Diagnosing and Solving Resonance Problems

by Phillip Garrett and Tom Lantrip, Southern Company Services, Inc.

One of the most common reasons for high vibration of plant equipment is some form of resonance of the equipment components or support structure. Every mechanical system has resonant frequencies (damped natural frequencies). If the system is exposed to vibration at these frequencies, it will amplify the vibrations. The effects of this amplified vibration can range from premature wear and excessive maintenance to material fatigue to complete structural collapse. Any time you're dealing with rotating machinery, such as the variety of pumps discussed in this article, vibration problems are a possibility.

Solving vibration problems can increase uptime and decrease maintenance, replacement and operating costs. It's a two-part process. First, you need to identify the natural frequencies and compare these frequencies to the operating speeds of your equipment. Second, to resolve the problem you have to make a choice between changing the operating speed or changing the resonant frequencies (or both).

Two Approaches to Identifying Resonances

You have two options for identifying resonant frequencies. With the analytical approach, you can use finite element analysis to build a computer model of the system (the piece of equipment, its support structure, etc.) and simulate its dynamics. With the empirical approach, you measure the frequency response of the actual system. The examples discussed here illustrate both approaches.

With either approach, you often need to consider additional elements as part of the mechanical system. For instance, the support structure for a pump can affect the pump's dynamics because it adds its own mass and stiffness properties to the equation. This is the reason why pieces of equipment that behave well before being installed sometimes misbehave once they are installed—and why equipment suppliers need to make sure that their products still operate properly after installation.

Run-Up and Coast-Down Testing

A common way to identify resonances empirically is to operate the equipment across its range of operating speeds while measuring the vibration it exhibits. Run-up and coast-down tests, which monitor vibration from standstill to maximum speed and back down, are a quick way to see if troublesome resonances are present in the system.

When you see a discrete peak in the magnitude that is accompanied by a phase shift at the same frequency, it's a good indication that a resonance exists there. Figure 1 shows the magnitude and phase of the vibration we measured during a coast-down test on a boiler feed pump. We acquired the data with proximity probes on the shaft and used order tracking to keep the measurement stable as we ramped the speed down.

The phase with respect to the tachometer on the shaft remains stable and suggests that the two resonances are associated with the pump's housing or mounting structure, not the shaft. If the vibration level is unacceptable, we need to either avoid operating speeds around 3600 and 4600 RPM or modify the dynamics to move the resonances up or down.

Stimulus-Response Testing

Another common test technique is exciting a structure with an external stimulus and measuring how the structure deflects in response. Impact testing is one of the easiest methods. You typically excite the system with an instrumented impact hammer and use a signal analyzer to measure this input force and the response of the system simultaneously. The resulting frequency response function provides both magnitude and phase plots to help you locate natural frequencies.

A second option uses an electric or hydraulic shaker to excite the structure. The shaker is driven by a source signal from the analyzer. A random noise signal excites across the entire frequency range; a sinusoid lets you sweep across and dwell at particular frequencies if needed (similar to doing run-up and coast-down tests). The shaker excitation is transmitted through a stinger rod to a load cell attached to the structure. The load cell provides a measure of the input force. As with impact testing, your signal analyzer measures the input force and the output response

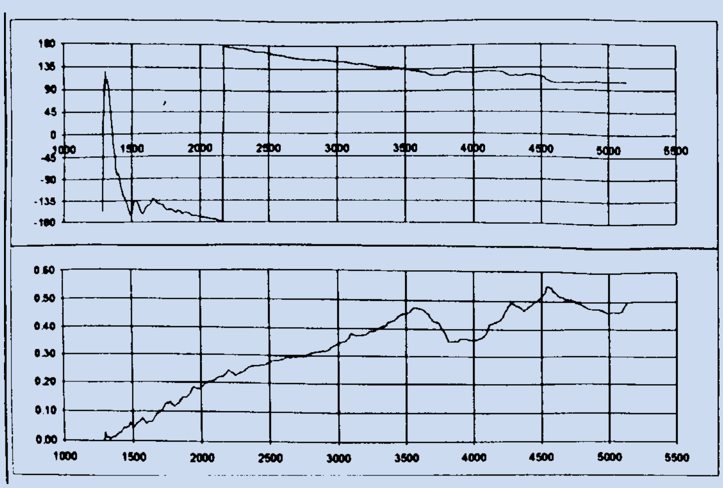
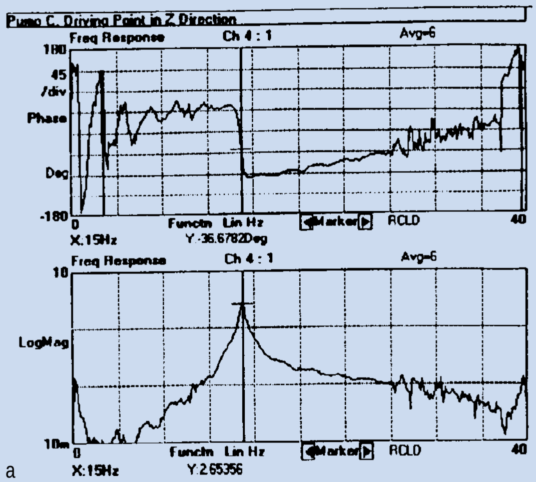


