LabVIEW™

Order Analysis Toolkit User Manual

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Worldwide Technical Support and Product Information

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About This Manual

This manual provides information about order analysis and the LabVIEW Order Analysis Toolkit.

Conventions

The following conventions appear in this manual:

» — The » symbol leads you through nested menu items and dialog box options to a final action. The sequence **File»Page Setup»Options** directs you to pull down the **File** menu, select the **Page Setup** item, and select **Options** from the last dialog box.

This icon denotes a tip, which alerts you to advisory information.

This icon denotes a note, which alerts you to important information.

bold — Bold text denotes items that you must select or click in the software, such as menu items and dialog box options. Bold text also denotes the names of parameters, dialog boxes, sections of dialog boxes, windows, menus, palettes, and front panel controls and buttons.

italic — Italic text denotes variables or cross references.

`monospace` — Text in this font denotes text or characters that you should enter from the keyboard, sections of code, programming examples, and syntax examples. This font is also used for the proper names of disk drives, paths, directories, programs, subprograms, subroutines, device names, functions, operations, variables, filenames, and extensions.

Related Documentation

The following documents contain information that you might find helpful as you read this manual:

- *LabVIEW Help* available by selecting **Help»VI, Function, & How-to Help**
- *Getting Started with LabVIEW*
- *LabVIEW User Manual*

1

Introduction to the LabVIEW Order Analysis Toolkit

The LabVIEW Order Analysis Toolkit enables you to use LabVIEW to measure and analyze noise, vibration, and harshness (NVH) generated by rotating or reciprocating machinery such as automotive and aircraft engines, power trains, turbines, pumps, compressors, and electric motors. In general, Order Analysis Toolkit applications fall into one of the following areas:

- NVH product testing
- Machine condition monitoring (MCM)

Order analysis can help you greatly improve device under test (DUT) knowledge. You can use order analysis to accomplish the following tasks:

- Reduce signals to a meaningful format
- Separate rotational and structural signal components
- Associate signal components with specific mechanical parts
- Provide repeatable measurements

Features of the Order Analysis Toolkit

The Order Analysis Toolkit is a powerful tool for sound and vibration measurement and analysis. The main features are:

- Rotational speed calculation for both analog and digital tachometer signals with averaging
- Multiple channel order tracking in fast run-up and run-down tests with multiple tachometer references
- Spectral distribution measurement in the frequency or order-domain as a function of time or rotational speed
- Time-domain order waveform extraction
- Various plots such as orbit plots, timebase plots, bode plots, polar plots, color maps, waterfall plots, and cascade plots

- Order tracking without a tachometer reference
- Vibration signal compensation with even-angle or vector references

You can access any of these features with the VIs included in the Order Analysis Toolkit

Finding Examples

The Order Analysis Toolkit provides examples to help you get started using this toolkit. Select **Help»Find Examples** in LabVIEW to launch the NI Example Finder. Select **Toolkit and Modules»Order Analysis** in the **browse** tab to view all of the available examples, or use the **Search** tab to locate a specific example. Order Analysis examples come in two categories:

- Functions
- Getting Started

Accessing the Order Analysis Demo

The Order Analysis Toolkit includes an application designed to familiarize you with the toolkit functions, features, and capabilities. You can launch the Order Analysis Functions Demo and Gabor Order Tracking Start-up from the **Start** menu.

2

Introduction to Order Analysis

This chapter defines order analysis and introduces some of the methods, concepts, and applications for order analysis.

Definition of Order Analysis

Order analysis is a technique for analyzing noise and vibration signals in rotating or reciprocating machinery. Some examples of rotating or reciprocating machinery include aircraft and automotive engines, compressors, turbines, and pumps. Such machinery typically has a variety of mechanical parts such as a shaft, bearing, gearbox, blade, coupling, and belt. Each mechanical part generates unique noise and vibration patterns as the machine operates. Each mechanical part contributes a unique component to the overall machine noise and vibration.

One of the most common analysis methods to analyze noise and vibration signals is fast Fourier Transform (FFT) analysis. The FFT power spectrum identifies and quantifies the frequency components of noise and vibration signals. You can use the FFT power spectrum for machinery diagnostic purposes by associating certain frequency components with specific mechanical parts.

Figure 2-1 illustrates an FFT analysis performed on vibration signals generated by a PC fan. The PC fan has four coils and seven blades. The vibration signal of the PC fan is the superposition of the vibration from the shaft, coils, and blades. The shaft rotates at the same rate as the rotational speed, whereas the passing rate of the coils and blades are four and seven times that of the rotational speed. The vibration signal generated by the shaft is at the same frequency as the rotational speed. The vibration signals generated by the coils and blades are at frequencies four and seven times the rotational speed. The coil and blade vibration signals are the fourth and seventh harmonics of the rotational speed. If the PC fan rotates at a constant speed, the FFT power spectrum of the vibration signal shows peaks at the rotational speed and the fourth and seventh harmonics of the rotational speed.

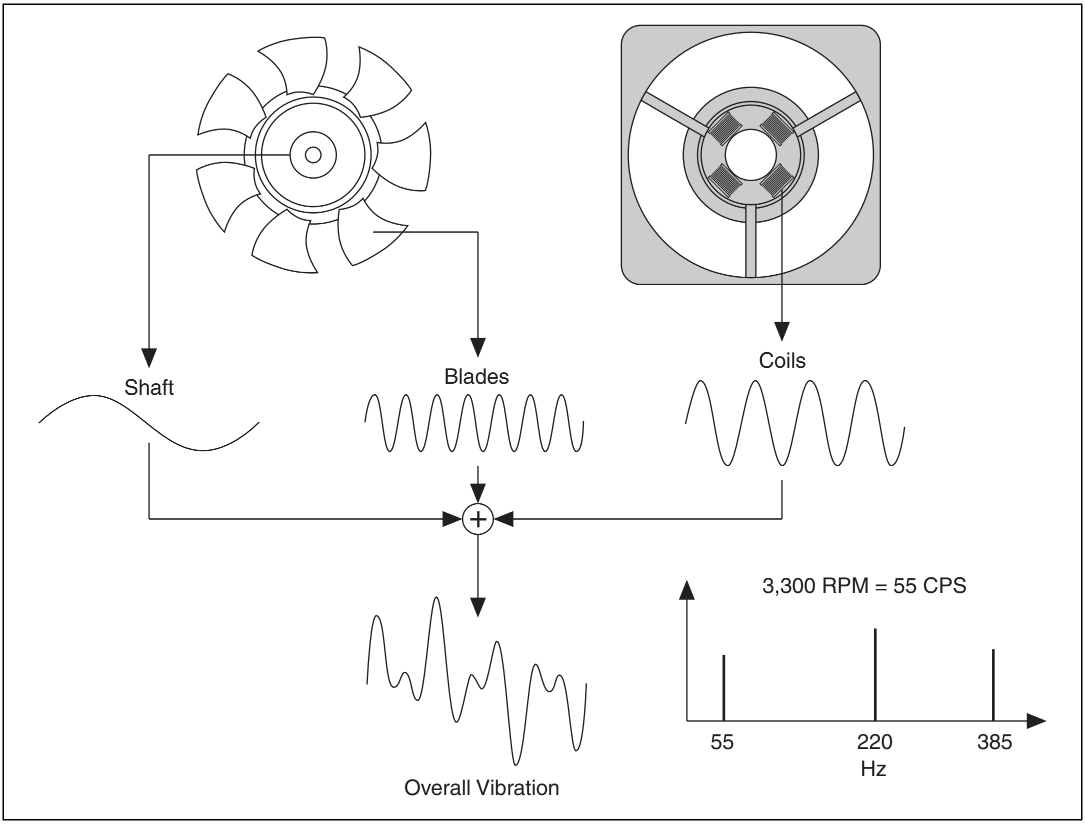


Figure 2-1. FFT and Order Analysis on a PC Fan

In rotating or reciprocating machinery, many mechanical characteristics change with speed. You only can observe some mechanical faults, such as resonance, as the rotational speed approaches or passes the critical speed. For this reason, machinery noise and vibration tests usually require a run-up or coast-down test. However, when the rotational speed is changing, the frequency bandwidth of each individual harmonic gets wider. Because each individual harmonic bandwidth becomes wider as the speed changes, some frequency components might overlap. The resulting FFT power spectrum becomes blurred and can no longer help you identify characteristic vibration components. Figure 2-2 shows the blurred FFT power spectrum of the PC fan when the rotational speed changes from 1,000 to 4,000 revolutions per minute (rpm). You cannot identify any obvious peaks associated with particular mechanical parts in Figure 2-2.

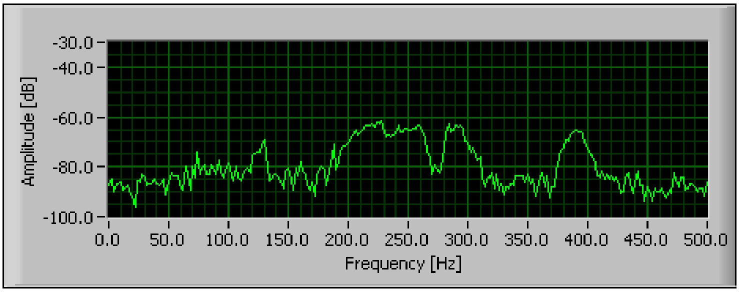


Figure 2-2. Blurred FFT Power Spectrum With Changing Rotational Speed

Order analysis techniques are suitable for analyzing noise and vibration signals when the rotational speed changes over time. Order is defined as the normalization of the rotational speed. The first order is the rotational speed and order *m* is *n* times the rotational speed. Order components are the vibration harmonics of the rotational speed. In the case of the PC fan, the shaft vibration is the first order vibration. The coil and blade vibrations are the fourth and seventh order vibrations, respectively.

With order analysis, you can uncover information about harmonics buried in the FFT power spectrum due to changing rotational speed. Figure 2-3 shows the order power spectrum of the same signal used to compute the FFT power spectrum shown in Figure 2-2. The order power spectrum is one of the order analysis techniques available in the LabVIEW Order Analysis Toolkit. The order power spectrum shows more clearly defined peaks associated with the different mechanical parts. The peak at the first order corresponds to the shaft vibration. The peak at the fourth order corresponds to the vibration generated by the coils. The peak at the seventh order corresponds to the vibration generated by the blades.

Figure 2-3. Order Spectrum With Changing Rotational Speed

In general, order analysis techniques relate noise and vibration signals to the rotational speed. Order analysis techniques also reduce these signals into characteristic components, associate these components to mechanical parts, and provide repeatable noise and vibration measurements. You can obtain information about individual mechanical parts as well as the entire machine with order analysis.

Order Analysis Methods

The Order Analysis Toolkit provides two methods to perform order analysis:

- Gabor transform
- Resampling

Gabor Transform

The Gabor transform based method performs order analysis by analyzing noise and vibration signals in the time-frequency domain.

Traditional FFT analysis is ineffective at analyzing machinery noise and vibration signals with changing rotational speed. Fourier transform only provides the frequency domain information. When the fundamental frequency such as rotational speed changes over time, the FFT is unable to reflect this variation. Joint time-frequency analysis (JTFA), which provides both the time and frequency domain information, can overcome the limitation of FFT analysis. The most basic JTFA method is the short-time Fourier transform (STFT). When applying an STFT to a signal, you can identify the order components in the time-frequency domain even if the speed is variable.

Figure 2-4 shows the STFT results of an example vibration signal on an intensity graph, and the corresponding speed profile. The x-axis and y-axis of the intensity graph are time and frequency, respectively. The bright shade in the graph represents significant vibration amplitude. Spectral Map signal speed is increasing from approximately 1,400 rpm to 3,700 rpm during a run-up test. Several curves appear on the intensity graph that change with the speed. These curves are the order components. The order component frequencies are increasing over time as the speed increases.

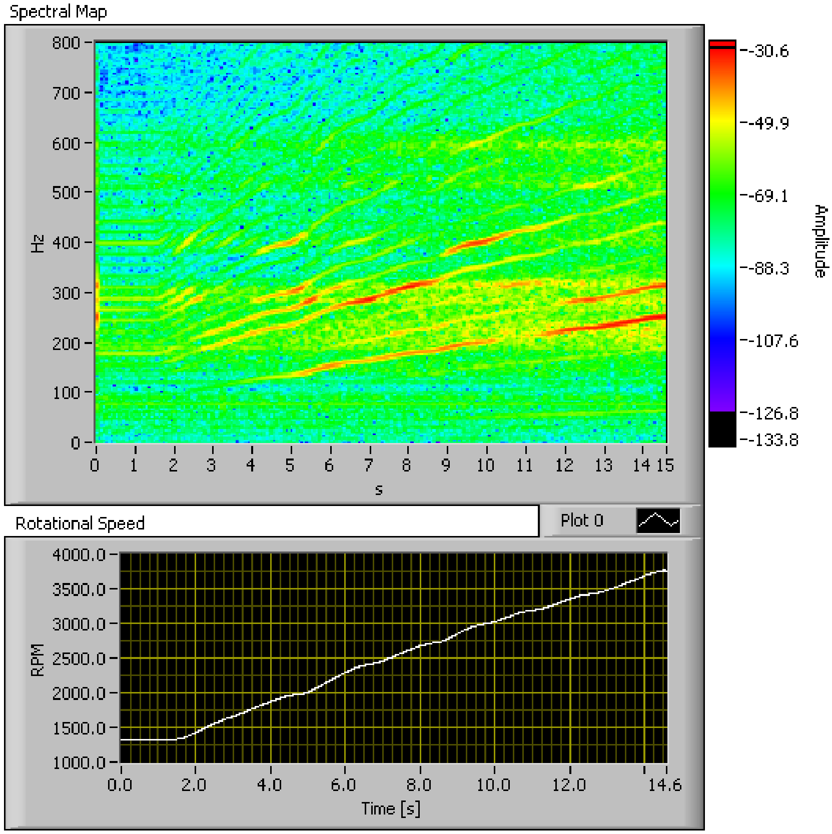


Figure 2-4. Frequency-Time Display of Vibration Signal in Run-up Test

The Gabor transform is a type of invertible joint time-frequency transform. With invertible joint time-frequency transforms, you can recover any time-domain input signal or an approximation of the signal by applying an inverse transform to the transform of the signal. The Gabor transform results are called Gabor coefficients. The inverse Gabor transform is known as Gabor expansion. You can think of the Gabor transform as a specific type of STFT. The difference is that by using Gabor expansion you can recover the time-domain signal from the Gabor transform, but not a general STFT.

This ability to recover time-domain signals is a feature of the Gabor transform and expansion. Gabor transform and expansion allows you to extract signal components related to rotational speed from the Gabor coefficients, or the time-frequency representation. With the Gabor technique, you can extract the signal components associated with any particular orders.

Resampling

When applying an FFT to even time spaced samples, or a time waveform, you can calculate the frequency components that are periodic in time. Order components take place *n* times per revolution and are periodic in rotational angle. Signals that are spaced evenly in rotation angle are even-angle signals. Similarly, if the noise or vibration samples are spaced evenly in the rotation angle, you can apply an FFT to the even-angle spaced samples to calculate the order components that are periodic in rotational angle. You can think of the even-angle signals as those acquired when the machine rotates over a constant angle. You can use standard FFT methods to perform order analysis with an even-angle signal.

