

Getting Started with Order Analysis

NI Sound and Vibration Measurement Suite Version 5.0

This document provides an introduction to the order analysis tools that the NI Sound and Vibration Measurement Suite provides. This document also contains exercises that you can use to learn how to build order analysis applications with the Order Analysis Express Measurements VIs. These exercises take a short amount of time to complete and help you get started with the order analysis tools.

The following resources contain information you might find useful:

- *LabVIEW Help*, available by selecting **Help»Search the LabVIEW Help**
- *Getting Started with LabVIEW*
- *LabVIEW Sound and Vibration Analysis User Manual*

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Introduction to Order Analysis

Order analysis is a technique for measuring and analyzing sound and vibration signals generated by rotating or reciprocating machinery, such as engines, compressors, turbines, and pumps. These machines have a variety of parts, and each part contributes a unique sound and vibration pattern to the sound and vibration pattern of the whole machine. With order analysis, you can identify and isolate these sound and vibration patterns to analyze the performance and quality of each machine part individually. The information you gather with order analysis often is difficult to acquire with traditional sound and vibration analysis methods.

Traditional sound and vibration analysis methods such as Fast Fourier Transform (FFT) analysis cannot detect mechanical characteristics that change with speed. Order analysis, on the other hand, enables you to identify data at various orders, or harmonics of the rotational speed. The first order refers to the speed at which the machine rotates. Each order thereafter is a corresponding multiple of the rotational speed. The second order is twice the rotational speed and the third order is three times the rotational speed and so on. Using order analysis, you therefore can analyze signal variations due to changes in speed.

Order Analysis Applications

In general, you can perform order analysis in the following types of applications:

- machine condition monitoring (MCM)
- noise, vibration, and harshness (NVH) testing

MCM applications typically analyze vibration response data to identify defective parts and ensure continuous performance. NVH applications typically analyze sound and vibration data to verify the quality of a system and identify parts that produce unwanted sound or vibration.

Unlike MCM applications, NVH applications generally analyze the sound and vibration of machine parts that function properly. For example, commercial airplane engineers might use NVH analysis to reduce cabin noise. With NVH analysis, the engineers can isolate and identify the source of the unwanted noise, such as the aircraft engines. The engineers then can redesign the rotating part of the engines and verify the improvement, again using NVH analysis.

You can use the order analysis tools in the NI Sound and Vibration Measurement Suite to develop both MCM and NVH applications. This document focuses on using these order analysis tools for NVH applications. The Sound and Vibration Measurement Suite provides Order

Analysis VIs and indicators with which you can develop a complete NVH application, from the logging of online data to data analysis and presentation.

Refer to the *LabVIEW Help* for more information about order analysis theory and applications.

Performing Order Analysis with Example VIs

The Sound and Vibration Measurement Suite includes examples to help you get started with order analysis. Select **Help»Find Examples** in LabVIEW to launch the NI Example Finder. Select **Toolkits 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.

You use an example VI that the Sound and Vibration Measurement Suite provides to perform the exercises in the *Building an Order Analysis Application* section.

Building an Order Analysis Application

In this section, you use the order analysis tools in the NI Sound and Vibration Measurement Suite to build a noise, vibration, and harshness (NVH) testing application. You use these tools to perform offline order analysis on example data. This example data represents the speed and vibration amplitude of a computer fan during a run-up test. The exercises in this section illustrate the common analysis methods you can use to acquire information about the orders in the data.



You can complete the exercises in this section in approximately 40 minutes.

Description of the Device under Test

An effective order analysis application requires a thorough knowledge of the device under test (DUT). The more information you have about the DUT, the more useful the analysis you perform can be in understanding the behavior of the system.

The DUT for the exercises in this section is a computer fan with four coils and seven blades. The example data you use represents a 15-second run-up test of the computer fan. Run-up and run-down tests are useful for identifying orders that generate significant amplitude only when the DUT approaches or surpasses the critical speed, or resonant frequency.

Analyzing the Example Data

The Order Analysis Express Measurements VIs provide common analysis methods you can use to acquire information about the orders in a sound or vibration signal. You can use these Express VIs to analyze the computer fan run-up data.

In the following exercises, you use the Getting Started Exercise (Empty) example VI as a template to build an order analysis application with the Order Analysis Express Measurements VIs. You can access the Getting Started Exercise (Empty) example VI by selecting **Help»Find Examples** from the pull-down menu and selecting **Toolkits and Modules»Order Analysis»Getting Started** in the **NI Example Finder** window.

When you complete these exercises, the block diagram of the Getting Started Exercise (Empty) example VI should appear similar to the block diagram of the Getting Started Exercise (Completed) example VI, as shown in Figure 1.

