Where is that vibration coming from?

» Production plant analyzes resonance anomaly; looks at condition monitoring program as a profit center

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Sometimes in industry, mechanical "circumstances" change. When it happens, a machine train identical to other machine trains can suddenly become atypical. This was exactly the case for Process Water Supply Pump A, whose behavior was very similar to that of its sister pump trains, until something changed. In this article we discuss a problem that was abruptly encountered, the methods used to investigate it and the solution devised.

One of four identical pump trains mounted to a common piping system experienced a catastrophic motor (75 hp, 4 pole) failure. The motor could not be saved, and a new motor was purchased and installed. After installation, the pump was started with the new motor. High vibration caused the installers to immediately shut it down (Figure 1). The new motor had been laser aligned to the pump; therefore the alignment was not suspect; therefore vibration data was taken.

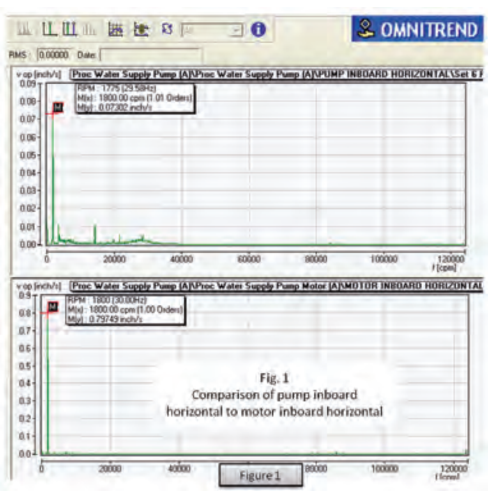


Figure 1

It can be seen in Figure 1 that the horizontal peak at turning speed on the pump, while easily the dominant peak in the spectrum, is much lower than the horizontal turning speed peak on the motor (amplitude scale is 10x higher on the motor). Shaft runout on the motor was measured and found to be acceptable. The motor and pump were uncoupled, and when the motor was run by itself the vibration was mostly gone. The coupling showed signs of wear, so it was replaced.

When the new coupling was installed, the two shafts were again aligned according to precision maintenance specifications and the motor/pump train was restarted. The vibration was virtually the same as before. Now a complete set of vibration readings was taken and compared. The table below (Figure 2) shows the readings on the pump and motor.

Units ips	OB Hor	OB Vert	OB Ax	IB Hor	IB Vert	IB Ax
Pump	0.03708	0.02044	0.01426	0.06937	0.01018	
Motor	0.62331	0.00384		0.58532	0.02637	0.04457

Figure 2

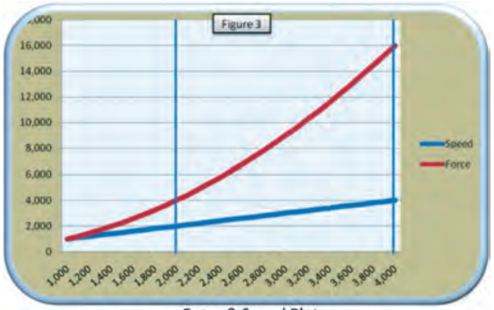
Initial vibration amplitudes on pump and motor

Inequality of amplitudes

The inequality of the amplitudes in different directions was obvious. Every point that was taken on the pump had amplitudes well within acceptable ranges, but so were most of those taken on the motor, with the glaring exception of the two horizontal readings. In fact, the disparity was so great between the horizontal and vertical readings on the motor that the initial reaction was to check the accelerometer and cable connections on the vertical readings.

The motor outboard horizontal amplitude was 162 times the amplitude of the outboard vertical. The inboard horizontal amplitude was only 22 times the value of the inboard vertical. How can anything vibrate that much in one direction and have little to no effect in other directions? The answer of course is resonance.

