

# Getting Started with the Order Analysis Toolkit

This document introduces how to get started with the Order Analysis Toolkit (OAT) to accomplish basic measurement and analysis for the noise and vibration signals generated by rotating or reciprocating machinery. It covers three parts:

- Introduction to order analysis
- Noise and vibration patterns of common mechanical parts
- Performing noise and vibration analysis with the OAT

## Introduction to 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 the 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 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.

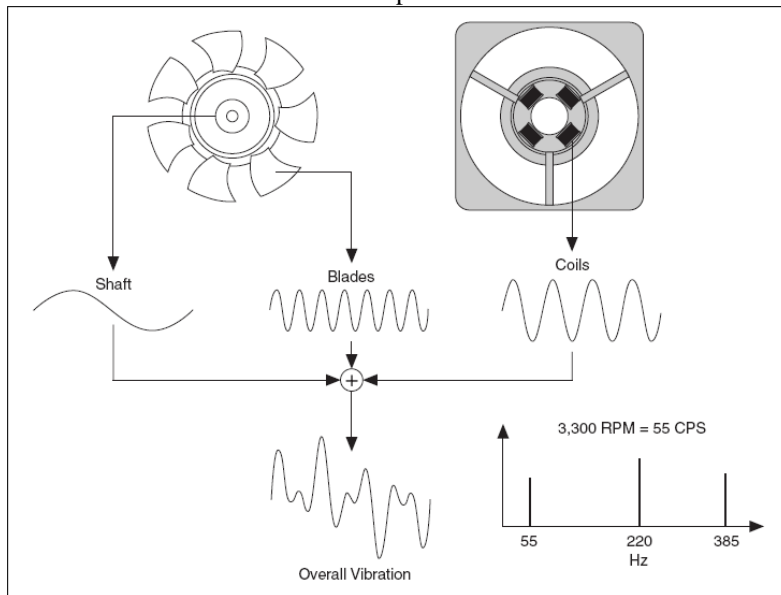


Figure 1 FFT Analysis on PC Fan Vibration

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 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.

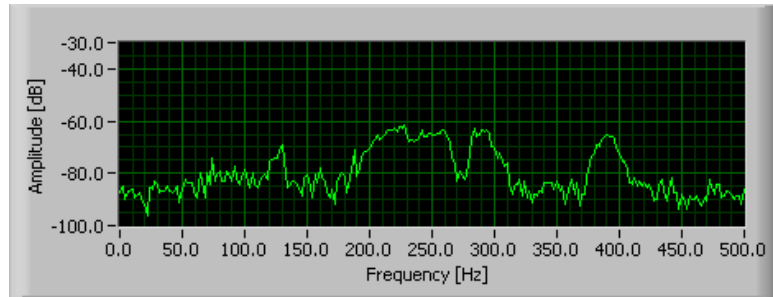


Figure 2 Blurred FFT Power Spectrum with changing rotational speed

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  $n$  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 3 shows the order power spectrum of the same signal used to compute the FFT power spectrum shown in Figure 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.

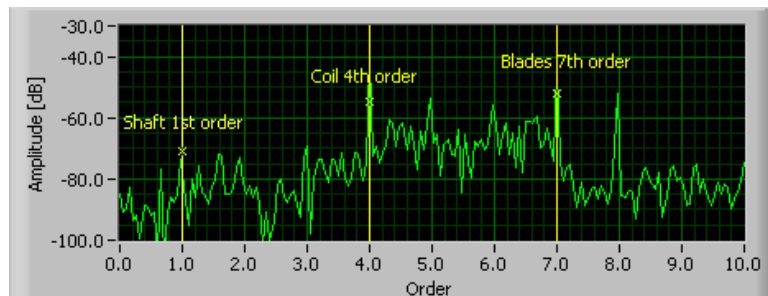


Figure 3 Order Power Spectrum with Changing Rotational Speed

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.

## Noise and Vibration Patterns of Common Mechanical Parts

---

Rotating or reciprocating machines are comprised of a variety of mechanical parts like shaft, bearing, gearbox, coupling etc. The conditions of the mechanical parts mainly determine the overall machine conditions. If the mechanical parts of the machine are well tuned, ideally the machine will generate very low vibrations. On the contrary, the existing flaws in mechanical parts will usually cause the machine to vibrate significantly. Therefore, the machine vibrations can be used as good indicators of the mechanical faults.