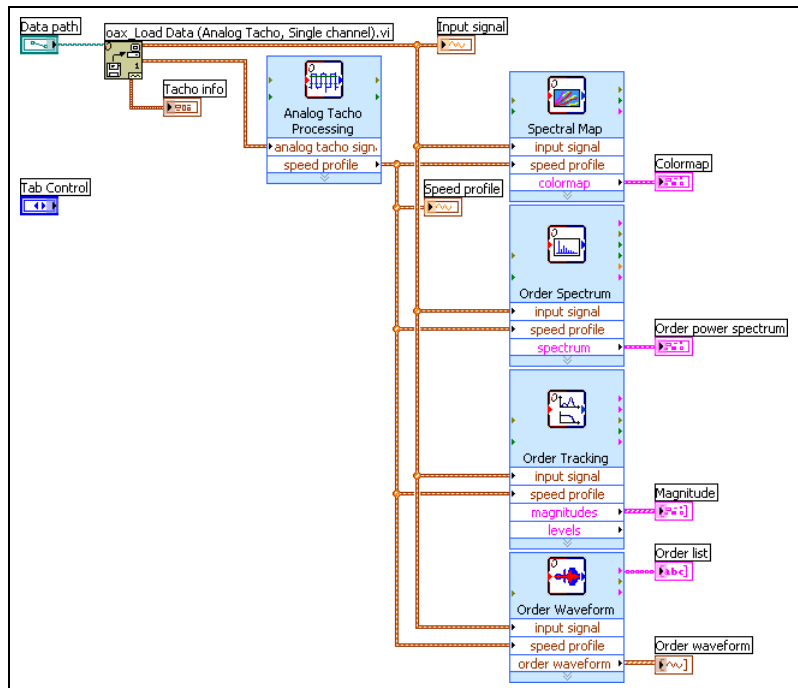


Figure 1. Block Diagram of the Getting Started Exercise (Completed) Example VI

The Getting Started Exercise (Completed) example VI uses the colormap, order power spectrum, magnitude, and order waveform plots to analyze the sound and vibration data from the computer fan. Each plot displays the

same information from a different perspective. You can use these plots to analyze the example data and gain a fuller understanding of the DUT.

Loading the Example Data

You can use the Getting Started Exercise (Empty) example VI as a template VI to build an order analysis application that analyzes the example data with a variety of plots.

Complete the following steps to load the computer fan run-up data to use in the Getting Started Exercise (Empty) example VI.

1. Launch the Getting Started Exercise (Empty) example VI.
2. Click the **Browse** button next to the **Data path** text box and navigate to the PC Fan runup.dat file in the labview\examples\Order Analysis\Example Data directory.
3. Click the **OK** button. The filename appears in the **Data path** text box.
4. Click the **Run** button to run the Getting Started Exercise (Empty) example VI.
5. Select **File»Save As** and save the VI as `Getting Started Exercise.vi` in an easily accessible location.

The Getting Started Exercise VI displays the waveform of the computer fan run-up data in the **Input signal** plot on the front panel. This VI also returns the tachometer information for the input signal in the **Tacho info** indicator. Notice that the number of pulses per revolution of the tachometer is two.

Analyzing the Speed Profile

The **Input signal** plot of the Getting Started Exercise VI is a vibration signal plot. Vibration signal plots illustrate how sound or vibration signals change over time. You can use a speed profile plot to illustrate how rotational speed changes over time. You then can use these two plots in parallel to observe how raw sound or vibration changes with speed.

The Analog Tacho Processing Express VI uses an analog tachometer signal to determine the rotational speed of a DUT. You can use this Express VI to compute the rotational speed of the computer fan.

Press the <Ctrl-E> keys to switch to the block diagram of the Getting Started Exercise VI. Notice that the `oax_Load Data (Analog Tacho, single channel)` VI loads the example data and returns the vibration signal, an analog tachometer signal, and information about the tachometer. You also can see several indicators on the block diagram of the Getting Started Exercise VI. You will use these indicators in later sections.

Complete the following steps to compute the rotational speed of the computer fan and to display the information in a speed profile plot.

1. On the **Order Analysis Express Measurements** palette, select the Analog Tacho Processing Express VI and place it on the block diagram of the Getting Started Exercise VI. A configuration dialog box appears.
2. On the **Configuration** page of the configuration dialog box, set **Pulse/Revolution** to 2. Recall that you acquire the pulse per revolution information in the **Tacho info** indicator when you run the Getting Started Exercise VI for the first time.
3. Click the **OK** button to save the current configuration and close the configuration dialog box.
4. Wire the **analog tacho signal** output of the oax_Load Data (Analog Tacho, single channel).vi to the **analog tacho signal** input of the Analog Tacho Processing Express VI.
5. Wire the **speed profile** output of the Analog Tacho Processing Express VI to the **Speed profile** indicator.

The block diagram should appear similar to Figure 2.

