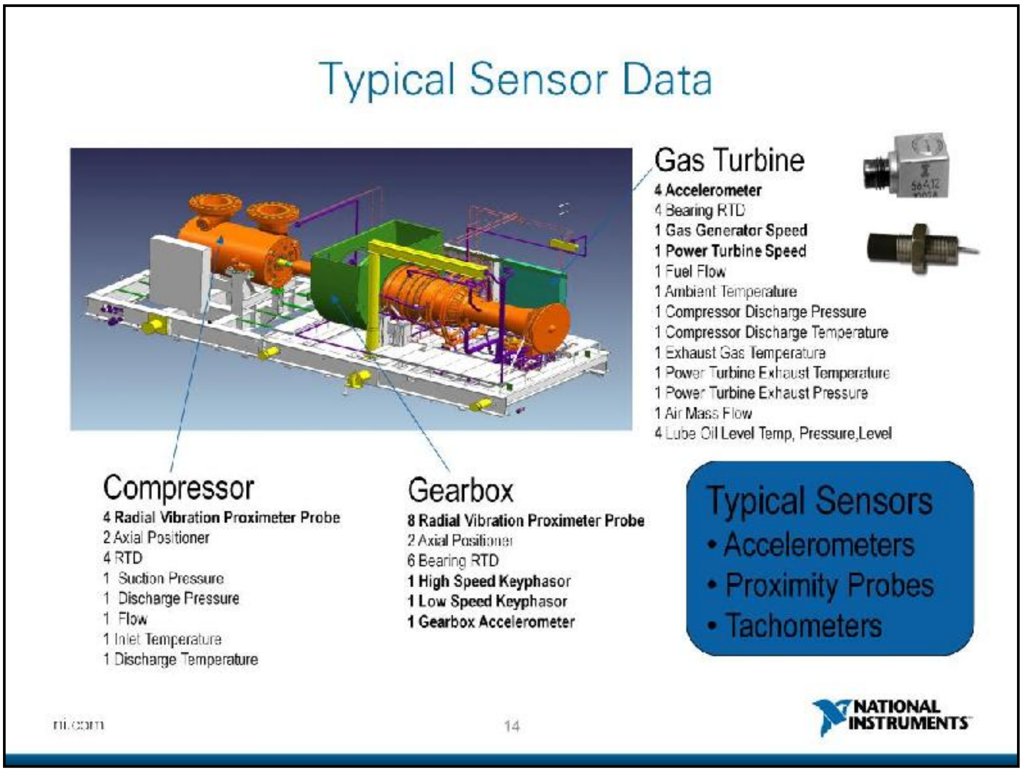
The Fourier Transform is a signal processing tool used to identify repetitions in a data set. Since a machine rotates, its vibration signals repeat each rotation. The Fourier Transform identifies these repetitive signals and allows the maintenance team to monitor the repetitive vibration from individual mechanical components such as bearings and gears.

Using a carefully selected data acquisition system to acquire the data, the next step in machinery monitoring for vibration is to perform frequency analysis. This graphic shows the typical vibration frequency of several machine vibration phenomenon. While the machine being monitored or under test may be rotating at 30 to 200 hz, its bearing fault frequencies may be 10 or 20 times as high as rotational frequency. Similarly gear fault frequencies may be 20 to 50 times as high as rotational speed.

The workhorse analysis tool for vibration monitoring is the Fast Fourier Transform, or FFT. This tool allows us to focus attention on particular frequency space to completely understand the vibration characteristics of the mechanical components, including amplitude, frequency, phase, harmonics, sidebands, and so forth.



For example in rotating machinery there are several common failure modes which can be monitored for by vibration sensors and vibration signal processing.

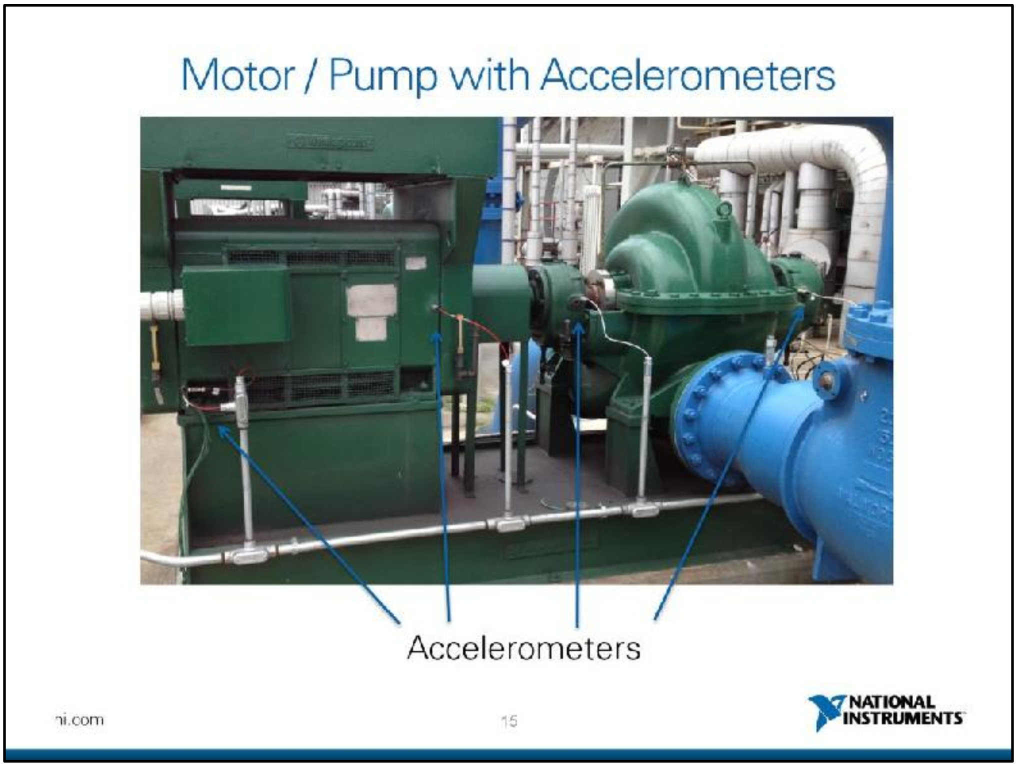


To enlist predictive maintenance techniques, you need information from the machine.

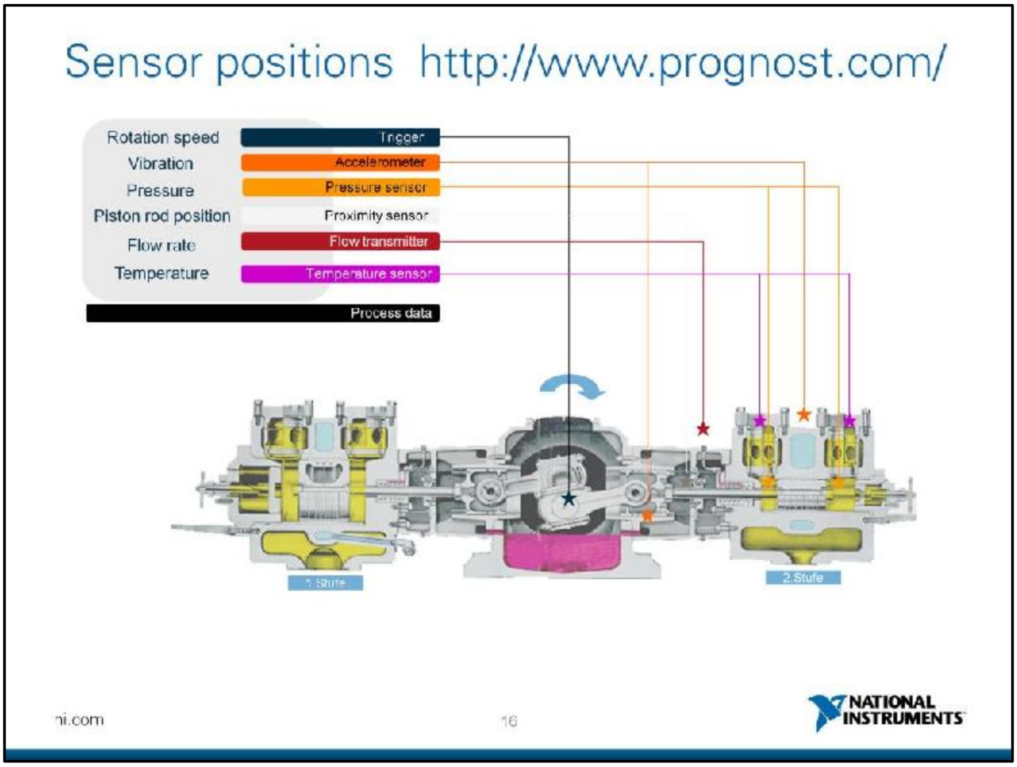
So here is a large industrial machine, this could be an air compressor creating the drive for pneumatics used to assembly aircraft.

The typical sensor measurements performed on a machine consist of an accelerometer, proximity probe, tachometer, and other process variables.

Combining machine vibration with operation parameters helps round out the sensory inputs for asset health management applications.



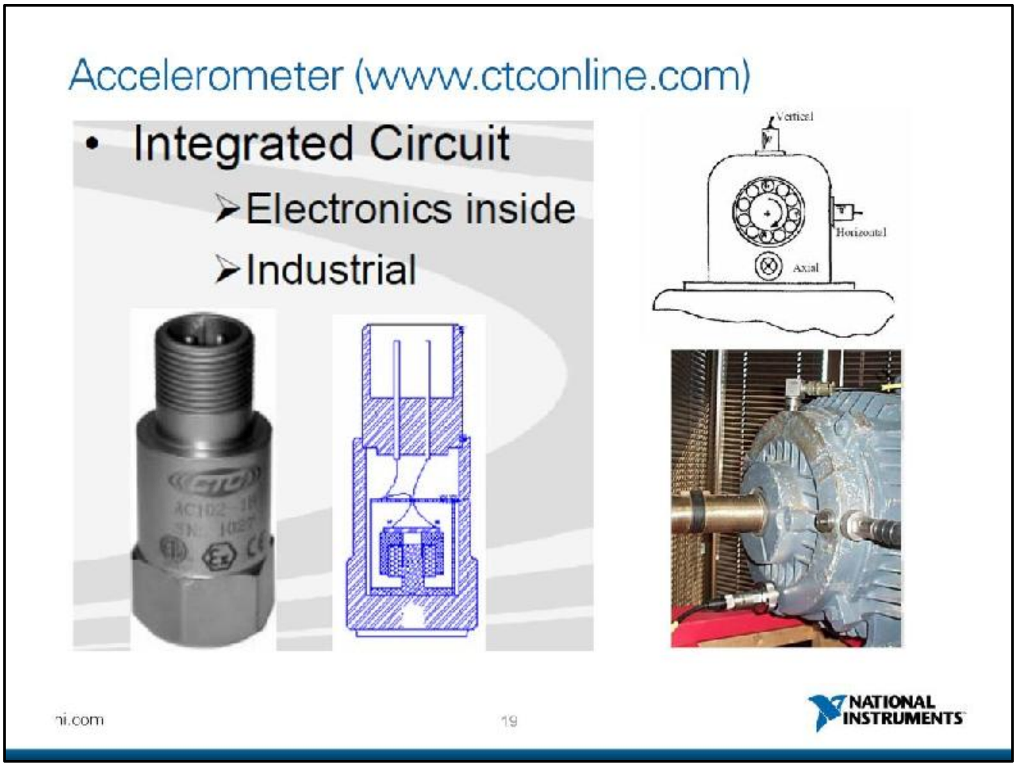
Just as a reference point, here is a motor drive pump with accelerometers mounted at each of the four bearing locations (two on the motor, and two on the pump).



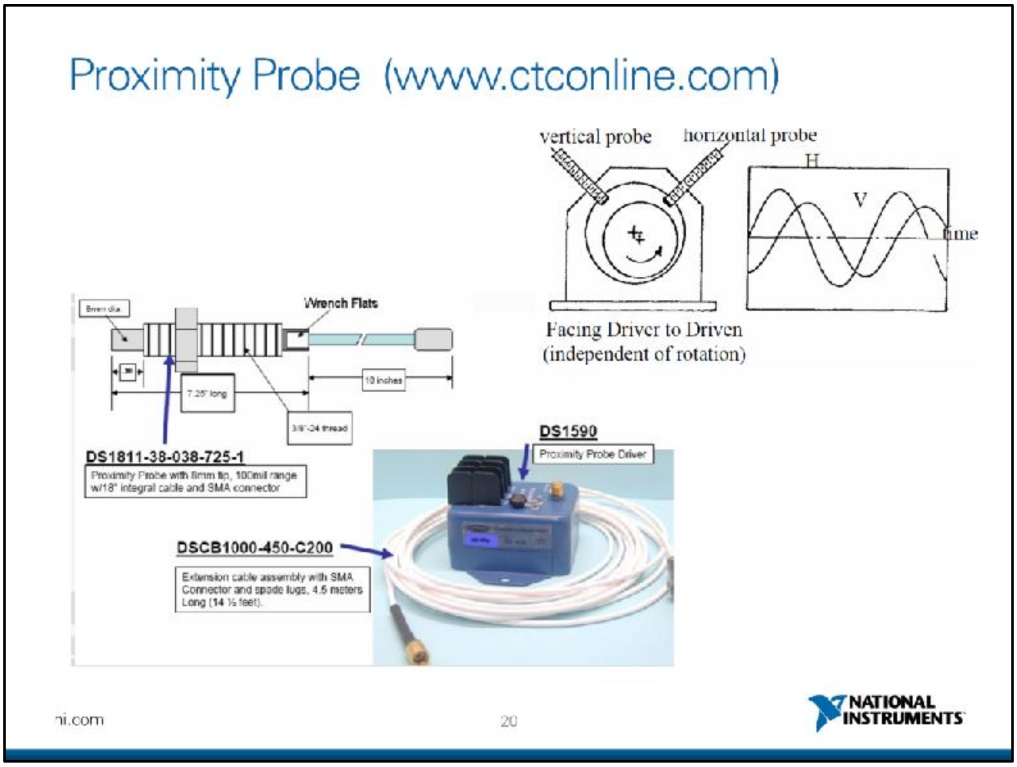
Some machines are much more complex, as indicated by this diagram from Prognost, a supplier of reciprocating machine monitoring solutions.

Lets take a look at what is required to both capture usable vibration data, and to interpret it for failure or degradation analysis.

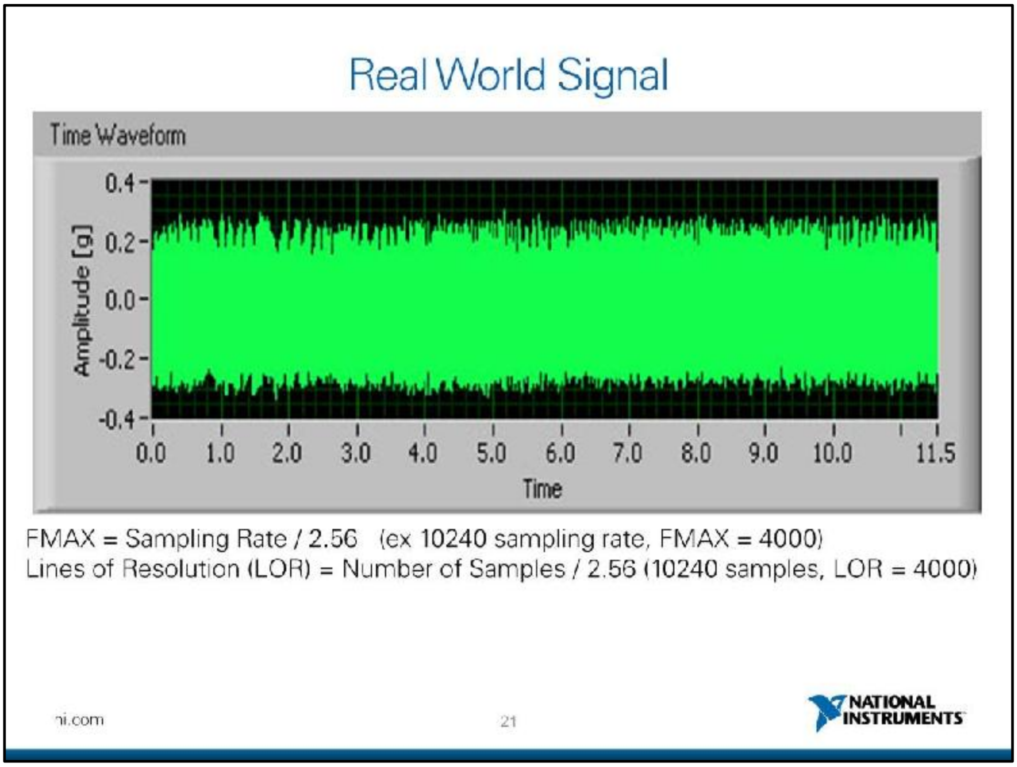
First we will review data acquisition systems for vibration analysis.



Accelerometers are the most common sensor used for vibration analysis. Most accelerometers use an integrated piezoelectric circuit. The circuit obtains voltage oscillations from a crystal which responds to vibratory motion.



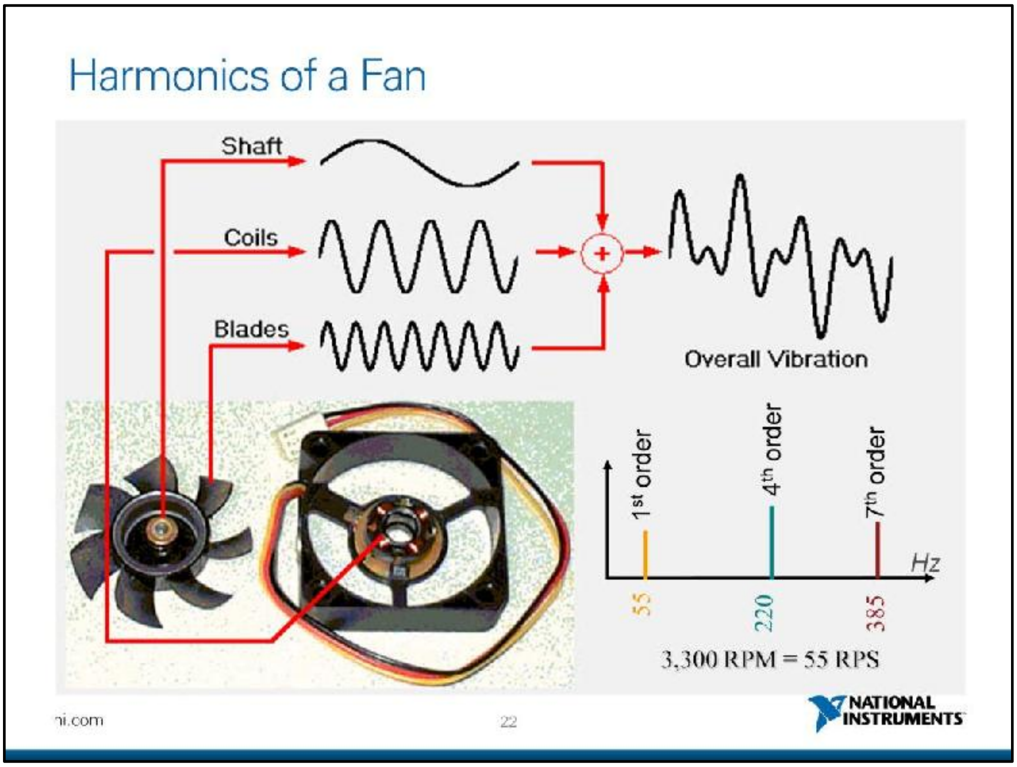
Displacement probes are another vibration sensor, typically used in TurboMachinery applications. The proximity probe uses a magnetic eddy current field to sense the dynamic movement of a shaft surface. As the shaft vibrates due to unbalance, misalignment and so forth, the distance between the tip of the probe and the shaft changes, inducing changes in the magnetic field. A proximity probe driver, demodulates the eddy current changing field into a voltage that represents the instantaneous distance between the tip of the probe and the surface of the metallic shaft.