To understand the amplification capability of a resonance, it is beneficial to visualize some of the common forces present and acting on a rotating machine such as the pump train being discussed. The type of rotating force we are concerned with varies depending on the mass, eccentricity and speed of the rotor. Assuming that the mass and eccentricity of the rotor are constant, one can vary the speed and vary the force along with it. Increasing the speed of this pump motor should increase the force linearly, but force is a function of speed squared, so if you double the speed, the force is quadrupled. Figure 3 charts speed and force. The mass and eccentricity are given a number that will



Force & Speed Plot

yield 1,000 lbs of force at 1,000 rpm, so they begin at the same place on the chart. The horizontal (X) axis is speed and the vertical (Y) axis is force.

Notice that as the blue line representing speed doubles from 1,000 rpm to 2,000 rpm, the red line representing force has now reached 4,000, having quadrupled because of the speed doubling. It is important to understand this, because the response vibration of a machine might be expected to increase like the blue speed line as speed is increased, but in fact, the response vibration in a machine should follow the slope of the red force line. Following the slope of the red force line looks dangerous enough as speed is increased on a machine, but when you add a resonance, the slope of the response vibration amplitude can go nearly vertical. We will use a variation of this chart a little later to help visually illustrate the amplification of vibration on our pump motor.

Bump test performed

In order to verify that a resonance was present now in a machine that had run at the same speed without resonance for years, a bump test (or impact test, which is a response test where the broad frequency range produced by an impact is used as the stimulus) was carried out. However, there was a problem. The other three pumps, all within very close proximity, mounted on the same general foundation and connected to the same piping, had to be left running. And even though they were all on speed controls, they were most commonly run at motor rated speed, which is where the problem occurred. Figure 4 shows a screen capture from the

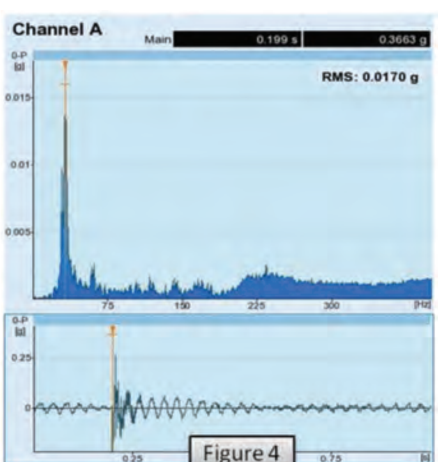


Figure 4
First Bump Test

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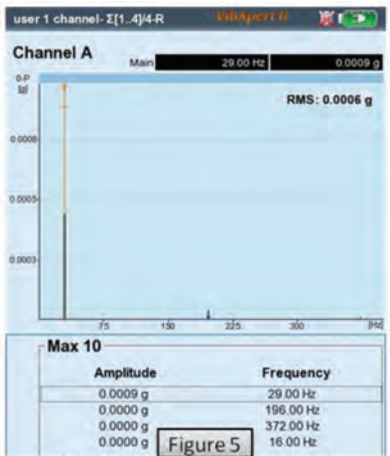
instrument in the field "seeming" to confirm a resonance very near to motor rated speed.

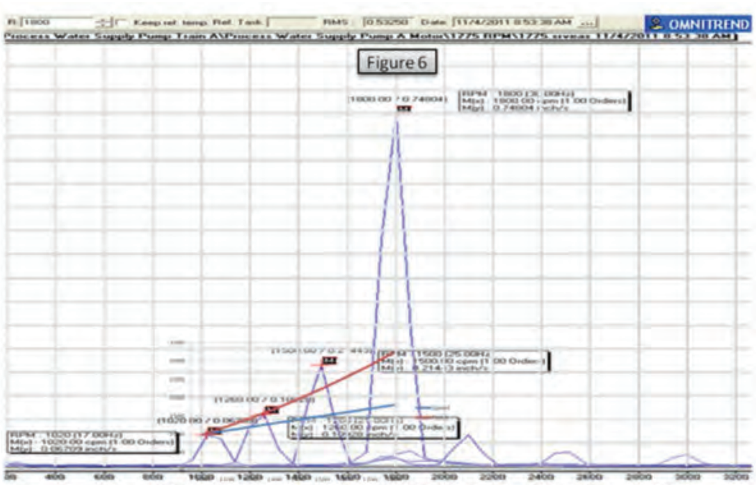
Notice the waveform of the bump test. Not only did it not ring down to zero, it did not start at zero. The energy from the other pumps migrated into the accelerometer contaminating the bump test. Although contaminated, the test still yields interesting information, especially in the waveform. The migrating vibration before the bump appears to be dominated by virtually the same frequency as dominates immediately after the bump.