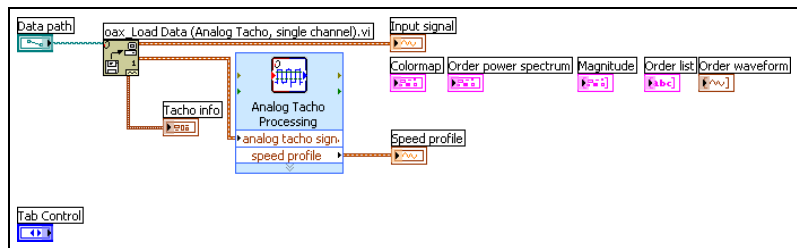


Figure 2. Creating the Speed Profile

6. Run the Getting Started Exercise VI to calculate the rotational speed of the computer fan and to display the information in the **Speed profile** plot.
7. Save this VI.

On the front panel, the **Waveform and Speed** tab displays vibration signal and speed profile plots of the example data. From the **Input signal** plot, you can see that the vibration amplitude of the computer fan generally increases over 15 seconds. The **Speed profile** plot shows that the rotational speed of the computer fan increases steadily from approximately 1,400 RPM to 3,700 RPM over 15 seconds. The **Input signal** and **Speed profile** plots therefore illustrate that the vibration amplitude is approximately linearly related to the rotational speed of the computer fan.

Analyzing the Colormap

A colormap is a three-dimensional display of a sound or vibration spectrum as a function of time or speed. The spectrum can be a frequency or order spectrum.

Use the Spectral Map Express VI to compute the spectral map of a sound or vibration signal. This Express VI can return the spectral map in a colormap or a waterfall graph. You can use this Express VI to create a colormap of the computer fan run-up data.

Complete the following steps to compute and display the colormap of the computer fan run-up data.

1. Press the <Ctrl-E> keys to switch to the block diagram of the Getting Started Exercise VI.
2. On the **Order Analysis Express Measurements** palette, select the Spectral Map Express VI and place it on the block diagram. A configuration dialog box appears.
3. Click the **OK** button to save the current configuration and close the configuration dialog box. In this application, you can use the default configuration settings when you run the Spectral Map Express VI for the first time.
4. Wire the **waveform signal** output of the `oax_Load Data (Analog Tacho, single channel)` VI to the **input signal** input of the Spectral Map Express VI.
5. Wire the **speed profile** output of the Analog Tacho Processing Express VI to the **speed profile** input of the Spectral Map Express VI.
6. Wire the **colormap** output of the Spectral Map Express VI to the **Colormap** indicator.

The block diagram should appear similar to Figure 3.

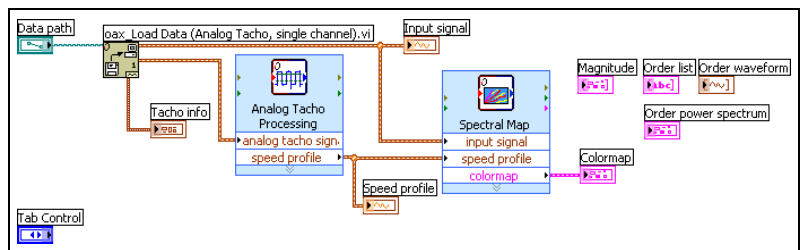


Figure 3. Creating the Colormap

7. Run the Getting Started Exercise VI to compute and display the colormap of the computer fan run-up data.
8. Save this VI.

On the front panel, click the **Colormap** tab to view a colormap of the computer fan run-up data, as shown in Figure 4.

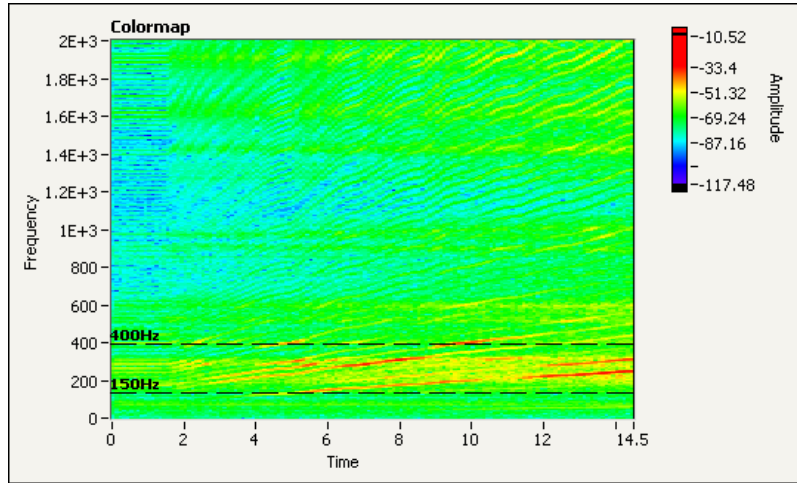


Figure 4. Frequency-Time Plot

By default, this plot displays frequency against time. Red portions of the colormap indicate areas of strong amplitudes. Notice that several red lines appear on this colormap. These red lines correspond to strong vibrations at different frequencies in the data. Notice that the strongest vibrations occur at frequencies between 150 Hz and 400 Hz. This range most likely includes several resonant frequencies from the DUT.