The vibration signal captured by the data acquisition system will contain many vibratory components. To properly extract the individual vibratory components, we need to set our FMAX or sampling rate, high enough to "see" the vibration frequencies of bearings, gears, vanes and other mechanical movements we are interested in.

We also need to capture a long enough (in time) waveform from the vibration sensor, in order to separate each of the vibration components from the time waveform. The more samples in the data capture, the more resulting lines in the FFT Spectrum.

Often, there are many other mechanical components represented in the measurement including electrical noise. These additional forcing functions and electrical noise complicate the task of interpreting the sensor measurement. These real world issues make it important to consider measuring vibration signals with the appropriate frequency span and duration (in time).

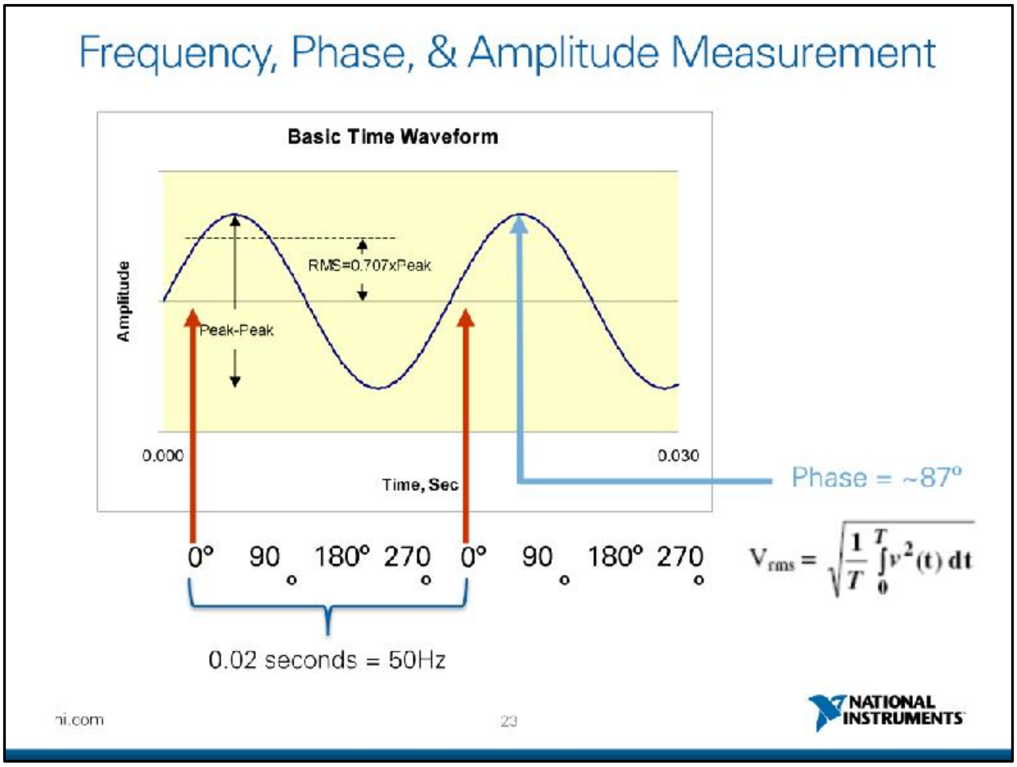


Lets look at a quick example: Here we have three vibratory motions adding together to create an overall vibration pattern.

When we acquire the vibration of a PC cooling fan. The major sources include:

1. Imbalance of the rotor. It generates the vibration at the frequency of the rotating speed. This is often called it the 1st order harmonic of rotating speed.
2. Electric-magnetic force from the coil. This fan has 4 coils, which drives the fan 4 times per revolution. So the vibration contributed by coil is at the frequency 4 times the rotating speed, so we call it the 4th order.
3. 7 blades of the fan. They generates the vibration at 7th order.
4. The harmonics of E-M force, 8th, 12th, and so on orders.

So if the machine is running at 3300 RPM (55Hz), we would set our sampling rate at 11 times 55 times 12 or 7260 samples per second.



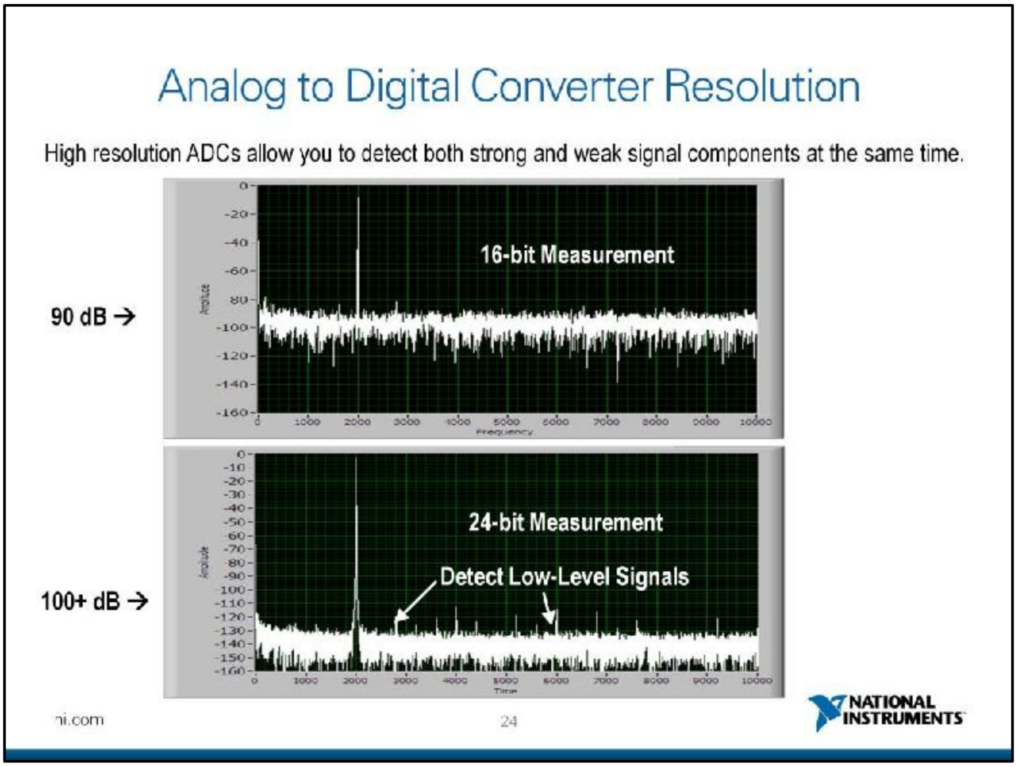
When measuring vibration we are measuring three parameters from vibration sources, Frequency, Amplitude, and Phase.

Frequency is the inverse of the time for a complete vibration motion pattern to repeat. If for example we use the 0 crossing in this graph, the time between two zero crossings in rising directions is approximately 0.02 seconds. 1/0.02 seconds is 50 Hz. The frequency is 50Hz.

Phase is relative timing difference between a tachometer pulse (0º) and the peak of the vibration magnitude. It is expressed in degrees.

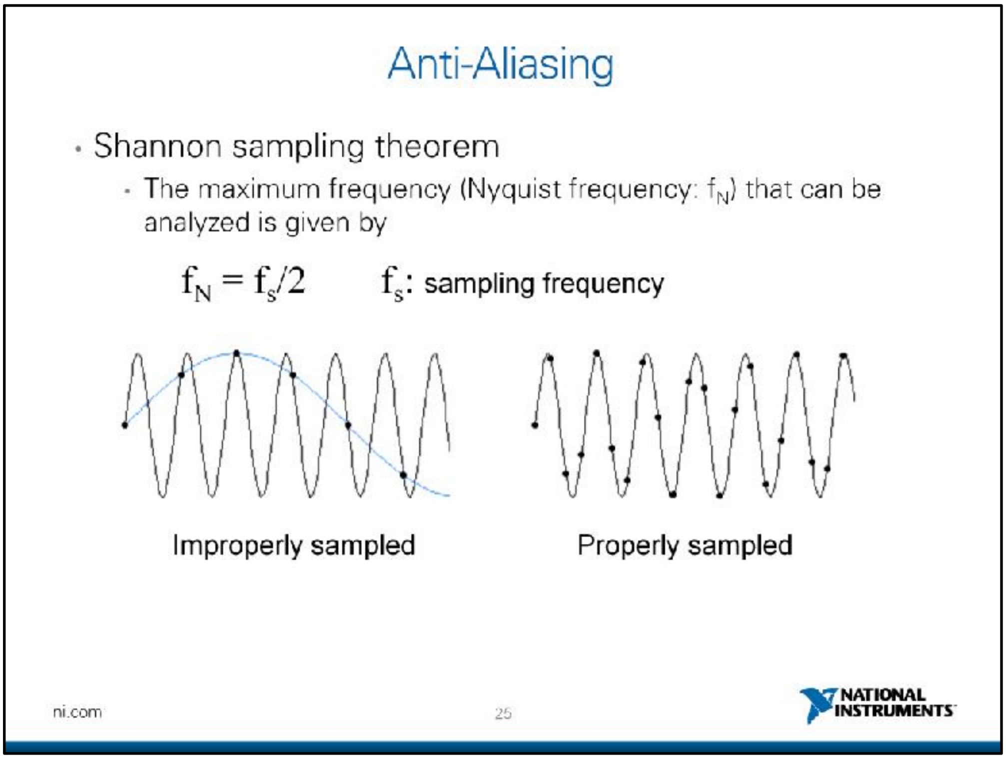
For overall amplitude, you can measure and report it in Pk-Pk values or in RMS values. Vibration sensors typically use Pk-Pk. Traditional electrical AC signals are measured in RMS.

But this is a simple sine wave, what does a real vibration sensor look like?



To make vibration measurements, we also need to distinguish large vibration sources from small vibration sources. For example, the 1 times vibration from unbalance is often a dominating vibration source in the time and frequency domains. However, we also would like to see smaller vibration sources as they begin to appear. These might include bearings, gears, and so on. The ability to detect both strong and weak signals is a function of the dynamic range of the measuring instrument. A core feature of the vibration data acquisition and analysis instrument is its Analog to Digital Converter (ADC) bits of resolution.

Lower resolution ADCs may not provide enough range to see small signal components that may indicate machine problems. Higher resolution ADCs give you insight into the small components of a signal so that you can detect machine faults earlier and plan for repairs rather than being caught unprepared.

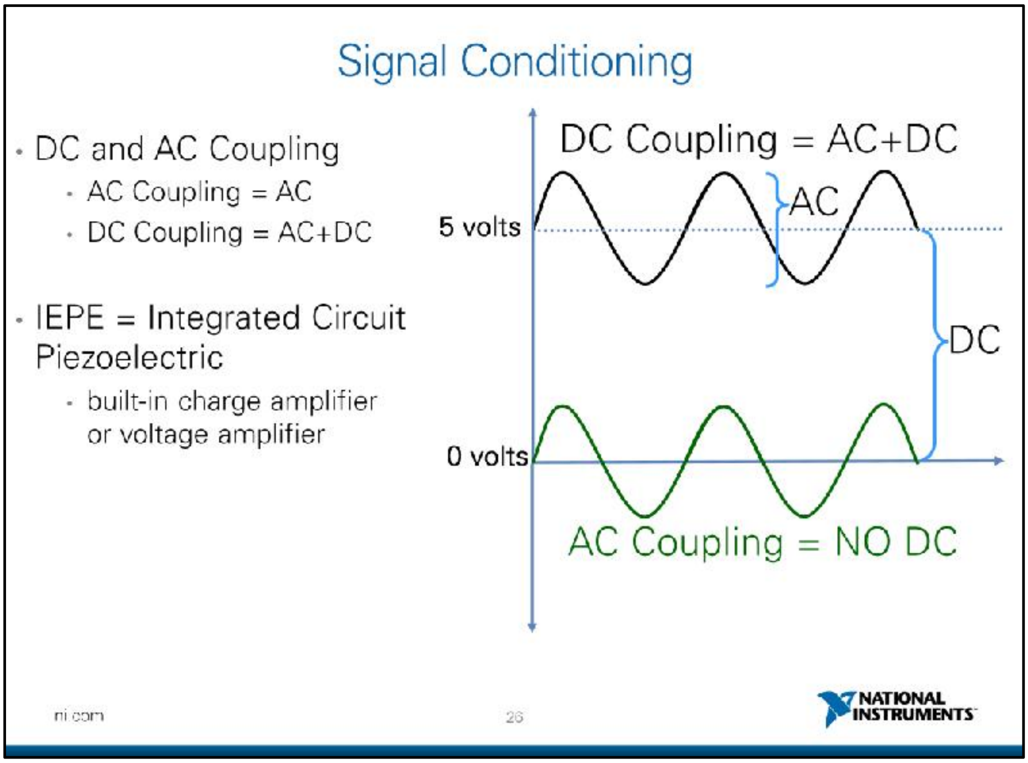


Another aspect of the vibration data acquisition device is alias protection.

Lets take a look at anti-aliasing a bit more closely.

According to Shannon sampling theorem, the highest frequency (Nyquist frequency: f_N) that can be analyzed is $f_N = f_s/2$, where f_s is the sampling frequency. Any analog frequency greater than f_N will, after sampling, appear as a frequency between 0 and f_N. Such a frequency is known as an “alias” frequency. In the digital (sampled) domain, there is no way to distinguish these alias frequencies from the frequencies that actually lie between 0 and f_N. Therefore, these alias frequencies need to be removed from the analog signal before sampling by the A/D converter.

Anti-Aliasing analog front ends are the most important feature of a machinery vibration monitoring application.

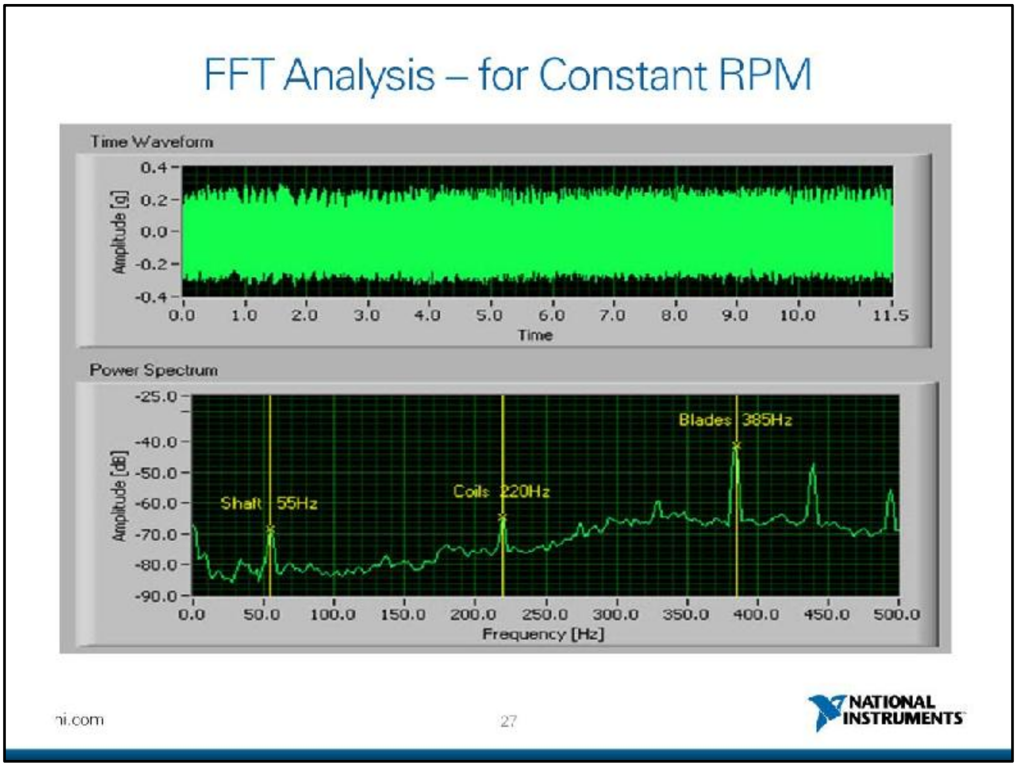


Since most vibration sensors use a 24V DC power source, AC coupling is required to remove the bias voltage from the vibration signal.

AC coupling consists of using a capacitor to filter out the DC signal component from a signal with both AC and DC components. The capacitor must be in series with the signal. AC coupling is useful because the DC component of a signal acts as a voltage offset, and removing it from the signal can increase the resolution of signal measurements. AC coupling is also known as capacitive coupling.

DC coupling describes any voltage signal acquisition in which both AC and DC components are measured.

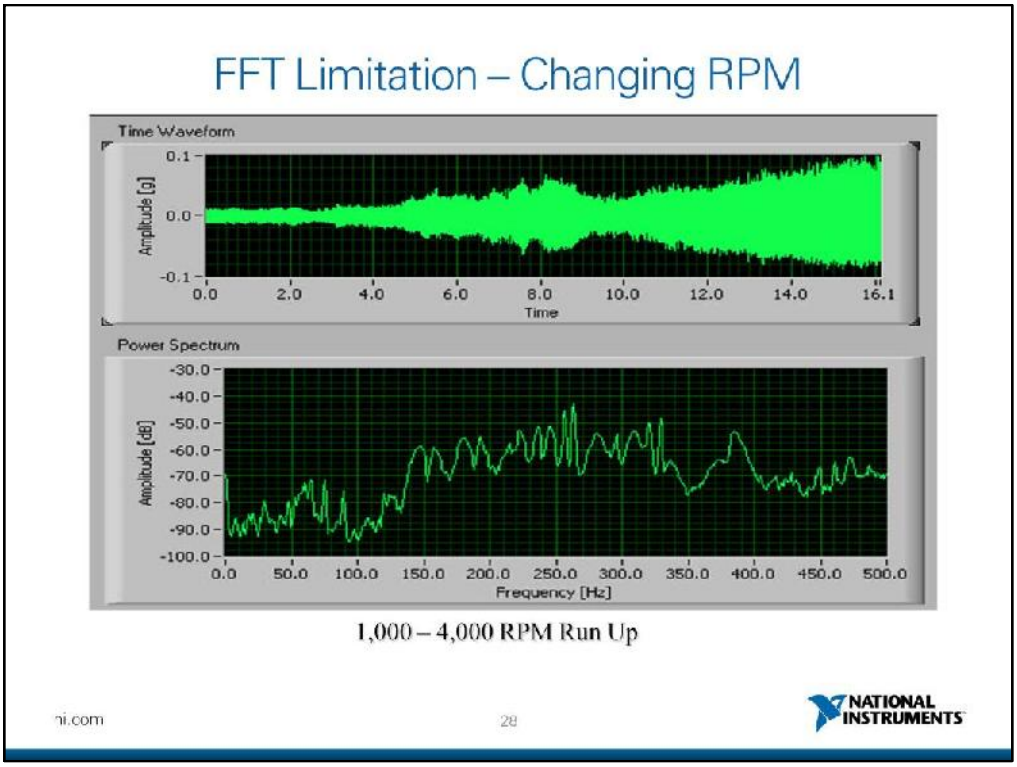
IEPE technology is marketed under several more recognizable brand names. Although other companies make IEPE based accelerometers, this does not imply that they are compatible with equipment that claims Integrated Circuit Piezoelectric compatibility. One of the key variations from company to company is the amount of current necessary to power the sensor.