In order to acquire even-angle samples, you must adjust the sampling rate according to the rotational speed. The adjusted sampling rate is called a synchronous sampling rate. In practice, it requires complex additional hardware to set a variable sampling rate to acquire samples with a synchronous sampling rate. Applying anti-alias filtering when the sampling rate is variable is also difficult. The Order Analysis Toolkit provides software resampling to avoid the challenges of hardware implementation. Typically, you acquire noise and vibration signal with a fixed sampling rate and then use software to resample the signal with the synchronous sampling rate.

Figure 2-5 describes the effect of resampling on a simulated vibration signal in a run-up test. Each point on the shaft represents a sampling position. As the shaft rotates faster, the intervals between adjacent samples become larger. Accordingly, the period of the signal gets lower and the frequency span becomes wider. With so many elements changing, identifying the characteristic components is difficult. After resampling, all the samples appear with constant angle intervals. The period of the even-angle signal is constant and you can identify the order components.

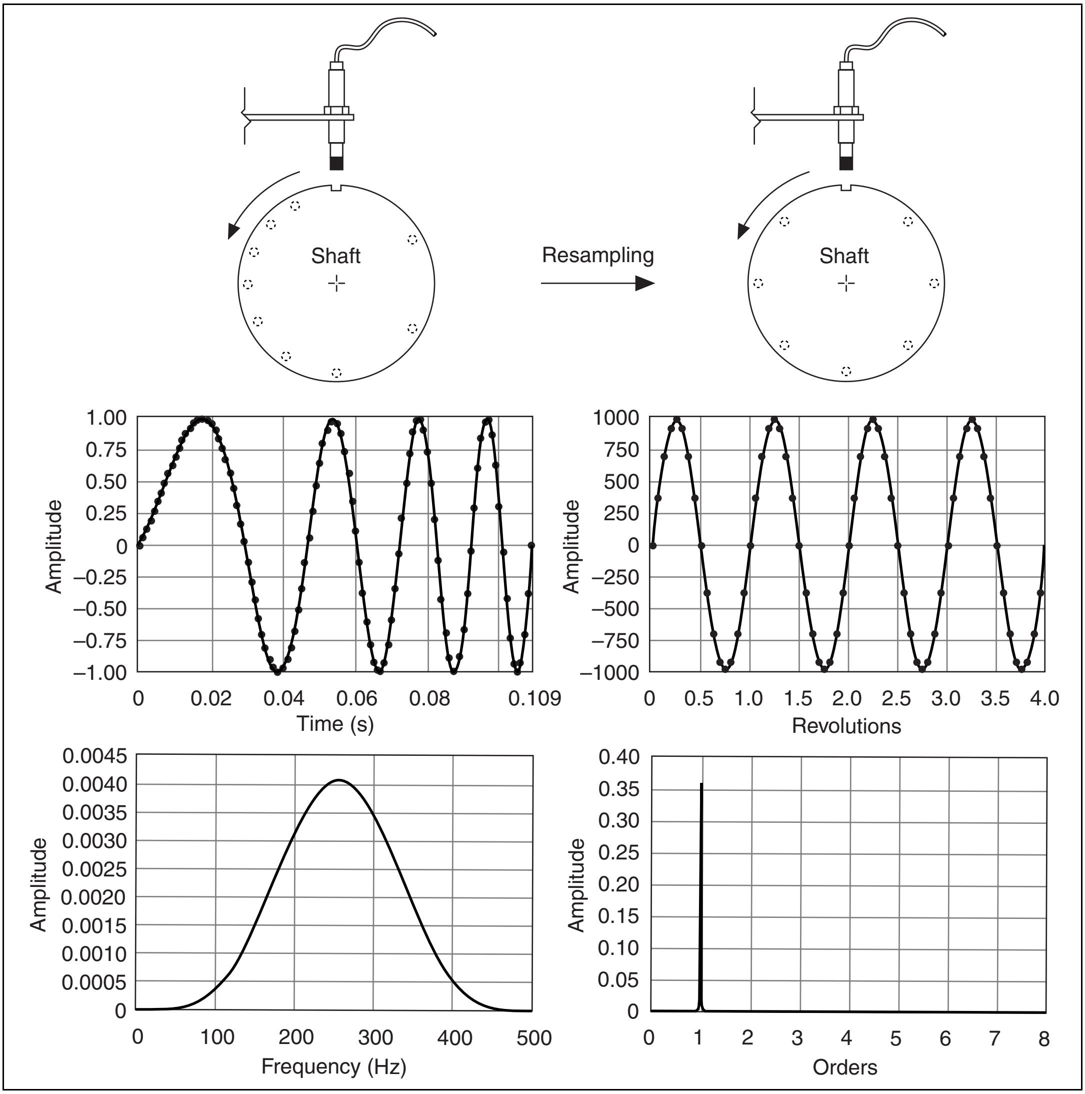


Figure 2-5. Even Time-Spaced Samples Converted to Even-Angle Signal

Comparing Order Analysis Methods

The resampling-based order analysis method typically provides better order resolution. The resampling method works for both NVH and machine-condition monitoring (MCM) applications. You can choose the resampling-based order analysis method for multichannel online processing applications in both run-up and coast-down tests, and constant speed situations.

The Gabor transform-based order analysis method can generate order waveforms. This feature is not available with the resampling-based method. You can use the generated order waveform to evaluate the sound quality aspects of order-related tones by listening to the tone or subtracting the tone from the overall signal. The Gabor transform-based order analysis method also can work for multi-axle order analysis. Multi-axle order analysis analyzes crossing orders related to two or more independent speed signals, such as with hybrid car testing in which the electrical motor and gas engine run at different speeds. National Instruments does not recommend applying the Gabor transform-based order analysis for online applications because of the computational complexity.

Order Analysis Application Areas

You can use order analysis during every stage of a rotating machine product lifecycle, from design, to manufacturing, to operation.

Design and Validation Applications

You can perform order analysis during the research and development stage. Order analysis can help you locate sources of unwanted noise and vibrations. You can lessen or remove the noise and vibration by changing the design of specific mechanical parts. Order analysis can help you separate rotational and structural vibrations to determine critical machine speed and resonance characteristics. You can validate and modify machine structures according to the analysis results.

Manufacturing Applications

You can perform order analysis to set vibration measurement baselines. You can test machine performance and quality with the baselines you create. You also can use order analysis to fine-tune a machine in the field. You can use order analysis for typical adjustments such as balancing and alignment before products ship.

Operational Applications

Machines like turbines, pumps, or compressors require careful monitoring and maintenance during operation. Vibration signals are good indicators of machine physical condition. Order analysis can help you check working conditions as well as detect faulty components.

Order Analysis Application Process

You can break a typical order analysis application into three primary steps–acquiring data, analyzing data, and presenting data. The Order Analysis Toolkit, together with NI software and data acquisition (DAQ) devices, can help you complete the entire order analysis application process. Figure 2-6 gives a more detailed picture of the application process. **Data Source** refers to the data acquisition component. Steps from **Scaling and Calibration** to **Analysis** represent the analysis component. The last step, **Display**, is how you present the order analysis results.

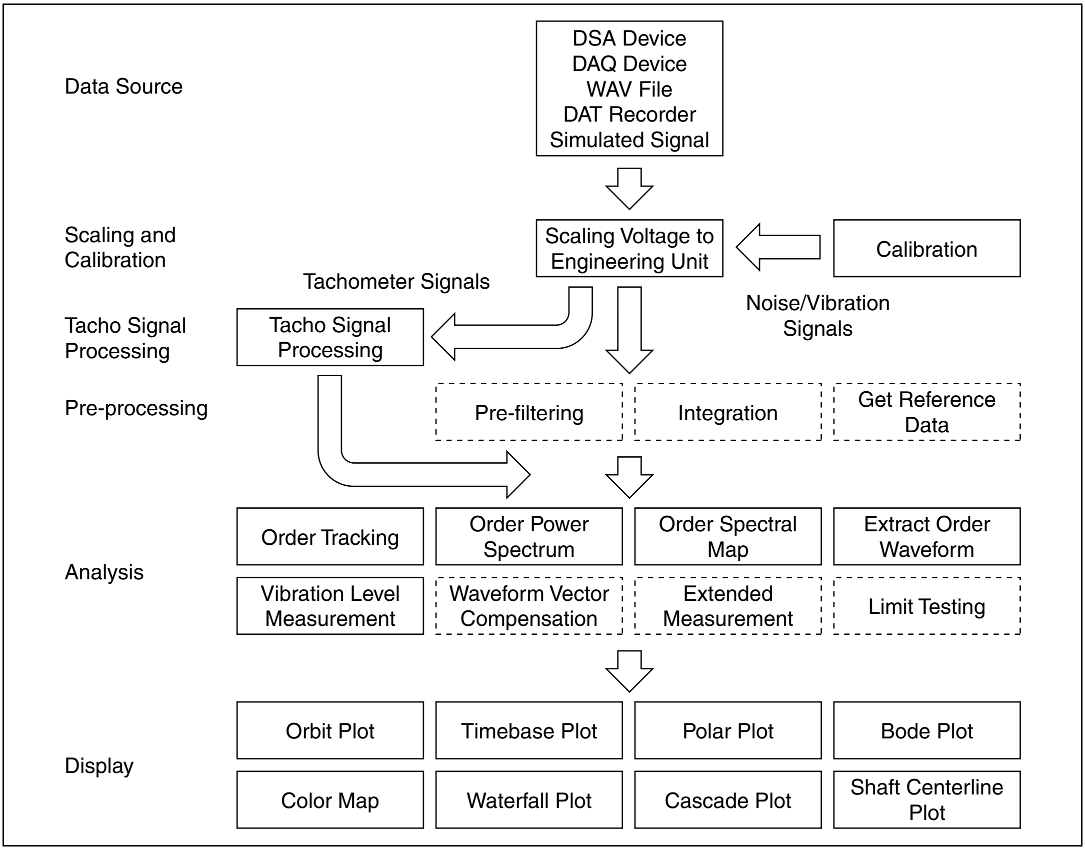


Figure 2-6. Order Analysis Application Process

Note The dashed boxes in Figure 2-6 indicate optional operations.

3

Order Analysis Data Acquisition Systems

This chapter describes the order analysis data acquisition (DAQ) system, such as signal types and transducers. This chapter also provides tips for making accurate measurements.

Signal Types and Transducers

This section introduces the signal types used in order analysis, as well as how to select a transducer to obtain the appropriate signal. Three important signals for common order analysis functions are vibration, noise, and tachometer signals.

Vibration Signals

There are three basic types of vibration transducers:

- accelerometer
- velocity transducer
- displacement transducer

Each transducer has specific distinguishing characteristics and common applications associated with it.

Accelerometer Signals

The accelerometer is the most widely used vibration transducer for measuring vibrations on stationary machinery elements. An accelerometer is a full-contact transducer mounted directly to a system or device under test (DUT). The benefits of an accelerometer include linearity over a wide frequency range and a large dynamic range. Due to the rugged and reliable construction of accelerometers, you can use most accelerometers in hazardous environments.

Accelerometers typically are used in applications involving frequencies from a few hertz to tens of kilohertz. Most accelerometers usually have low dynamic signal response below 10 Hz, making them less useful for low frequency measurements. The usable frequency range of an accelerometer is typically15 Hz to10 kHz or above. Figure 3-1 shows the typical frequency response characteristics of an accelerometer.

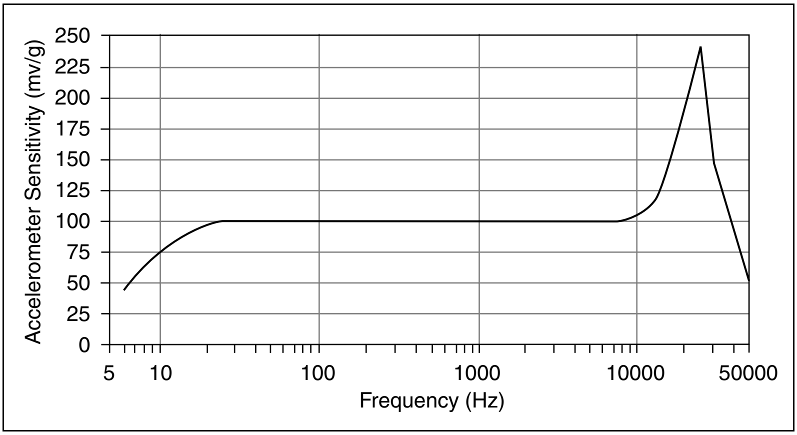


Figure 3-1. Typical Frequency Response Characteristic of an Accelerometer

Accelerometers commonly are used to measure casing or machinery vibrations. Mechanical parts like gearboxes, bearings, and motors often are tested with accelerometers.

Velocity Signals

Velocity transducers measure the absolute motion of a system or DUT with a good response range from 15 Hz to 1.5 kHz. Due to their limited response range and other limitations, accelerometers often are used in place of velocity transducers in many applications. You can obtain velocity output from an accelerometer using the integration function provided in the LabVIEW Order Analysis Toolkit. Refer to Chapter 4, *Order Analysis Preliminary Processing*, for information about the integration function.

Displacement Signals

Displacement transducers, such as shaft-sensing proximity probes, often are used to obtain measurements such as the relative displacement of a rotating shaft surface. A proximity probe is a noncontacting transducer mounted on a stationary mechanical structure. A proximity probe has excellent signal response between DC and 1.5 kHz as well as flat phase response in the operational range. Proximity probes typically are used for lower frequency measurements.

A proximity probe mainly is used for permanent monitoring and machine protection measurements for DUTs with fluid film bearings. Because the flexible fluid film bearing and heavy housing usually generate low-frequency external vibration responses, the accelerometer or velocity transducer cannot effectively measure the vibration. By measuring the relative displacement of the shaft, the permanently mounted proximity probe can measure the vibration through shaft motion. Proximity probes also are used for functions such as radial or axial position monitoring and rotational speed calculation. A proximity probe is a common tachometer type.

A proximity probe is susceptible to shaft surface scratches, circular irregularity, shaft bow, and other types of electrical runout. Accurate displacement signal measurements require runout compensation to remove these signal errors. The Order Analysis Toolkit provides VIs to acquire a runout reference and remove the runout error. Refer to Chapter 4, *Order Analysis Preliminary Processing*, for information about runout compensation.

Selecting a Vibration Transducer

System attributes and signals of interest typically determine the transducer type to use. These attributes include vibration type, system type, and signal frequency range.

Relative or Absolute Vibration

If the vibration you are monitoring is a signal such as relative displacement from shaft motion or bearing clearance, then you need to use a proximity probe. If the signal of interest is something such as the casing vibration of a gearbox or motor, an accelerometer is typically the best option.

System Rigidity

With a mechanical system composed of flexible heavy rotors and fluid film bearings like those commonly found in turbo machinery, the vibration does not transmit to the outer casing well. In these cases you need to use proximity probes to directly measure shaft motion. If the system or DUT components are stiff enough to transmit vibrations effectively, such as with most rolling-element bearings, accelerometers can measure the vibration effectively. In some cases, a combination of proximity probes and accelerometers can generate better results.