You also can customize a colormap to display RPM against order. Complete the following steps to compute a colormap for the example data that displays RPM against order.

1. On the block diagram, double-click the Spectral Map Express VI to display the configuration dialog box.
2. On the **Configuration** page of the configuration dialog box, change the **Plot type** to **RPM-Order**. An RPM-Order plot displays how the vibration amplitude at different orders changes with the rotational speed. From the **Colormap** plot in Figure 5, you can see that the amplitude of the seventh order is the strongest around 2,600 RPM.

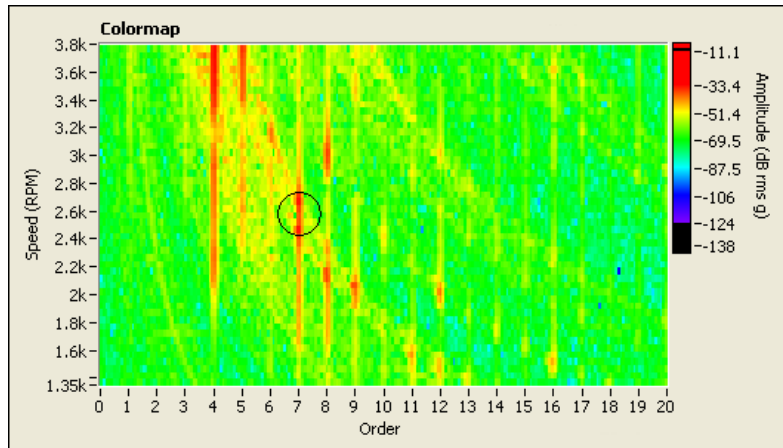


Figure 5. RPM-Order Plot

With this **Colormap** plot, you also can identify orders that correspond to loud noises or strong vibrations that you observe. For example, suppose the computer fan generates loud noises between 2,800 RPM and 3,000 RPM. From the RPM-Order plot, you can see that the fourth and the eighth order contribute the most to the loud noises in this speed range.

3. Click the **OK** button to save the current configuration and close the configuration dialog box.

A colormap plot therefore provides an overview of how the intensity of a signal relates to time, speed, frequency, and order.

Analyzing the Order Power Spectrum

An order power spectrum provides a quantitative description of the rotation-related components of a signal. You can use an order power spectrum to find and compare significant orders.

You can use the Order Spectrum Express VI to compute the order power spectrum of a sound or vibration signal. As you observed with the **Colormap** plot, the vibration amplitude of the seventh order is the strongest around 2,600 RPM. You can use the Order Spectrum Express VI to compute the order power spectrum of the example data at 2,600 RPM and to find the significant orders.

Complete the following steps to compute and display the order power spectrum of the computer fan run-up data at 2,600 RPM.

1. On the **Order Analysis Express Measurements** palette, select the Order Spectrum Express VI and place it on the block diagram. A configuration dialog box appears.
2. On the **Processing Settings** page, set the **Processing mode** to **Delta Speed**.
3. In the **Limit range** options, set the **Start speed (RPM)** to 2600 and set the **End speed (RPM)** to 2600.
4. On the **Spectrum Settings** page, set **Linear/dB** to **Linear**.
5. Click the **OK** button to save the current configuration and close the configuration dialog box.
6. Wire the **waveform signal** output of the `oax_Load Data (Analog Tacho, single channel)` VI to the **input signal** input of the Order Spectrum Express VI.
7. Wire the **speed profile** output of the Analog Tacho Processing Express VI to the **speed profile** input of the Order Spectrum Express VI.
8. Wire the **spectrum** output of the Order Spectrum Express VI to the **Order power spectrum** indicator.

The block diagram should appear similar to Figure 6.

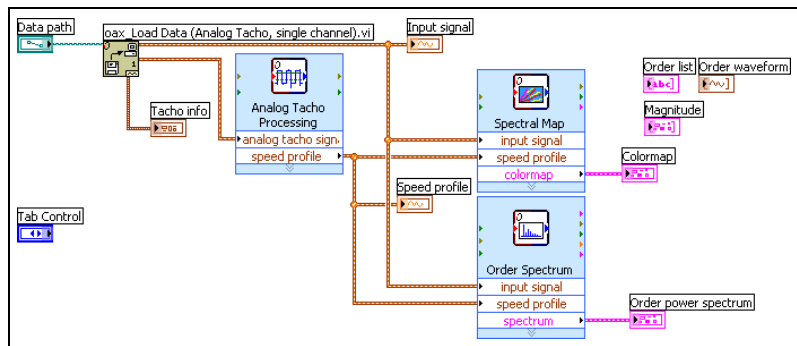


Figure 6. Creating the Order Power Spectrum

9. Run the Getting Started Exercise VI to compute and display the order power spectrum of the computer fan run-up data.
10. Save this VI.