Lets now look at the benefits of order tracking.

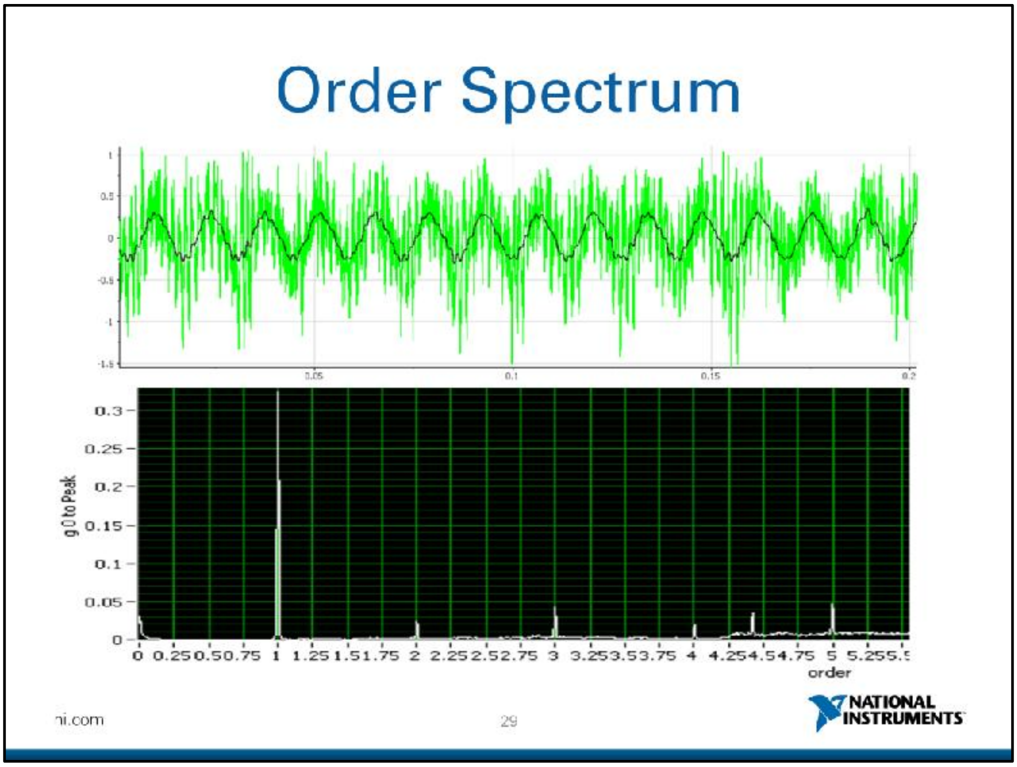
Looking at our original fan, this is the vibration signal acquired by an accelerometer, when the fan was running at 3,300 RPM. The FFT power spectrum is shown below the time waveform.

The spectrum has peaks at 55, 220 and 385 Hz, which are 1st, 4th and 7th order caused by shaft, coils and blades.



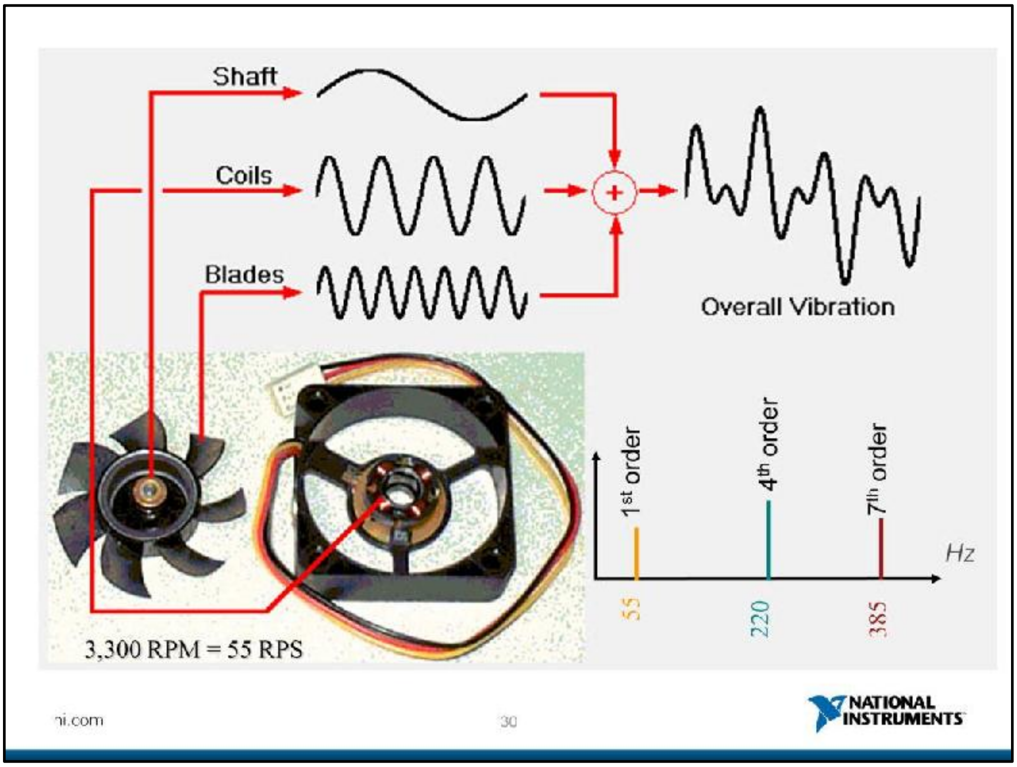
Our challenge with the FFT is the Fourier transform can only deal with the constant speed scenarios.

If the rotating speed is changing, the harmonics / orders are smeared. In this slide, a vibration signal is acquired during the run-up of the fan from 1,000 – 4,000 RPM. The power spectrum does not show any meaningful peaks.



However, similar to the FFT, the order spectrum can provide a spectrum with harmonics of rotating speed instead of harmonics of time.

RMS averaging and adapt to changes in speed, thus preventing skew in the spectrum. An order spectrum is performed, by first resampling the time waveforms into even-angle waveforms, and then performing a spectrum.



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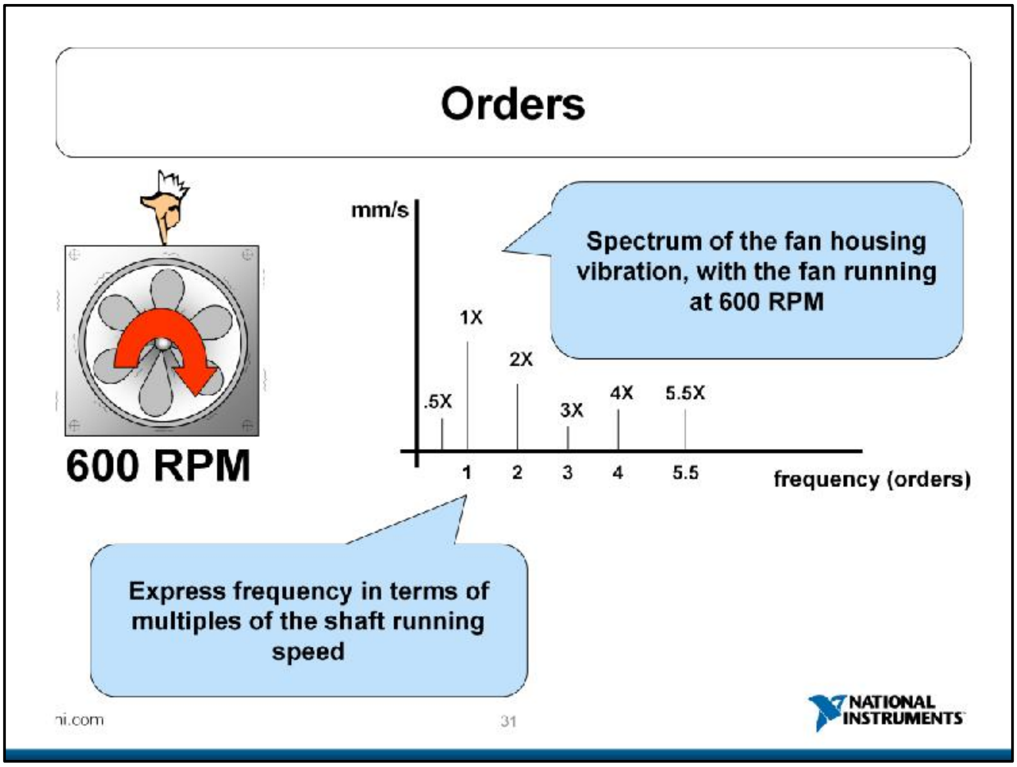
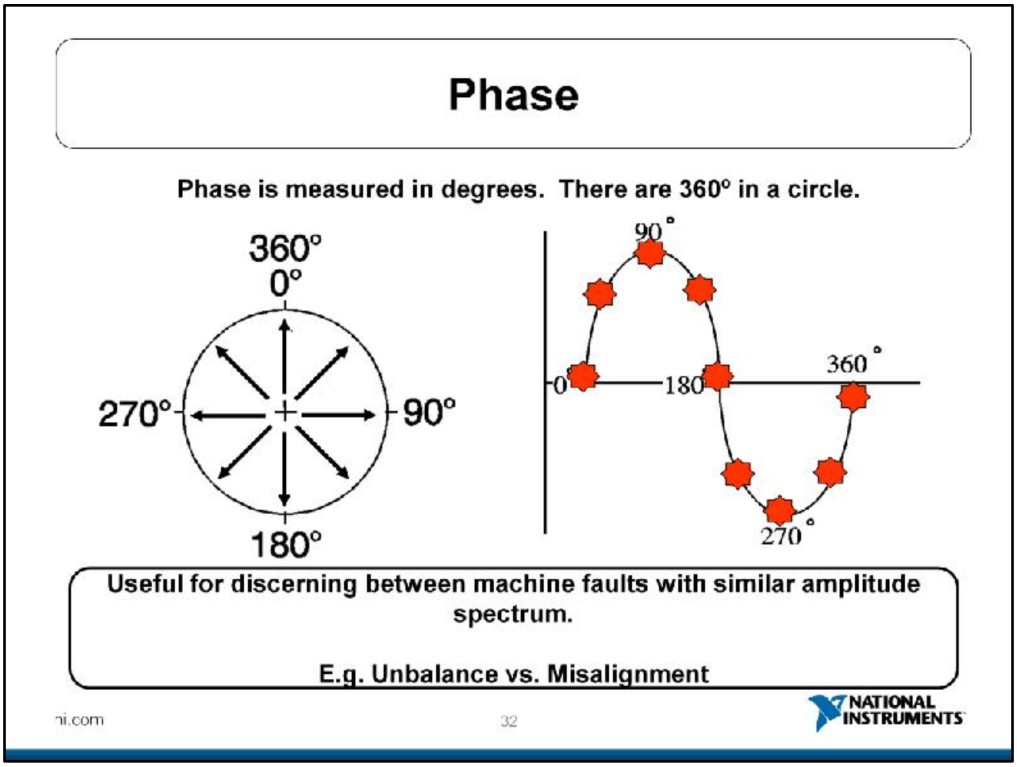
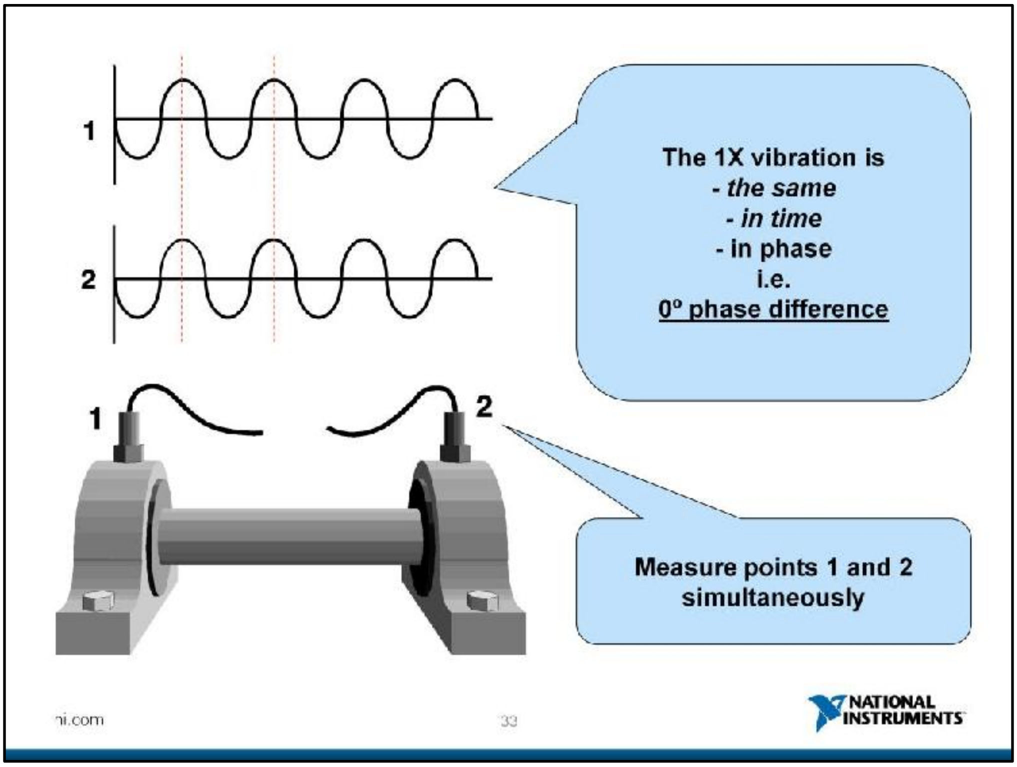


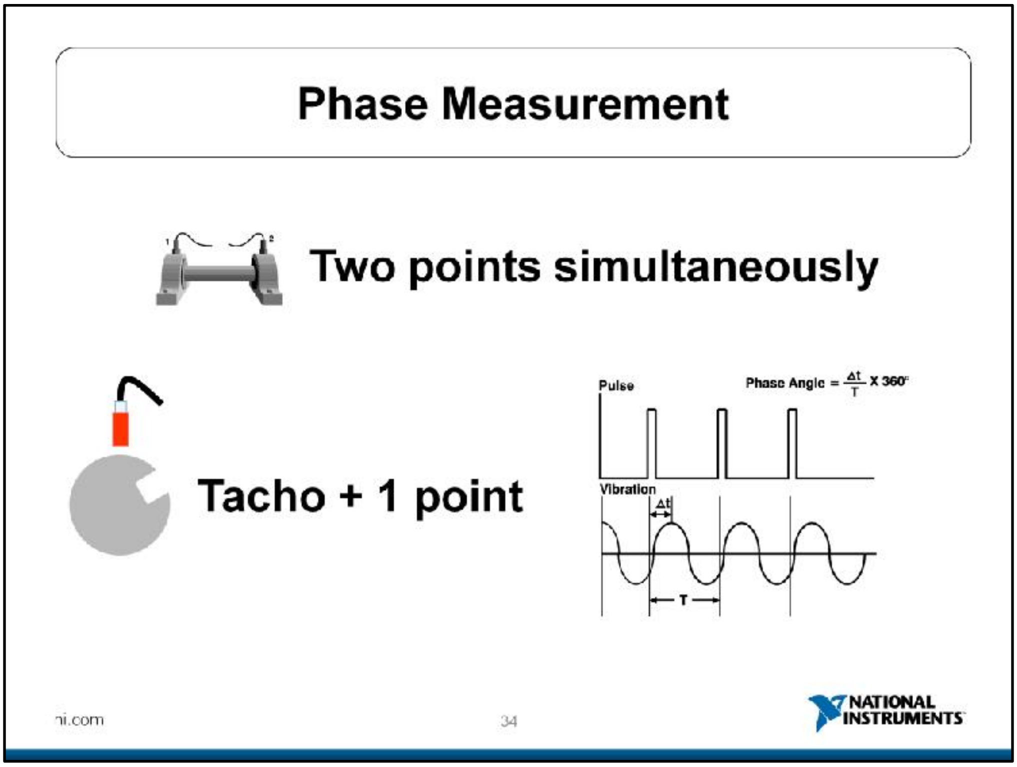
Order spectrum are the most common way to look at vibration spectrum.



Recall our earlier definition of phase.

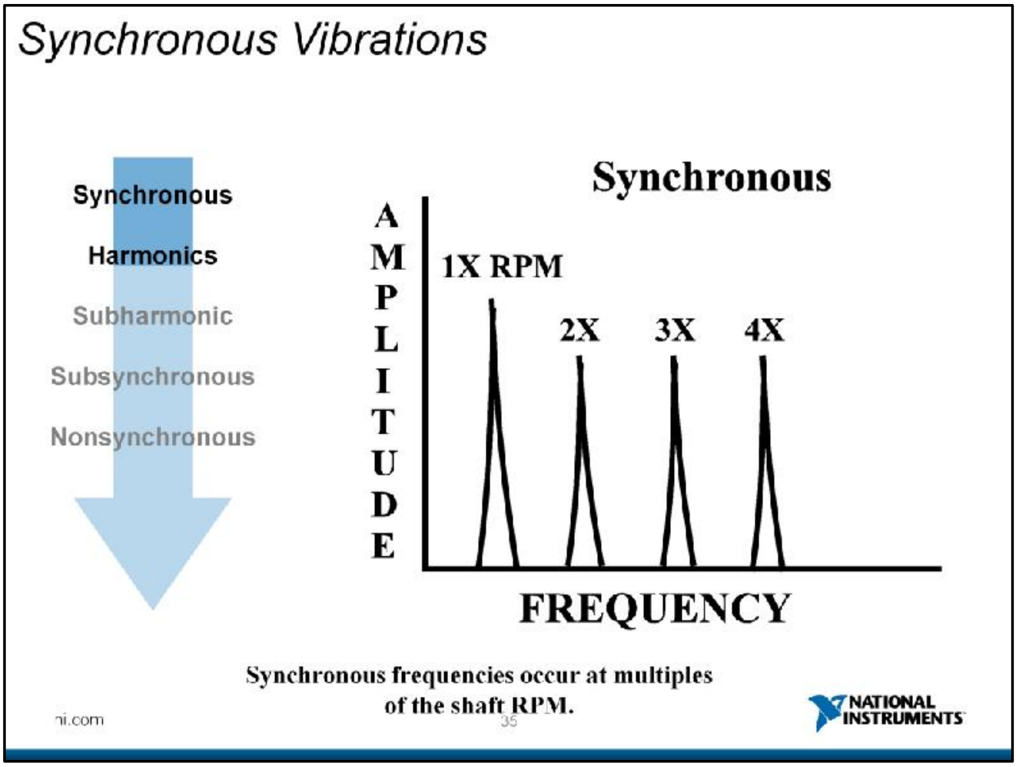


Phase can be useful in visualizing and understanding how the machine moves as a complete drive train. Here both bearings move in sync with each other in a coordinated up and down motion.

