

Order-X Application Note

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Measurement of the static bending and resonance frequencies of rotating shafts is a common task undertaken by a test engineer. Such measurements are frequently performed using non-contact transducers mounted on the stationary parts of machines. Following example demonstrates how static deflection of a rotating shaft can be extracted from its vibration spectrum and how its resonance frequencies may be identified using the **Order-X** transformations.

The flywheel displacement on a 6 cylinder engine was measured using two proximity sensors attached on the engine block. The static bending of the connected crankshaft and the resonance frequencies of the crank-flywheel system were to be identified using the measurement data. The test setup employed two proximity sensors attached on the engine block, at right angles from each other, to measure the relative displacement of the flywheel with respect to the engine. The schematic test setup is shown in Figure 1.

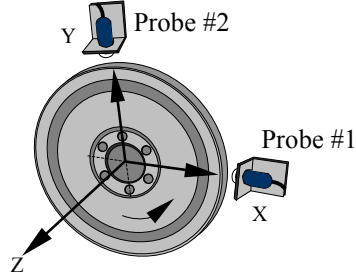


Figure 1. Schematic measurement setup.

In the measurement setup shown in Figure 1, probe #1 measures the displacement of the flywheel in the X coordinate direction while the displacement in Y direction is measured by probe #2.

The vibration data was acquired from 1200 to 6500 engine rpm at 100 rpm increments with engine under full load. The spectra of the measured data, is shown in Figure 2.

Realizing that this measurement was made from a stationary coordinate system one expects the vibration frequencies of the crank-flywheel system to shift by amounts equal to the crank rotational frequency. However, frequency shifts are not necessarily in one direction. They could

be towards lower and/or higher frequencies. For instance, in the waterfall plots of Figure 2, the V shaped separation of the resonant vibrations is due to greater frequency shifts as the engine speed is increased. The three lines of the **Order-X** cursor plotted in Figure 2 are designed to indicate such frequency shifts. That is, if the rotating shaft is vibrating at a frequency indicated by the center line of the cursor, the shifted frequencies due to a measurement in a stationary coordinate system could only be at the frequencies indicated by the side lines of the cursor. The **Order-X** cursor is just an indicator of where the frequencies might shift. It is designed to help an analyst to quickly identify any possible spectral shifts in measured data.

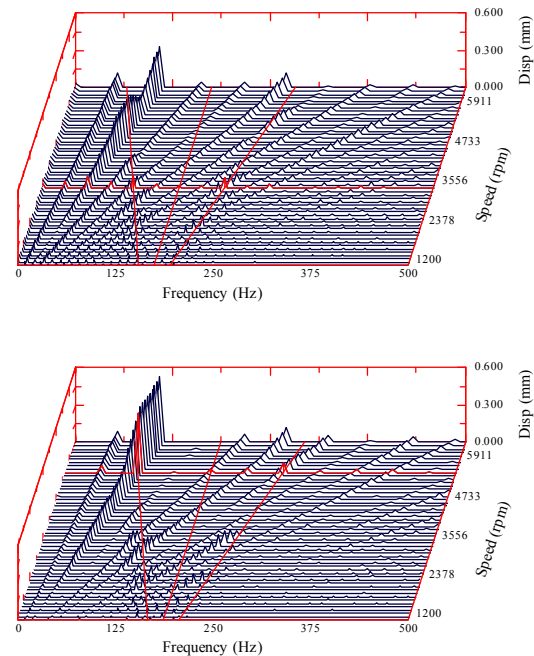


Figure 2. Spectral waterfall plots of the measured vibration data.

The static bending of the crank in its rotating coordinate system is a zero frequency phenomenon. When measured from a stationary coordinate system, its frequency also shifts and a statically bent and rotating crank appears vibrating at the frequency of first order vibrations. Hence, some of the first order vibrations in Figure 2 are due to the static bending of the crank-flywheel system. However, it is not possible to determine, from Figure 2

alone, how much of the first order vibration is due to static bending and what portion belongs to the vibrations shifted from second order.