On the front panel, click the **Order Power Spectrum** tab to display the **Order power spectrum** plot for the computer fan run-up data, as shown in Figure 7.

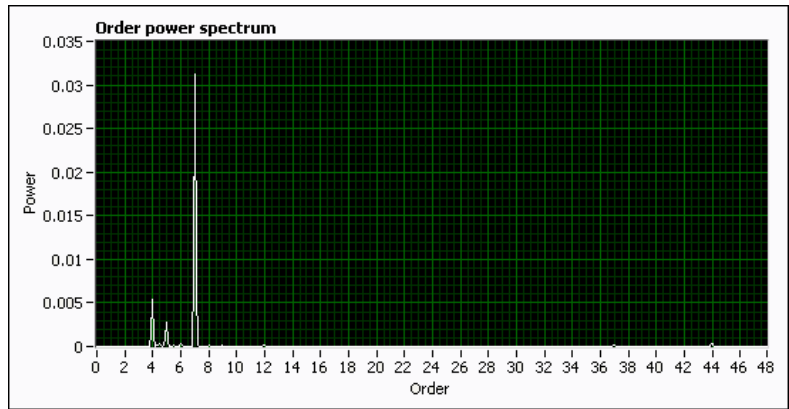


Figure 7. Order Power Spectrum at 2,600 RPM

The **Order power spectrum** plot displays the order amplitudes at 2,600 RPM. Notice that the seventh order has the strongest amplitude on the plot. The fourth order also is strong at 2,600 RPM. The seventh and fourth orders correspond to the seven blades of the fan and four coils of the electric motor, respectively.

Similarly, as you observed with the RPM-Order plot in the Spectral Map Express VI, the seventh order loses amplitude at around 2,900 RPM, and the eighth order gains amplitude around this rotational speed.

Complete the following steps to compute and display the order power spectrum of the computer fan run-up data around 2,900 RPM.

1. On the block diagram, double-click the Order Spectrum Express VI to display the configuration dialog box.
2. On the **Processing Settings** page of the configuration dialog box, set the **Start speed (RPM)** to 2900, and set the **End speed (RPM)** to 2900.
3. Click the **OK** button to save the current configuration and close the configuration dialog box.
4. Run the Getting Started Exercise VI.

On the front panel, you can see that the eighth order now has a much greater amplitude than the seventh order does, as shown in Figure 8.

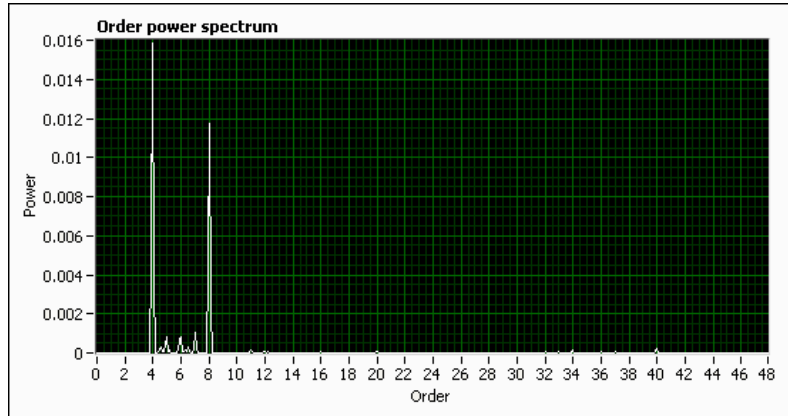


Figure 8. Order Power Spectrum at 2,900 RPM

Again, the fourth order also is significantly strong at around 2,900 RPM. The eighth order and other order multiples of four correspond to the four coils of the electric motor of the computer fan.

An order power spectrum plot therefore provides detailed information about the strength of each order at a specific speed. You also can use the Order Spectrum Express VI to compute the strength of each order at a specific time and to perform spectrum averaging.

Analyzing the Magnitude Plot

A magnitude plot can help you analyze a sound or vibration signal by focusing on particular orders.

Use the Order Tracking Express VI to compute the magnitude of designated orders. Recall that the **Colormap** plot showed the seventh order of the computer fan run-up data has a strong amplitude at 2,600 RPM. You can use a magnitude plot to observe this order in more detail.

Complete the following steps to compute and display the magnitude of the seventh order of the computer fan run-up data.