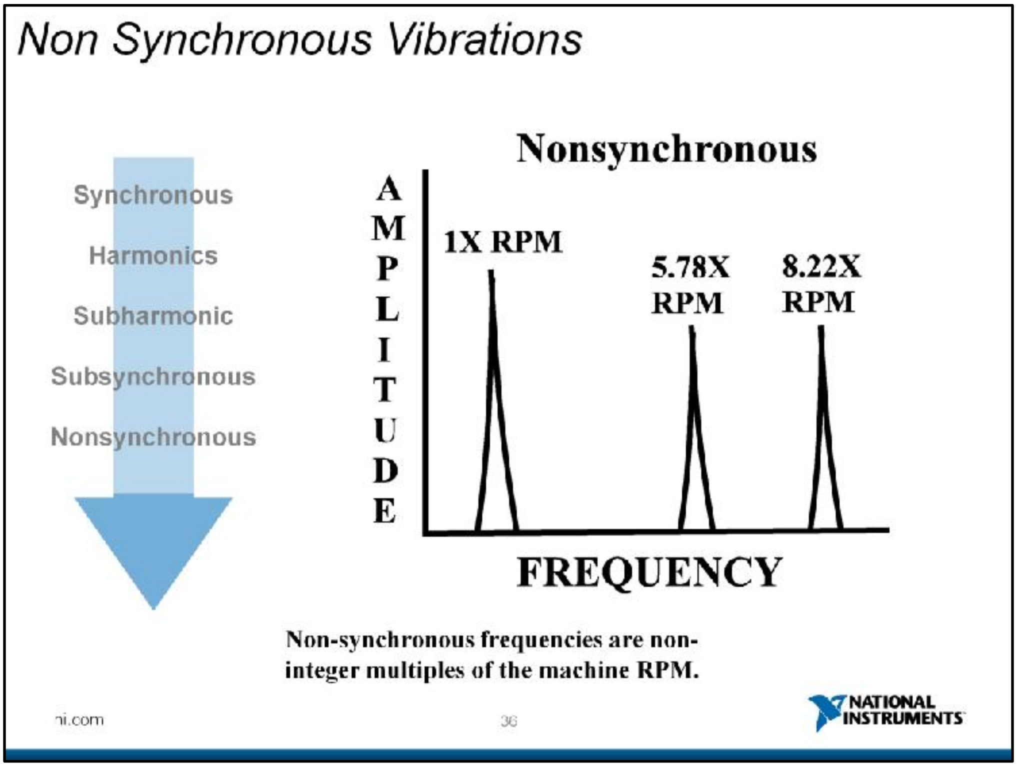


We can make phase reference by measuring two vibration channels at the same time, or by measuring one vibration channel with respect to the speed sensor on the shaft.

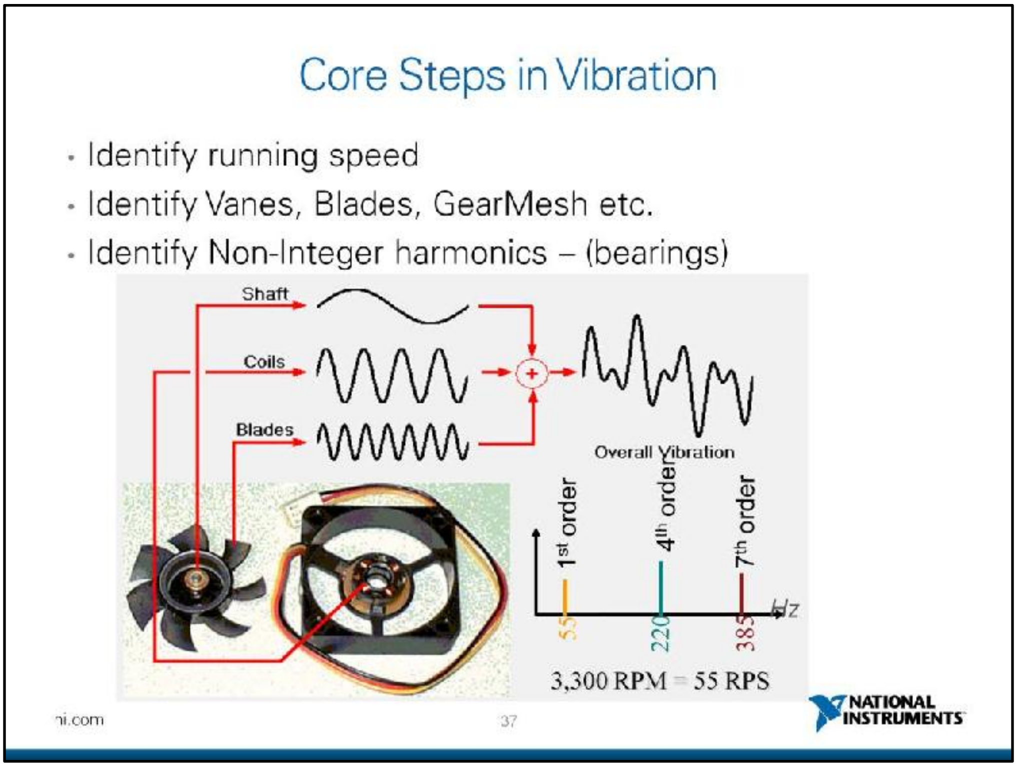
Again phase is important in helping to distinguish the type of unbalance, and to distinguish mis-alignment, bent shaft, and several other synchronous vibration conditions.



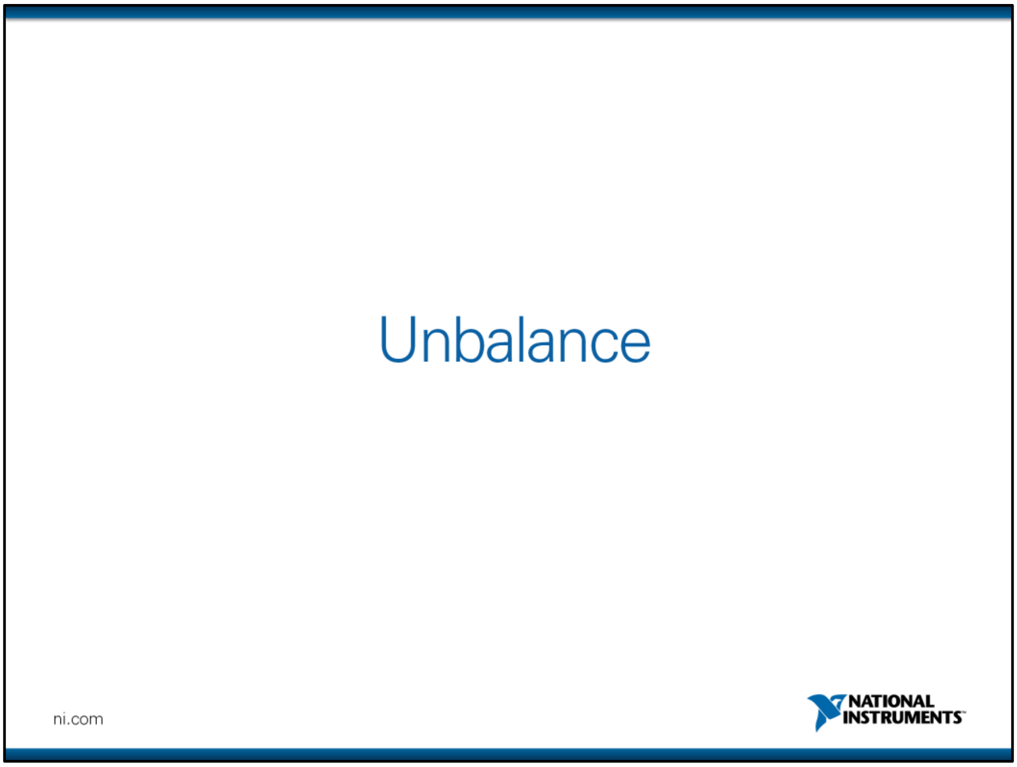
There are two types of vibrations in a rotating machine. Synchronous vibrations that are harmonics of rotating speed.



Non-synchronous vibrations often are from Roller Bearing mechanical interactions. We will see a bit more about roller bearings in a moment. Non-Synchronous vibrations can also come from resonance, electrical faults, and from nearby machinery.

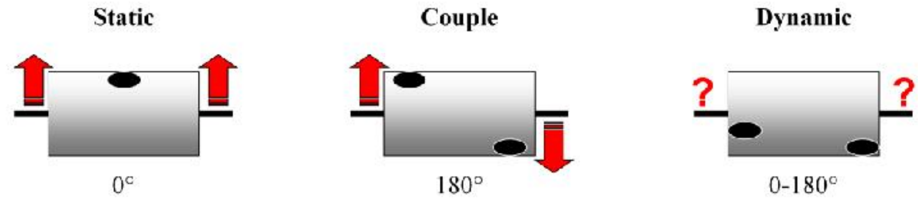


When one first looks at a vibration spectrum, it is best to identify in the spectrum those synchronous vibrations and relate them to the known mechanical features of the machine.



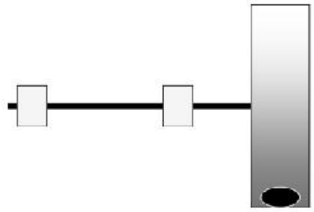
Lets now take a look at some common rotational mechanical faults in rotating machinery.

Unbalance – 1X



- Appears as 1X RPM in spectrum. Amplitude will increase by square of speed.
- Approx 90° phase difference between H and V readings
- 2 plane correction required for couple / dynamic. 1 plane for static
- Couple & Dynamic may also cause a little axial vibration
- Strong vibration source which may excite natural frequencies

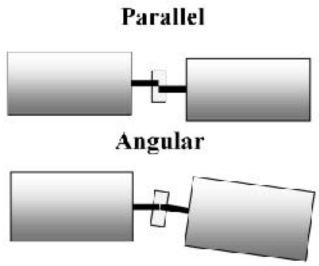
Overhung Rotor Unbalance – 1X

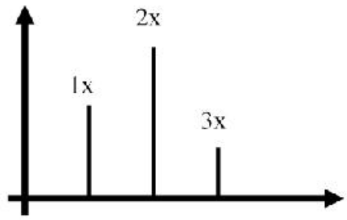


- High 1X amplitude in radial and axial directions
- Approx same phase difference between H and V readings on both bearings
- Rotor usually has both static and couple unbalance - require correction in 2 planes.

Misalignment

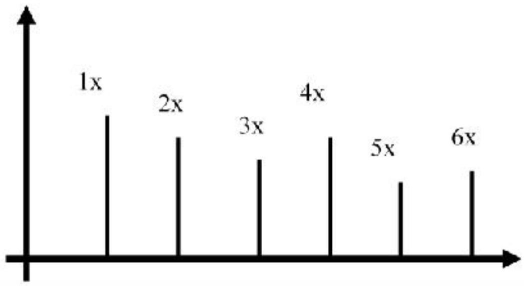
Misalignment





- Appears as 1x, 2x, 3x in spectrum. 2x often higher than 1x
- Unlike unbalance, H & V amplitudes may be very different
- Angular misalignment causes <u>axial vibration</u> as well
- Most often a combination of parallel and angular
- Amplitude will not increase with speed.
- 180 phase difference across coupling in axial (angular) or radial (parallel) directions.

Looseness



- Emphasized by unbalance
- 2 types: rotating looseness - excessive sleeve / bearing loosensess
- and: non-rotating looseness - loose foundation, component rattle (many harmonics)
- Appears as many harmonics of the shaft running speed

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Bearings

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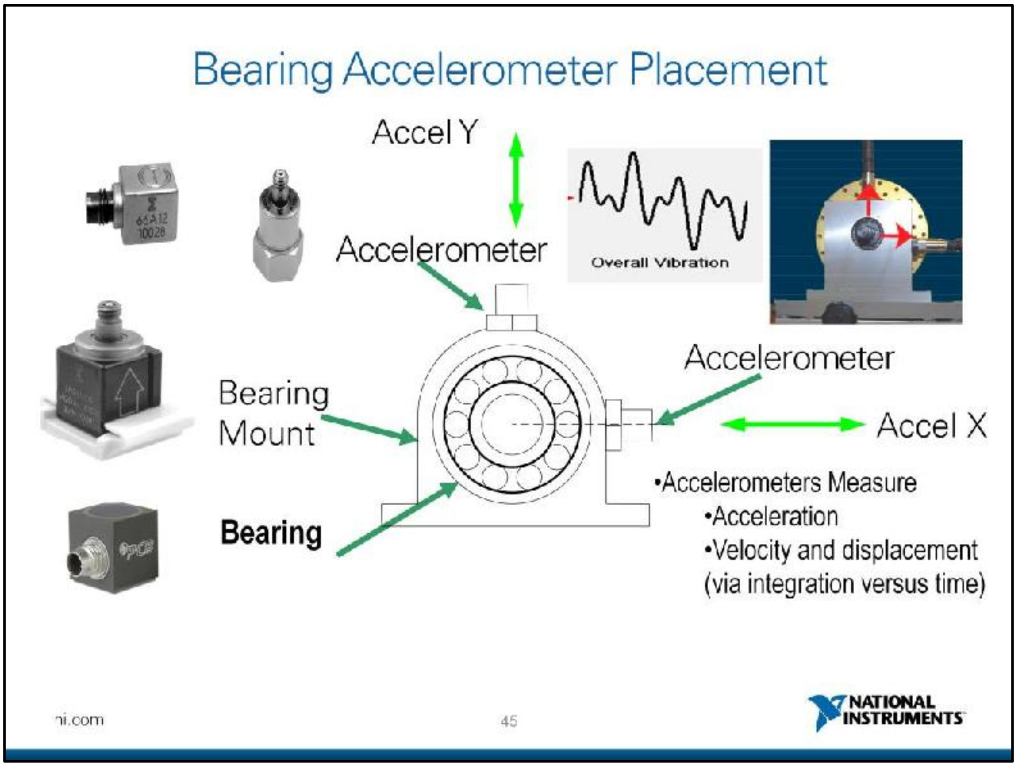
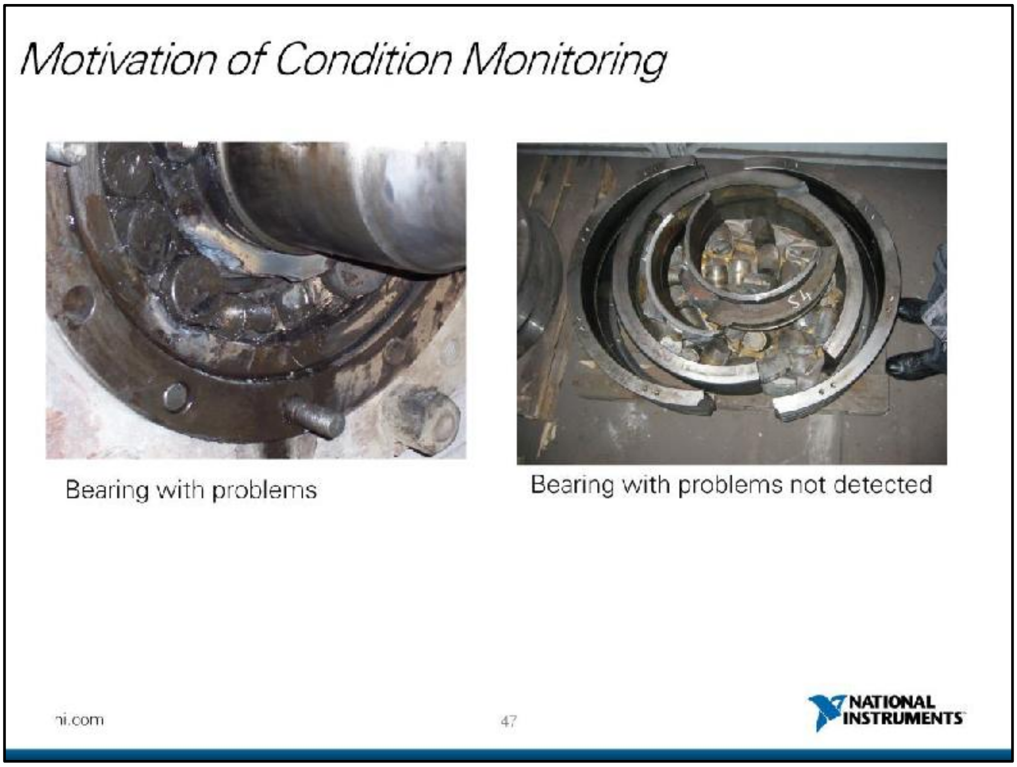


Another stimulus for accelerometers is the normal movement of the machine or unit under test. In the case of a rotating machine, rotation is the stimulus that creates vibration.

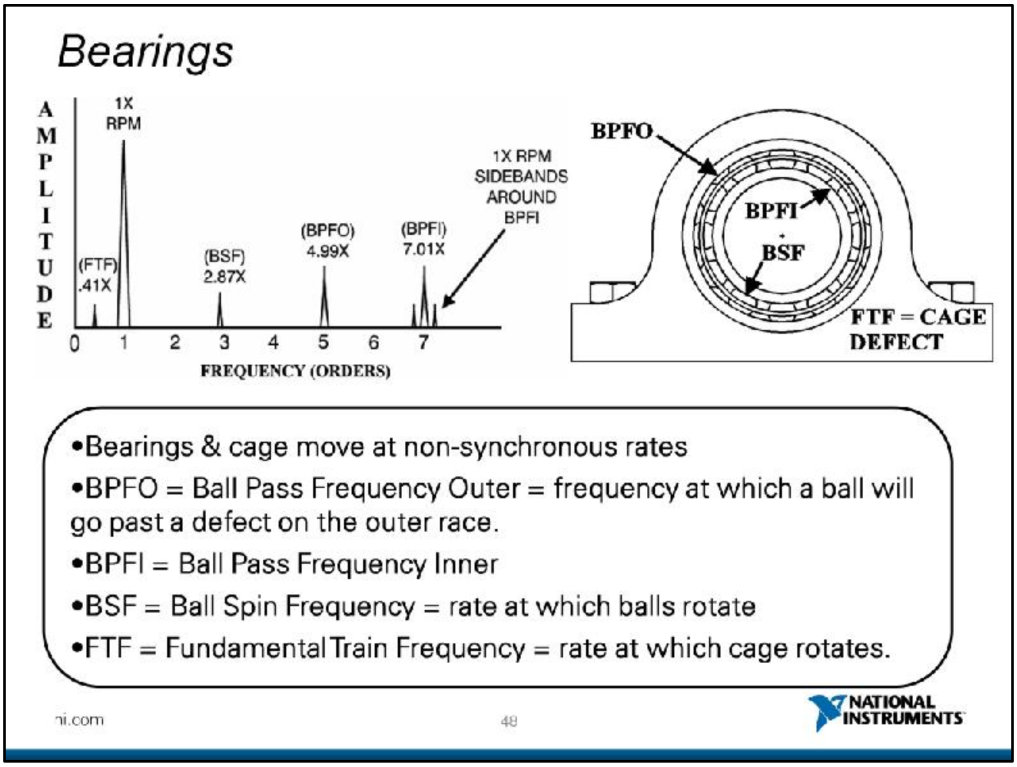
Accelerometers measure vibration that is transmitted thru the mechanical structure of the machine. Typical accelerometer applications include bearings, gearboxes, electrical motor, frame or footing vibration.

Because of their proximity to bearings, bearing mounts are a common location for accelerometer sensors to measure vibration signals. The diagram shows a bearing mount with accelerometers that measure acceleration in the X and Y directions shown in green.
Bearing wear is a common problem with rotating machinery because the bearings are commonly the transmission path for rotor forces caused by other vibration forces. As such, worn bearings are often only symptoms of other problems. For instance, stress caused by a bent shaft often contribute to bearing wear.

