Order Analysis

Analyzing the health and behavior of rotating machinery is a key application for dynamic signal analyzers (DSAs). Rotating machines produce repetitive vibrations and acoustic signals related to rotational speed. These relationships are not always obvious with standard dynamic signal analysis, particularly with variations in the rotational speed. A measurement technique called order analysis is the secret to sorting out all the many signal components that a rotating machine can generate.

Synchronizing the measurement
With flexible settings for frequency span and resolution, a typical DSA can do a great job of isolating noise and vibration components, as long as the machine is operating at a fixed speed. As the speed changes, however, the signals of interest shift up or down in frequency, making analysis difficult if not impossible. Synchronizing the DSA's data collection with the machine's rotational speed is therefore a key step in order analysis.

Synchronization usually starts with a tachometer, which provides a pulse or an integral number of pulses for each revolution. This signal indicates that the machine has finished one cycle and is beginning the next. A single tach pulse indicates when the rotating machine has reached a particular angular position. After capturing two tach pulses, you can determine rotating speed by counting clock cycles between the tach pulses. A third pulse will then tell you if the machine is changing speed. Using the tach pulse to trigger the DSA synchronizes the machine and the measurement.

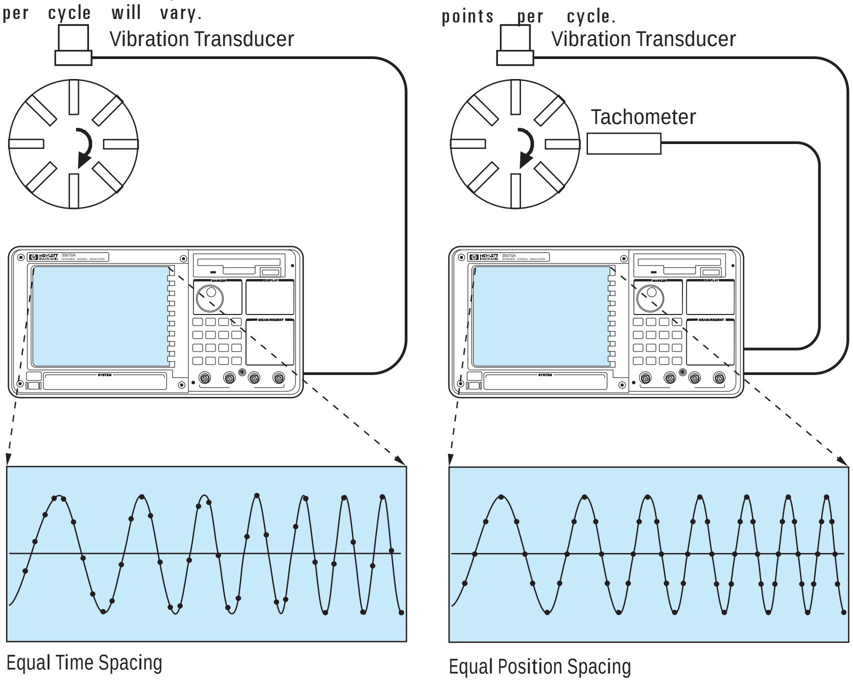
DSAs use an analog-to-digital converter to collect a block of data. In regular spectrum analysis, this block of data consists of voltage values spaced at regular time intervals. When you start gathering a block of such points, you also determine the finish time. This is one of the difficulties with order analysis. If the machine is changing speed, how do you fill the block just as you get the next tachometer pulse? Three techniques are commonly used.

- Shaft encoders are electro-optical devices that generate thousands of digital pulses per revolution, gating time samples into the data block.
- A ratio synthesizer and tracking filter emulates a shaft encoder with alias protection.
- With the digital resampling technique, the DSA digitizes data at a very high rate, collecting and storing tightly spaced time samples. As tach pulses arrive, the analyzer resamples the time points into correctly spaced data.

With each of these three techniques the goal is a set of points evenly spaced by shaft position, not by time (Figure 1). This yields data in the revolution domain, rather than in the time domain. Again, the key benefit here is that the measurement rate tracks the rotational speed of the machine.

Figure 1:
Time Domain Samples
If samples are gathered at equal time intervals, the number of samples per cycle will vary.

Shaft Position Samples
Synchronizing samples to shaft position gives a constant number of points per cycle.