Common mechanical faults like imbalance, misalignment, mechanical looseness, bearing fault, resonance, gearbox defects have specific vibration characteristics. Table 3-1 summarizes the relationships between the common mechanical faults and vibration components.

Table 3-1. Noise or Vibration Characteristics of mechanical faults

<b>Mechanical faults</b>	<b>Vibration components</b>
Imbalance	1x component
Misalignment	1x and 2x components.
Mechanical looseness	Harmonics of 1x and 0.5x components
Resonance	High vibration amplitude and large phase change at certain speed range

Gear defect	Gear mesh $n_x$ components ( $n$ is the number of gear teeth); usually modulated by rotational speed components.
Fan / blade defect	Harmonics of $n_x$ components ( $n$ is the number of fan/blade).
Rolling-element bearing defect	Non-synchronous vibration components, usually modulated by rotational speed components.
Journal bearing defect	Sub synchronous order components, typically around or smaller than $0.5x$

**Note**

$1x$  means 1<sup>st</sup> order component and  $n_x$  means  $n^{\text{th}}$  order component.

The noise and vibration components of the possible mechanical faults are usually the most important information of the machine. The key tasks in noise and vibration analysis in most applications are to extract the patterns from the noise and vibrations signals and evaluate the condition of the mechanical parts with the patterns. The Order Analysis Toolkit can help you to get those characteristic components.

## Performing Noise and Vibration Analysis with the OAT

---

### Application Process Overview

A common order analysis application is usually comprised of 5 steps:

- Acquire noise or vibration signals and tachometer signal.
- Preprocess the noise or vibration signals.
- Process the tachometer signal to get the rotational speed profile.

- Perform order analysis with the noise or vibration signals and speed profile.
- Display the analysis results in different formats.

Figure 4 shows the above five steps in the whole application process.

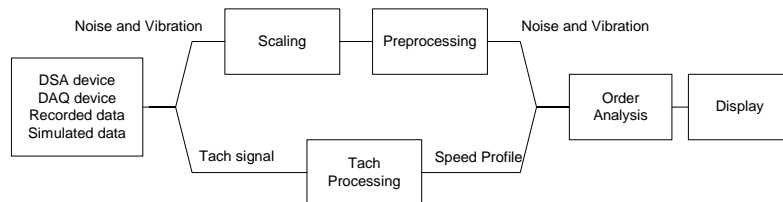


Figure 4 Common Order Analysis Application Process

## Functions in the OAT

To have a quick look at the functions in the OAT, you view the demo VI shipped with the toolkit. Select **Start>>All Programs>>National Instruments>>LabVIEW Order Analysis Toolkit>>Order Analysis Functions Demo**. This VI provides demos for most of the order analysis functions. You can select different functions and in each function you can see different data. This VI will help you to know what each order analysis function look like.

## Test Setup

The most widely performed tests are the run-up and run down tests. These kinds of tests provide comprehensive information of the machine at its operational speed range. Some mechanical patterns such as the resonance can only be detected when the rotational speed passes the resonant speed range. Thus only run-up or run down test can help identify the resonant speed.

Test under constant rotational speed is another common test. It can help you to get machine conditions at specific speed and to form the test metrics with results from constant speed test.

To perform machine vibration test, you need to have at least one vibration transducer and one tachometer. The vibration transducer can be accelerometer, velocity transducer or proximity probe. The vibration acquisition channel and transducer channel should be synchronized to acquire data.

When dealing with an unknown machine, performing off-line analysis with the recorded data is the common choice. You can acquire and record the data first, analyze these data later. The *Log Data (Analog Tacho, DAQmx).vi* or *Log Data (Digital Tacho).vi* (if you use counter to acquire tachometer) can help you to acquire and record data. You can access the VI by selecting **Help>>Find Examples** in LabVIEW and navigating to **Toolkits and Modules>>Order Analysis>>Getting Started in Task** view.

## Order Analysis Steps

After acquiring the noise or vibration signals, you can apply the VIs in the OAT to extract information from the signals. You can use *Getting Started with OAT (Offline, Analog Tacho).vi* to get started with the fundamental functions in the OAT. This VI includes the following order analysis functions:

- Time Waveform and Speed Profile
- Spectral Map
- Order Power Spectrum
- Magnitude and Phase

Figure 5 shows the front panel of this VI. As you can see, these four functions appear in the front panel as four tab pages. You can access the VI by selecting **Help>>Find Examples** in LabVIEW and navigating to **Toolkits and Modules>>Order Analysis>>Getting Started in Task** view.