Bearing Illustration

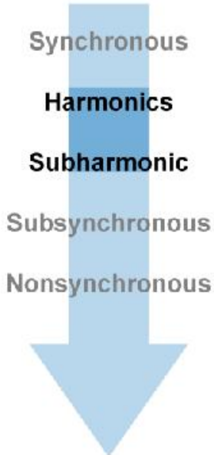


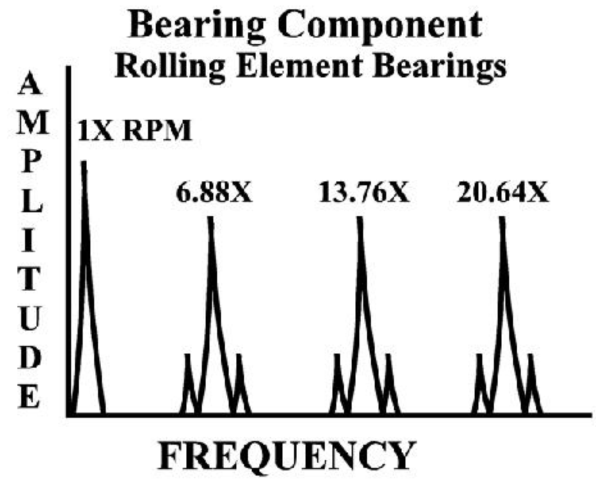
Here you see a bearing in a cement mill with well developed problems. One can see the heat stress, metal fatigue visibly. This machine was not monitored, the bearing seized up (froze), came apart, and caused the expensive electrical motor trying to turn this shaft to burn up. What could have been a $5000 one day repair, became a $50,000 multi day repair.



Here is a closer look at bearing frequencies. As you can see, vibration signature analysis can tell quite a lot about bearing vibrations. There are four main signal components in a roller element bearing. The Ball Pass Frequency of the outer race, the ball pass frequency of the inner race, the ball spin frequency, and the fundamental train frequency. You will want to review the video provided with this material for an excellent illustration.

Roller Bearing Harmonics





Harmonics are frequencies which are multiples of a reference frequency. "Harmonics of the shaft frequency are synchronous."

$$BPFI = \frac{n}{2}\left(1 + \frac{B_d}{P_d}\cos\theta\right)RPM$$

$$BPFO = \frac{n}{2}\left(1 - \frac{B_d}{P_d}\cos\theta\right)RPM$$

$$BSF = \frac{P_d}{2B_d}\left[1 - \left(\frac{B_d}{P_d}\right)^2 (\cos\theta)^2\right]RPM$$

$$FTF = \frac{1}{2}\left(1 - \frac{B_d}{P_d}\cos\theta\right)RPM$$

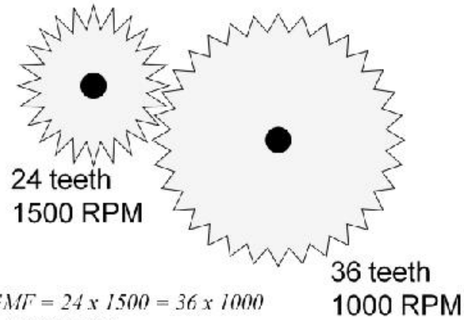
P_d = Pitch diameter
n = number of balls
B_d = Ball diameter
θ = Contact angle

The Manufacturer or a bearing frequency database will provide these.

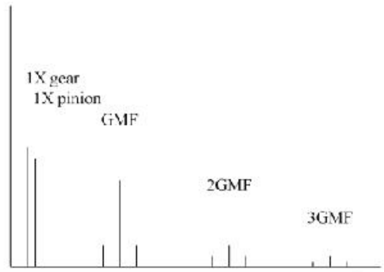
Short Cuts
BPFI = 0.6n X
BPFO = 0.4n X

Gears

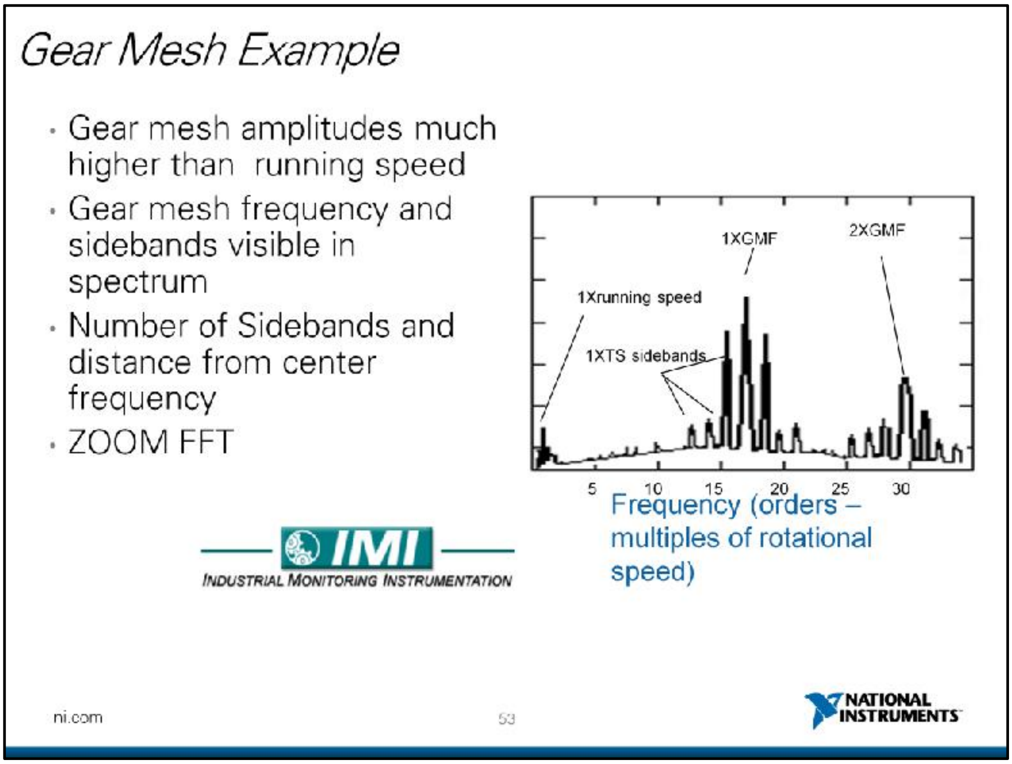
Gears - Normal Vibration



GMF = 24 x 1500 = 36 x 1000
= 36000 CPM



- **GMF = # teeth x shaft RPM = same for both sides of gear**
- **small GMF and 1X peaks for both shafts are normal**
- **time waveform appears regular**
- **sidebands at 1X either RPM**

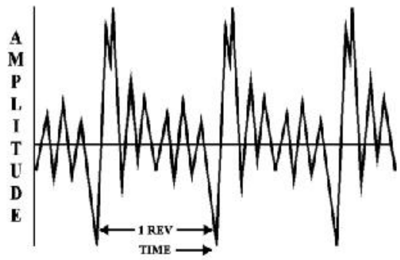


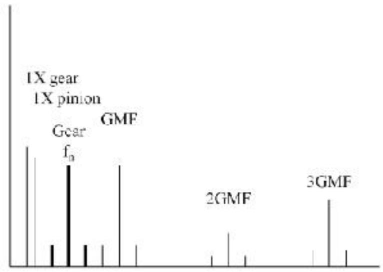
An extension to the FFT is the zoom FFT. The resolution of the FFT result is dependent on the amount of data collected. The zoom FFT stores up consecutive blocks of data until the desired frequency resolution of the X-axis is obtained. Further more, the zoom-FFT only analyzes the raw signal for repetitions in the desired frequency range.

Gear frequencies are an example use case for zoom-FFT. Gear mesh amplitudes are at much higher frequencies than running speed. The gear mesh frequency and sidebands are visible in the spectrum. Here, a zoom-FFT will help to further understand the sideband peaks, their relationship to the center frequency, amplitude ratios, and so forth. Often, shaft sidebands around gearmesh suggest input shaft problems.

A computer-based machinery monitoring and diagnostic tool provides the engineer with the ability to easily adjust FFT and Order spectrum tools to easily analyze complex problems such as gear-mesh frequency analysis.

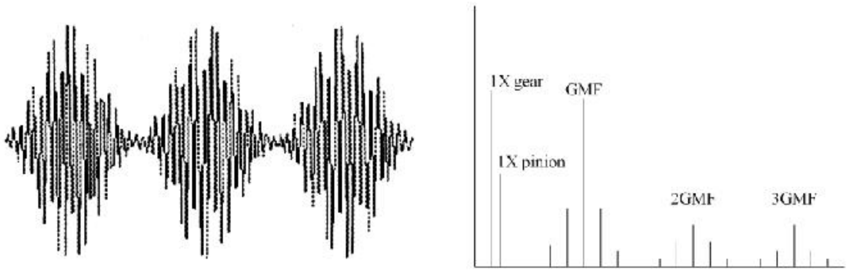
Gears - Tooth Problem





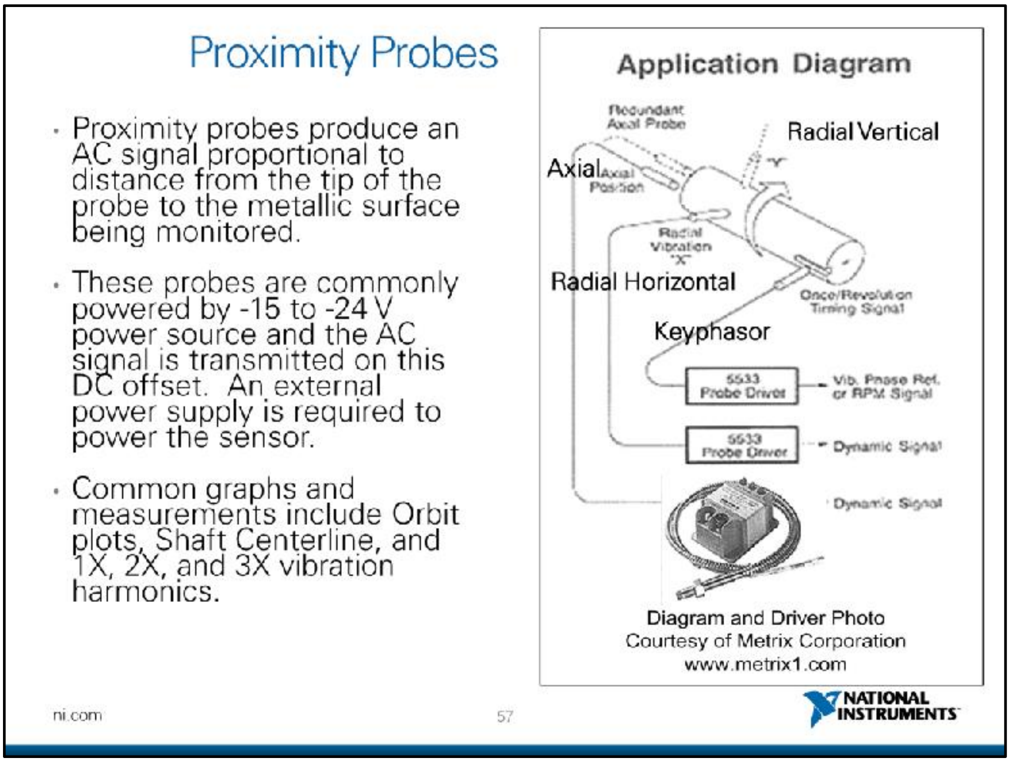
- Appearance of gear natural frequency, f_n
- Increase in GMF harmonics, especially 3X
- Very obvious repetitive disruption in time domain
- Sidebands spaced at running speed of the bad gear

Gears - Eccentric

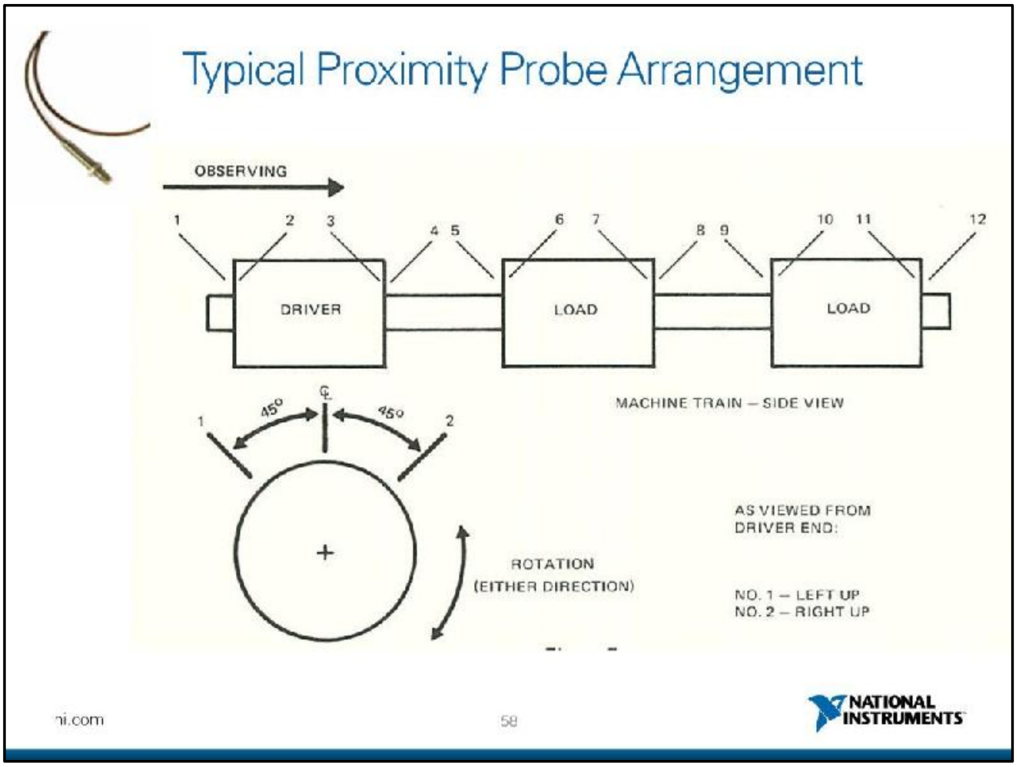


- Time domain will appear amplitude modulated
- More side-bands will appear, spaced at RPM of eccentric gear
- 1X of eccentric gear will be higher

TurboMachinery

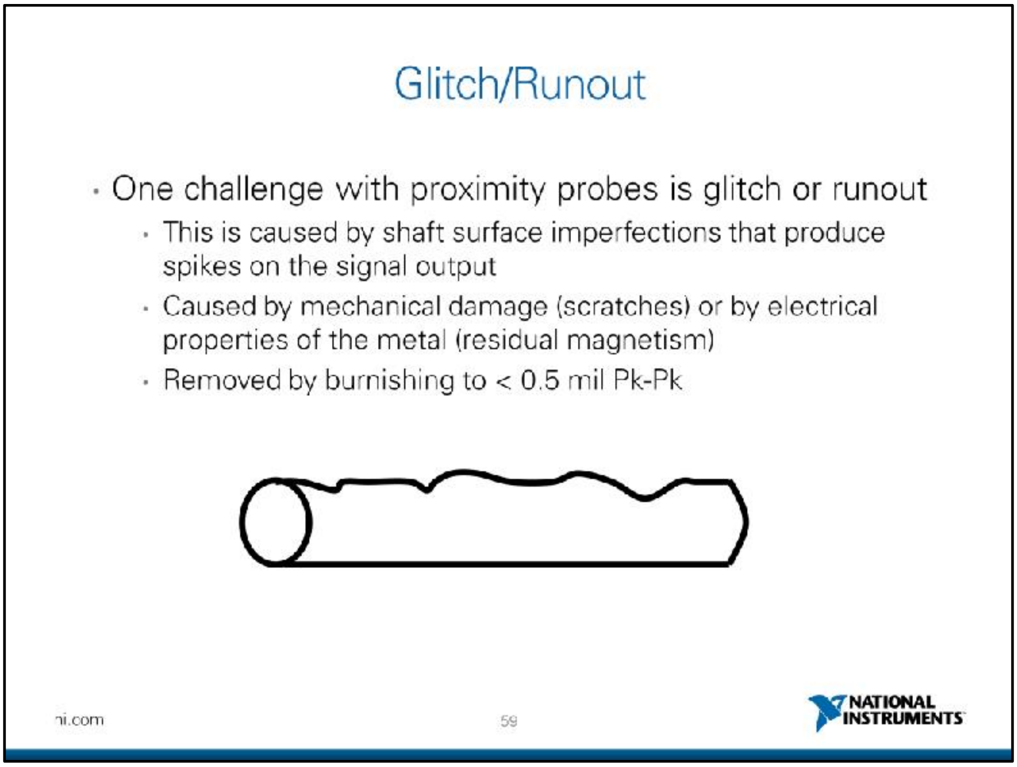


Another common transducer used for rotating machinery monitoring is the proximity or eddy current probe. These probes are non-contact vibration measuring devices used to monitor shaft vibrations. Shaft vibrations are typically indicative of unbalance, misalignment, and mechanical looseness. Proximity probes are probably one of the more common sensors used for larger machinery applications and for rotor dynamics research.



Probes are placed and referenced from observing the drive shaft from the driver end of the machine train.

In a typical setup, you'll have a driver (steam turbine) and a load (compressor). You would have two sets of proximity probes per device (inlet and outlet).

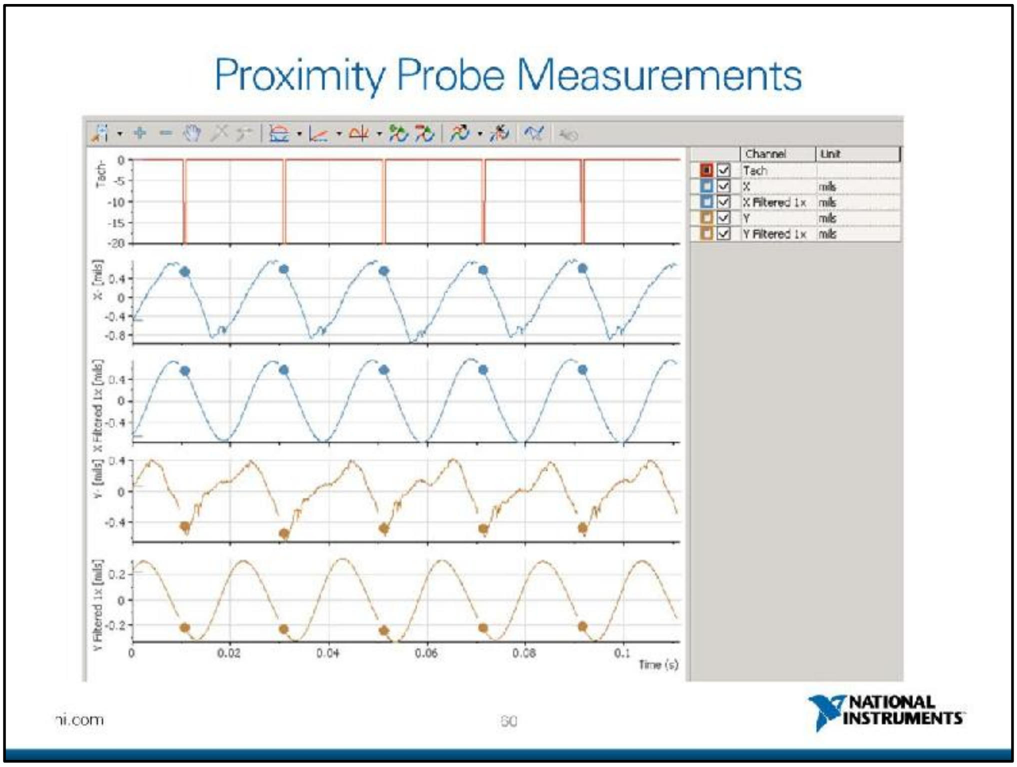


Oh, and sometimes the mechanic creates an imperfection on the shaft. This is order related as it occurs at the same angular location on the shaft, how do we get this removed?

