Liquid Air-Separation Compressor Testing

using the IOtech 600 Series

Serious compressor problems often appear during startup and shutdown. During this time, dynamic stresses from acceleration and deceleration inertia typically run higher on certain components than when the compressors operate at constant speed, and the stresses may aggravate a defect. Also, some anomalies may be more observable. This is not to say that problems do not arise during steady-state operating conditions; they do, but they may be less obvious during the onset of a failure.

Centrifugal compressors that separate liquid air belong to the dynamic compressor family and operate at extremely high speeds. They contain a large bull gear that drives high-speed pinions, which develop the pressure. A prime mover, such as an electric motor, connects its drive shaft to the compressor unit through a coupling to spin the bull gear.

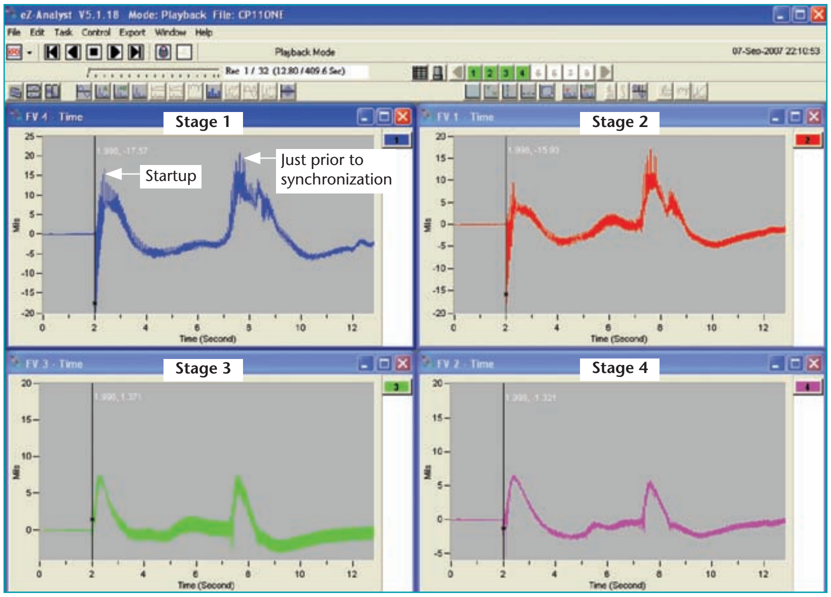

Figure 1. *The plot shows the motion on all four stages during the first ten seconds of startup. All stages experience periods of abnormally high vibration. The torsional pulse rate is 7200 CPM at zero rpm, and as the speed increases; the torsional pulse rate decreases to zero. Therefore, during the startup phase, a time comes when the pulse rate may equal a natural, torsional frequency — the most likely cause of the second peak. After the motor reaches synchronous speed, the amplitudes level off and then remain relatively constant.*

During the start up or shut down, events take place very quickly and it requires a system with real-time recording capability to detect and identify problems that may arise.

For example, Nelson Baxter, a consultant with AZIMA Corp., Woburn, Mass., was recently requested to measure the startup operation of a four-stage, 5.0 k-hp liquid-air separation compressor. The purpose of the test was to evaluate the unit's condition and detect any root problems that previously might have caused an excessive vibration transient in the first stage that resulted in a subsequent trip event. Baxter initially recorded some sub-synchronous instability, but for five succeeding days, no unusual vibration transients appeared.

The data recorded during the test came from IOtech's 650u Dynamic Signal Analyzer (DSA). The client's original data acquisition system is acceptable for recording overall data, but it has no time or spectra data collection capabilities. In contrast, the 650u DSA collects data from each probe continuously, and then streams it to a computer's hard drive for post-processing analysis. The DSA was set to collect 5120 samples/sec during the startup phase. It recorded each revolution of all four stages from startup through the first seven minutes of operation. Following the startup it was then reconfigured to obtain waveform and spectra data every minute or during a level increase thereafter.

Although the system continued to operate without an automatic shutdown from excessive vibration transients, Baxter closely analyzed the recorded data. During the first ten seconds of startup, he found that all four stages of the compressor experienced periods of extremely high vibration. The bull gear generated tangential forces that substantially shifted the centerlines of the pinion shafts. He also found an unexpected amount of high-amplitude, dynamic sinusoidal motion during two separate periods; the first immediately upon switch closure, and the second near the synchronous point.

