Monitoring Vertical Motors

By Dr. Robert M. Jones • SKF

Abstract

Vibration analysis of vertically mounted motors presents the analyst with a unique challenge, as there is a high probability that resonance is strongly influencing the vibration spectrum. This paper provides a discussion of resonance, detailing how resonance may affect vertical motor conditions. Case histories and their problem solutions are provided.

Discussion

Every plant probably has a number of motors installed in the vertical position; sump pumps in the basement, fire pumps down at the river or reactor coolant pumps inside containment. Vertical motor installations present the vibration engineer, or technician, with a special problem related to resonance. The actual monitoring of the bearings, alignment, looseness and other parameters does not change, but influence from resonance problems is much more likely with a vertical installation.

First, let's review the term "resonance". Looking to Mr. Webster to find the formal definition of the word:

- *Resonance* – "The state of a system in which an abnormally large vibration is produced in response to an external stimulus occurring when the frequency of the stimulus is the same, or nearly the same, as the original frequency of the system".

A common misconception is that resonance is a source of vibration; it is not. Stated correctly, resonance is an amplifier of an existing vibration. In the definition above, the "external stimulus" can be a very small input, which by itself is not a problem. However, when amplified by machine resonance, the external stimulus vibration can be greatly amplified and lead to multiple problems, such as bearing failure, structural degradation and, ultimately, catastrophic failure.

Figure 1. SKF's Micrologs – portable data collectors / analyzers.

Every machine has a natural frequency (or resonance frequency, the terms are often used interchangeably). A bell, when struck, will ring at its natural frequency. Similarly, a machine will “ring” at its natural frequency when impacted with a mass that’s large enough to excite the machine’s mass. To compound the problem, every machine will have a number of natural frequencies, and these frequencies differ when struck in the horizontal versus the vertical or axial. According to information from sources at NASA, the International Space Station structure has over 300 natural frequencies (now that’s a complex machine)!

When a machine is in the design process, its various components are mathematically stated in terms of their stiffness and spring mass. These factors are then calculated to determine the machine’s theoretical natural frequency. An often-used parameter is that the calculated natural frequency should not be within 20% of any forcing functions, primarily the machine’s rotating speed. For example, a motor that will operate at 1 800 RPM should not have any calculated natural frequencies in the range of 1 440 to 2 160 CPM.

- 1 800 × 0,20 = 360
  1 800 ± 360 = 1 440 to 2 160

While this seems relatively straight forward, problems begin to occur when this motor is connected through a gearbox or belt drive to a unit whose components operate at a speed less than 1 440 or above 2 160 CPM. For example, it is not unusual to have a motor mounted vertically either on top of a gear box, or on the same framework, to reduce the driven unit’s speed to a lower speed.

If, for example, the gear mesh frequency works out to 27 150 CPM, then it is possible that it will excite a natural frequency in the motor in that range (e.g., a bearing fault frequency). In this example, the gearbox is running fine, but the motor rotor is vibrating heavily and destroying the motor bearings, as their ball pass frequency outer race (BPFO) is very near 27 150 CPM.

Another compounding factor with vertical motors is that gravity does not help dampen vibration inputs. With horizontally mounted motors, gravity tends to hold the motor in a stable mode, and the two bearings provide a measure of stiffness. However, a vertical motor is usually only supported by the bottom mounting flange, which is often bolted directly to the pump, gearbox or whatever is being driven. Just as a pencil laying in your hand is more stable than when balanced on your finger tip, the vertical motor operates in a somewhat unstable position and is much more susceptible to outside forces.

In addition, often the motor is mounted improperly, or has had structural changes resulting in a condition where the natural frequency of the overall machine is no longer in its design range, but is instead within 20% of the rotating speed. Experience proves that with a vertical motor that has a vibration problem, the first thing to do is to perform a bump test to determine the motor’s actual existing natural frequency. Then, it may become necessary to relocate the natural frequency outside the 20% range.

In the following case histories, vibration examples, problems and solutions are discussed to help the reader identify and apply solutions to similar problems.

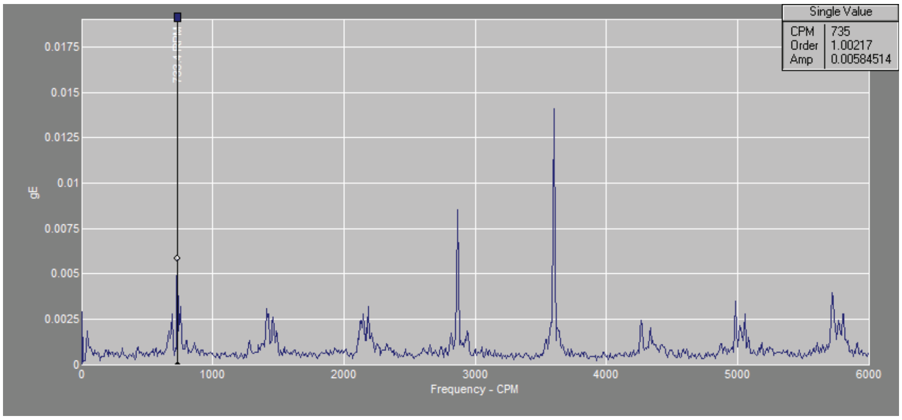

Figure 2. Spectrum showing typical resonance condition.