Low or High Frequency

Figure 3-2 shows how proximity probe and accelerometer sensitivity differs over frequency ranges. Measure lower frequency vibrations, such as shaft motion, with proximity probes. For DUTs or systems with high-frequency elements such as rolling-element bearings, gearboxes, or spinning blades, mounting an accelerometer on the casing or housing can generate better results.

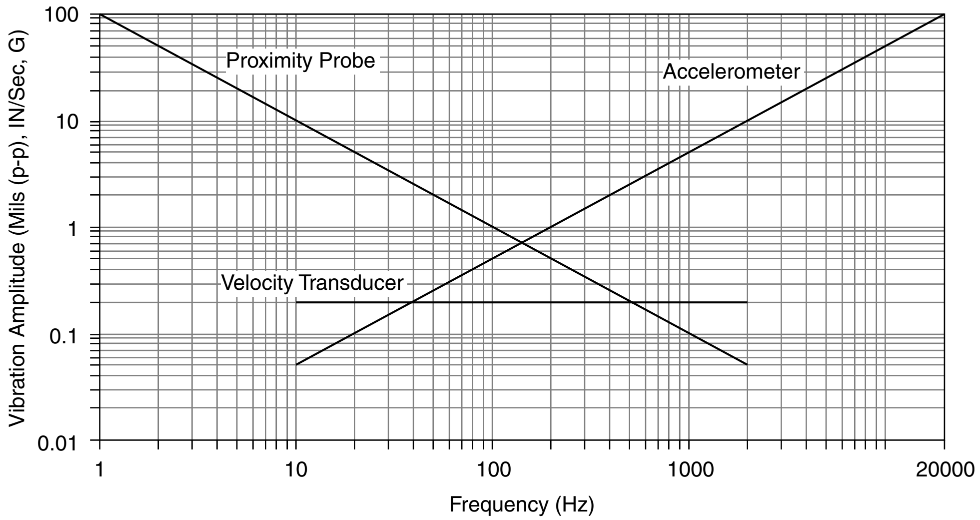


Figure 3-2. Typical Frequency Range of Common Vibration Transducers

Noise Signals

The most common type of noise transducer is a microphone, a device designed to produce an electrical signal that is proportional to the sound pressure, or pressure gradient, in the air immediately in front of the microphone. A microphone can measure the noise emitted from the rotating or reciprocating machinery. The noise signals typically are used for NVH test applications. Performing order analysis on the noise signals can separate the noise components emitted by different mechanical parts. This helps you evaluate the noises of individual mechanical parts as well as the physical conditions of the mechanical parts and the machine as a whole.

Tachometer Signals

Along with the vibration or noise signals, most order analysis applications require a tachometer signal to provide a rotational reference. The most common tachometers are proximity probes, optical transducers, and magnetic pickups. These transducers generate pulses at a rate proportional to the rotational speed, typically once per revolution. A proximity probe detects the presence of a keyway slot. The probe generates a pulse at certain fixed amplitudes as the keyway slot passes it. Optical probes observe a piece of reflective tape attached to the shaft. The coincidence of the reflective tape and the optical probe produces a pulse signal. Figure 3-3 illustrates a proximity probe and an optical probe working as tachometers to generate pulses. Optical transducers are well-suited to machines that cannot tolerate drilled holes or milled slots in the exposed shaft surface. Optical transducers also are appropriate for detecting pulses from high speed machines.

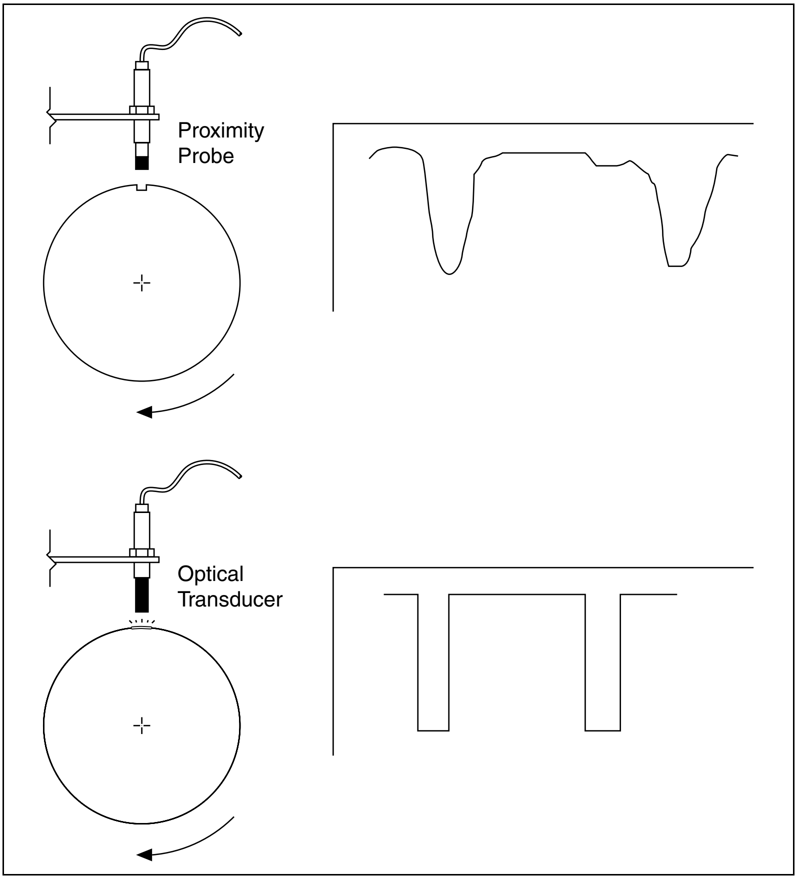


Figure 3-3. Proximity Probe and Optical Transducer Tachometers

An encoder is another common tachometer transducer. An encoder usually generates multiple, even several hundred or more, pulses per revolution. Due to this ability, encoders can usually generate more accurate speed results for low rotational speed measurements of less than 100 rpm.

Analog Tachometer Signals

Analog tachometer signals are tachometer signals obtained through the analog input channel of a DAQ device. You can acquire the analog tachometer signal with the same DAQ steps and Order Analysis Toolkit VIs you use to acquire other signals, such as sound or vibration signals. Synchronize the tachometer and sound or vibration acquisition channels. After acquiring the signals, use the VIs in the Order Analysis Toolkit to set thresholds and detect pulses in the analog tachometer signal.

Some DAQ devices might have difficulty acquiring very high rotational speed signals from tachometers or from encoders that generate hundreds of pulses per revolution. Even if you can choose a DAQ device that can sustain high enough sampling rates to provide sufficient resolution for the tachometer signal, it is not efficient to sample the noise on vibration signals at the same high rate due to the demands that synchronization places on the measurement and computational effort. In this case, acquiring the tachometer signal with an analog measurement channel might not be a good choice. You can avoid unnecessary computation and system resource expenditure by running the acquisition of the noise or vibration signals at lower frequency or by using a counter device to acquire a digital tachometer signal.

Digital Tachometer Signals

A digital tachometer signal is a tachometer signal properly conditioned for acquisition from the “gate” input channel of a counter device. The counter device can detect the pulses directly, eliminating the need for additional VIs to set a threshold for the tachometer signal. A counter device typically also operates at a much higher sampling rate than the analog input channels used to acquire sound and vibration signals. For these reasons, a counter device is ideal for acquiring tachometer signals at high speeds or generated by encoders. A digital tachometer signal is usually more accurate than an analog tachometer signal. Digital tachometer signals require the output tachometer signal to be transistor-transistor logic (TTL) compatible. Acquiring a digital tachometer signal also requires additional devices such as a counter/timer device and a signal conditioning device to condition the tachometer signal to TTL compatibility.

Another possible approach to acquiring a tachometer signal is using a multifunction reconfigurable I/O (RIO) device such as the NI PXI-7831R. This kind of device allows you to use the LabVIEW FPGA Module to configure the digital lines as inputs, outputs, or counters. You also can perform tachometer signal conditioning with the device as well as configure a 64-bit counter.

Data Acquisition Tips

This section discusses some data acquisition concepts and strategies. You can use this information to help ensure the data processed by the Order Analysis Toolkit VIs is as accurate as possible for more accurate measurements and analysis.

Aliasing

Aliasing is the phenomenon by which frequencies greater than the Nyquist frequency are shifted erroneously to lower frequencies. Detecting if the acquired signal has aliased frequencies after the signal is digitized is extremely difficult, if not impossible. The Nyquist frequency is calculated with the following formula:

$$f_{Nyquist} = \text{sample rate}/2$$

When acquiring data with an NI dynamic signal acquisition (DSA) device, alias protection is automatic. The DSA device employs analog and digital lowpass filters to reject the frequency components above the Nyquist frequency.

When acquiring data with other DAQ devices, NI strongly recommends that you apply anti-aliasing filters to each channel prior to the data acquisition.

Sampling Rate

The scan rate, or the sampling rate in NI-DAQmx, determines how often an analog-to-digital (A/D) conversion takes place. A fast input sampling rate acquires more points in a given time and can form a better representation of the original signal than a slow input sampling rate.

The sampling rate is determined by two key parameters, maximum rotational speed and maximum order to analyze. For sound and vibration signal acquisition, choose the sampling rate according to the following equation:

$$\text{sample rate}_{\textit{sound and vibration}} = 2.56 \times \text{max order} \times \text{max speed (RPM)}/60$$

When using an analog input channel to acquire a tachometer signal, set the sampling rate to a higher rate. When performing run-up or run-down tests, the measurement results are highly dependent on the accuracy of the tachometer pulse measurement. You typically want to select a tachometer signal sample rate at least four times larger than the sound and vibration signal sampling rate. Use the following equation to calculate the tachometer signal sampling rate:

$$\text{sample rate}_{tacho} = 4 \times 2.56 \times \text{max order} \times \text{max speed (RPM)} / 60$$

Note The max order is the **actual max order** output in the OAT Convert to Even Angle Signal VI. The maximum order can be much higher than the one you specify when the number of pulses the tachometer generates in each revolution is larger than what is in the **max order** control.

The synchronized analog input channels for tachometer and sound and vibration signals usually work at the same sampling rate. When measuring high orders running at a fast speed, you must set the sampling rate to a very high value. The fast sampling rate for the tachometer signal leads to unnecessary processing for the slower sound and vibration signals. Based on the sampling rate of your DAQ device, you might not be able to set the sampling rate to the required value.

In this case, you can use a counter device to acquire the tachometer signal and keep the sound and vibration signal sampling rate at an appropriate value. When using a counter device synchronized with a DSA device, the counter can acquire the tachometer signal at a much higher rate than the DSA acquisition rate. Using this combination of devices can generate more accurate measurement results.

4

Order Analysis Preliminary Processing

For most order analysis applications, you typically need to preprocess the noise, vibration, and tachometer signals before you apply order analysis algorithms. For example, you can select the frequency band of interest with filters. You also can remove baseline drifting in the tachometer signal by detrending the signal.

This chapter briefly discusses order analysis preliminary processing steps, including scaling and calibration, tachometer signal processing, vibration preprocessing, and reference signal processing.

Scaling and Calibration

This section describes the scaling and calibration functions available in the LabVIEW Order Analysis Toolkit. Scaling to engineering units (EU) and calibration typically are performed at the beginning of many order analysis applications. These steps give the analysis VIs a calibrated signal in the correct engineering units.

Scaling to Engineering Units

Typically, scaling a signal to the appropriate EU occurs before any analysis. Use the SVL Scale Voltage to EU VI to scale the signal to the appropriate EU.

All measurement and analysis VIs in the Order Analysis Toolkit expect input signals, and return results, with the appropriate EU. Some examples of signals and supported EU include time-domain signals in seconds, frequency spectra in decibels with the proper reference, and phase information in degrees or radians. To handle EU properly, the high-level VIs need to operate on a signal scaled to the appropriate EU.

Note If you use any method outside the Order Analysis Toolkit to apply scaling to a waveform, do *not* use the SVL Scale Voltage to EU VI. NI provides several tools and methods to apply scaling to a waveform. These tools include, but are not limited to, NI-DAQmx tasks or global channels created with Measurement & Automation Explorer (MAX), the DAQ Assistant, or the DAQmx Create Virtual Channel VI.

Calibration

You typically perform system or sensor calibration before acquiring data for order analysis. Most calibrations are performed with a dedicated calibrator, such as a pistonphone for microphones or a shaker for accelerometers.

The Order Analysis Toolkit provides sensor-specific calibration VIs, such as the SVL Calibrate Microphone VI for microphones and SVL Calibrate Accelerometer VI for accelerometers. The sensor-specific VIs are similar to the general-purpose SVL Calibrate Sensor VI, but the sensor-specific VIs offer the advantage of having default values commonly used for pistonphones or hand-held shakers. All of the Calibration VIs use characteristics of the calibrator, such as reference calibration value and frequency, to perform calibration.

Tachometer Signal Processing

The Order Analysis Toolkit provides several VIs in the Tacho Signal Processing VIs to process the analog and digital tachometer signals. You can use these VIs to perform signal conditioning on tachometer signals, locate tachometer pulse positions, and calculate rotational speed.

Locating Pulse Positions

The OAT Analog Tacho Process VI locates tachometer pulses in analog tachometer signals. You can set the threshold, pulse width, and slope with this VI to identify the time instances of tachometer pulses. For digital tachometer signals, the OAT Digital Tacho Process VI calculates the tachometer pulse time instances by comparing the counter timebase value with the tachometer counts read from the counter.

Calculating the Rotational Speed

The OAT Analog Tacho Process VI and OAT Digital Tacho Process VI both output the rotational speed as a function of time. These VIs employ a digital differentiator method to calculate the rotational speed from the tachometer pulses. The rotational speed is calculated as the first derivative of rotation angle with the following equation:

$$\omega(t) = \frac{d\theta}{dt}$$

where ω is the frequency.

Removing Trend in Analog Tachometer Signal

Trend in analog tachometer signals can influence where you set the threshold to locate tachometer pulse positions. Use the OAT Detrend Analog Tacho Signal VI to remove the trend from the signal. Choose an appropriate detrend level between zero and one, according to the trend property in the tachometer signal. As the value of the detrend level increases, the trend value becomes closer to the value of the analog tachometer signal. When the detrend level approaches one, the trend converges with the original analog tachometer signal.

Figure 4-1 shows how the detrend function effectively removes the trend from an analog tachometer signal. The lighter line is the signal with a sine trend. The scale of the lighter line is on the left of the plot from –6 to 6. The darker line is the detrended signal. The detrended signal line scale is on the right from –1 to 1. You can set a uniform threshold to detect pulse time instances in the detrended signal, whereas you could not set a uniform threshold with the original signal.