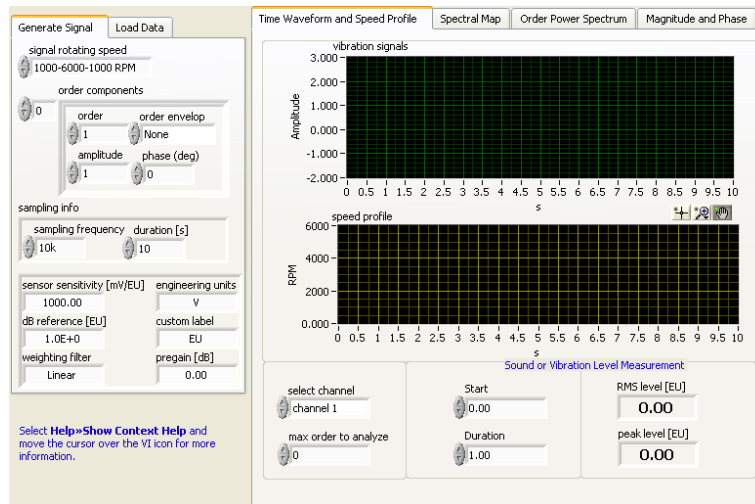


Figure 5 OAT Getting Started Example Front Panel

To help you better understand the analysis functions, a typical application, analyzing the gear teeth defects in an automotive transmission gearbox, is presented. Through the following examples, you can learn how to use order analysis functions to get information from the noise or vibration signals.

The test is to find out nicks on the gear teeth of the 1st gear in a 5-speed manual transmission gearbox. The gear ratio of the 1st gear is 38:12. The driving bull gear has 12 teeth. The test is a combination of run-up and run down. The bull gear runs up from 700 RPM to 2400 RPM in 3 seconds, stays constant for 0.5 second and then runs down to 700 RPM in 3 seconds. The data is acquired with an accelerometer mounted on the gearbox casing and a tachometer measuring the shaft speed of the bull gear.

The data is acquired and recorded with *Log Data (Analog Tacho, DAQmx).vi*. With *Getting Started with OAT (Offline, Analog Tacho).vi*, you need to select the tab page Load Data and run the VI. In the popup data file directory window, you need to select the data ***Gear Teeth with Nicks.dat*** and start the analysis.

## Step 1: Time Waveform and Speed Profile

In noise or vibration analysis, the first step is usually to view the noise or vibration signals and the speed profile. You can check the speed profile to

see if it reflects the test information correctly. You can also calculate the vibration level of the vibration signals of a certain time block.

Change the value of start and duration and re-run this VI; you can get the RMS and Peak vibration level of the vibration signal of different time blocks. Figure 6 shows the time waveform of the vibration signal and the speed profile. You can see the speed goes up, keeps constant and goes down in 7 seconds.

Because there exist several high order components in the signal, you need to select a high value such as 100 in **max order to analyze** control on this page. This value determines the maximum order you can analyze in the other order analysis functions.