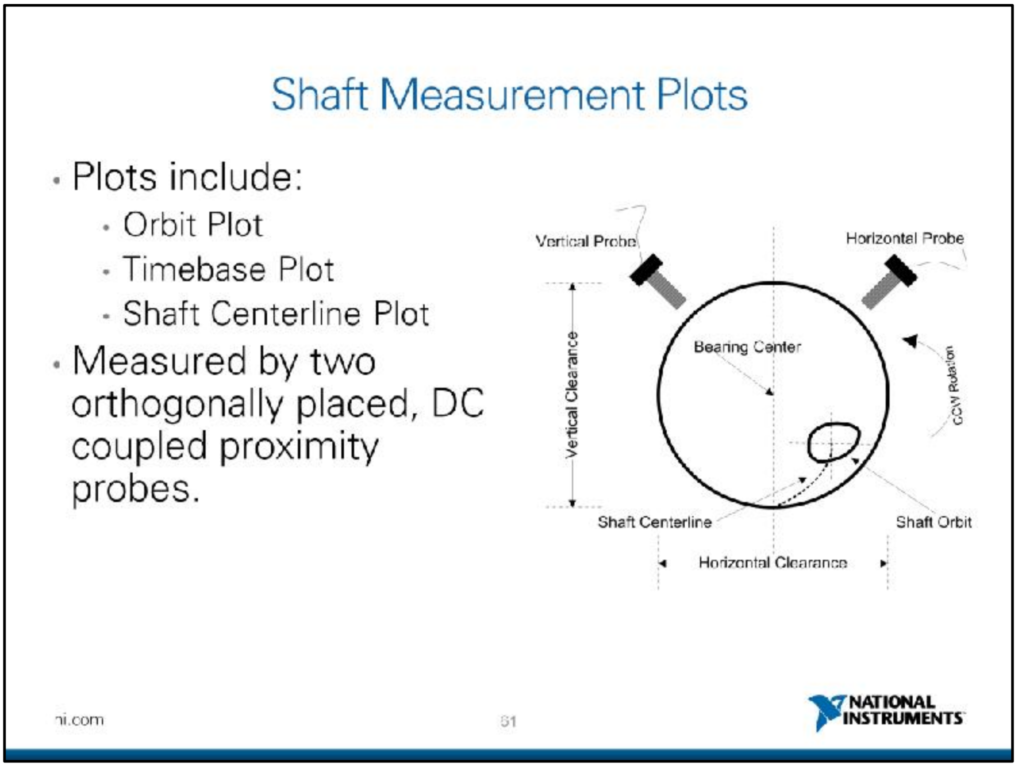
The exaggerated idea is shown at the bottom of the slide.

The order analysis has run-out compensation that takes a slow-roll profile and removes it from proximity probe data.

What else?



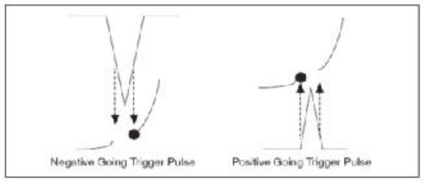
In many time waveform graphs depicting vibration from turbo machinery proximity probes, we will display the speed sensor (top) and then both the unfiltered and filtered (1X) time waveforms. By displaying both the filtered and the unfiltered time waveforms, the analyst is able to visually see both the vibration likely due to unbalance (1X) and the remaining contributors of vibration in the machine.



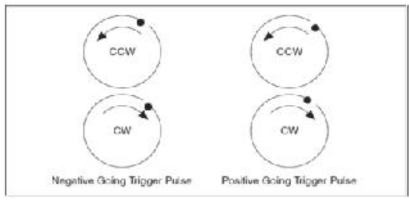
With two probes in each plane of the turbine shaft, it is possible to visualize the rotational pattern of the shaft. In large critical machine trains this can be very important to help identify problems with any turbine driven equipment.

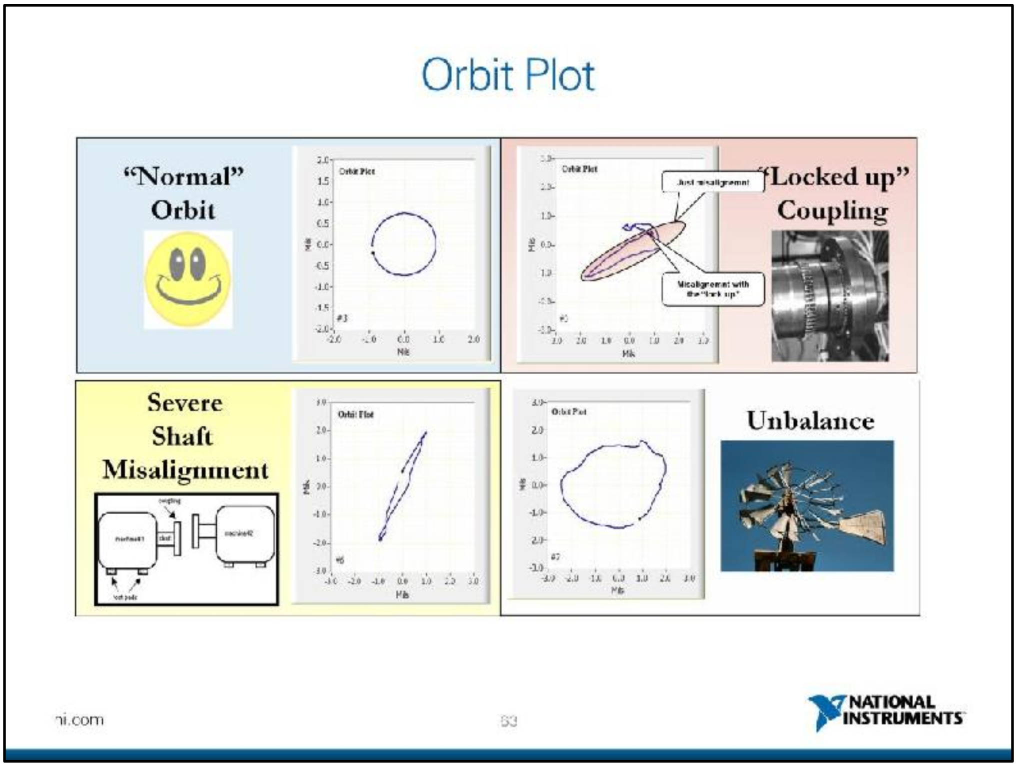
Blank-Bright Sequence

- Blank-bright sequence on plots are determined by trigger signal pulse direction.



- Blank-bright sequence can be used to indicate orbit direction.

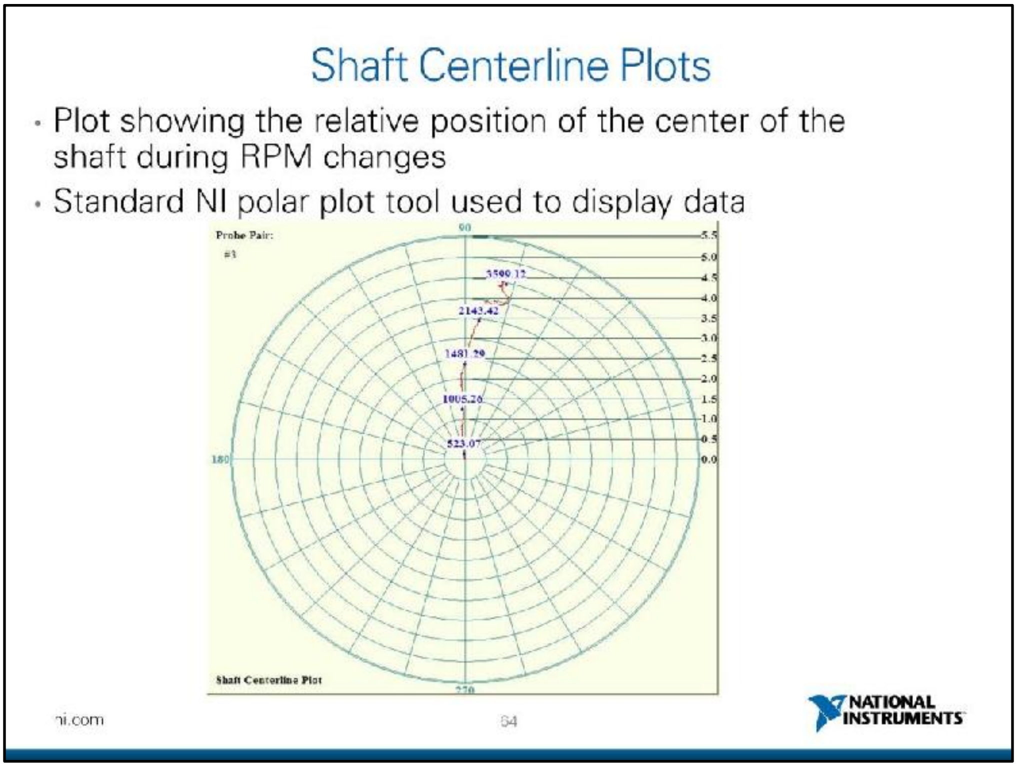




Orbit plots show us what the shaft of the machine is doing. How is the coupling and alignment? Orbit shapes often can lead to specific diagnosis as to the source of vibration.

Locked up coupling – a lubricated coupling (most common in international situations) where the lubrication between the mating sets of teeth in the coupling is gummed up or even "welded" together. Hence, instead of a standard misalignment, the shaft sticks and then jumps.

Unbalance is most often caused by a poorly distributed weight (situations where the weight of the rotating equipment is not perfectly centered on the shaft).



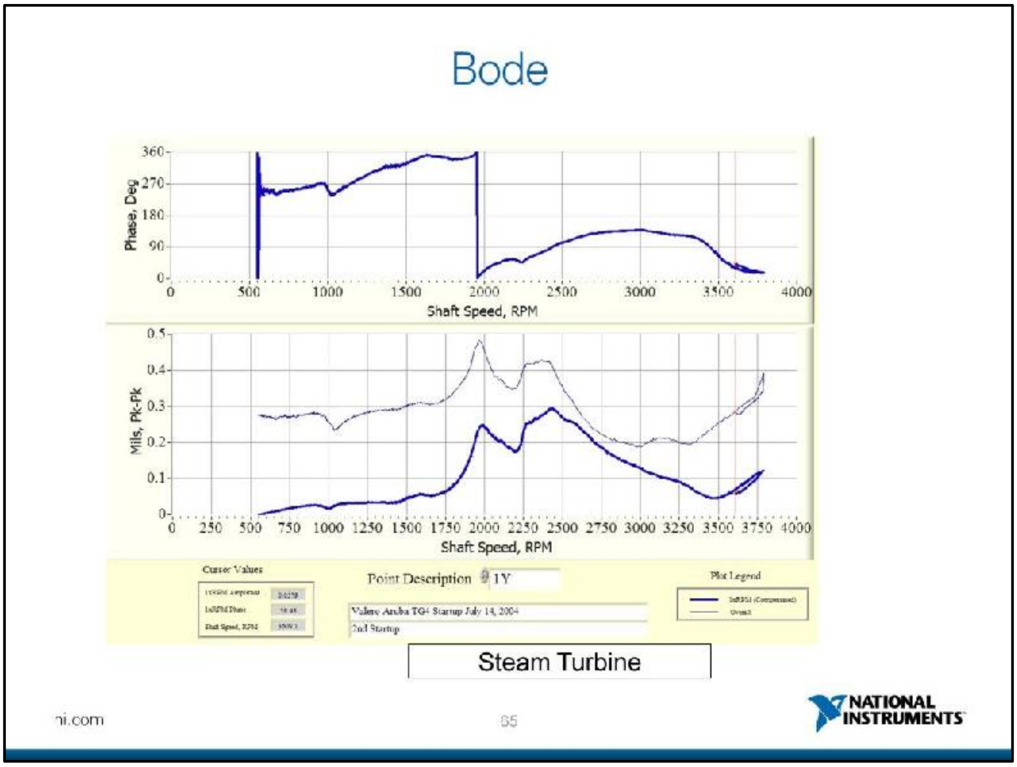
There are many other analysis and plots one might be interested in for on-line or test cell applications.
Shaft Centerline, Waterfall, Zoom Order, Envelope, Impact Detection, and so on.

For example, The purpose of the shaft centerline is to show the direction of the center of the shaft over RPM changes.

So lets get down to business.

If there was a bearing problem, the shaft would start to “drift and flop”. The shaft centerline is used on every startup/shutdown to check the health of the bearings.
•Bearings with excessive clearance (due to wear in the bearing liner caused by sand and other debris in the assembly).

The Orbit looks at the “AC” side. The shaft centerline looks at the “DC” side. You can use the shaft centerline and the orbit together to diagnose more advanced problems. (For example, if there is a bearing problem, you may end up with a double circle in the orbit… and it may also show up with a trail off to one side in the shaft centerline.)



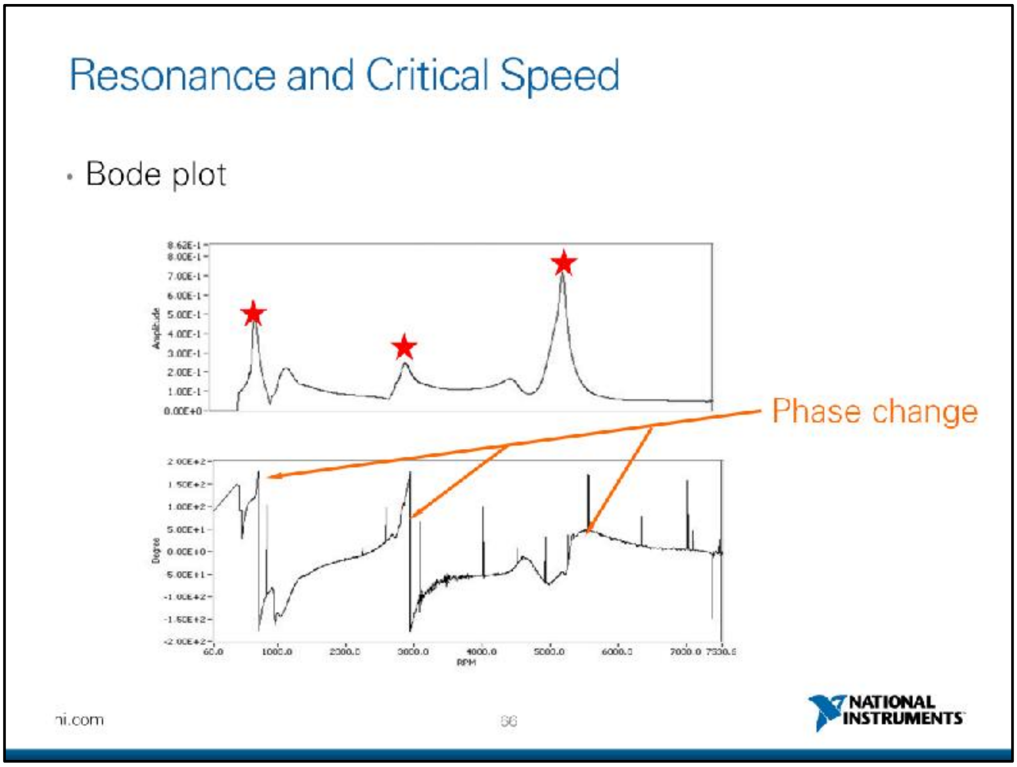
For diagnostics or test cell applications, the vibration expert wants to determine the frequency response of the machine.

It is challenging as there are many frequency responses in a machine.

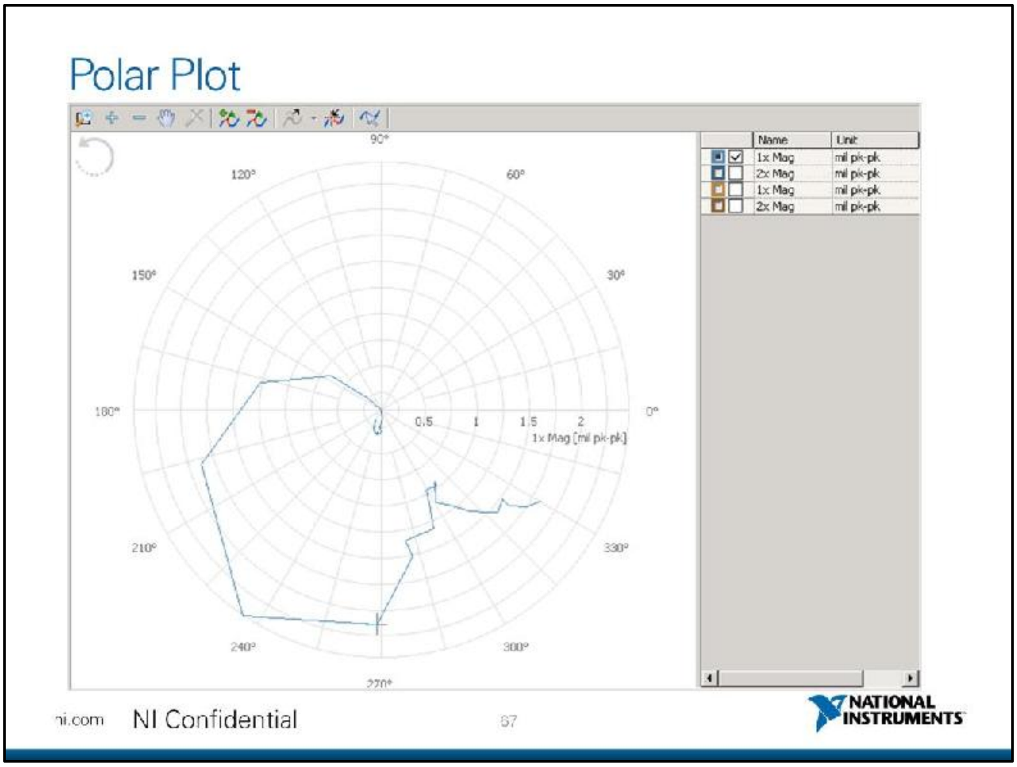
So we use the order analysis toolkit to isolate each frequency response, or in other words to track the orders of a range of speed (the stimulus).

The bode plot is a common way to plot out a single order output. In this case, we are showing the 1X component. Based on the plot above, there are two critical speeds. The magnitude of the vibration (relative between the housing and the shaft – using proximity probes) has two peaks. The peaks are due to resonances within the entire system – normally called critical speeds on rotating machinery.

The plot at the top is showing the phase relationship. Note the dramatic phase change is really not that (the plot is a 0 to 360 degree plot) drastic at all.

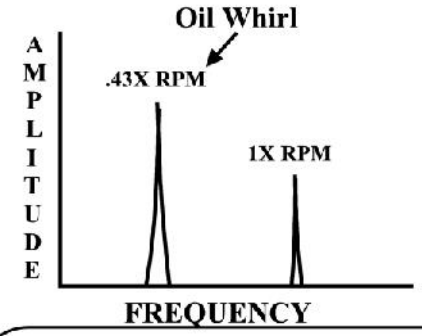


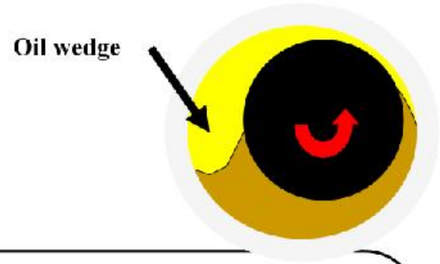
A bode plot is another means of identifying those critical speeds where typical machine rotational vibration will stimulate a resonant frequency of the machine causing accelerated or amplified vibrations. Most machine operators prefer not to run their machines at critical speeds.



The polar plot is yet another way to visualize phase and magnitude of vibration from a single sensor as a turbine driven machine starts up or shuts down.