Case histories

A large refinery owned a pair of pumps that were driven by vertical motors "A" and "B". The "B" pump had been a maintenance problem for over 10 years and was referred to as "ol' shaky". A new maintenance foreman decided it had gone on long enough when he checked the records and learned that in the past 10 years the "B" pump had incurred $104 000 more in repair costs versus the "A" pump.

Figs. 2 and 3 show typical spectrums seen when the rotation speed (1X) is the influence that is exciting the machine's resonance.

In these spectrums, note the pattern often referred to as "haystacks" (the typical pattern is especially obvious in **fig. 3**). These are spaced at harmonic intervals of 1X.

In the example refinery's situation, the motor was very large and could not be excited by striking it with a large hammer.

Noting that the natural frequency can be changed by either adding mass or stiffness, we place a hydraulic jack and a four by four piece of wood between the wall and the motor. As we stroked the jack, we increased the motor's stiffness. With each stroke, the amplitude came down and the spectral haystacks diminished.

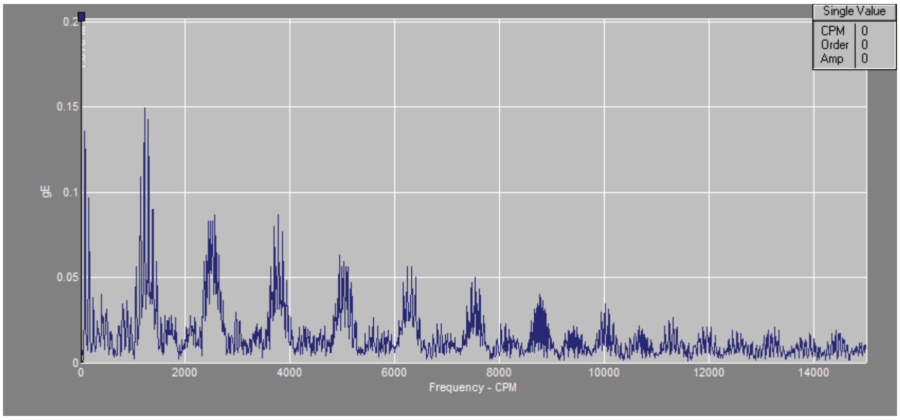

Figure 3. An even more typical resonance condition with obvious haystacks.

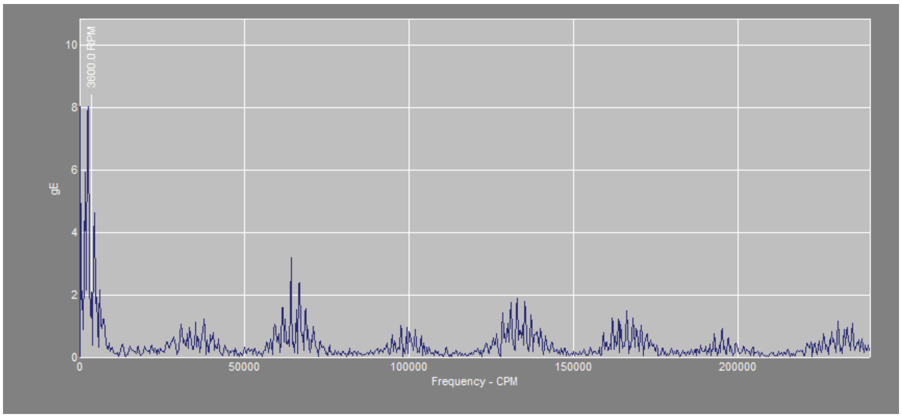

Figure 4. Vertical motor in a resonance condition.

We had found the cause of the vibration, but not the reason for the difference between the two pumps. After removing the motor and checking the base and foundation, we discovered that the motor was out of alignment and the base was 0,006 in. off plumb. This combination of errors reduced the unit's design stiffness and placed it in a resonance condition.

Another unique condition that occurs with both vertical and horizontal motors occurs when, for production reasons, a variable speed drive (VFD) is added to the motor power system. An example of this is a conveyor system that is operated at various speeds to enhance production. One system we examined operated a 300 HP motor for eight years at a line frequency of 60 Hz, with no problems. When a VFD was added and the conveyor operated at 54 Hz, motor bearings began to fail about every six weeks. The problem was resonance that did not occur at 60 Hz, but did occur at 54Hz. In this case, harmonics of the 1X frequency (3 240 CPM) matched the bearings' BPFO.

Fig. 4 shows one last spectral example of a 3600 RPM vertical motor operating in a resonance condition.

Conclusion

Vertical motors offer a unique challenge to the vibration technician. In addition to the usual problems of alignment, structural stability and bearing analysis, the possibility of resonance must be considered and examined.

Please contact:

SKF USA Inc.
Condition Monitoring Center – San Diego
5271 Viewridge Court · San Diego, California 92123 USA
Tel: +1 858-496-3400 · Fax: +1 858 496-3531

Web: www.skf.com/cm

PUB CM3095 EN · March 2011