1. Press the <Ctrl-E> keys to switch to the block diagram of the Getting Started Exercise VI.
2. On the **Order Analysis Express Measurements** palette, select the Order Tracking Express VI and place it on the block diagram. A configuration dialog box appears.
3. On the **Configuration** page, set the **Orders to track** to 7.

4. Click the **OK** button to save the current configuration and close the configuration dialog box.
5. Wire the **waveform signal** output of the `oax_Load Data (Analog Tacho, single channel).vi` to the **input signal** input of the `Order Tracking Express VI`.
6. Wire the **speed profile** output of the `Analog Tacho Processing Express VI` to the **speed profile** input of the `Order Tracking Express VI`.
7. Wire the **magnitudes** output of the `Order Tracking Express VI` to the **Magnitude** indicator.

The block diagram should appear similar to Figure 9.

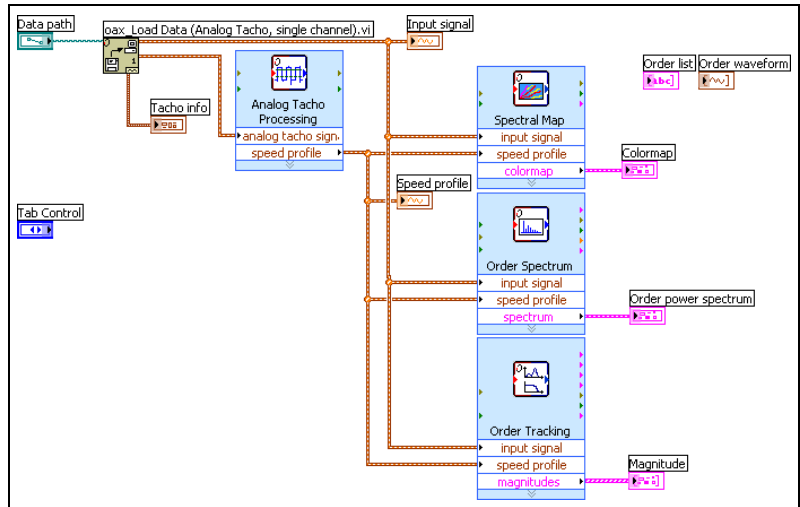


Figure 9. Creating the Magnitude Plot

8. Run the `Getting Started Exercise VI` to compute and display the magnitude of the seventh order of the computer fan run-up data.
9. Save this VI.

On the front panel, click the **Order Tracking** tab to display the **Magnitude** plot for the seventh order of the computer fan run-up data. You can see that this order has greater amplitude around 2,600 RPM, with a dip between 2,450 RPM and 2,650 RPM, as shown in Figure 10. This dip is difficult to observe with the colormap alone.

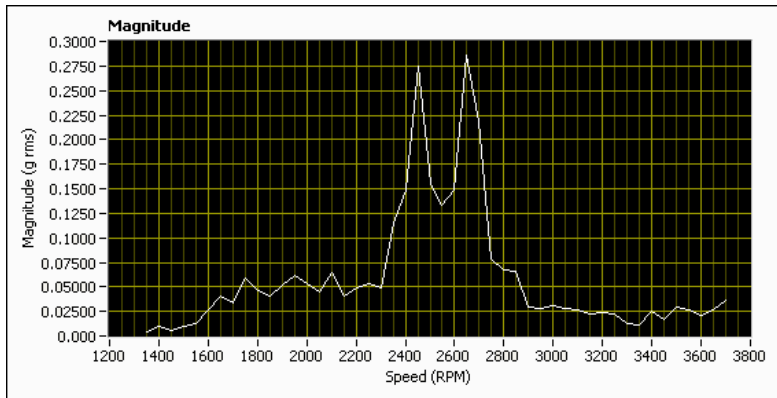


Figure 10. Magnitude Plot of the Seventh Order

You also can use the Order Tracking Express VI to compare the magnitudes of different orders. For example, if you add a second element to the **Orders to track** input and set the element to 8, the **Magnitude** plot displays the seventh and eighth orders together, as shown in Figure 11.