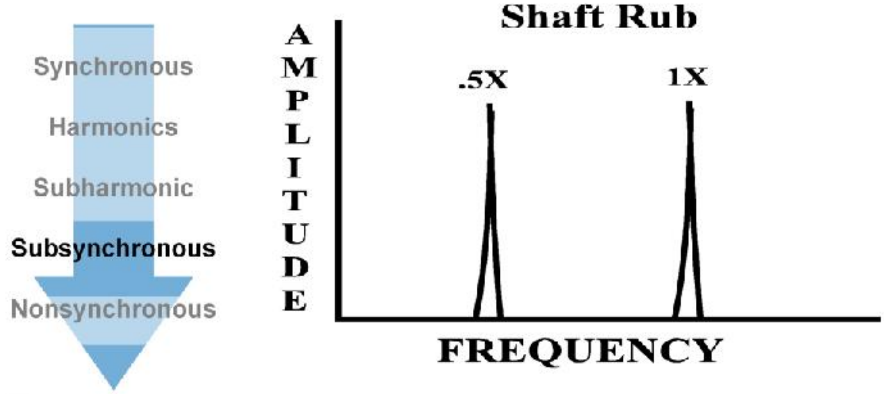
Oil Whirl



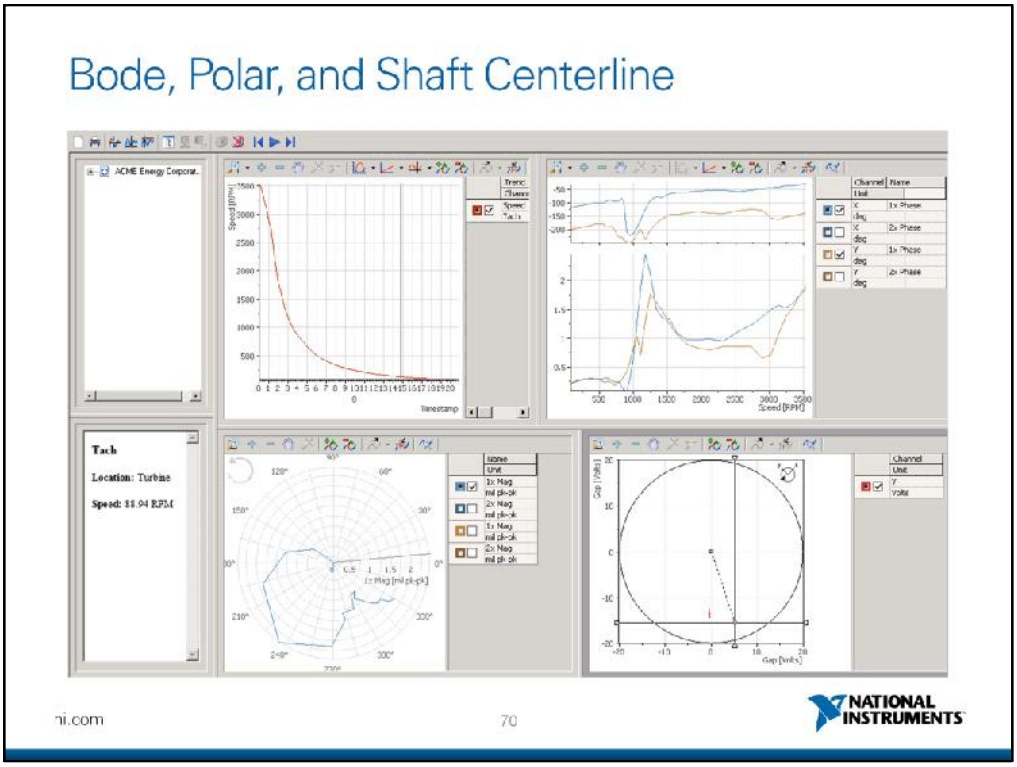


- Occurs when shaft has excessive clearance & light radial load
- Journal migrates around bearing < 0.5 RPM
- Appears as *subsynchronous* vibration at 0.38 - 0.48 RPM
- Easily confused with 0.5X - check data acquisition settings (resolution)
- Serious condition - must be corrected quickly.

Shaft Rub

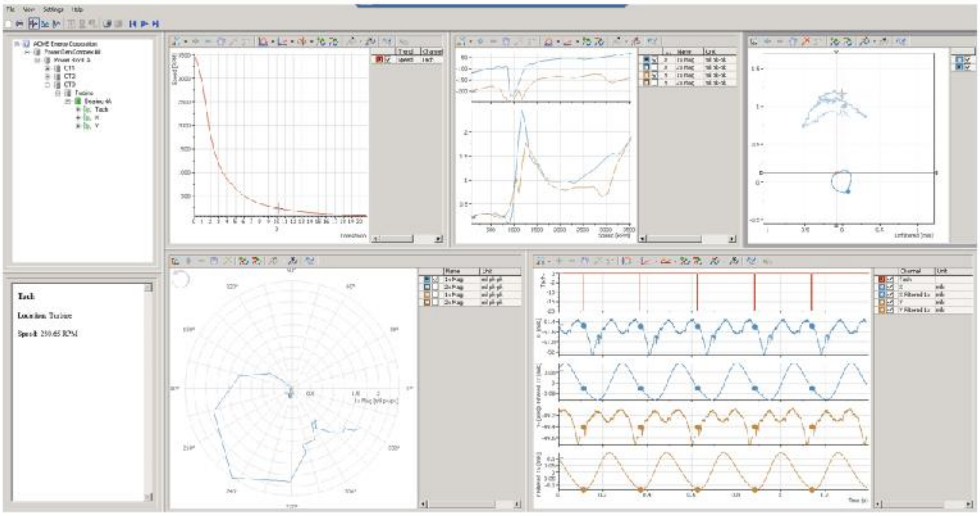


- Appears as sub-harmonic 0.5 X RPM
- Occurs when shaft is rubbing the surface of a fluid-film bearing
- Easily confused with oil whirl - check resolution



Watching multiple graphics during a start-up or a coast down is desirable.

Bode, Time Waveform, Orbits, Polar



Monitoring Systems

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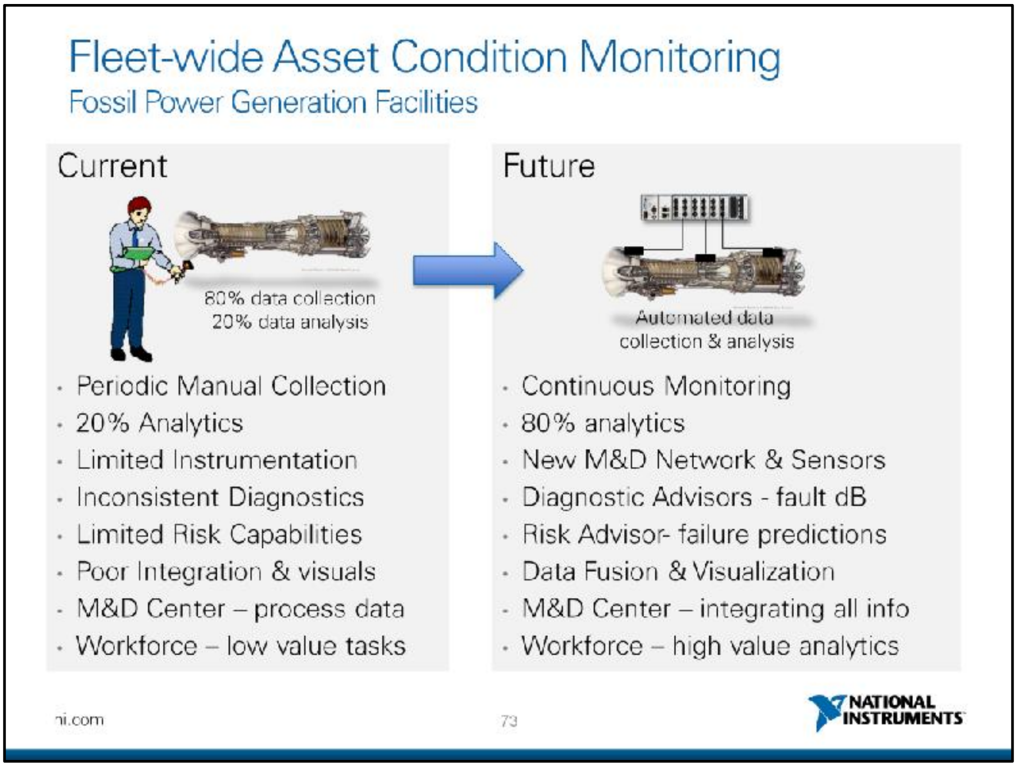
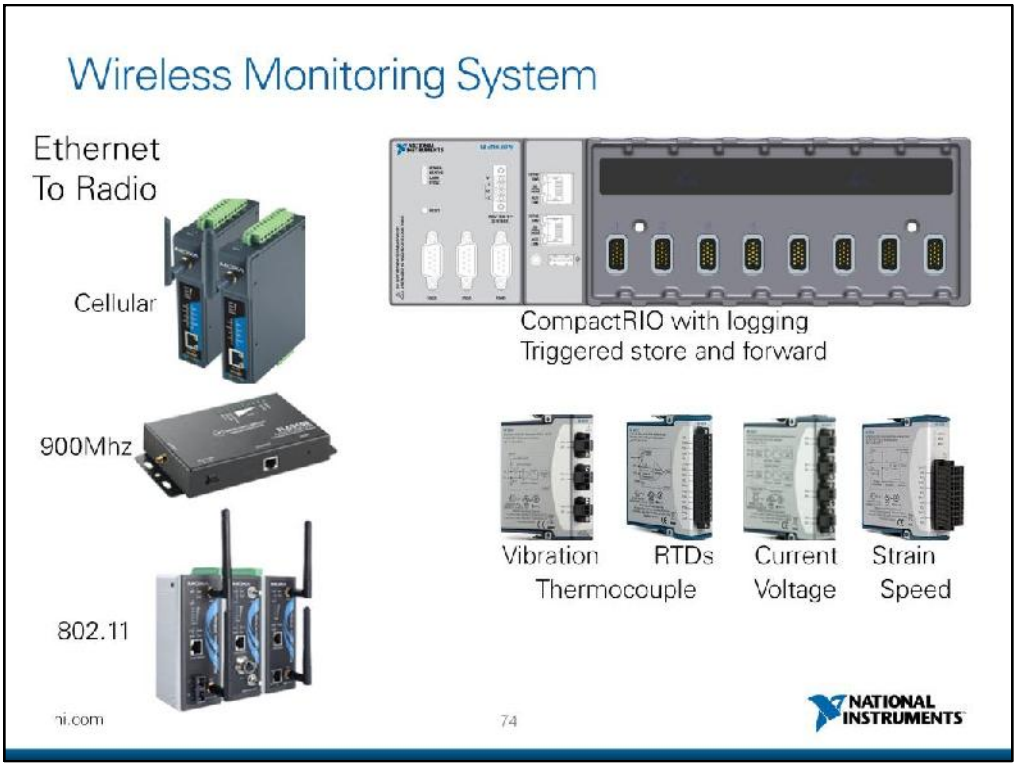
NATIONAL INSTRUMENTS



Many operators of rotating machines are working to optimize their equipment maintenance process. These operators want to move from manual vibration data collection to an automated continuous monitoring system. In this way, the vibration analysts and other machinery experts are able to spend more time review sensory vibration readings as compared to collecting the readings.

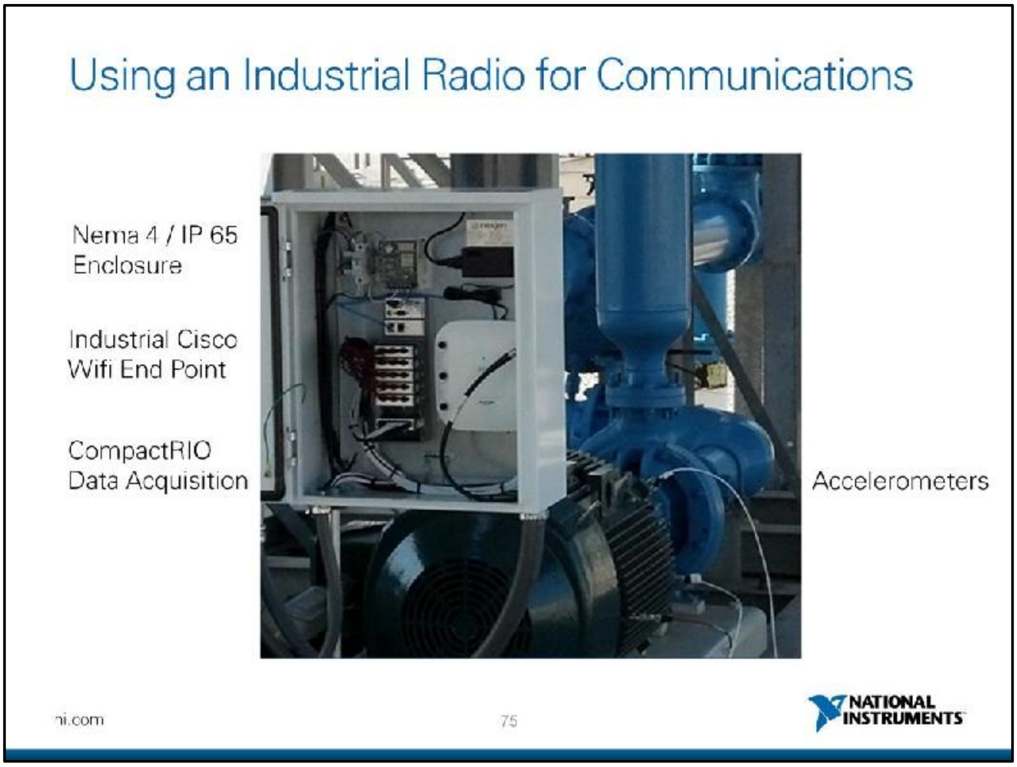
By bringing data from multiple machines together in one place, it becomes possible to conduct comparative analysis, comparing one pump's vibration pattern to another. Further, collaboration is easier with an on-line monitoring system, and it is easier to integrate vibration sensory data with other maintenance records.



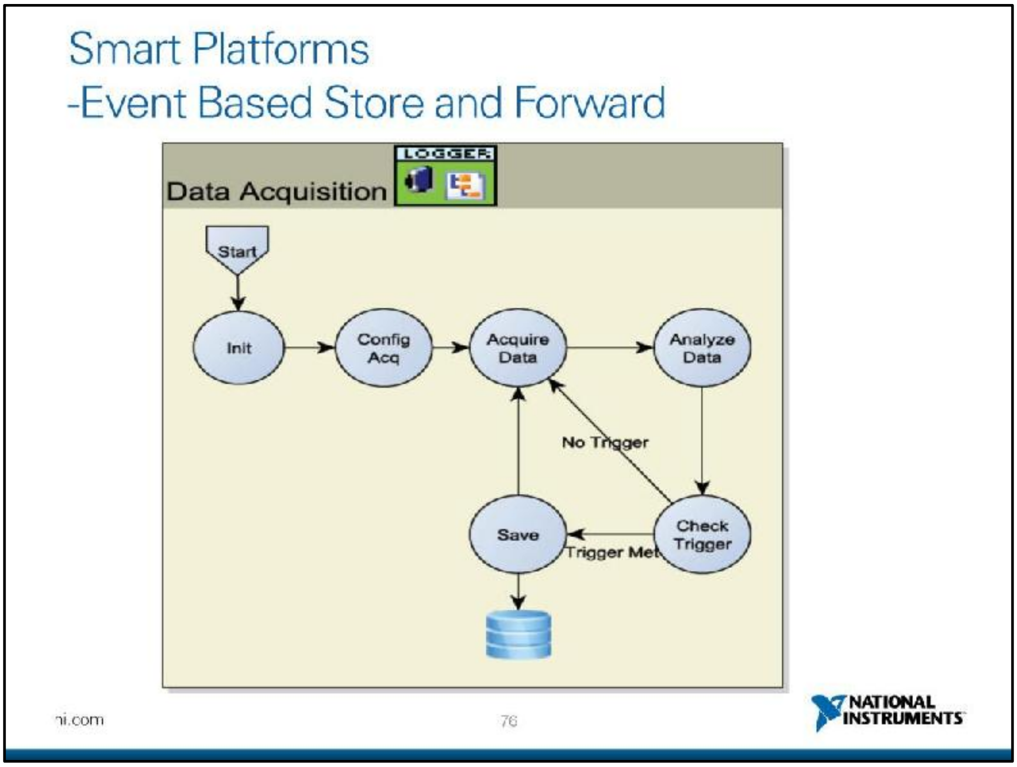
To capture vibration and process sensory data, triggered by events, an on-line always on monitoring system is desired. An open and modular system allows for vibration and related sensor types to be digitized at the same time. With onboard intelligence and storage, the correct data recording settings can be achieved to yield the desired FMAX and Lines of Resolution.

When wireless is required, there are many options for configuring a powerful wireless data acquisition system. Using the NI Value based CompactRIO chassis with specific I/O modules, AND by leveraging the previously mentioned reference design, it is quick and easy to deploy a ready to run application that is remotely configurable. The reference design also produces live data streams as well as captured TDMS data files.

With CompactRIO, it is easy to use wired or wireless Ethernet for remote monitoring. Shown here are several radio Ethernet solutions National Instruments customers have used.



In many cases, an industrial data acquisition device can be placed very close to the rotating machinery. This helps reduce the cable runs, and lowers the installation costs. By incorporating wifi or similar radios, communications cabling is also avoided. In the panel shown here, a industrial CISCO radio transmits time waveform data files over 300 feet to the maintenance building.

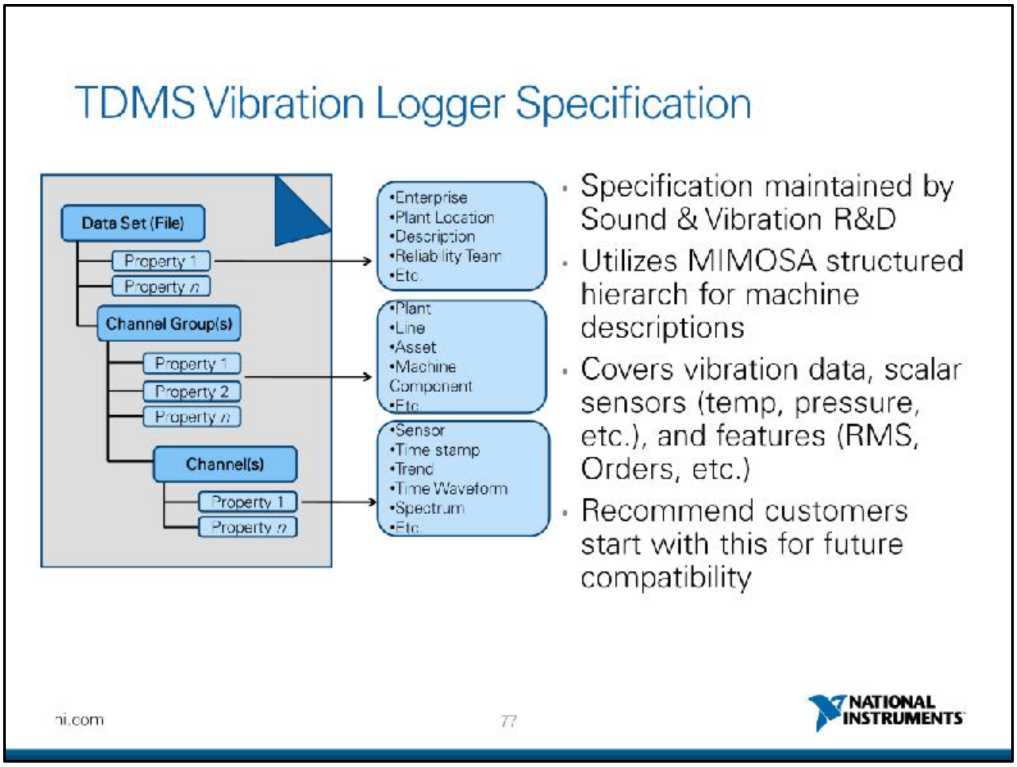


Inside the CompactRIO hardware, NI has implemented an architecture we call "Event Based Store and Forward". Event Based Store and Forward is a decision based data logger. By using its onboard solid state drive, the CompactRIO stores locally and can operate if the network is not available. In many cases, the CompactRIO can store many days worth of events.