These events explain why the compressor shows such high levels of motion during startup. (See Figure 1.) Data analysis indicates that, most likely, the two peaks in the dynamic amplitude come from the bull gear's torsional response. The torque pulse generates

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the first peak during initial motor startup. The second peak appears to come from the synchronization pulse rate, around 80% of full speed, which indicates a suspected natural, torsional frequency. This is not particularly surprising, since synchronous motors are commonly known to generate torsional vibration during startup. After the motor reaches synchronous speed, the amplitudes level off and then remain relatively constant.

After the unit stabilizes, stage 3 generates the highest vibration level. Figures 2 and 3 show that stage 3 has a large amount of "glitch." These time-based wave shapes were taken from stage 3 when operating at a relatively low speed. They show 1.5-mil amplitude notches every revolution. Notches such as these that appear at low speeds usually indicate a scratched shaft, the most probable reason that the stage 3 proximity probe shows abnormally high values. Finally, Figure 4 is a waterfall display showing how the vibration varies with time at normal running speed.

Conclusion

The compressor unit did not indicate noticeable rubbing during startup. However, it did go through some extremely high vibration levels as shown in the continuously collected time-data graph. These vibrations probably arose before, as well, but instrumentation like the IOtech 650u Digital Signal Analyzer that could capture the vibrations, previously had never been available at the site. The high levels of motion do show the need to have enough clearance in the seals. The second item that the advanced instrumentation made clear was that a flawed surface finish of the shaft being monitored by the probe was the most likely cause of the vibration on the third stage. Scratches probably generated the sharp pulses that were seen at low speeds. Observing the time-based wave that appears when the shaft rotates at low speed reinforces this assumption; it looks the same here as it does when running at full speed or 215 Hz.

The steady-state data were sampled each minute with the provision that any increase in vibration would also trigger the data-capture feature. The trigger did initiate a few data sets, but none appeared to be high enough to trigger a trip. Unfortunately, the source of the original trip remains unknown. A random event might have caused the sub-synchronous vibration to spike, which is always present at some level on the first stage, or the original instrumentation had an intrinsic transient problem.

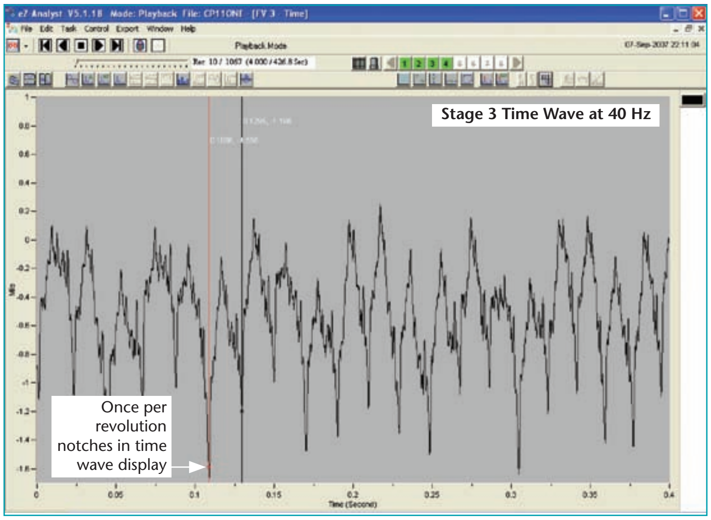


Figure 2. *This stage indicates the largest glitch when rotating at about 40 Hz. Notches shown at these speeds typically indicates scratches on the shaft.*

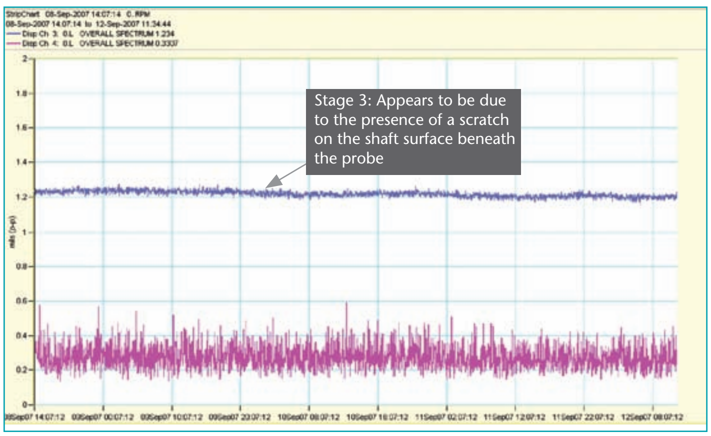


Figure 3. *These data come from stages 3 and 4 recorded over a five-day period. Most of the vibration shown in the top trace appears to be generated by a scratch on the shaft surface directly beneath the measurement probe.*