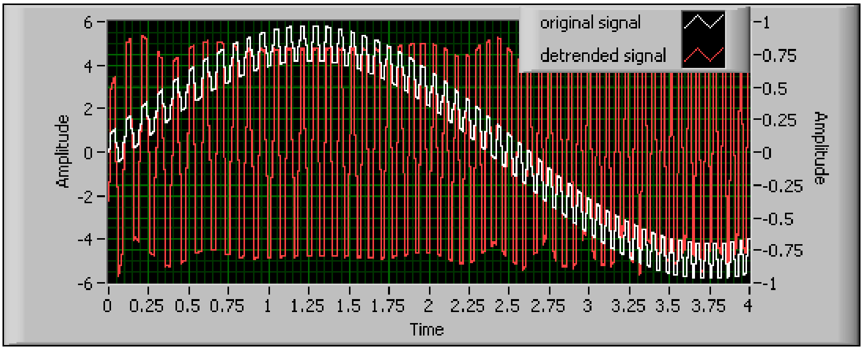


Figure 4-1. Comparison of Detrended and Original Tachometer Signal

Compensating for the Input Filter Delay

All DSA devices, and some DAQ devices with anti-aliasing or other filter protection, have an input filter delay that you might need to compensate for in an application. When acquiring a tachometer signal with an analog data acquisition channel, you do not have to compensate for the input filter delay. The vibration and tachometer acquisition channels use the same anti-aliasing filter. Therefore, the vibration signal and tachometer signal contain the same delay. However, if you acquire the tachometer signal with a counter device, you must compensate for the input filter delay in the vibration acquisition channel. This requirement is because the counter device does not have an anti-aliasing filter that delays the signal. Use the OAT Build Digital Tacho Info VI to compensate for the acquisition channel input filter delay. For the NI 447X and NI 446X series DSA devices, the phase delay is automatically computed by the OAT Build Digital Tacho Info VI. For other types of DAQ devices, you must enter the appropriate device information to perform the compensation. You can find the group delay information for individual DAQ devices in the device specifications.

Calculating a Speed Profile Without a Tachometer Signal

Some test environments do not allow you to install a tachometer onto the DUT to get the speed reference. If this is the case, use the OAT Tachless Speed Profile Generator VI to compute the simulated speed profile. This VI computes the simulated speed profile by performing some interactive operations on the sound or vibration signal spectral maps. Use the simulated speed profile to extract order waveforms and compute order magnitude from order waveforms. Due to the lack of a real tachometer trigger signal, you cannot get accurate phase information with a simulated speed profile.

Note You cannot use the simulated speed profile with resampling based order analysis VIs such as the OAT Convert to Even Angle Signal VI and OAT Spectral Map VI. The simulated speed profile only works with Order Analysis VIs based on Gabor transform, such as the OAT Extract Order Waveform VI and OAT Extract Most Significant Order Waveforms VI.

Generating a Simulated Speed Profile

A window with a time-frequency color map appears every time you run the OAT Tachless Speed Profile Generator VI. You must manually specify the order components on the color map to generate the simulated speed profile. To specify the order components and generate the simulated speed profile, complete the following steps:

1. On the block diagram, connect the **sound or vibration signal** output of the OAT Tachless Speed Profile Generator VI to the OAT Tachless Speed Profile Generator VI and run this VI.
2. In the **Fundamental Speed Tracker** window that appears, adjust the **Window Length** to allow the best view of the plot.
3. Select the most significant order and place a set of control points on the order trace by right-clicking on the trace and selecting **Add Control Point** as shown in Figure 4-2.

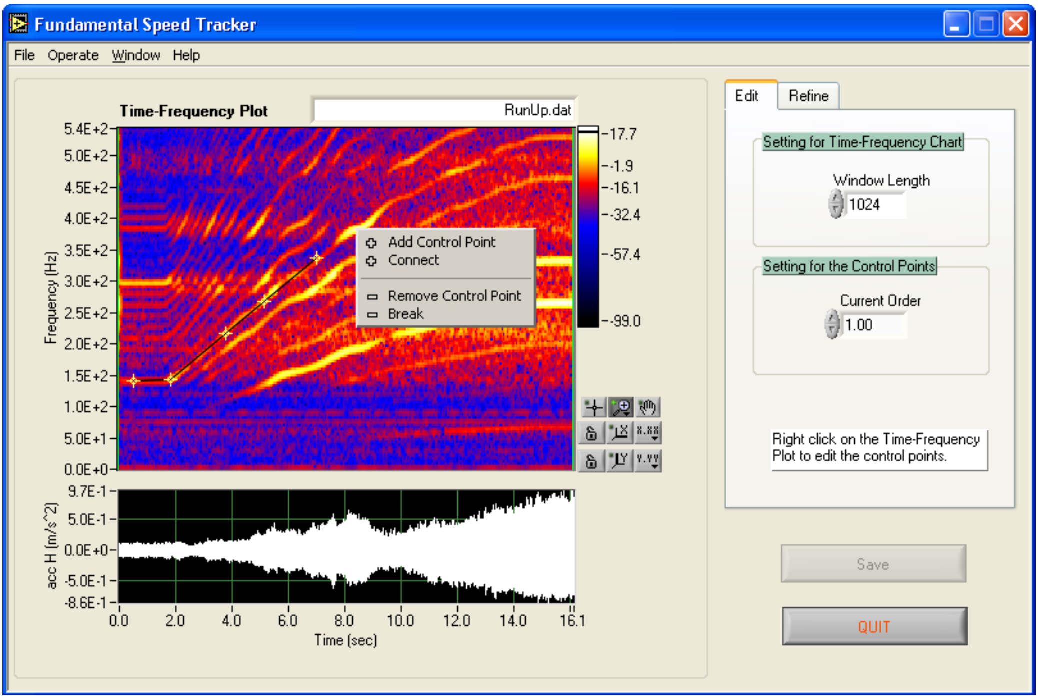


Figure 4-2. Adding Control Points on the Most Significant Order

4. Specify the order number to which you have added control points in **Current Order**.
5. Select the **Refine** tab.
6. Set the **Mask Width** to a value sufficient to cover the most significant order. You also can add other significant orders in **Reference Orders** to help refine the most significant order. Figure 4-3 shows the options available on the **Refine** tab.

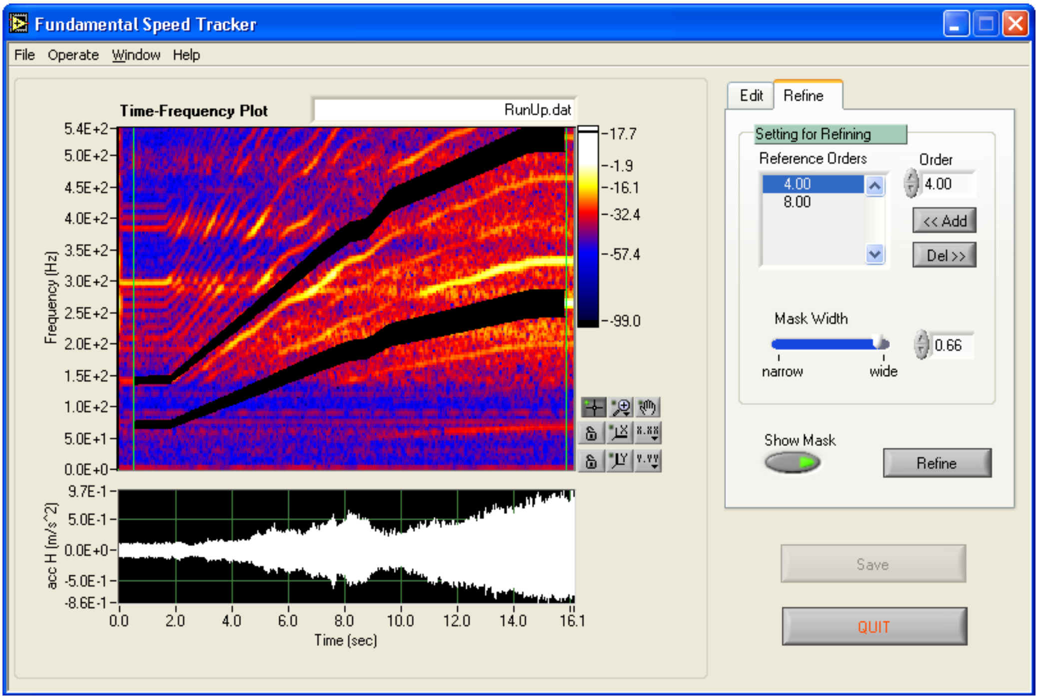


Figure 4-3. Refine Selected Order

7. Click the **Refine** button to get the final order lines in the **Time-Frequency plot**. The OAT Tachless Speed Profile Generator VI computes the simulated speed profile based on this order line. Figure 4-4 shows the final order line.

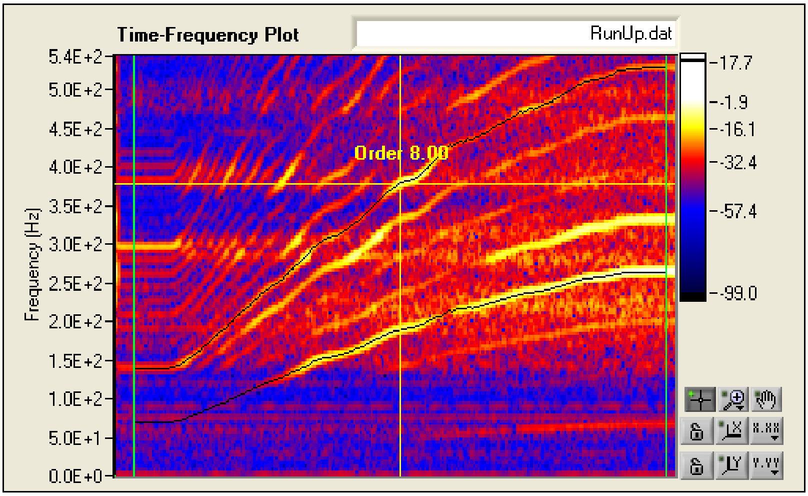


Figure 4-4. Final Order Line

8. If you want, compute the order waveform and magnitude with the simulated speed profile. Figure 4-5 shows the simulated speed profile.

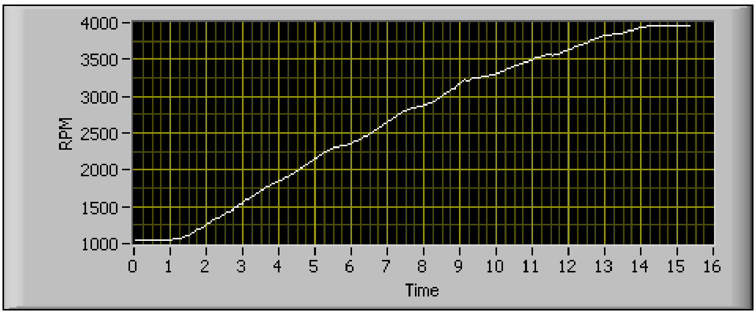


Figure 4-5. Simulated Speed Profile

Vibration Preprocessing

Vibration preprocessing refers to the preliminary analysis functions applied to the acquired vibration signal prior to any order analysis functions. Vibration preprocessing consists mainly of two functions:

- Filtering
- Integration

Filtering

When measuring vibration signals, you typically measure over a fixed frequency range. For example, when measuring the vibration levels of a gearbox, you know that the casing velocity should be within the range 10 Hz to 1 kHz, while the gear casing vibration acceleration should be within the range 1 kHz to 10 kHz. With some basic knowledge of the DUT, you can formulate the requirements for highpass, lowpass, or bandpass filters. Make sure you complete all filtering steps before integration.

You can find the OAT IIR Preprocess Filter VI and OAT FIR Preprocess Filter VI. Use these two VIs to design common lowpass, highpass, bandpass, and bandstop filters, as well as filter the input signals.

The OAT IIR Preprocess Filter VI provides Butterworth, Chebyshev, Inverse Chebyshev, and Elliptic methods to design an Infinite Impulse Response (IIR) filter. You can specify the filter type, frequency range, band specifications, and filter order to design the IIR filter.

The OAT FIR Preprocess Filter VI uses the Kaiser window method to design a Finite Impulse Response (FIR) filter. You can specify the filter type, frequency range, and band specifications for that filter.

Tip Refer to the *LabVIEW Analysis Concepts* manual for more information about FIR and IIR filters.

You can filter the signal with the same VI used to design the filter. The VIs in the Order Analysis Toolkit only provide basic functions for filter design and implementation. For more advanced filter design and implementation, you might consider using the LabVIEW Digital Filter Design Toolkit.

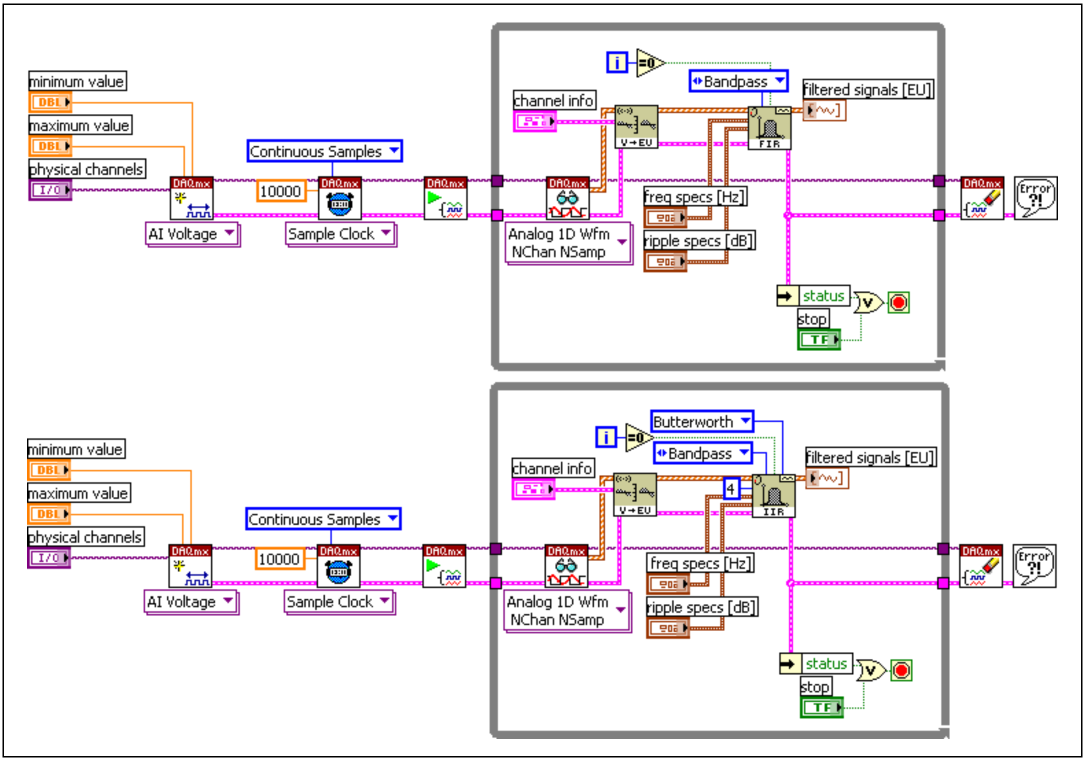


Figure 4-6. Continuous DAQ and FIR or IIR Filtering

Integration

Use the integration function to convert between acceleration, velocity and displacement. If you need to operate on velocity or displacement signals after acquiring acceleration or velocity signals, you can integrate the acquired signal to yield the desired result.