Applying the **Order-X** transformation to the measured data yields the displacement spectra of the crank-flywheel in its rotating coordinate system. The result of the transformation is shown in Figure 3.

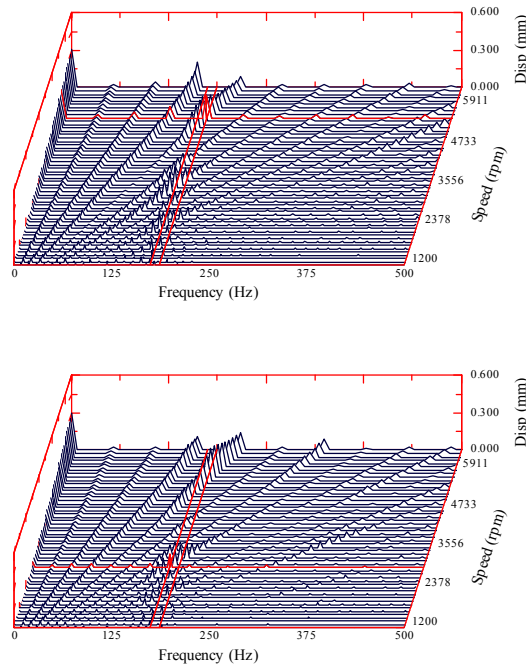


Figure 3. Spectral waterfall plots of the measured vibration data after an **Order-X** transformation.

As a result of **Order-X** transformation, the static displacement at zero frequency line of the waterfall plots is now free of any contamination by other vibration orders. Furthermore, all other vibration orders are transformed to their proper frequencies. The two closely coupled bending resonance of the crank-flywheel system now appear on constant frequency lines, as they should, indicated by two frequency cursors at 175 and 187 Hz respectively.

The waterfall plots display the amplitude spectra of the transformed vibrations. Hence, the direction of static bending is not properly shown. In Figure 4, two frequency cuts from the static component of the waterfall plots are shown. Here, the static bending of the crank is in positive direction of the rotating x and y axes below 2000 rpm. As the crank speed increases above 2000 rpm static deflection grows in negative x and y direction and reaches about 0.3 mm at 6500 rpm. It is a coincidence that x and y displacements are almost equal.

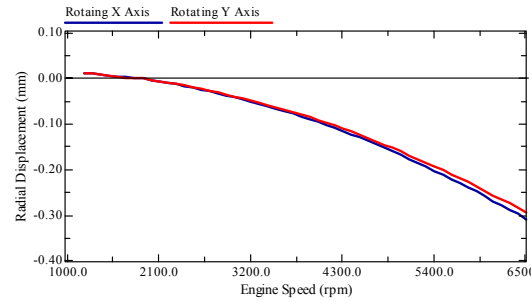


Figure 4. Static deflection of the crank in rotating x and y directions.

Data taken for **Order-X** transformations must be triggered to identify the directions of the rotating x and y axes. The rotating x and y axis are collinear with the stationary X and Y axis at the time of trigger which should be done without any delays set in either channel. Hence, rotating coordinates may be marked before or after a measurement by bringing the shaft to trigger position and marking the rotating x and y axes in the directions of the stationary X and Y axes. If the stationary axes are non-orthogonal, only the direction of the rotating x axis is marked as described above and the y axis is determined using the right hand rule, taking into consideration that the z and Z directions are collinear.

During the test, the data acquisition equipment was triggered when crank is at the top dead center of cylinder 1. At this point the first crank arm was pointing towards the stationary X axis. Hence, the rotating x axis is in the first crank arm direction. Using this information the bending direction of the crank can now be determined. For example, at 6500 rpm, this crankshaft is statically deflected about 0.42 mm at 225 degrees from the direction of number 1 crank arm.

As demonstrated in this example, **Order-X** transformations provide significantly more information than what may be otherwise deciphered from the measurements made in a non-rotating coordinate system. In fact, this is the only reliable method of accurately measuring the static deflection of rotating shafts, since, static deflection cannot be measured with body fixed transducers.

Using **Order-X** transformations saves time and considerable instrumentation cost by greatly simplifying measurement test setups.