Negative Averaging Bump Test

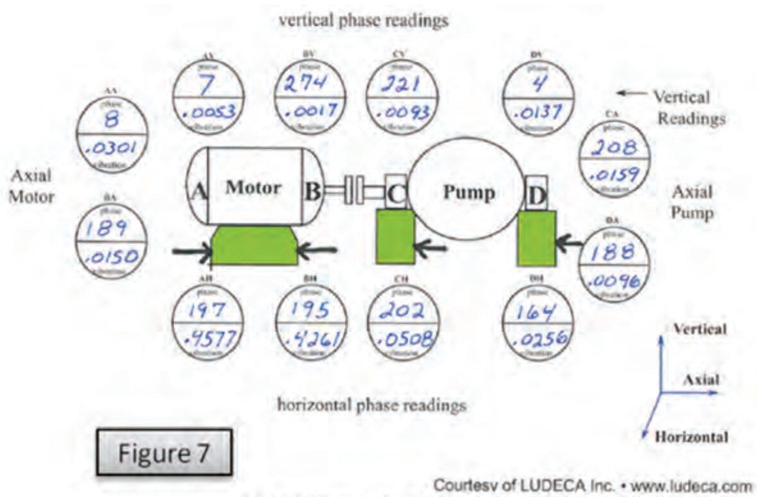
To overcome the problem of residual vibration from the other machines, a negative averaging bump test was done, even though the motor it was performed on was not running. The result (Figure 5) confirmed the resonance in the horizontal on the motor at 1740 cpm.

The negative averaging technique is a very effective way to "average out" ambient vibration. A bump test using negative averaging begins like a standard bump test, but after the spectrums with "bumps" are captured, several more normal spectrums are captured and their result is subtracted out of the bump test spectrums using an averaging process. When done correctly, what remains in the target spectrum is essentially the bump response, and is virtually devoid of the ambient vibration.



Overlay of Running Speed Peaks With Speed and Force Plot

On this particular pump train, the analyst was able to run the machine at different speeds. In fact, although the most common operating speed was motor rated speed, three other speeds were not uncommon. Figure 6 is an overlay of four spectrums taken at different operating speeds. It is a good illustration of the amplification capability of a resonance. The chart overlaying the spectrums is the same as Figure 3, except it only shows a speed increase from 1,000 rpm to 1,800 rpm so it can be matched with the spectrums. With this overlay, we can see how, as the running speed increases, the peaks show the machine response, compared to the force increase. It is a very impressive illustration of the amplification power of a resonance in a rotating machine. Compare the red line (force) to the peak at 1,800 rpm.



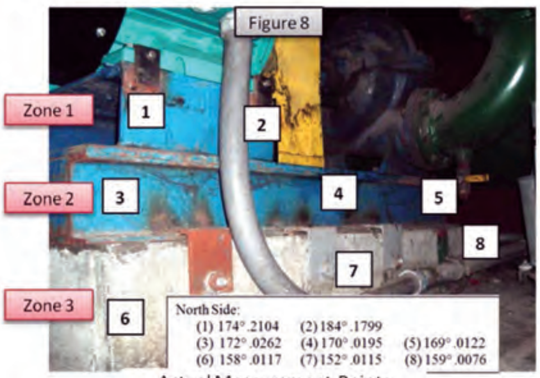
Phase/Amplitude Bubble Chart

Problem drill down

Now the task was to determine why, after many years, this pump motor had become a problem. It was the same size, mounted in the same place, and running the same speed it always had. To determine what exactly was involved in the resonation and how it was occurring, bubble charts of the phase and amplitude of the vibration on the motor, motor mounts and foundation were created using cross channel phase.