You can use the SVL Integration VI to integrate time-domain signals. For more information about the basic concepts of integration and challenges using the SVL Integration VI, refer to the *LabVIEW Sound and Vibration Toolkit User Manual*, available on `ni.com`.

Reference Signal Processing

DUT imperfections can result in distortion or unwanted signals in many order analysis applications. These imperfections primarily affect the accuracy of proximity probe signals. The proximity probe measures the distance between the probe tip and the shaft surface. Due to the existence of shaft scratches, shaft bow, and other mechanical or electrical runout, the shaft imperfections and resulting unwanted signals distort the vibration signals of interest. When the shaft rotational speed is low, shaft imperfections dominates the vibration signal measured by the proximity probes. Therefore, allow the shaft to rotate at a low speed to collect the reference signal, and then subtract the reference signal from the signal you acquire during normal operation to remove the imperfection errors. This is called slow-roll compensation. The reference signal is the slow-roll reference signal. The slow-roll speed is typically below 10 percent of the first resonance speed.

To perform slow-roll compensation, complete the following steps:

1. Extract the slow-roll reference signal. Use the OAT Get Vector Reference VI to extract the vector reference signal. Use the OAT Get Even Angle Reference VI to extract the even-angle reference signal from the slow-roll vibration and tachometer signal.
2. Remove the reference signal from the acquired vibration signals. Use the OAT Compensate Vector Signal VI to remove the slow-roll errors in the vector signal. Use the OAT Compensate Even Angle Signal VI to remove the slow-roll errors from the even-angle signal. Even-angle signal compensation typically is performed prior to displaying an unfiltered orbit plot and unfiltered timebase plot. You can compensate the even-angle signal with an even-angle reference or vector reference.

You usually need to compensate for centerline offset when you compute the centerline plot of shafts. This requires another type of reference signal called a DC gap reference. The DC gap reference is the DC values of the probes when the shaft is at rest.

To perform a shaft centerline position measurement, complete the following steps:

1. Measure the XY proximity probes DC gap voltage values at rest. Use the OAT Get Gap Reference VI to compute the DC gap.
2. Subtract the at-rest values from the measured DC voltages and combine the results to form the shaft centerline plot. Use the OAT DC Gap Estimator VI to subtract the DC gap value at rest from the acquired DC gap value.

Note For more information about how to use the VIs to extract and compensate for a reference signal, refer to the examples in the Order Analysis Toolkit.

5

Order Analysis Functions and Displays

The LabVIEW Order Analysis Toolkit provides several tools to acquire, analyze, and present noise and vibration information. These tools include the spectral map, order waveform, order spectrum and order magnitude and phase functions. You can use the analysis and display tools in the Order Analysis Toolkit to analyze noise and vibration signals and improve your knowledge of the DUT.

This chapter briefly discusses the order analysis functions and available order analysis displays. This chapter also discusses the analysis and display steps in the order analysis application process.

When programming with the Order Analysis Toolkit, you might encounter three signal types: waveform, even-angle, and vector signal. A waveform signal is the time signal acquired with a fixed time sampling rate. An even-angle signal is a resampled signal with a constant number of samples per revolution. A vector signal is a complex signal comprised of the magnitude and phase of a certain order. All three signals might work as the input signals, intermediate results, as well as the final output results in different functions and displays.

The order analysis and display VIs use different signal types as inputs and outputs and have a different programming flow. Understanding the programming flow can help you better use the order analysis function and display VIs. Figure 5-1 shows a comprehensive flowchart for all order analysis and display VIs. The leftmost block is the well-conditioned and preprocessed data source containing both the waveform signals and speed profile. Through some intermediate and final processing functions, the rightmost blocks are the order analysis results and displays. Look for the specific function you need from the rightmost portion of the chart and trace the programming flow for that function. For example, if you want to display a filtered orbit plot, you need to convert the waveform signal to an even-angle signal. Then you must use the OAT Order Magnitude and Phase VI to convert the even-angle signal to a vector signal. In some cases, you might want to remove the slow-roll errors in the vector signal. Finally, you need to use OAT Orbit Plot VI to display the results. The boxes in dashed lines are optional operations.

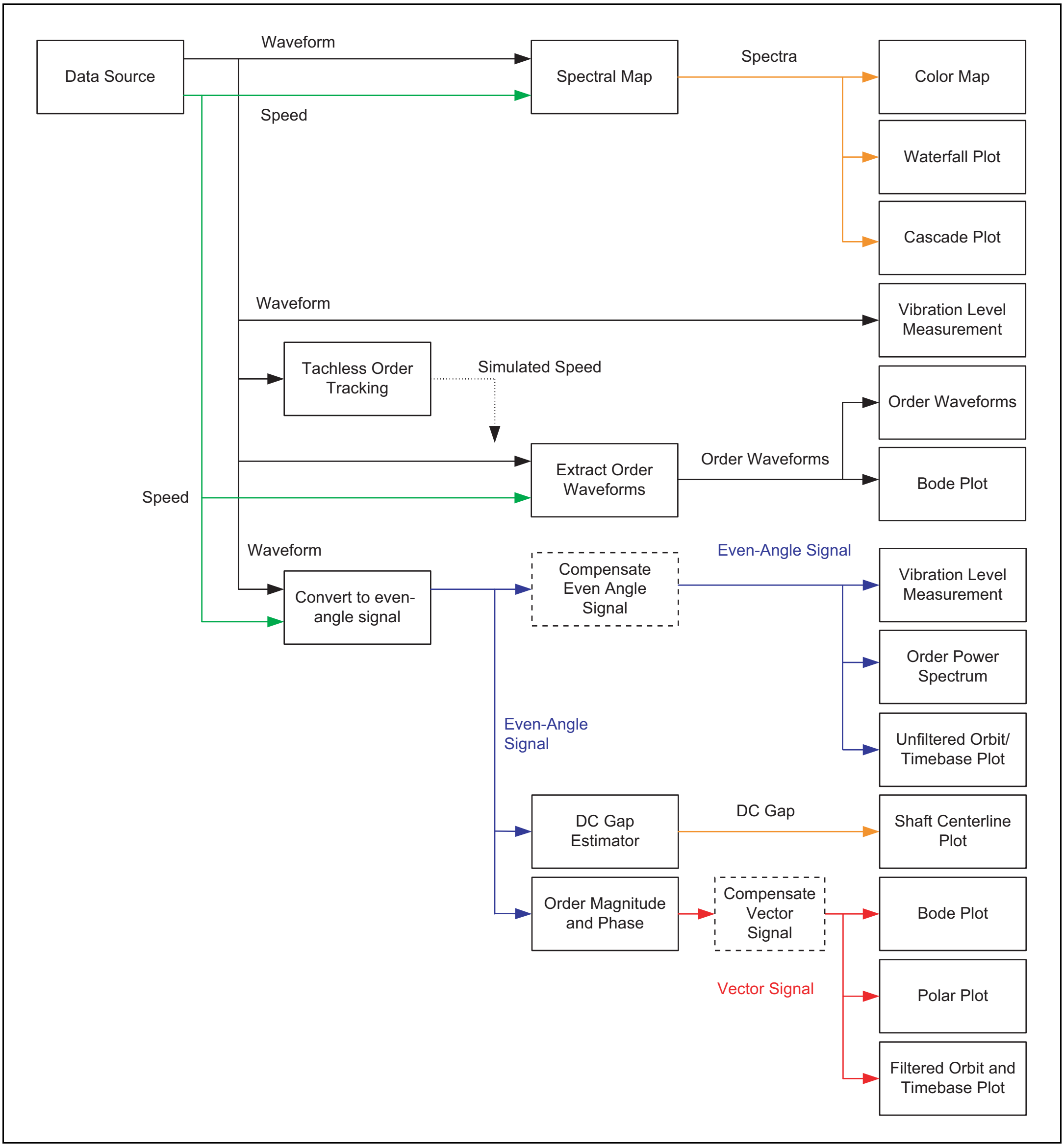


Figure 5-1. Programming Flow Chart of Order Analysis Functions and Displays

Spectral Map

A spectral map is a three-dimensional display of a noise or vibration spectrum as a function of time or speed. The spectrum can be a frequency or order spectrum. A spectral map provides an excellent overview of the frequency or order content of a signal related to the incremental time or speed. A spectral map can help you locate strong noise or vibration components, identify the components changing with the rotational speed, and the fixed components within a certain frequency range.

Figure 5-2 shows the spectral map of the vibration signal acquired from a gearbox casing in a run-up and coast-down test. On this spectral map the strong order components change with time. In the frequency range from 1.8 kHz to 3.0 kHz, the vibrations are stronger than in other frequency ranges. That range is the resonance range of the gearbox. In general, a spectral map helps you get overview information such as how the signal components change, and the location of the significant frequency or order components.

Because a spectral map provides overall signal information, it is usually performed as the first step in order analysis applications. You can locate the signal components of interest from the view of time, speed, frequency, or order. After you locate the components of interest, you can perform some more detailed analysis with other functions such as order power spectrum, order magnitude and phase, or order waveform.

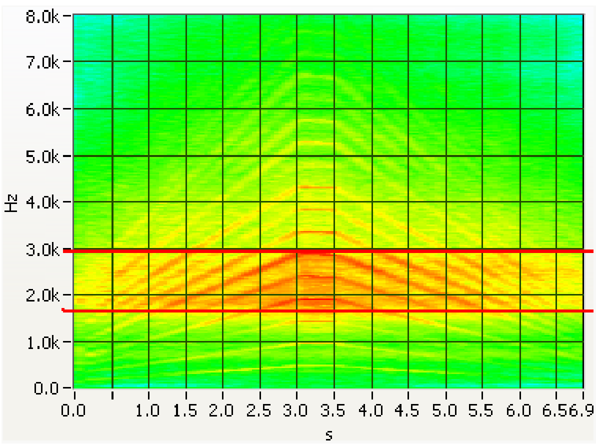


Figure 5-2. Gearbox Vibration Signal Spectral Map

You can use the OAT Spectral Map VI to generate the spectral map data as a two-dimensional array. You can display the spectral map data in a color map, waterfall plot or cascade plot for offline or online analysis.

Color Map

A color map displays the spectral map data in a customized intensity graph. The color map uses different colors on the plot to represent the signal power distribution.

When displaying a signal with a color map, you can select any one of eight plot types in the OAT Spectral Map VI to view different information related to time, speed, frequency and order. Figure 5-3 shows vibration results from a run-up test in a Frequency-Time and RPM-Order display. In Figure 5-3, you can see the Frequency-Time and RPM-Order information related to different units.

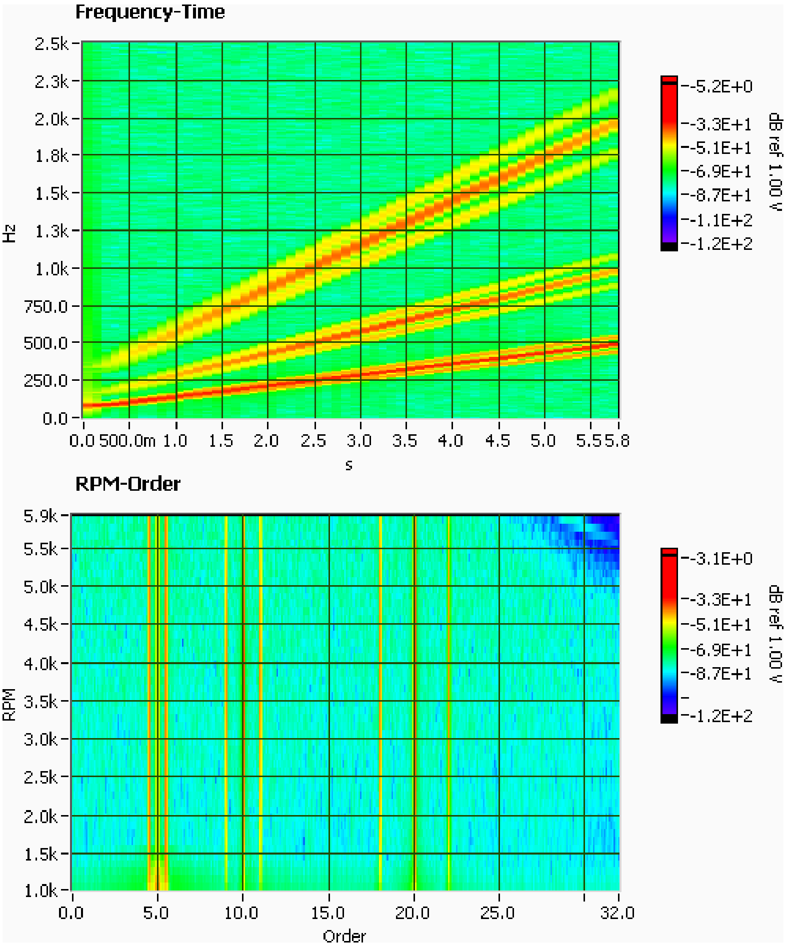


Figure 5-3. Frequency-Time and RPM-Order Display of Vibration Signal

A colormap is used primarily for offline analysis. By comparing the display results with different formats and units, you can get a complete knowledge of the signal and determine further analysis steps.

Connect the spectral map data to the OAT Config Color Map Indicator VI palette to create and display the color map.

Waterfall Plot

Use a waterfall plot to observe frequency or order spectrum changes versus time. A waterfall plot consists of a series of spectra acquired at consecutive times. The abscissa displays frequency or order. The ordinate axis shows the time. The third axis is the amplitude or power. Figure 5-4 shows a waterfall plot.

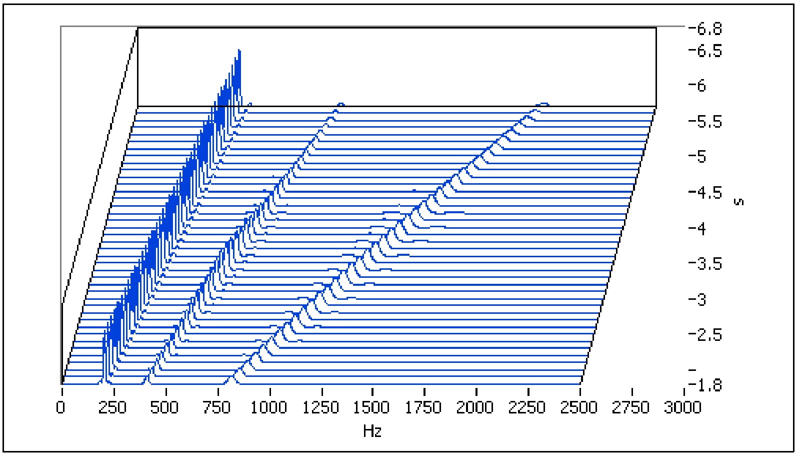


Figure 5-4. Waterfall Plot

A waterfall plot is used primarily for online analysis, because it shows how vibration changes with time and indicates which components are related to rotational speed. Connect the spectral map data to the OAT Waterfall Plot VI to display a waterfall plot.