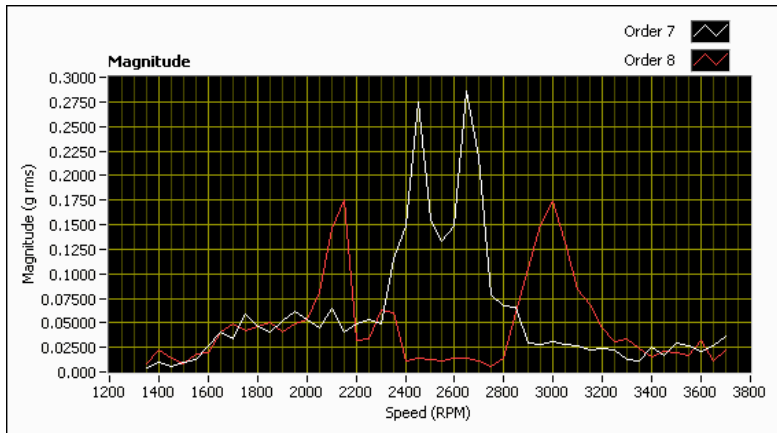


Figure 11. Magnitude Plot of the Seventh and Eighth Orders

As you observed with both the **Colormap** plot and the **Order power spectrum** plot, the amplitude of the eighth order increases as the amplitude of the seventh order decreases between 2,800 RPM and 3,000 RPM. The **Magnitude** plot provides a detailed view of exactly how the two orders change in magnitude with changing speed.

In the configuration dialog box of the Order Tracking Express VI, you can set the **X-axis selection** of the **Magnitude** plot to display the order magnitude against time, speed, or number of revolutions. You also can use

the **Magnitude View** options to specify the type of quantitative measurement you want to use to calculate and display the magnitude.

Whereas an order power spectrum shows the magnitude or power values of all orders at a specific period in time or at a specific speed, the **Magnitude** plot provides detailed information about particular orders that you specify.

Extracting Order Waveforms

You can extract order waveforms to isolate specific orders from a sound or vibration signal. The order waveform provides detailed information about the specific order you extracted from the input signal. You then can perform further analysis, such as sound playback and sound synthesis, on these significant orders.

Use the Order Waveform Express VI to extract order waveforms. As you observed with the **Colormap**, **Order power spectrum**, and **Magnitude** plots, the seventh order is one of the orders that has strong amplitude in the computer fan run-up data. You can use the Order Waveform Express VI to extract and display the order waveform of the seventh order of the computer fan run-up data.

Complete the following steps to extract and display the order waveform of the seventh order from the computer fan run-up data.

1. On the **Order Analysis Express Measurements** palette, select the Order Waveform Express VI and place it on the block diagram of the Getting Started Exercise VI. A configuration dialog box appears.
2. Click the **OK** button to save the current configuration and close the configuration dialog box. In this application, you can use the default configuration settings when you run the Order Waveform Express VI for the first time.
3. Wire the **waveform signal** output of the `oax_Load Data (Analog Tacho, single channel)` VI to the **input signal** input of the Order Waveform Express VI.
4. Wire the **speed profile** output of the `Analog Tacho Processing Express VI` to the **speed profile** input of the Order Waveform Express VI.
5. Wire the **order list** output of the Order Waveform Express VI to the **Order list** indicator.

- Wire the **order waveform** output of the Order Waveform Express VI to the **Order waveform** indicator.

The block diagram should appear similar to Figure 12.

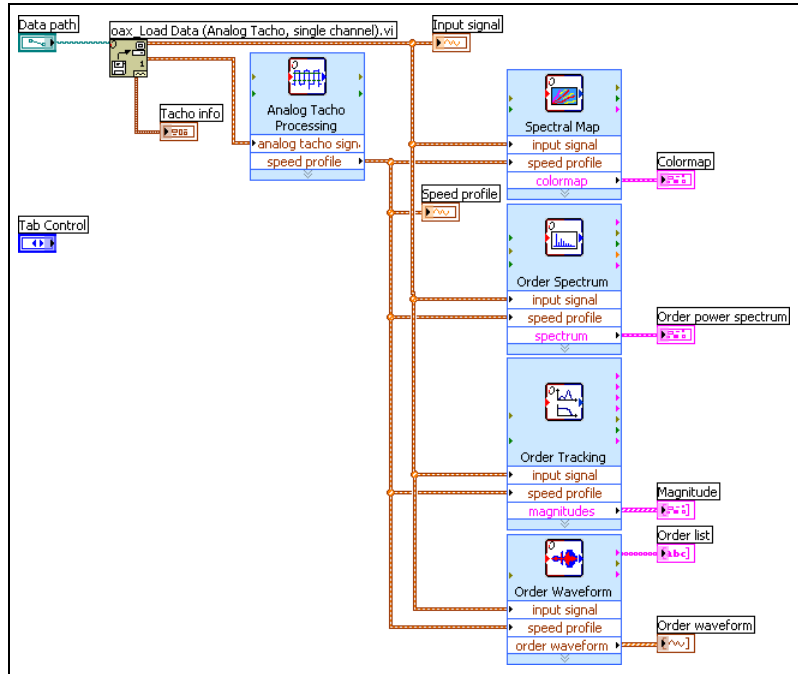


Figure 12. Extracting Order Waveforms

- Run the Getting Started Exercise VI.
- Double-click the Order Waveform Express VI to display the configuration dialog box. You can see the colormap of the computer fan run-up data in the **Colormap** plot.
- On the **Order Selection** page, set **Order to preview** to 7.
- Click the **Extract** button to extract the order waveform of the seventh order.
- Select the seventh order in the **Extracted orders** list.
- Click the **Export** button to export the order waveform of the seventh order to the block diagram. Clicking the **Export** button also adds the seventh order to the **Output list**.
- Click the **OK** button to save the current configuration and close the configuration dialog box.
- Run the Getting Started Exercise VI again to extract and display the waveform of the seventh order of the computer fan run-up data.
- Save this VI.