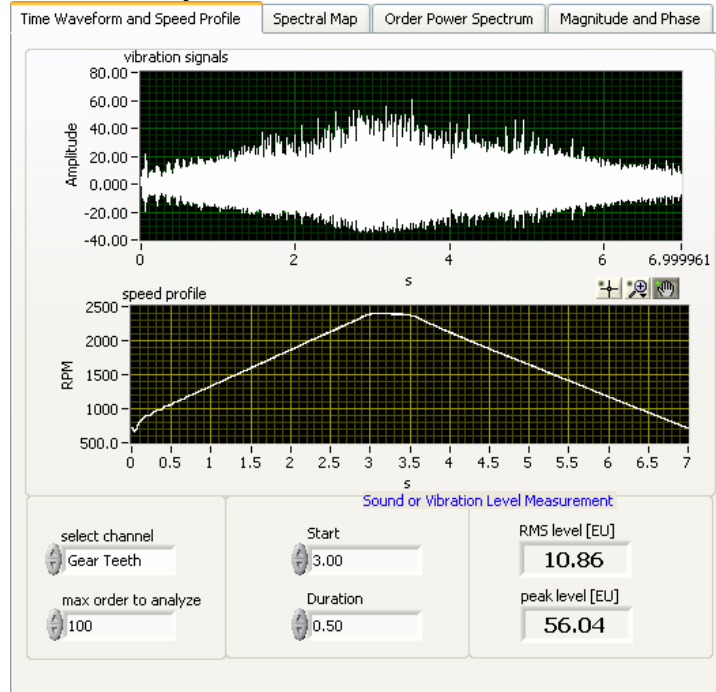


Figure 6 Time waveform and speed profile of the gearbox vibration signal

## Step 2: Spectral Map

After checking the time waveform and the speed profile, you can use the Frequency-Time spectral map to have an overview of the noise or vibration signals. From the spectral map, you can locate the strong spectral components. You can recognize the components that are

changing with the rotational speed and the components that are fixed in a certain frequency range. This can help you to identify order components, which change with speed, and resonant components, which only happen at certain frequency range. If the vibration components in a frequency range are significantly stronger than others, this frequency range can be the machine resonant frequency range. By locating the order components and resonant components and with some knowledge of the machine, you can have some basic ideas of what features to extract in the vibration signals.

Switch the tab control to Spectral Map in *Getting Started with OAT (Offline, Analog Tacho).vi*. Set the **step size** to 0.05 and **freq/order bins** to 8192 to get a better view of the time and frequency components in this plot. The spectral map of the gearbox vibration signal is shown in Figure 7. In the plot, some vibration spectra vary with the rotational speed. These spectra are obviously order components in the vibration signal. Components in the frequency range 1.8k -3.0k are significantly strong. This frequency range is possibly the resonant frequency range, because vibration components within this range are strongly amplified.

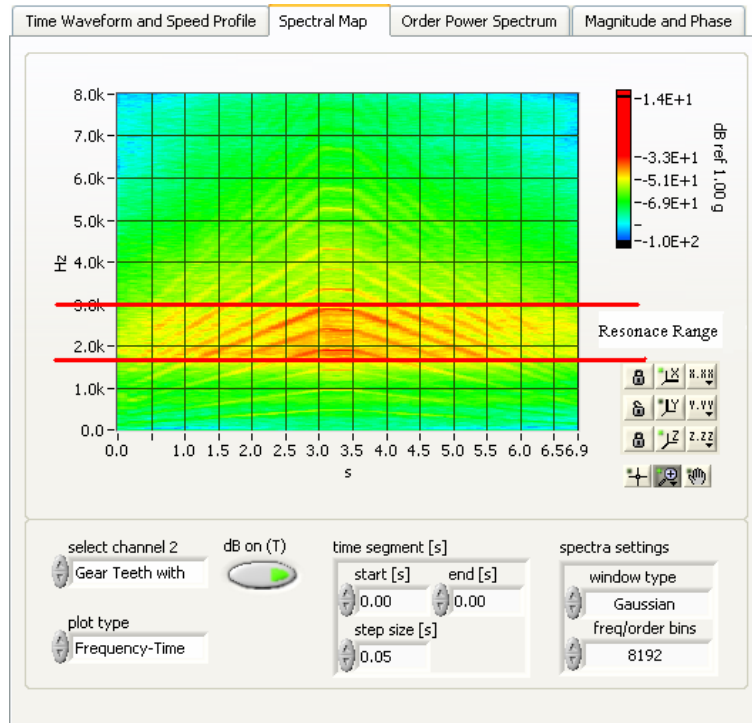


Figure 7 Spectral Map of the gearbox vibration signal

Using the tool on the graph palette of the plot to zoom into the spectra map at the resonant frequency range, you can see several small spectral lines between two significant spectra in Figure 8. Load the data **Good Gear Teech.dat** and zoom into the spectra map of the same frequency range, you can not clearly see these small spectral lines in Figure 9. This can be an important characteristic of the faulty teeth.