Cascade Plot

Use a cascade plot to observe frequency or order changes versus rotational speed. A cascade plot consists of a series of spectra acquired at consecutive speeds, either increasing or decreasing. The abscissa displays frequency or order. The ordinate axis shows speed and the third axis is the amplitude or power. Figure 5-5 shows a cascade plot.

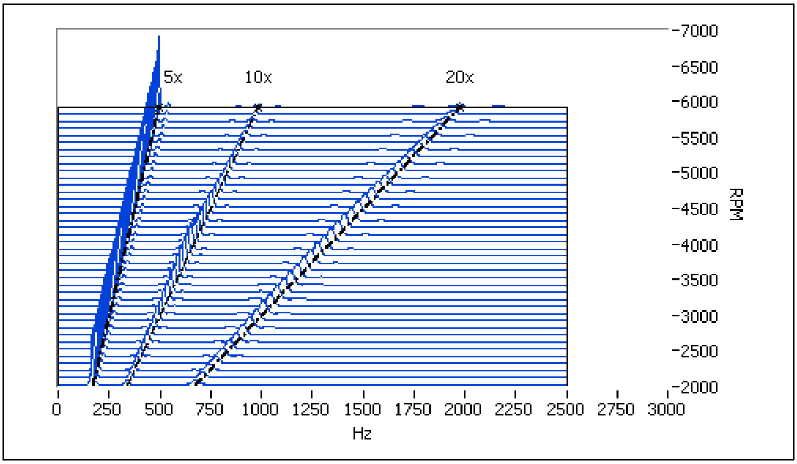


Figure 5-5. Cascade Plot

You can use a cascade plot for both online or offline analysis. A cascade plot is used primarily to show results for tests such as run-up and coast-down tests. The components that move across the plot as the speed changes are the order components, while fixed frequency components move straight up the plot. You can use this cascade plot feature to recognize machine resonances which occur at fixed frequencies.

Connect the spectral map data to the OAT Cascade Plot VI to create a cascade plot.

Order Power Spectrum

An order power spectrum measurement gives a quantitative description of the amplitude, or power, of the orders in a signal. It provides a good view of all order components of a signal. This can help you find significant orders and compare the level of different order components.

When analyzing machinery noise and vibration, you usually perform an order power spectrum measurement after displaying a spectral map. After you identify a certain time block as the signal of interest on the spectral map display, you can perform an order power spectrum on this signal block to get more detailed order information. You can identify the characteristic order components, form a quantitative spectrum measurement of the orders, and compare the amplitude of different orders. Figure 5-6 shows a typical order power spectrum for a gearbox. You can identify the significant orders from this plot, measure the amplitude of the orders, and compare different orders from this plot.

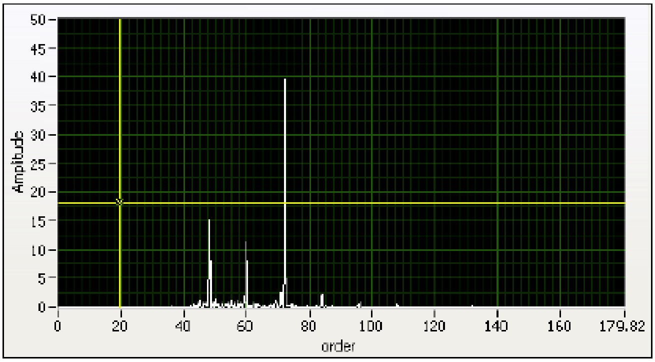


Figure 5-6. Order Power Spectrum

Use the OAT Convert to Even Angle Signal VI to convert a waveform to an even-angle signal. Use the OAT Order Power Spectrum VI to compute the order power spectrum. The OAT Order Power Spectrum VI applies an FFT on the even-angle signal and calculates the power spectrum of the FFT results. When calculating the order power spectrum, the FFT takes a block of even-angle signals and returns a discrete spectrum. In the spectrum, the order information is resolved into a finite number of lines, or bins.

Spectrum Averaging

Averaging successive measurements usually improves measurement accuracy. You typically average the spectrum, but not the time record directly. The OAT Order Power Spectrum VI supports spectrum averaging. You can choose from the following averaging modes to perform spectrum averaging:

- RMS averaging
- Vector averaging
- Peak hold
- Weighting mode

RMS Averaging

Performing RMS averaging on the spectrum can reduce the signal fluctuation, but not the noise floor. Because RMS averaging averages the power of the signal, the averaged RMS spectrum does not contain phase information. The VIs compute RMS averaging for order power spectrum according to the following equation:

$$\langle X^* \cdot X \rangle$$

where X is the complex FFT of the even angle signal x

X^* is the complex conjugate of X.

Vector Averaging

Vector averaging, also called coherent averaging or time/angle synchronous averaging, can reduce the noise floor in the even-angle signal. Vector averaging computes the complex quantity and averages the real and imaginary parts separately. The VIs compute vector averaging for order power spectrum according to the following equation:

$$\langle X^* \rangle \cdot \langle X \rangle$$

where X is the complex FFT of the even angle signal x

X^* is the complex conjugate of X.

When performing vector averaging, use a triggered even-angle signal. Otherwise, you might eliminate strong order components in the averaged spectrum. Use the OAT Output Triggered Even Angle Signal VI to generate a triggered signal for vector averaging.

You must specify a trigger period when using the OAT Output Triggered Even Angle Signal VI. The trigger period determines how frequently to trigger the signal output. The trigger period must be equal to the period of significant order components in the signal. The trigger period the VI uses is the smallest integer that is a multiple of the specified trigger period and greater than the block size. For example, when the significant order component is 0.5 order, the sample rate is 160 samples/revolution, and the block size is 512, set the trigger period to 2 revolutions. Figure 5-7 shows how the triggered even-angle signal is output.

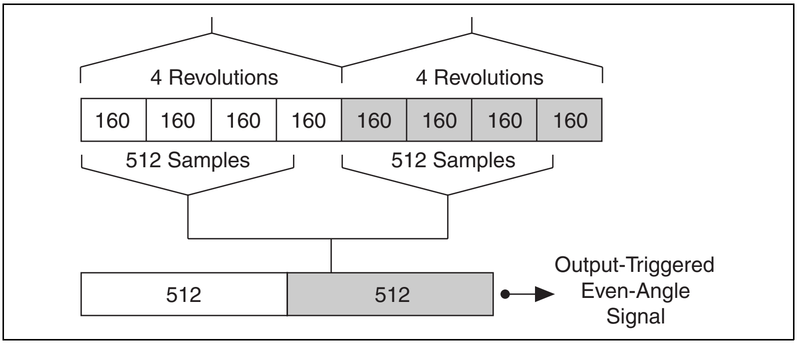


Figure 5-7. Triggered Even Angle Signal Generation

Choosing Between RMS and Vector Averaging

Use RMS averaging when applying an order power spectrum to an unknown even-angle signal. RMS averaging works with signals with different order components and generates good spectrum results.

Use vector averaging when you already have some knowledge of the signal and want to reduce the noise floor in the signal. Carefully trigger the even-angle signal to generate good spectrum results.

Peak Hold

Peak hold averaging is performed at each individual order line and retains the RMS peak levels of the averaged quantities from one FFT spectrum to the next. Peak hold averaging is most useful when configuring a measurement system or when applying a limit to an order spectrum. The VIs compute peak hold averaging for order power spectrum according to the following equation:

$$MAX(X^* \cdot X)$$

where X is the complex FFT of the even angle signal x

X^* is the complex conjugate of X.

Weighting Mode

You can choose from the following weighting modes when performing RMS or vector spectrum averaging:

- Linear
- Exponential

Linear weighting weights each individual spectrum by the same amount in the averaged spectrum. Linear weighting is used most often for analysis purposes.

Exponential weighting weights the most recent spectrum more than the previous spectra, which makes the averaged spectrum more responsive to changes in the input signal. This responsiveness makes exponential weighting ideal for the configuration phase of a measurement. Exponential weighting also is useful for monitoring applications, because the averaged spectrum responds to a singular event. A linearly averaged spectrum might not respond noticeably to a singular event, especially with a large number of averages.

Extended Measurement

You can use the Extended Measurement VIs to perform extended measurement on the order power spectrum results:

- SVL Unit Conversion VI
- SVL Spectrum Peak Search VI
- SVL Power in Band VI
- SVL Limit Testing VI

Unit Conversion

Use the SVL Unit Conversion VI to switch the order power spectrum between magnitude and power spectra, switch between dB on and off, change the dB reference, or change the peak unit.

Spectrum Peak Search

The SVL Spectrum Peak Search VI estimates the order and the amplitude of the order components that satisfy the search criteria specified in the peak search settings. The spectrum must exceed the specified threshold for the VI to identify a single order component. Specify the threshold in the same units as the input spectrum.

Power in Band

The SVL Power in Band VI measures the total power within a specific order range. The VI computes the power in band from the order power spectrum according to the following equation:

$$Power = \frac{\sum_{start\ order}^{stop\ order} PS}{ENBW}$$

where PS is the order power spectrum.

ENBW is the equivalent noise bandwidth of the applied window.

Order Waveform, Magnitude, and Phase

An order waveform is the time signal associated with a certain order, that is synchronous to the rotational speed. You can compute the magnitude and phase of a specific order from the order waveform. You also can compute order magnitude and phase from an even-angle signal. Unlike order power spectrum which provides information for all of the orders of a certain time block signal, order waveform, magnitude, and phase provide information only for one particular order relative to time. Order magnitude and phase also can provide the order information relative to speed when you perform a run-up or coast-down test. The display of magnitude and phase information relative to speed is a Bode plot. Order magnitude and phase help you view noise or vibration signals from another perspective by focusing on particular orders.

Use the spectral map or order power spectrum to identify the most significant orders. After identifying the most significant orders, you can extract order waveform, magnitude, and phase to get detailed information for individual orders.

Order Waveform

Figure 5-8 shows the original waveform and extracted order waveform. You can see the contribution of the fourth order to the overall waveform signal. You can also calculate the running RMS value of a certain order from order waveform, which you then can use to indicate the amplitude of a certain order.

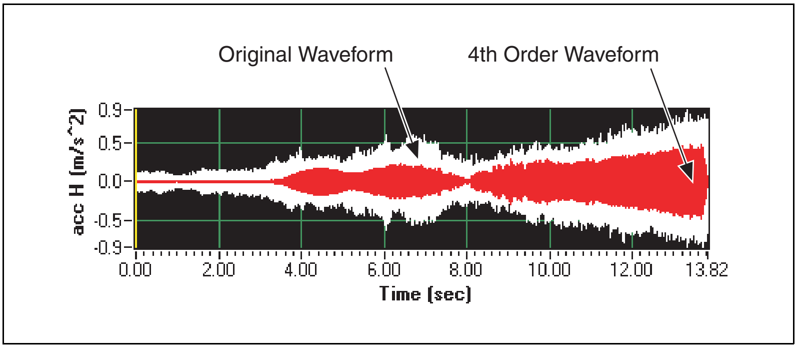


Figure 5-8. Original Signal and Extracted Order Waveform

One feature of order waveform extraction is the ability to play back the time signal. Playing back the time signal enables you to listen to the sound of a certain order or a combination of orders. This feature is useful for both testing and monitoring applications, or any application where a microphone acquires the signal. You can use it to perform noise analysis and locate a noise source by comparing the noise generated by different orders or order combinations. The most common applications utilizing this feature are in sound quality engineering. You can analyze and synthesize the sound of several orders and evaluate the subjective perception of these sounds. In automotive NVH tests, one example is the evaluation of power train components like the engine to get a more comfortable noise level for the passengers.

Use the OAT Extract Order Waveforms VI to compute the order waveforms of specified orders. You also can compute the order components with the highest power with the OAT Extract Most Significant Order Waveforms VI. Specify the number of significant orders you would like to extract, and the VI returns the most significant order waveforms.

To better select the order of interest and specify the appropriate bandwidth, you may interactively extract the order from a time-frequency color map with cursor positions. You can move the cursor to the order of interest on the time-frequency color map and specify the bandwidth to cover that order. Figure 5-9 shows the color map and the extracted order waveform.

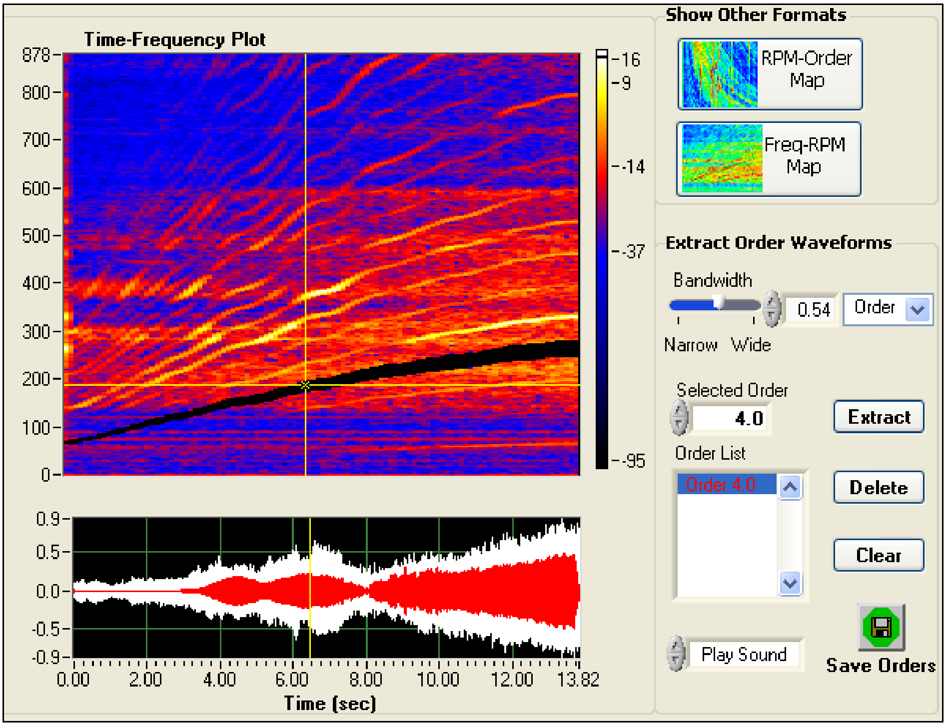


Figure 5-9. Interactively Selecting Orders in a Color Map to Extract Order Waveforms

Order Magnitude and Phase

Many mechanical faults are associated with certain orders, analyzing order magnitude and phase can help you detect mechanical faults directly. For example, a strong first order magnitude indicates imbalance in most cases. Analyzing the first order magnitude can help you identify the imbalance. Moreover, the magnitude and phase of the first order can help you correct the imbalance by adding weights on the appropriate rotor positions.

Use the OAT Order Magnitude and Phase VI to calculate the order magnitude and phase from an even-angle signal or order waveform. The output of the magnitude is expressed in RMS value. You can use the SVL Unit Conversion VI to convert the output to zero-peak or peak-peak value.

Phase Definition

Phase describes the relative timing between two signals. Phase is the angle difference of the measured point and reference point. You can use phase to locate the imbalance location on a rotor. Measuring the phase of vibration signals requires a reference signal or a reference trigger point. In machinery vibration analysis, the tachometer pulses work as the reference trigger points.