Frequency spectrum vs. order spectrum
The FFT process transforms time domain data to the frequency domain, creating a spectrum. Signals that are periodic (repetitive) in the time domain appear as peaks in the frequency domain. In order analysis the FFT transforms the revolution domain data into an order spectrum. Signals that are periodic in the revolution domain appear as peaks in the order domain. For example, if a vibration peak occurs twice every revolution at the same shaft position, a peak appears at the second order in the order spectrum.

What do order spectra look like? Figure 2 is an FFT spectrum map of an automobile engine run-up test from 665 to 3995 RPM. Figure 3 is an order spectrum map of the same measurement. The Y-axis in both maps is amplitude. The X-axis is frequency for the spectrum map and orders of rotation for the order map.

One obvious difference between the two maps is how the peaks line up. Each line of peaks on the order map clearly indicates a relationship between vibration and shaft position; the peaks in the spectrum map are difficult to relate to shaft speed. The maximum amplitude in the order map is at the 12th order and at 3815 RPM. This identifies the vibration in terms of engine speed, indicating a component is being excited 12 times per each engine revolution.

Order tracking

In Figure 3, the 12th order appears to be the most interesting, so you want to examine that order and to ignore the other orders. When you measure one order and exclude the others, the measurement is called an order track. Figure 4 shows this 12th order amplitude versus RPM for the engine run-up.

In the order track measurement, the relationship between the measured order vibration and the engine speed is clear. Order tracking helps you focus on exact components and to measure their contribution to the overall performance of a rotating machine.

Orders are essentially harmonics. But unlike harmonics, many interesting orders are noninteger multiples of the 1st order. A speed reducer has an output shaft order vibration at less than the first order. An automobile engine has order components that are higher ordered noninteger multiples. These may be gear mesh rates, timing chain engagement or valve action, for instance.

Applications

Order tracking and order analysis have become widely accepted rotating machinery measurements. Devices ranging from gear motors to gas turbines are tested this way. Even dental tools have been designed using order analysis. Some of the more unusual applications involve using order analysis to measure power line quality and for loudspeaker testing. These applications take advantage of the harmonic nature of the integer orders. ■

Frequency spectrum map of 6 cylinder engine run-up

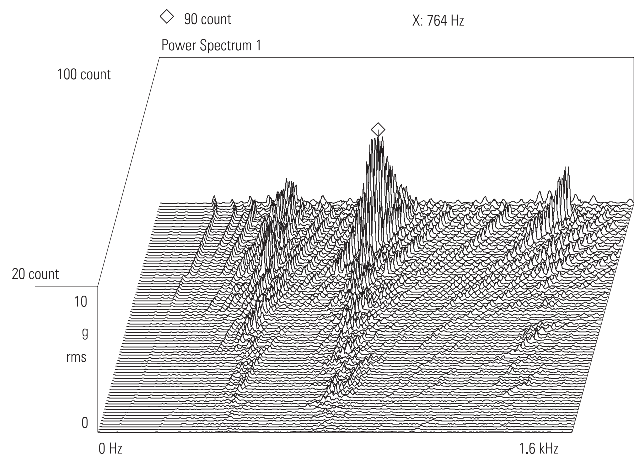


Figure 2: A frequency map reveals peaks but it is difficult to relate them to shaft speed.

Order spectrum map of 6 cylinder engine run-up

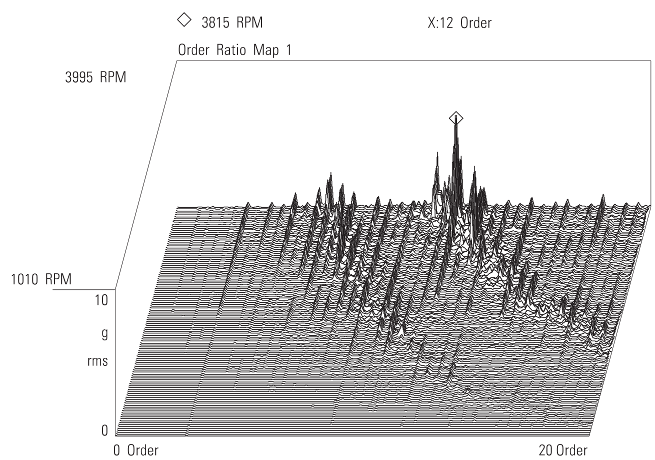


Figure 3: An order map clarifies the relationships between shaft speed and vibration amplitude.

Order track of 12th order, 6 cylinder engine run-up

Figure 4: Order tracking clarifies the relationship of a particular shaft speed to amplitude vs. rpm.