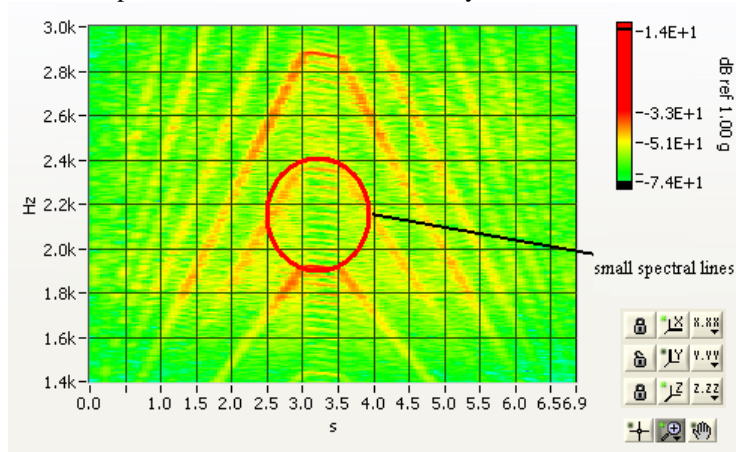


Figure 8 Zoom in spectral map of faulty gearbox vibration signal

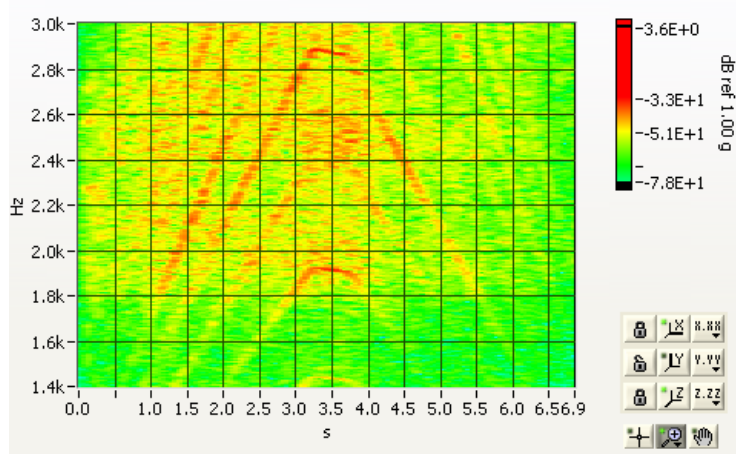


Figure 9 Zoom in spectral map of good gearbox vibration signal

### Step 3: Order Power Spectrum

Order power spectrum gives a quantitative description of the rotation related components (order components) of a certain time block. This will help you to find significant orders and compare these order components. Most of the machine faults can be identified by finding their characteristic order components in order power spectrum.

Switch the tab control to Order Power Spectrum in *Getting Started with OAT (Offline, Analog Tacho).vi* with **Gear Teeth with Nicks.dat**. Since the possible features found in spectral map are in 3- 4 seconds time block, you can change the start value to 3s and duration to 1s. Set **dB on** to FALSE, run this VI and use the zoom tool in the graph palette of the plot to view the spectrum from 0 to 180 orders. Figure 10 is the order power spectrum of the faulty gear data. There exist three significant orders: 48th order, 60th order and 72nd order. Since the driving gear has 12 teeth, the gear mesh component is the 12th order component. The three significant orders are harmonics of the gear mesh components. Using the zoom tool in graph palette of the plot to further zoom in the graph from 40 to 80 orders, you can see several side band components near the gear mesh components in Figure 12. These side band components are just the small spectral lines in spectral map. Compare to the order power spectrum of good gearbox vibration signal with the same configurations in Figure 11 and Figure 13, you can see that both the gear mesh components and the side band components of faulty gearbox are significantly larger.

Refer to the previous section, the vibration characteristics of gear defects are gear mesh  $nx$  components and modulated with rotational speed. Thus the harmonics of gear mesh components and side band components are the information you need to detect the existence of the gear defects.