The phase measurement in machinery vibration measurement uses the phase lag convention. Phase is defined as the angle difference measured from the peak of a vibration signal backward in time to the reference trigger point. This means the directions of numerically increasing angles are always set against the shaft rotation.

Figure 5-10 shows the relationship of the vibration signal and reference signal to zero degree phase. The shaft has a heavy spot and a keyway slot. When the keyway slot passes the tachometer, the tachometer detects a trigger pulse. The heavy spot causes the shaft to vibrate as the shaft rotates. When the heavy spot passes the proximity probe, the vibration reaches a peak. When the heavy spot passes the proximity probe and the keyway slot passes the tachometer simultaneously, the peak of the vibration does not lag or lead the reference trigger point. At this point the phase is zero degrees.

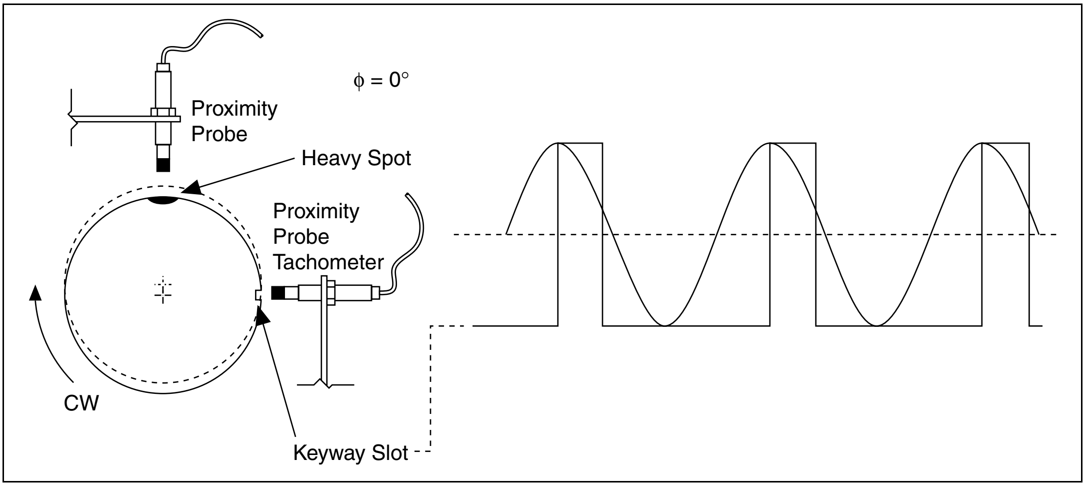


Figure 5-10. Zero Degree Phase Signal

The other part of the convention dictates that 90 degrees means that the peak of vibration lags 90 degrees behind the trigger point. Figure 5-11 illustrates the 90 degree phase. When the vibration signal reaches the peak, rotate the shaft backward (counter the rotation direction) until the keyway slot passes the tachometer. The number of degrees you rotate is the phase lag, or the phase value in machinery vibration measurement. Figure 5-11 shows the relationship of the vibration signal and reference signal to the 90 degrees phase convention.

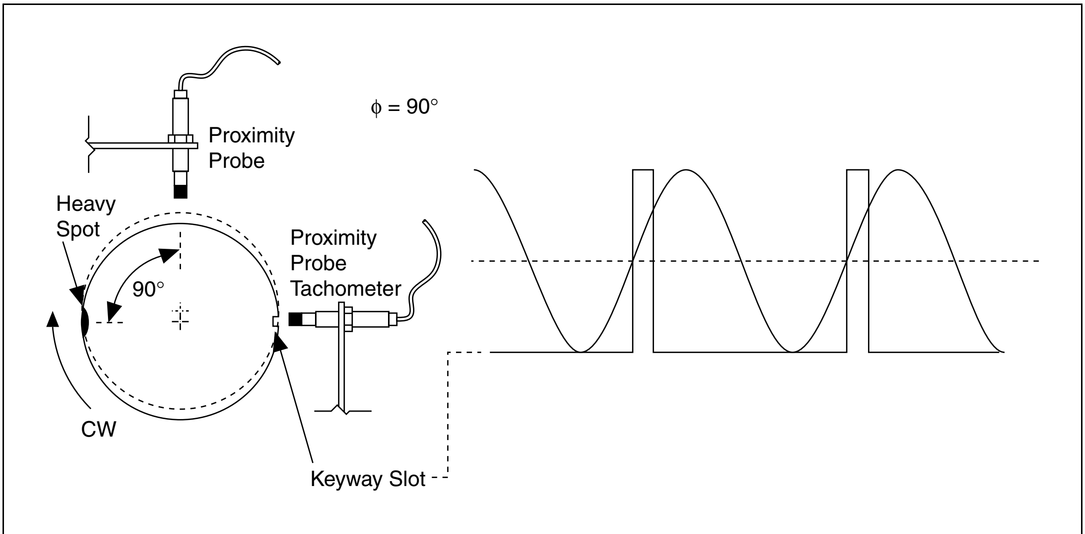


Figure 5-11. Ninety Degree Phase Signal

Bode Plot

A Bode plot displays order magnitudes and phases as a function of rotational speed or frequency. You typically use Bode plots for transient analysis in both start-up and coast-down conditions. A Bode plot can help to identify the resonance speed of a rotor or examine the rotor dynamics on an order basis. Figure 5-12 shows the resonance phenomena of a rotor in a Bode plot. When the rotor passes the resonance speed area, the magnitude reaches the peak and the phase shift approaches 180 degrees. Figure 5-12 shows that the resonance speed is at approximately 3,500 rpm.

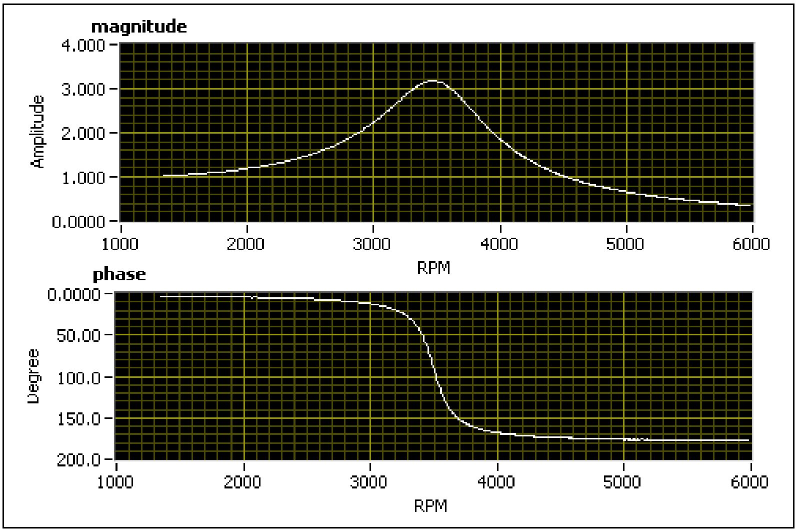
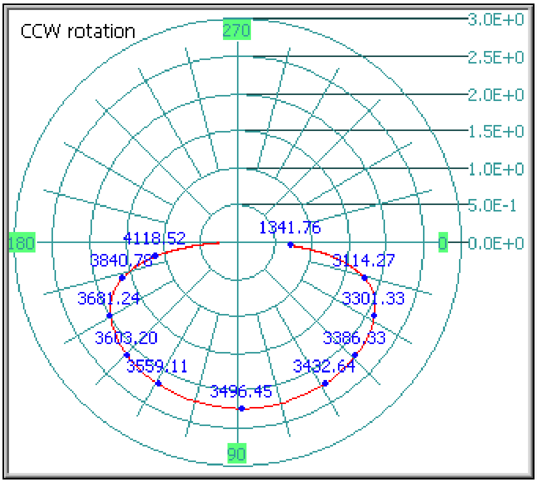


Figure 5-12. Bode Plot Display

Use the OAT Order Magnitude and Phase VI to generate a Bode plot.

Polar Plot

Polar plots and Bode plots often are combined to describe the rotating speed vector signal locus during speed changes. A Bode plot provides excellent change visibility with respect to speed, while the polar plot shows improved phase variation resolution. This is due to the nature of both the Bode and the polar plots. The x-axis in the Bode plot is speed or frequency, which allows you to see the changes in magnitude and phase over speed or frequency. In the polar plot, the plot displays the data in polar coordinates, which allows you to see the phase changes in the range of zero to 360 degrees. Figure 5-13 shows a polar plot. From this plot, you can see that the phase angle shifts 180 degrees after the speed passes the resonance range.



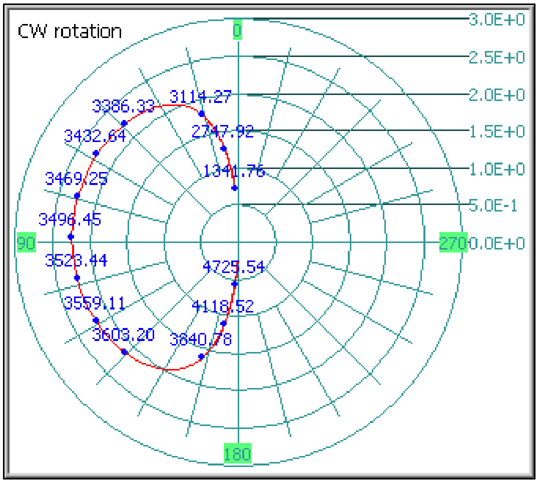


Figure 5-13. Polar Plot with Different Probe Angles and Shaft Rotation Directions

Use the OAT Polar Plot VI to display a polar plot. The polar plot zero degree point always is located at the transducer angular position. You can compare data from orthogonally mounted proximity probe pairs with a polar plot. Because the VI defines the phase of the vector signal as a phase lag value, the phase increases in the direction counter to shaft rotation in the polar plot. Specify the probe angle value and shaft rotation direction in the **channel settings** control to set the transducer angular position. The VI rotates the plot accordingly. Figure 5-13 also shows the polar plot when the probe is at zero degrees with a counter clockwise rotation direction and 90 degrees with a clockwise rotation direction. From this plot, you can see how the zero degree position changes according to the probe angle position and how the phase changes according to the shaft rotational direction.

Orbit, Timebase, and Shaft Centerline Plots

Use orbit, timebase, and shaft centerline plots to display shaft motion. Typically two proximity probes acquire the signals for these three plots. The proximity probes typically are mounted orthogonally on the fluid film bearing. An orbit plot shows the dynamic motion of the center of a rotating shaft with signals from two proximity probes. A timebase plot displays dynamic vibration amplitude information with the same proximity probe signals as the orbit plot. A timebase plot displays the signal as a function of time in one or more revolutions with two separate plots.

A shaft centerline plot displays the shaft center DC position changes within a bearing clearance range. An orbit plot represents the shaft center AC dynamic motion. Use a shaft centerline plot with an orbit plot to track both aspects of shaft motion.

Figure 5-14 shows how you might configure a system to display an orbit plot and a shaft centerline plot. In this plot, the outer circle depicts the bearing clearance. Two orthogonally mounted proximity probes measure the shaft motion. As the shaft speeds up in the counterclockwise (CCW) rotation direction, the center moves from the bottom of the bearing clearance to the normal operational center as shown by the shaft centerline. As the shaft continues in normal operation, the shaft center moves around the normal operating center as shown by the shaft orbit.

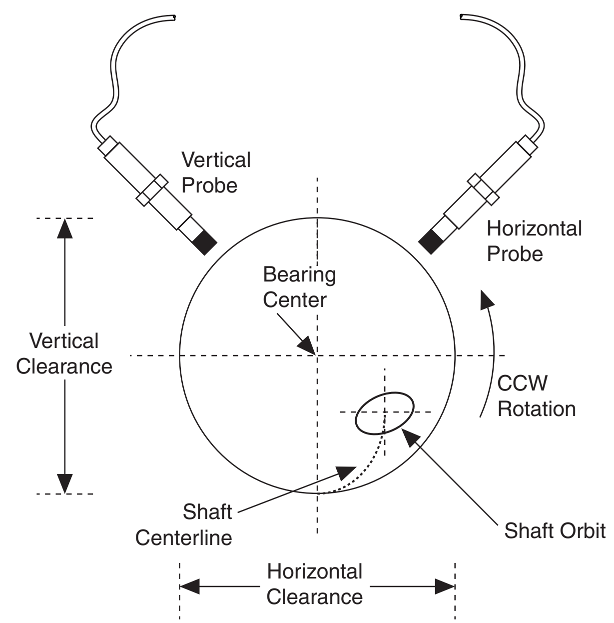


Figure 5-14. Shaft Centerline and Orbit Within Bearing Clearance

The most common use for the orbit, timebase, and shaft centerline plots is to monitor turbomachinery with fluid film bearings. Some turbomachinery mechanical faults have characteristic plot shapes. You can compare the acquired plots with any known characteristics to detect faults and diagnose machine problems.

Orbit Plot

An orbit plot is a plot that shows the dynamic motion of the center of a rotating shaft. An orbit plot generates a two-dimensional image of the shaft center motion. Figure 5-15 shows a filtered orbit plot and the typical setup for monitoring a rotating shaft with an orbit plot. XY proximity probes, two probes of the same type mounted 90 degrees apart, monitor the shaft. If you do not use orthogonally-mounted XY probes, the orbit might appear skewed.

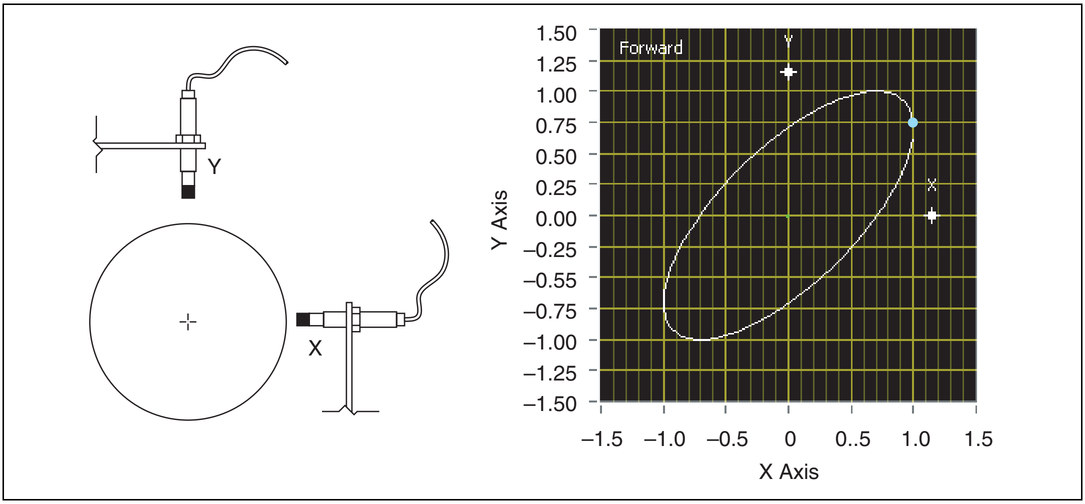


Figure 5-15. Orbit Plot

Use the OAT Orbit Plot VI to display both filtered and unfiltered orbit plots. The unfiltered plot shows the direct motion of the shaft center and displays all orders. An unfiltered orbit plot displays shaft motion based on data from an even-angle signal. A filtered plot shows the synchronous motion of a particular order. A filtered orbit plot displays the shaft motion based on vector signal data.