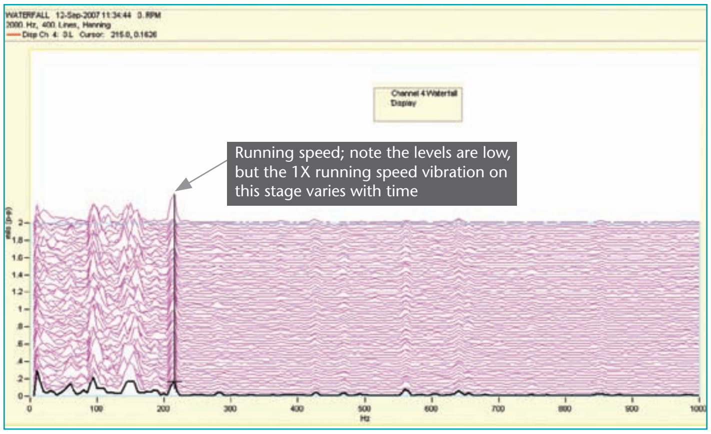


Figure 4. *A waterfall display of channel four shows the vibration at running speed. Although the levels are low, the 1X running speed vibration on this stage varies with time.*

IOtech 600 Series

Vibration data acquisition, analysis, and monitoring have never been easier than with the IOtech 600 Series of dynamic signal analyzers and eZ-Series software. More than 30+ years of engineering experience in vibration measurements have gone into the design of the 600 Series of DSAs. They come in either USB or Ethernet versions for maximum flexibility. The DSA hardware provides signal conditioning and data acquisition, while the eZ-Series PC-based software provides monitoring and analysis functions.

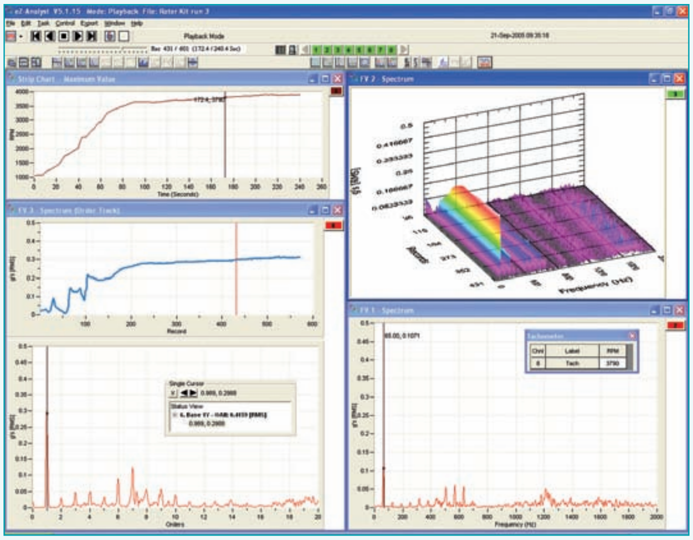
Features

- Analysis frequency ranges are software programmable from 20 Hz to 40 kHz
- 24-bit Sigma Delta ADC per analog input
- Spurious-free dynamic range of 108 dB typ
- AC/DC coupling, software selectable per channel
- TEDS support for accelerometers
- Pseudo-differential input
- Total harmonic distortion of -100 dB typ
- Channel-to-channel phase matching of <0.12 degrees at 1 kHz
- 8-bit digital I/O port
- USB 2 and 10/100BaseT Ethernet versions

Vibration analysis and monitoring has never been easier than with the 600 Series of dynamic signal analyzers and eZ-Series software

Software Overview

Four software packages are available for the 600 Series, each tailored to a particular vibration measurement and analysis application. Choose the package that suits your application now, and upgrade to additional packages as your requirements evolve.



eZ-Analyst adds real-time continuous and transient data acquisition in the time, frequency, or order domain

- **eZ-Analyst** provides real-time multi-channel vibration analysis, including overlay of previously acquired data while acquiring new data, strip charts of the throughput data files, cross channel analysis, and direct export to the most popular MODAL analysis packages, ME Scope and Star Modal.
- **eZ-TOMAS** provides on-line vibration recordings, limit checking, storage, and analysis of rotating machinery. Order track, Waterfall, Orbit, Polar, Bode, Spectrum, and Trend displays show machine startup or shutdown events, as well as diagnose long-term changes in machine health.
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