On the front panel, click the **Order Waveform** tab to display the **Order waveform** plot of the seventh order, as shown in Figure 13.

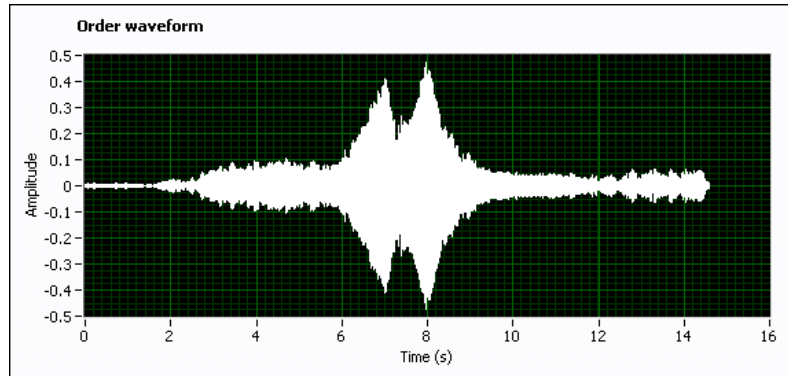


Figure 13. Waveform of the Seventh Order

You also can use the Order Waveform Express VI to extract multiple orders of a signal that generate the greatest amplitude, or produce the strongest noise. As you observed with the **Colormap**, **Order power spectrum**, and **Magnitude** plots, the fourth, seventh, and eighth orders have relatively strong amplitudes in the computer fan run-up data.

Complete the following steps to extract and display the waveforms of the combination of the fourth, seventh, and eighth orders.

1. Press the <Ctrl-E> keys to switch to the block diagram of the Getting Started Exercise VI.
2. Double-click the Order Waveform Express VI to display the configuration dialog box.
3. On the **Order Selection** page, set **Order to preview** to 4.
4. Click the **Extract** button to extract the order waveform of the fourth order.
5. Set **Order to preview** to 8.
6. Click the **Extract** button to extract the order waveform of the eighth order.
7. In the **Extracted orders** list, press the <Ctrl> or <Shift> key to select the fourth, seventh, and eighth orders simultaneously.
8. Click the **Export** button to export the combined order waveform of the fourth, seventh, and eighth orders to the block diagram. Clicking the **Export** button also adds the combination of the fourth, seventh, and eighth orders to the **Output list**.
9. Click the **OK** button to save the current configuration and close the dialog box.

10. Run the Getting Started Exercise VI.

11. Save this VI.

On the front panel, the **Order waveform** plot now displays both the waveform of the seventh order and the waveform of the combination of the fourth, seventh, and eighth orders, as shown in Figure 14.

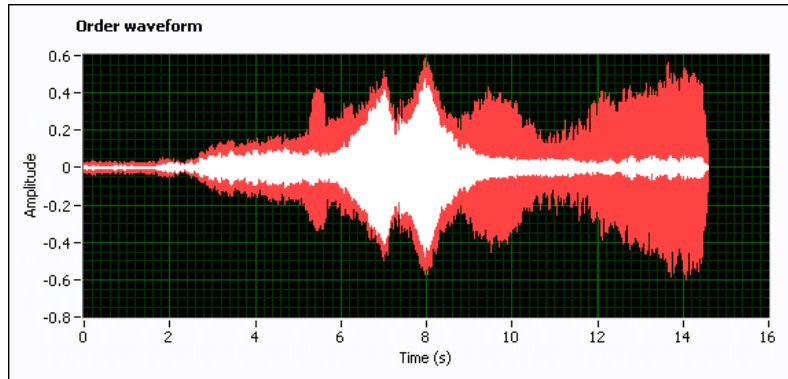


Figure 14. Comparing Order Waveforms

You can add different order waveforms together in different combinations. You then can play back the resulting waveforms as sounds and determine which combination is the most pleasing to the ear. This way, you can determine how to reduce the harshness of the signal and how to remove undesirable sounds and vibrations.

Summary

You can use the Order Analysis Express Measurements VIs to perform most common types of order analysis. You can use these VIs and the following plots to display data from different perspectives:

- Vibration signal plot
- Speed profile plot
- Colormap
- Order power spectrum
- Magnitude plot
- Order waveform

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