When creating an orbit plot, you need to pay attention to two important issues:

- Probe angle correction
- Blank-bright sequence and trigger pulse direction

Probe Angle Correction

In many cases, you cannot mount probes easily in the desired 90 degrees out of phase horizontal and vertical orientation. By default, the orbit display assumes the signals are from probes in the horizontal and vertical positions. To display the data with respect to a true vertical and horizontal coordinate system, you must virtually rotate the data by the probe angular offset from the desired coordinates. The OAT Orbit Plot VI can automatically rotate the orbit display to the true horizontal and vertical probe orientations. Specify the probe angle of the x-axis and y-axis probes in the **channel settings** control.

Blank-bright Sequence and Trigger Pulse Direction

In an orbit plot, there is a bright spot and a blank spot in the motion curve. The bright and blank spots in the orbit plot represent the trigger point for the tachometer observing the shaft rotation. In the trigger signal, the negative slope produces a blank spot while the positive slope produces a bright spot. A negative-going trigger pulse produces a blank-bright sequence. A positive-going trigger pulse produces a bright-blank sequence. Figure 5-16 illustrates each type of trigger pulse.

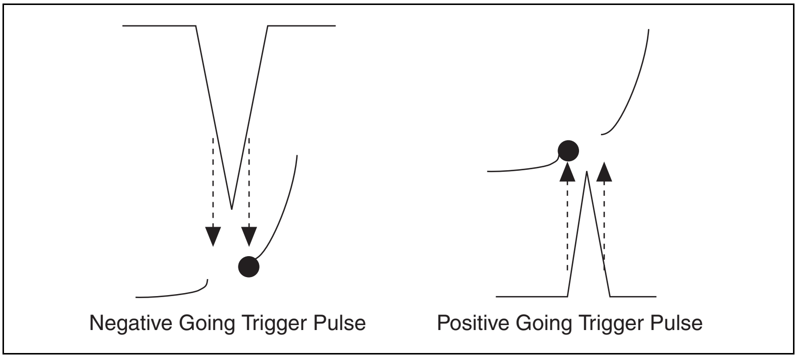


Figure 5-16. Trigger Pulse Direction and Associated Blank-Bright Sequence

A negative-going trigger pulse typically is used for a proximity probe observing a notch or a hole drilled into a shaft. A positive-going trigger pulse usually is generated for an optical transducer.

Use the blank-bright sequence in an orbit plot to determine the orbit procession direction. Typically, the orbit procession direction is described as forward or backward.

- Forward—orbit procession is in the same direction as the shaft rotation.
- Backward—orbit procession is in the reverse direction of the shaft rotation.

Note The blank-bright sequence represents the orbit procession direction. The orbit procession direction can be different from the shaft rotation direction. Some complex machinery instabilities display an order less than one that have a procession direction that is the opposite of the shaft rotation.

Figure 5-17 illustrates the variation of blank-bright sequences with pulse type and the orbit procession direction, both clockwise (CW) and CCW.

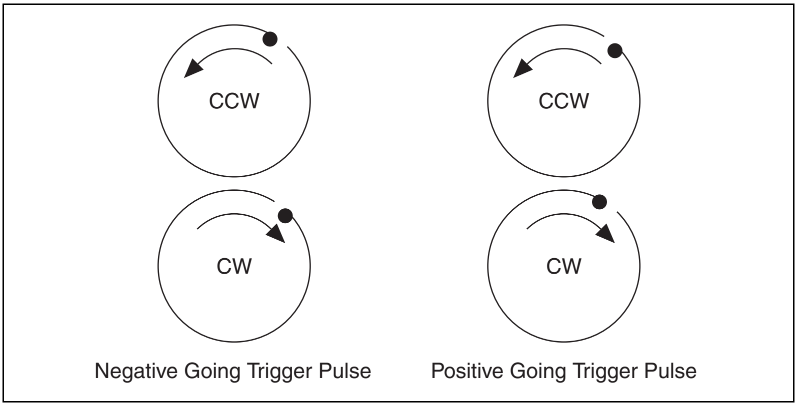


Figure 5-17. Variation of Blank-Bright Sequence with Pulse Type and Orbit Precession

Timebase Plot

A timebase plot displays the vibration amplitude of one or more revolutions of a shaft as a function of time. Whereas an orbit plot shows the whole picture of the rotating shaft, a timebase plot allows you to get a clearer picture of what an individual transducer is seeing in terms of vibration amplitude. A timebase plot also uses the blank-bright system to represent points on the plot. The timebase plot follows the same convention as the orbit plot. Figure 5-18 shows a typical unfiltered timebase plot for the x-axis and y-axis. Each dot on the plot represents the trigger pulse position.

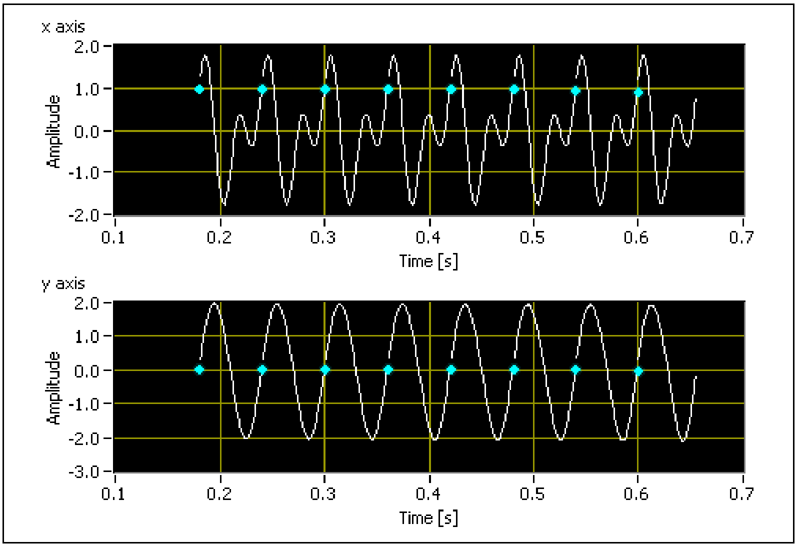


Figure 5-18. Typical Unfiltered Timebase Plot

Use the OAT Timebase Plot VI to draw both unfiltered and filtered plots. The unfiltered timebase plot displays shaft vibration with an even-angle signal. The filtered timebase plot displays the shaft vibration with a vector signal. A filtered timebase plot only shows the synchronous motion of a certain order.

Shaft Centerline Plot

Use a shaft centerline plot to display changes in radial rotor position with respect to a stationary bearing over a range of time or speed. The DC gap voltage from two orthogonally-mounted proximity probes determines the averaged position change. Figure 5-19 shows a typical shaft centerline plot during machine startup. The numeric values on this plot correspond to the rotational speed.

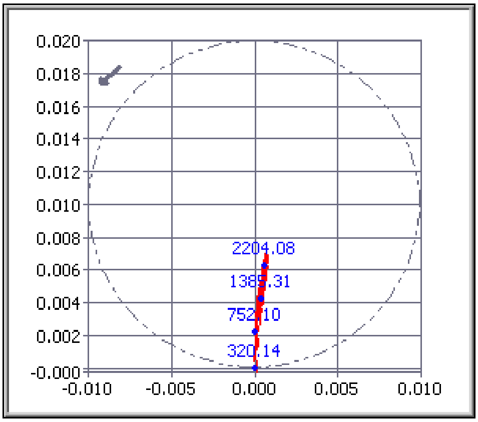


Figure 5-19. Shaft Centerline Plot

Drawing a Shaft Centerline Plot

You can use the OAT DC Gap Estimator VI to compute the DC gap values from the x-axis and y-axis proximity probes. You can use the OAT Shaft Centerline Plot VI to display the shaft centerline plot with the DC gaps.

The shaft centerline plot follows the same true vertical and true horizontal convention as the orbit plot in the Order Analysis Toolkit. You can use the OAT Shaft Centerline Plot VI to virtually rotate the plot to true vertical and true horizontal positions automatically by specifying the probe angles in the **channel settings** control.

When displaying a shaft centerline plot, you must specify the bearing clearance and shaft centerline start point reference. There are three types of start point references:

- Bottom—typically used for a horizontal machine train.
- Center—typically used for a vertical machine train.
- Top—typically used for overhung rotors such as fans and compressors.

The start point reference you choose greatly affects the clearance boundary circle position in the shaft centerline plot. Figure 5-20 shows three shaft centerline plots with different start point references.

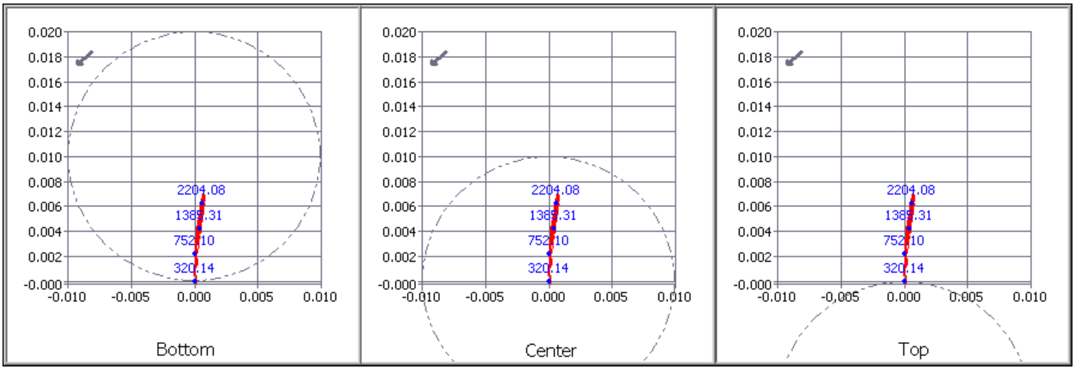


Figure 5-20. Shaft Centerline Plot with Different Start Points

Level Measurements

A level measurement is a common measurement technique available in the Order Analysis Toolkit. A level measurement gives a quantitative description of the overall vibration acquired from the transducer. Level Measurement & Limit Testing VIs work with time-domain or even-angle signals. You can use the vibration level measurement VIs to obtain the following values:

- Root-Mean-Square (RMS) level
- Running RMS level
- Peak level
- Max-min level
- Crest factor
- Exponential average level
- Decimated exponential average level

Measuring RMS Level

One common vibration level measurement is measuring the RMS level of the signal returned by an accelerometer. You also can perform a running RMS level measurement, which returns the RMS value computed over the last *n* revolutions for an even-angle signal, or the last *n* seconds for a waveform signal.

Computing Peak Level

Use the SVL Peak Level VI to compute the peak level of an even-angle signal. In peak-hold averaging, the VI computes the largest measured level value of all previous values and returns the value until a new value exceeds the current maximum. The new value becomes the new maximum value until a new value exceeds the new maximum.

Computing the Crest Factor

The crest factor is the ratio of the peak value over the RMS value of a given signal. The crest factor indicates the even-angle signal shape. The following equation defines the crest factor:

$$F_c = \frac{V_{pk}}{V_{rms}}$$

where F_c is the crest factor.

V_{pk} is the peak value of an even-angle signal.

V_{rms} is the RMS value of an even-angle signal.

You can use the SVL Crest Factor VI to compute the even-angle signal crest factor.

Even-Angle Signals in Integer Revolutions

In some cases, computing the vibration level requires working with the even-angle signal input in integer revolutions. Use the OAT Output Triggered Even Angle Signal VI to adjust the even-angle signal. Set the **block size** to a –1 default value so the number of revolutions in the even-angle signal output equals the integer times **trigger period**.

Limit Testing

The SVL Limit Testing VI allows you to specify a mask around a data set to define a pass range. You can enter a scalar value to the upper limit, lower limit, or both to specify a constant ceiling or floor for the data. This allows you to perform tests such as range detection. You can enter an upper limit mask, lower limit mask, or both to the SVL Limit Testing VI to define a pass range that varies in shape and level based on acceptable results at any given point in the measurement. You must enter at least one limit, or the SVL Limit Testing VI returns an error.

You can use this VI to analyze almost any results produced by the Order Analysis Toolkit. The supported datatypes include:

- waveform
- even angle signal
- order spectrum
- XY signal (speed profile, order magnitude and phase, etc.)
- peak (spectrum peak search result)
- scalar

A

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Glossary

Numbers/Symbols

∞	Infinity.
2D	Two-dimensional.

A

adaptive filter	A type of filter that operates on a recursive algorithm to achieve the goal of optimum. An adaptive filter is self-designing and suitable for tracking time variations of the input signal, but complete knowledge of the relevant signal characteristics is not available.
aliasing	A phenomenon in which an analog signal of a frequency greater than half the sampling frequency, or Nyquist frequency, appears after sampling at a frequency less than half the sampling frequency. *See also* anti-aliasing filter *and* Nyquist frequency.
anti-aliasing filter	Analog lowpass filters used before analog-to-digital conversion to filter out the frequencies greater than half the sampling frequency. *See also* aliasing *and* Nyquist frequency.

C

critical sampling	Occurs in Gabor transform when the window length equals the window shift step. In critical sampling, the number of Gabor coefficients $c_{m,n}$ equals the number of original data samples $s[k]$.

D

dB	Decibel.
dual functions	Pair of window functions for Gabor transform and Gabor expansion. The two dual functions are interchangeable. That is, you can use either of the dual functions for a Gabor transform while using the other dual function for a Gabor expansion.

F

FFT	Fast Fourier transform.
fundamental component	Portion of a signal whose frequency is at the fundamental frequency.

G

Gabor coefficient	The result of Gabor transform.
Gabor expansion	The inverse Gabor transform used on Gabor coefficients to recover a time domain input signal.
Gabor transform	One of the invertible joint time-frequency transforms.

H

harmonic	Frequencies that are integer or fractional multiples of a fundamental frequency.

L

LMSE	Least mean square error.

N

Nyquist frequency	Half the sampling frequency. Any analog frequency component above the Nyquist frequency will, after sampling, be converted, or aliased, to a frequency below the Nyquist frequency. *See also* aliasing *and* anti-aliasing filter.

O

order	A harmonic related to the rotational speed of a machine.
order analysis	The analysis of harmonics related to rotational speed. The application of harmonic analysis to rotating machinery

order curves	The high power density curves in a spectral map which indicate order components.
orthogonal-like Gabor transform pair	The pair is composed of a Gabor transform and a Gabor expansion when the Gabor coefficients $c_{m,n}$ found by each method are the projection of the signal on the synthesis window function $h[k]$.
over sampling	Occurs in a Gabor transform when the window length is greater than the window shift step. In over sampling, the number of Gabor coefficients $c_{m,n}$ is more than the number of original data samples $s[k]$.

R

resampling	A method to sample a time sequence at a different time interval.
RMS	Root mean square.
RPM	Revolutions per minute.

S

STFT	Short time Fourier transform.

W

window shift step	The shortest time interval between two windows. In the LabVIEW Order Analysis Toolkit, the window shift step is always equal to a quarter (0.25) of the window length. For example, if the window length is 2,048, the window shift is 512.