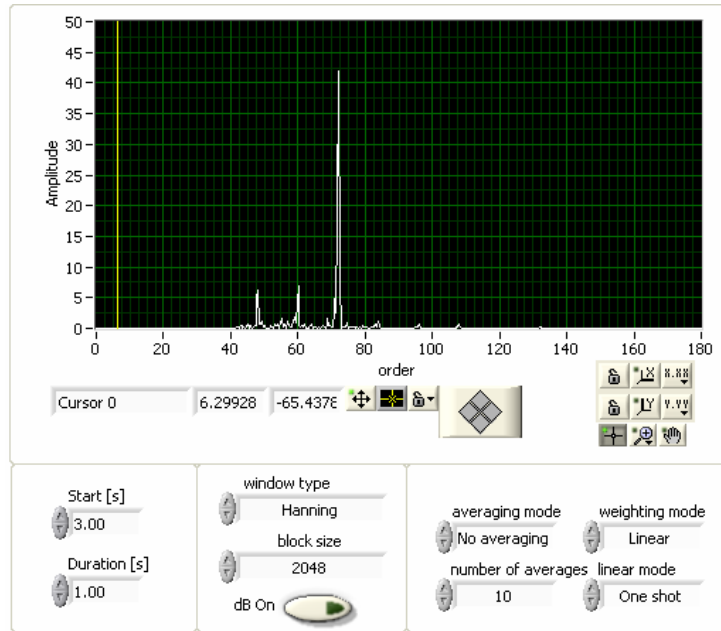


Figure 10 Order power spectrum of faulty gearbox vibration signal

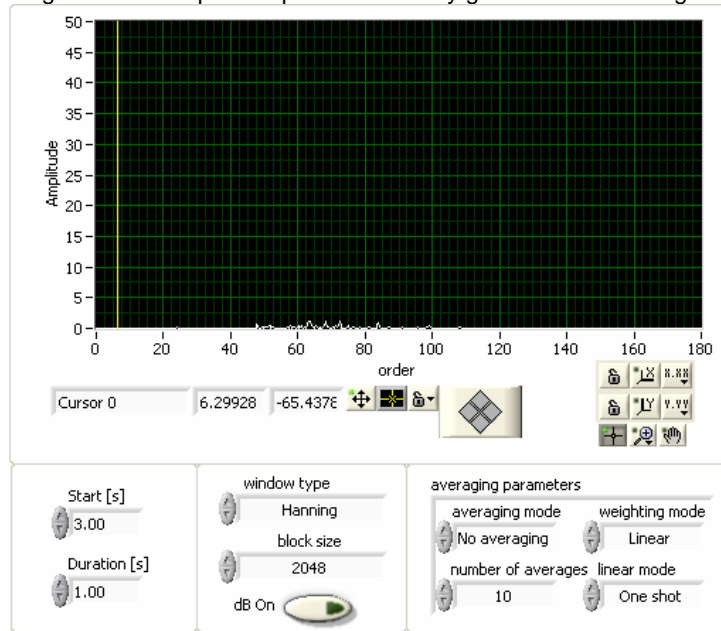


Figure 11 Order power spectrum of good gearbox vibration signal

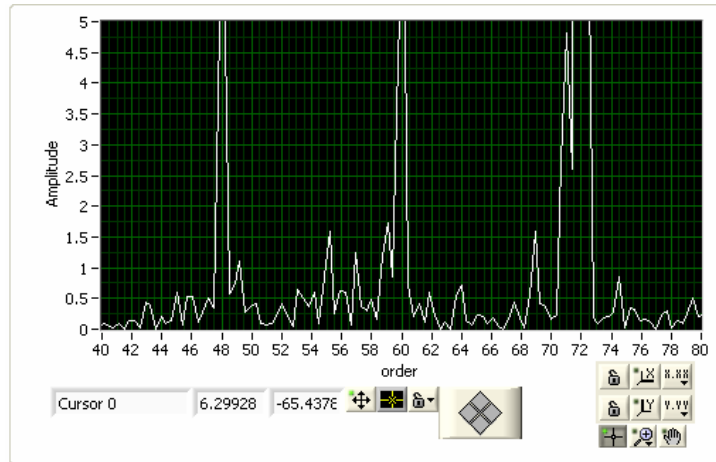


Figure 12 Zoom in order power spectrum of faulty gearbox vibration signal

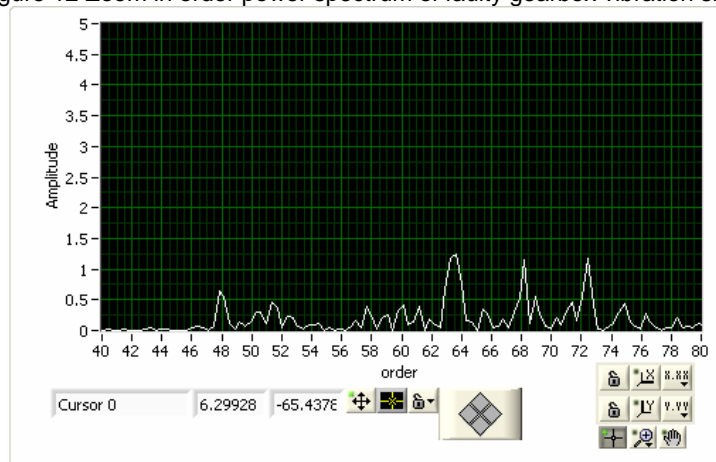


Figure 13 Zoom in order power spectrum of good gearbox vibration signal

### Step 4: Order Tracking (Magnitude/Phase)

Order Tracking (Magnitude/Phase) provides the information of the particular orders. You can find out how certain order components change with time or speed with order tracking. The magnitude is a good measurement index of the order component. Phase can be used to locate resonance and misalignment. Both of them can help you find different mechanical faults as well as verify the faults you find with order power spectrum.