Store and forward is important because as an embedded system the cRIO needs to operate in the absence of a network

It has several parts.

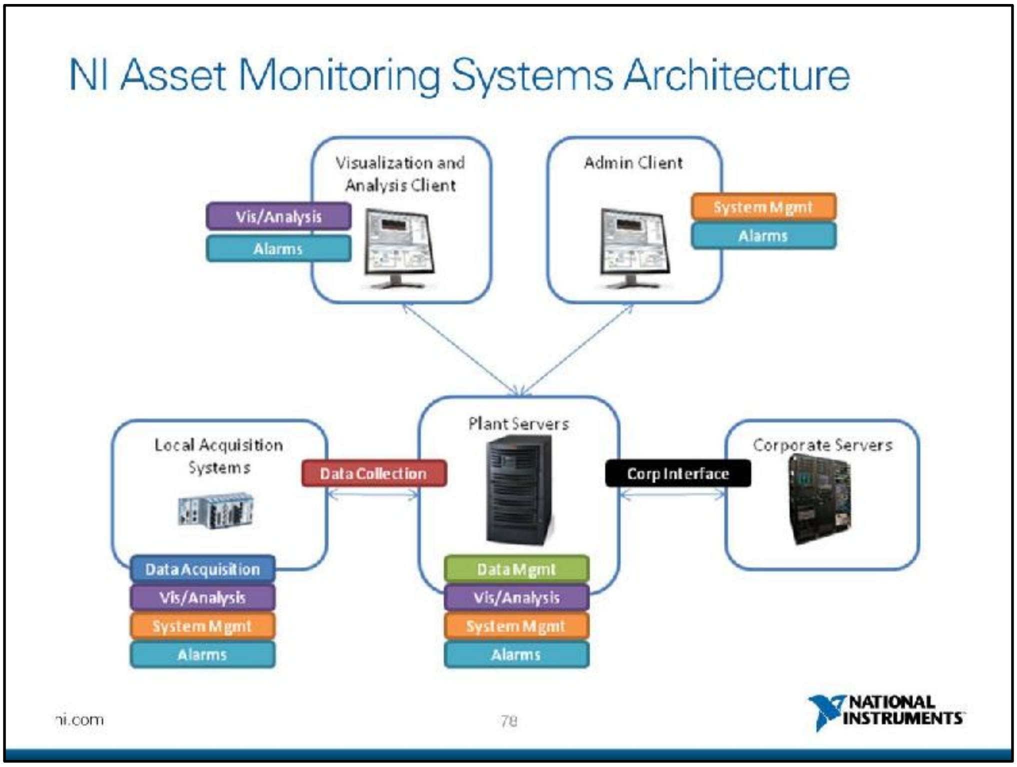
Init: Creates file structure and then starts acquisition
Check Trig: Monitors trigger conditions for waveform features or user input
New File: Opens a new TDMS file with a unique name
Acq & Save: Acquires data and saves data to TDMS file
Close File: Closes the TDMS file
Manage Drive: Looks at drive space and delete files if necessary.



The time waveform data files that are recorded, include a wide range of descriptive data.

To add Equipment Hierarchy, Sensor Location, and related Meta Data to the binary time waveform files, the NI Asset Monitoring System uses NI's TDMS (Technical Data Management Streaming) data structures. This dynamic data type allows expansion of the data structure in a file at runtime. The query language (NI DataFinder) works with TDMS files, even files with varying structures.

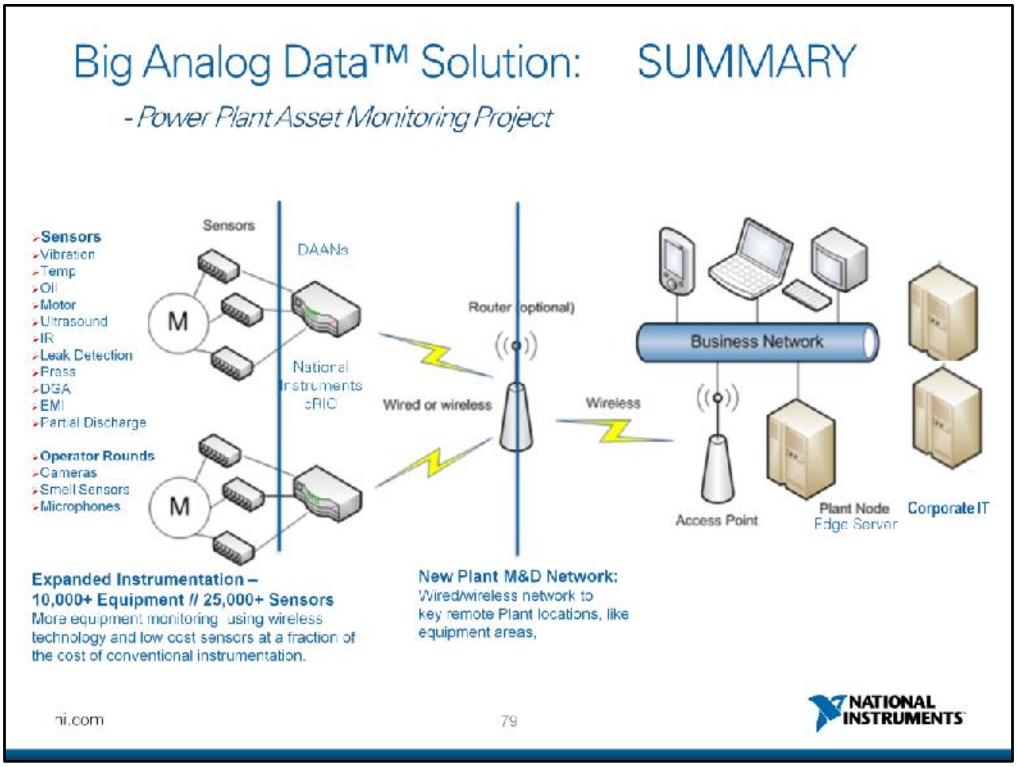
Raw time series data is stored in the file as a channel item. Any features extracted from the raw data are stored as properties of the channel. Derivative channels such as FFT, Trends, or filtering can easily be added to the channel listing.



When we put together all of these data acquisition system components, we are able to create a Asset Monitoring Systems Architecture.

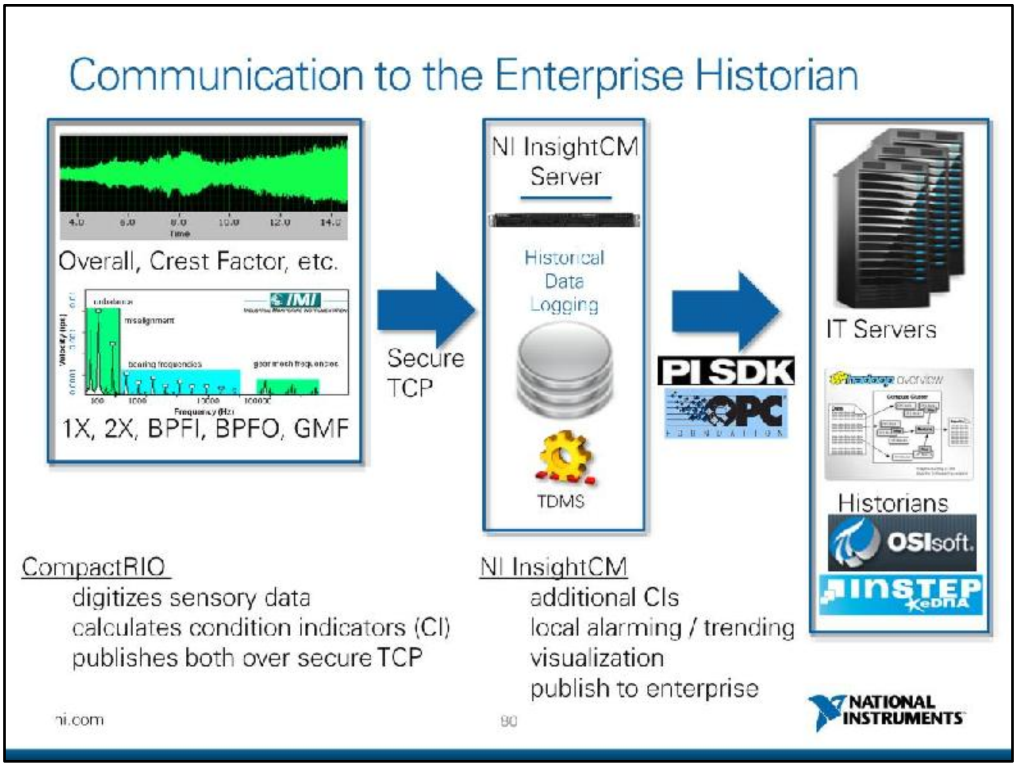
The National Instruments Asset (Condition) Monitoring Architecture has five major components.

1) The Data Acquisition and Analysis Nodes (DAANs) which gather vibration and process data on an event basis. Vibration data is analyzed in the node using order analysis to integrate to velocity from acceleration, and to calculate overall, 1x , and 2x amplitude and phase. Time Waveform data files with calculations and descriptive meta data are sent to the Plant Server computer
2) The plant server computer is a Windows 2008 server computer with enough drive space to store the data files, which are essentially the database for analysis. The data file format is TDMS, which is an open standard which can easily be loaded into excel. The Plant Server performs several background functions and often hosts two application functions.
    1) The server polls each of the DAANs for new data every few minutes, and when new data is found, it retrieves the data files from the CompactRIO DAAN.
    2) When new data arrives from a CompactRIO, the plant server publishes calculated condition indicating values as OPC (www.opcfoundation.org) tags. This is the interface to a plant historian.
    3) When new data arrives, it is added to the data index, the NI DataFinder.
    4) Optionally, data aging services reduce data to specific time slots per day, such as one data file per shift or one data file per day.
3) The enterprise is a customer supplier plant historian. This historian subscribes to the NI OPC server to receive vibration tag updates.
4) The Administration Client configures and commissions DAANs
5) The Visualization and Analysis Client provides off-line viewing of trends, time waveforms, Spectrum with harmonic and sideband cursors, and Waterfall Plots

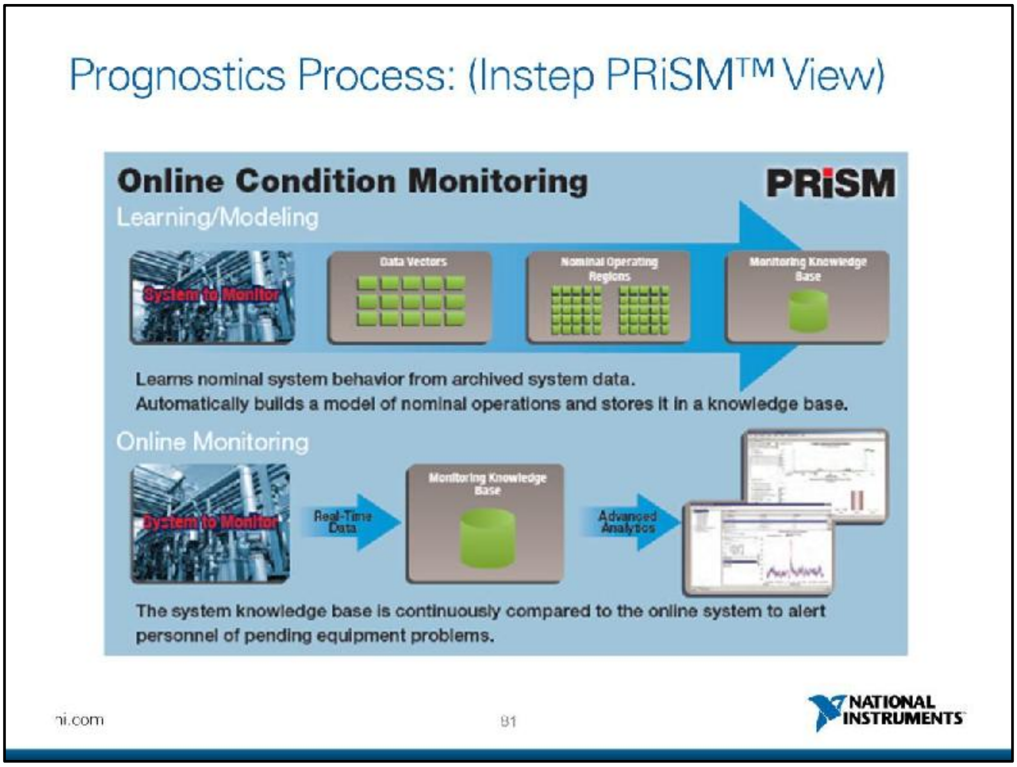


To help summarize, this graphic describes the fleet wide monitoring efforts now underway at several power generation plants in the Americas. Many data acquisition and analysis nodes are being deployed to initially capture vibration and temperature time waveforms based on time or speed events. Often, a business wireless tcp/ip network is used for data transfer to a business server in the PdM work area at the plant. This business server is accessible from other computers on the network for configuration and data analysis. This overall architecture is reflective of the Big Analog Data™ solution I showed earlier.

As we add more sensors, we have more analog data to work with. Yet intelligent analytics can reduce the data while “in-motion” to those features which indicate condition and degradation rates. With modern server technology, we have the resources at hand to fuse time waveform data and condition indicators with operational and maintenance notes to create the systems envisioned by EPRI, and its power generation members. With the right data, the right analytics, automation of diagnostics and prognostics yields advisory generation of the future.



This graphic is a summary of the asset monitoring application.



Instep Software LLC, provides an advanced pattern recognition tool for the power generation industry. PRiSM™ uses condition indicators and operational data stored in the plant historian to build data driven models of normal operational behavior under each of the operating conditions the asset experiences. During the on-line monitoring process, the condition indicators are compared to expected values of the models to provide alerts when parameters deviate from expected normal.

Summary

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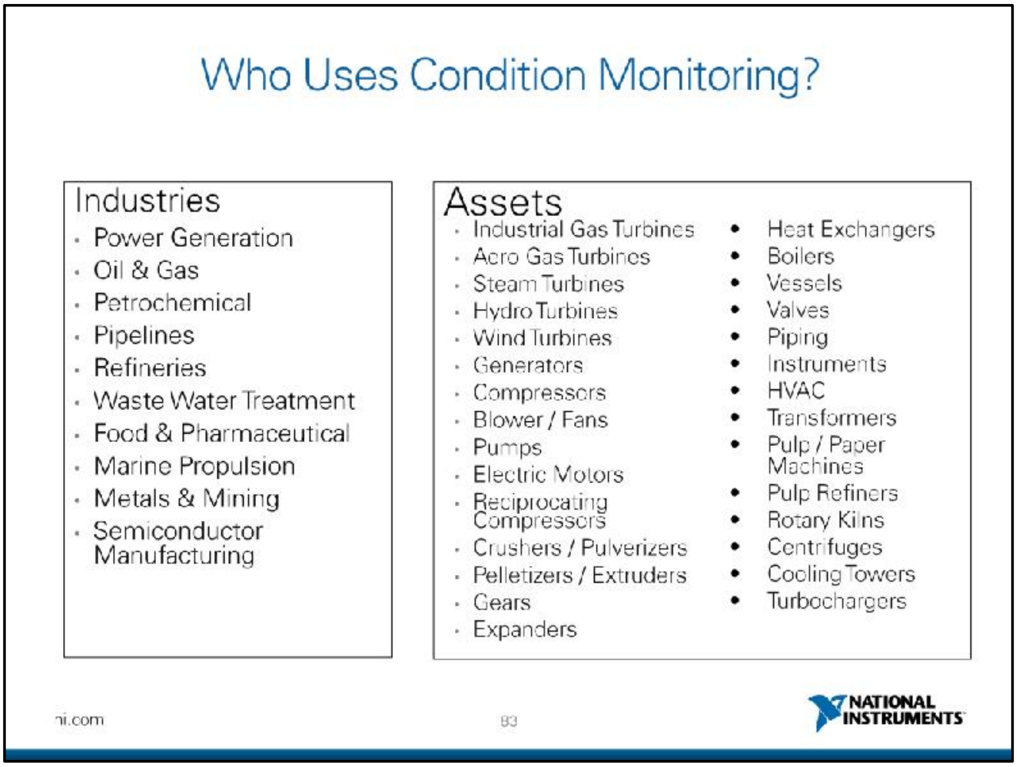
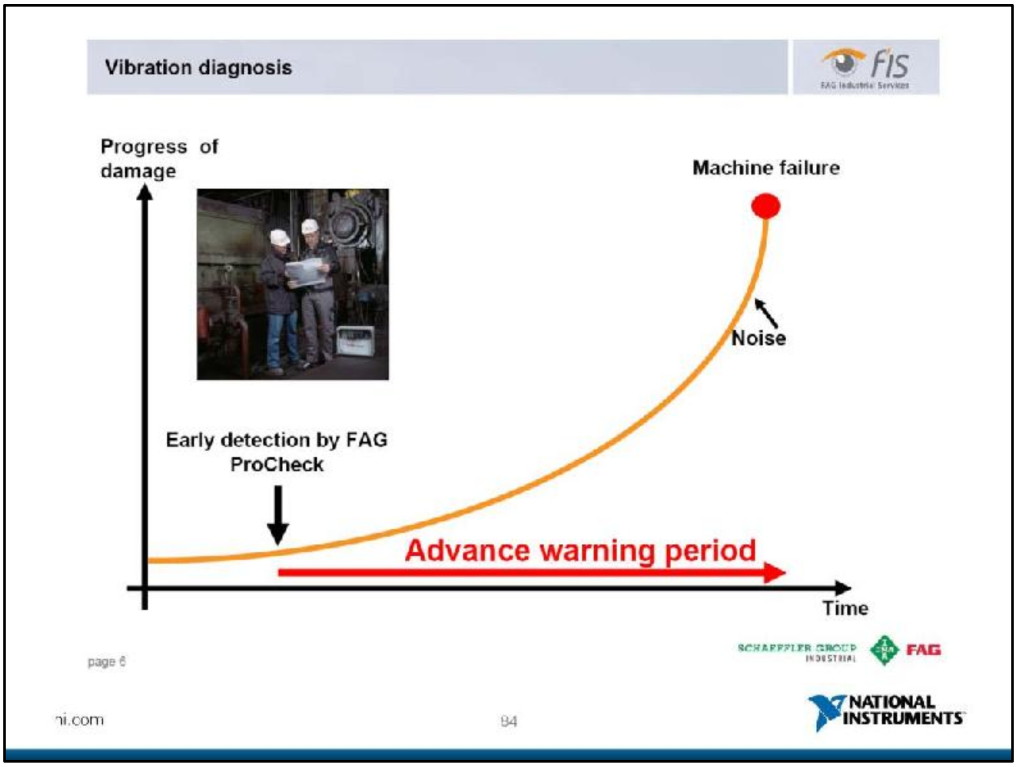


It is the expensive machinery doing the dirty jobs where predictive maintenance and machinery monitoring pays off.

Note most of the industries are process industries.
Class 1 Div 2 / Atex certification is often important.
These are often outdoor applications – temperature range and vibration immune characteristics are important.



The end goal is an early indication of degradation and the type of degradation so that work orders, machine shutdowns, and maintenance teams can plan for the event. With in-time planning, parts costs, labor costs, and production costs all benefit.

References

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- preston.johnson@ni.com