Figure 1: The insignificant phase shifting at about 3600 rpm suggests that the corresponding magnitude peak is a structural resonance, not a shaft resonance. You can see that the magnitude peaks at around 3600 and 4600 RPM, indicating two resonances. (Plotted with Microsoft® Excel.)



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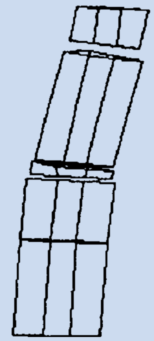

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Figures 2a & 2b: The frequency response function (a) showing a natural frequency at roughly 14.75 Hz. The operating deflection shape (b) shows the effect of the pump's 14.9 Hz running speed.

simultaneously, then plots magnitude and phase versus frequency to help you identify resonances.

Modifying Structural Dynamics

Identifying resonances is often the easiest part of resolving a vibration problem. If you can't change the operating speed of the equipment, you usually have to conduct further analysis and modify the structure to change its dynamic properties. Since resonant frequencies are related to the mass and stiffness of a system, adding mass or changing stiffness (e.g., adding bracing or removing support) can be effective in shifting the resonances outside the operating speed range.

Plotting the system's operating deflection shape is a useful technique for analyzing the effects of resonances and planning modifications. You start by creating a family of frequency response function measurements. Structural analysis software can then plot the shape of the vibration deformation over the structure's geometry. Figure 2 shows the results of a test on a condensate pump, illustrating how the pump deforms when operating. The problem in this case is that the resonant frequency is at roughly 14.75 Hz, very close to the operating speed of 14.9 Hz.

The analytical approach of creating computer finite element models offers another powerful option for solving resonance problems. During initial start-up of a large coal-fired power plant, circulating water pumps exhibited high vibration levels at operating speed. Impact testing identified a resonant frequency within 1% of the pump operating speed in one horizontal direction and another resonance within 4% in the other horizontal direction. Since the pumps were very large (2500 HP, 140,000 lb.), we needed a considerable amount of stiffness to increase both resonant frequencies above the pump operating speed. A finite element model showed that bracing against the steel framing of the building would raise both frequencies 10% above operating speed. After modifications were in place, another round of measurements verified that the vibration had decreased enough to be well within acceptable levels.

In many vibration cases, adding stiffness is the best solution. In one case involving a boiler feed pump foundation, however, we faced a three-part problem. First, this particular resonance was difficult to resolve simply by stiffening the support structure. Second, there were other resonant frequencies below the operating range that we might have shifted up into the operating range had we tried stiffening. Third, we had some potential physical interference with existing piping and instrumentation.

As with the circulating water pump, a finite element model pointed the way toward a solution. The model showed that while stiffening would be technically feasible, it would require extensive modification. The alternative was to soften the structure and thereby lower the resonant frequency. All we had to do was cut slots in the steel foundation, which lowered the resonance from 79.7 Hz to 67.1 Hz. This saved both the cost and downtime involved with fabricating steel stiffening plates and welding them in place.

Solutions for a Wide Range of Problems

Pumps are a common application for resonance measurement and modeling, but the techniques apply to a wide range of vibration problems in many industries. Learning how to identify and correct resonance problems can help your company significantly reduce both downtime and equipment repair and replacement costs. ■