Figure 7 is the first bubble chart. It can be seen that the entire motor was vibrating from end to end "in phase." The "bubbles" in the chart show the relative phase on top, and the amplitude in inches per second (ips) on bottom. The motor outboard horizontal amplitude and phase of 0.4577 ips at 1970 is comparable to the inboard amplitude and phase of 0.4261 ips at 1950. This illustrates how directional the problem was. There is simply nothing of significance that is not in the horizontal direction and on the motor. After this chart was made, it was decided that to save time, data would be taken only in the horizontal direction. Other data could be taken in the future if necessary.

Figure 8 is a picture of the machine and its base with markers showing different points where data was taken, and a table showing the amplitude and phase data. There are three levels of base and foundation. Zone 1, where the readings labeled "1" and "2" were taken, is the mount to which the motor is bolted. Zone 2, where the readings labeled "3," "4" and "5" were taken, is the intermediate foundation (pump skid) to which the motor mount is welded and is itself mounted to the concrete foundation (level 3) where the readings labeled "6," " 7" and "8" were taken.



Actual Measurement Points

It can be seen in the table in Figure 8 that, as you travel upward from the foundation, each level is higher in amplitude, but they are all in phase. Notice also that the amplitude increases very little from Zone 3 to Zone 2, but there is nearly a 10x increase from Zone 2 to Zone 1. When comparing the bubble chart in Figure 7 to this data, one sees that the amplitude is about 2.5x higher on the motor than on the mount (Zone 1 in Figure 8), and virtually in phase. Now we get the idea of this motor rocking violently from side to side, from the interface between Zone 1 and 2 and up. Figure 9 illustrates the movement of this motor and its mount. It is shown in the maximum negative amplitude on the left, at rest or at zero in the center and the maximum positive amplitude on the right. This all represents one cycle of vibration at the turning

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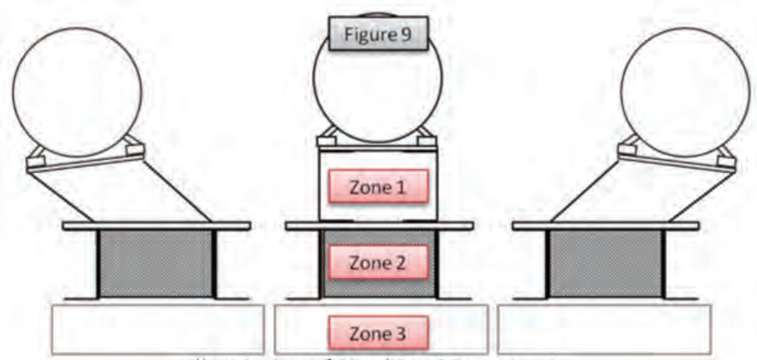


Illustration of Machine Movement

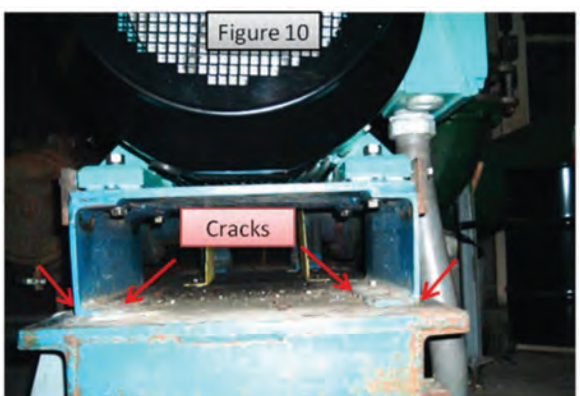
speed of 30 hz.

Figure 9 clearly shows how the motor mount and motor were rocking at the interface of Zones 1 and 2. This shows how the machine was vibrating due to a horizontal resonance, but the question why it was vibrating in this manner after years of operation without this behavior still remained.