Switch the tab control to Magnitude and Phase in *Getting Started with OAT (Offline, Analog Tacho).vi* with **Gear Teeth with Nicks.dat**. Since the important components are the harmonics of gear mesh components and side band components, you can choose 71st and 72nd order components to view their magnitude and phase. Input 71 and 72 in **order to compute** control and run this VI again. Comparing the results in Figure 14 and Figure 15, which represents the data from the faulty gear and good gear, you can see the magnitudes of 71st and 72nd order components of faulty gearbox are significantly larger. This further verifies the conclusion from order power spectrum.

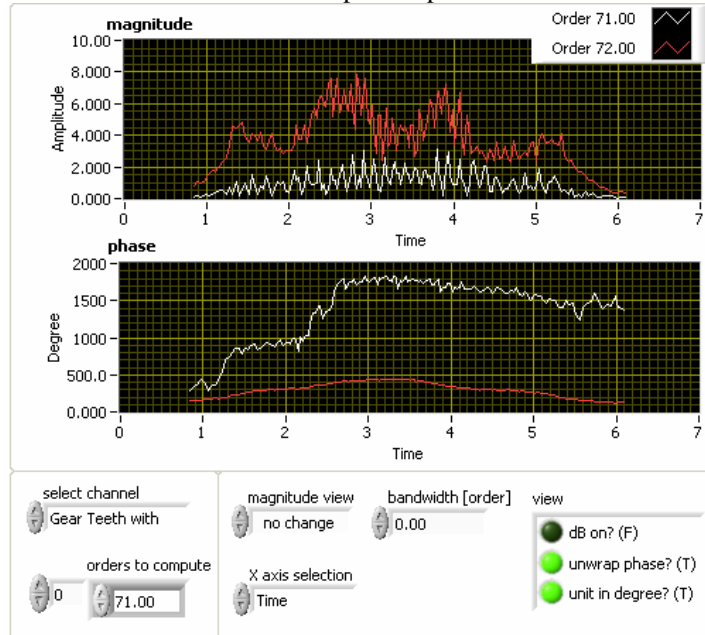


Figure 14 Magnitude and phase of the faulty gearbox vibration signal

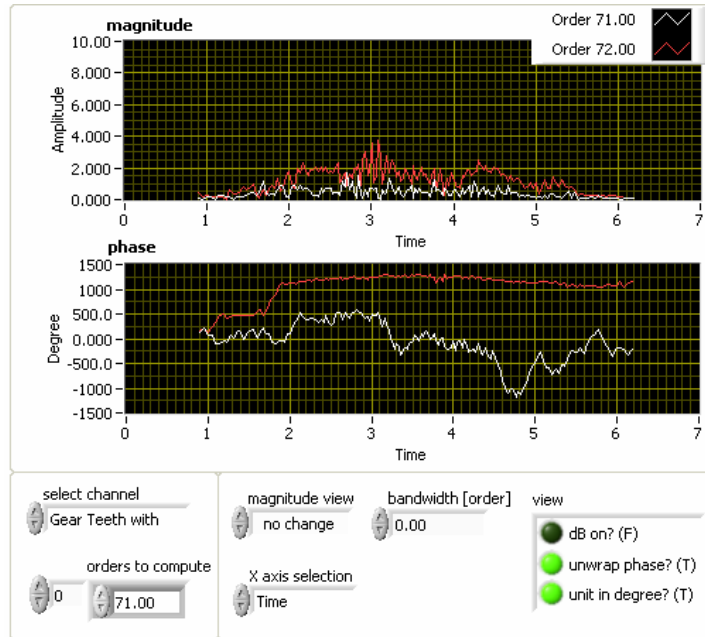


Figure15 Magnitude and phase of good gearbox vibration signal

## Further Analysis

Further analysis may include setting limits to the vibration level, magnitude or certain orders and spectrum envelop in order power spectrum. In the above example, you can set a test metrics with these limits to find the faulty gearbox.