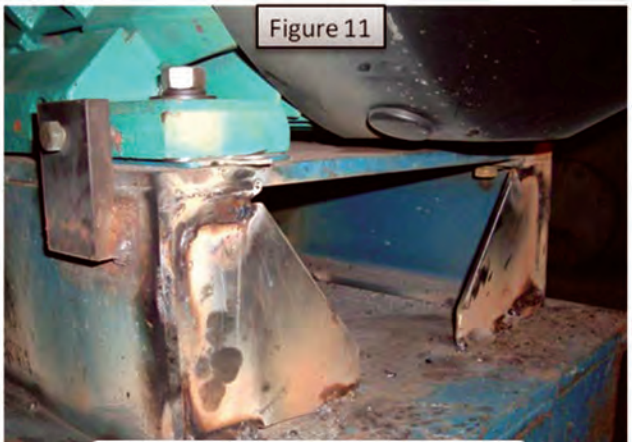
Avoided cost, avoided downtime and reduced stores due to lead time created by predictive maintenance make condition monitoring one of the most "profitable" departments in most manufacturing facilities.

Solution attained

Figure 10 shows another view of the motor on its mounting. It was decided that the mount needed some internal bracing. While inspecting to determine the best placement of the gussets, cracks were found on the welds that connect the channels of Zone 1 to the top of Zone 2, which were hardly visible to the naked eye (see Figure 10). In fact, only extremely close scrutiny revealed most of them. It was believed that the violent catastrophic failure that occurred earlier caused some welds to crack, lowering the stiffness of the motor/mount assembly and bringing its natural frequency down near to operating speed. When the new motor was installed, it was doomed also, if the situation wasn't remedied.



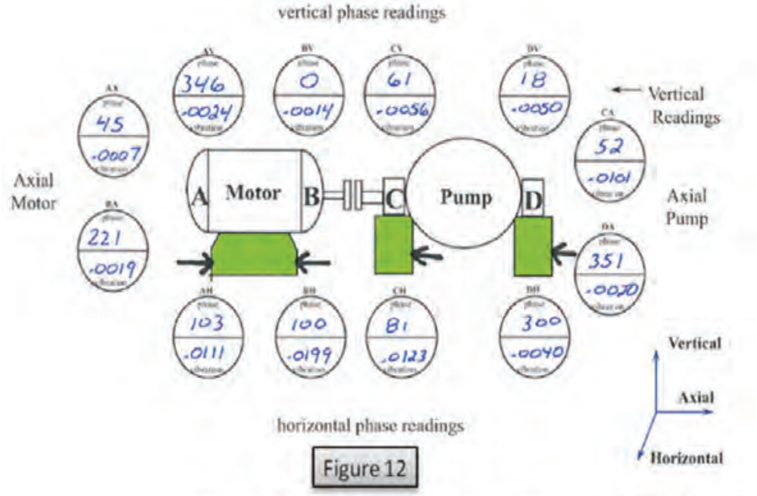
Cracked Welds Where the Mount attaches to the Skid



Mount After Repairs and Additions

The welds were repaired and gussets were made and installed to beef up the mount. Figure 11 shows the mount after the final repairs and Figure 12 shows the bubble chart made after the repairs and enhancements to the mount.

The value of a vibration analyst is easy to see in such a case, but is often overlooked in day-to-day operations. The truth is, through their efforts, scenarios like the one that brought about this case example are many times prevented from happening in the first place. The greatest need in many condition-monitoring programs is for improvement in reporting the value of their service.



Final Bubble Chart After Repairs

Avoided cost, avoided downtime and reduced stores due to lead time created by predictive maintenance make CM one of the most "profitable" departments in most manufacturing facilities.

In modern industry, equipment is being manufactured with the minimum of materials. This case history illustrates how equipment that is running well today could be just a cracked weld or a loose fastener away from incredibly destructive behavior. Such behavior is caused by physical properties that are all around us. Often we ignore, or are unaware of many of these properties, at least until something changes.

Lubrizol is one of the world's leading suppliers of specialty chemicals for the transportation, industrial and consumer markets. Reaching the far corners of the globe with laboratories and manufacturing facilities in 27 countries. Lubrizol started in a small garage in Cleveland, Ohio, in 1928.

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