Ultrasound Testing Enhances Vibration Analaysis

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Vibration analysis of rotating equipment is not an exact science. It is well recognized that similar vibration spectra can be produced by dissimilar mechanical faults. For example, soft foot, imbalance, misalignment or sheave wear can all produce elevated shaft speed vibration.

An important component of vibration analysis is the use of supplemental test information. Supplemental test information provides specialized data that permits the vibration analyst to focus on specific machine behavior that defines the precise mechanical problem. For example, the analyst might supplement vibration readings with phase readings to distinguish between imbalance and misalignment.

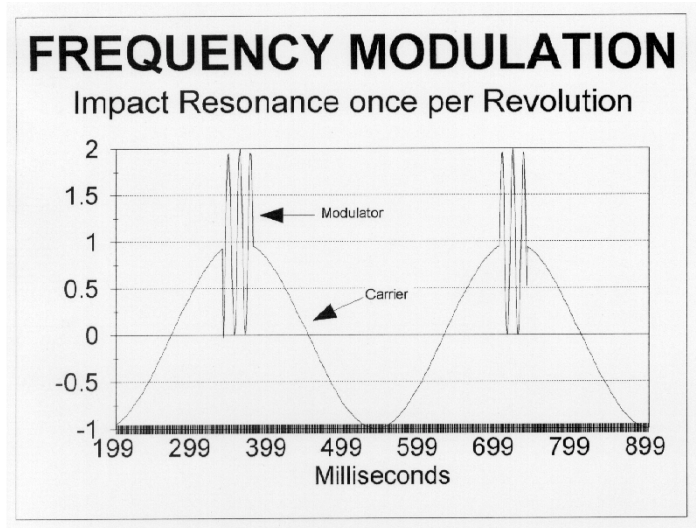
Analysts at Mid Atlantic Infrared Services (MAIS) have supplemented their vibration testing procedures through spectral analysis of the output signal from ultrasonic detection instruments.   This supplemental testing procedure has greatly improved the analysis of bearing and other types of mechanical faults.

The ultrasonic instrument detects vibrations from 20 kHz to 100 kHz. Vibration in this frequency range is produced by various types of mechanical faults. Predominant sources of ultrasound in a machine include rubbing or impacting types of faults.   The instrument processes the ultrasonic signal to produce an audible signal which is heard using headphones. Typically, the analyst produces a fault diagnosis by qualitatively assessing the sound level and characteristics heard in the instrument headphones.

The ultrasonic instrument produces sound in the headphones by “demodulating” the raw ultrasound signal. Demodulation of a vibration signal is a process that has received substantial attention over the past few years as a method of identifying gear or bearing failures.

Signal modulation occurs when two related mechanical events occur simultaneously. Their sine waves combine to produce the modulated waveform. Signal modulation can be understood from the adjacent plot.

This plot is a representation of a once per revolution impact. For example, suppose a pump has a single high vane. Once per revolution the high vane makes an impact. The once per revolution vibration signal is indicated by the waveform marked “Carrier”. When an impact occurs, a broad band signal is generated that contains all frequencies. Since all frequencies are present, any machine resonances are excited by each impact. The vibration at these resonant frequencies is amplified. This is similar to what occurs during a “bump test” to determine a resonance. Excited high frequency vibration is represented in the example drawing by the waveform marked “Modulator”. Thus, the resonant vibration resulting from the once per revolution impact is modulating the once per revolution signal. The demodulated signal in this case will return just the carrier. It will indicate the frequency at which the modulating is occurring. That is, it will indicate the frequency at which the impact is occurring.



We can apply this example to the ultrasonic instrument. Suppose our gear with the high tooth is rotating at 3600 RPM. Every 16.7 milliseconds, the gear excites all resonances. The ultrasonic instrument examines vibration at a frequency band centered at 30Khz. Every 16.7 milliseconds, the instrument picks up vibration within its measurement range. The demodulated signal produced by the instrument has a frequency of 3600 CPM. This is the frequency heard in the instrument headphones.

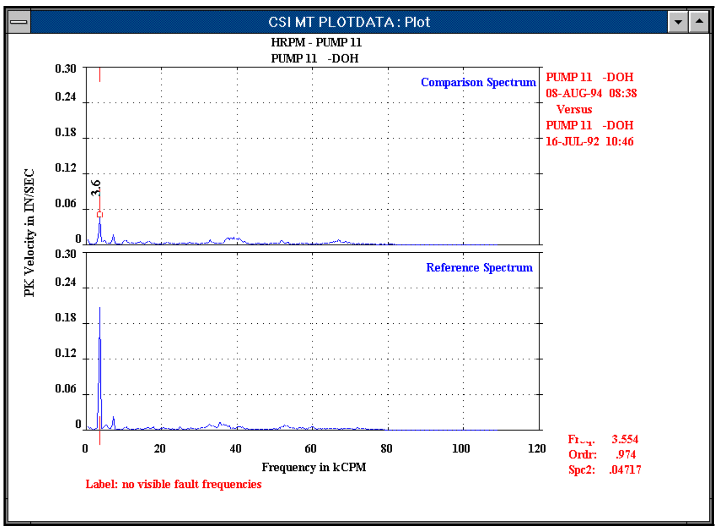
We can now take this procedure one step farther. Instead of using headphones, we take the output signal from the ultrasonic instrument and input the signal into a spectrum analyzer. We will obtain a waveform with a frequency of 3600 CPM.

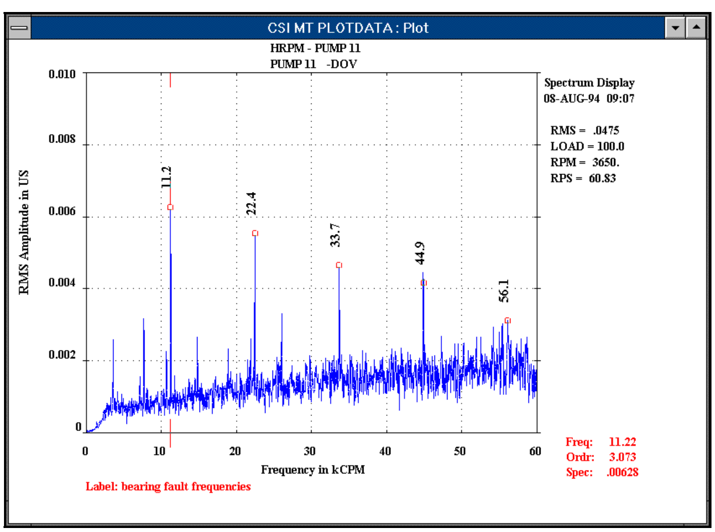
In 1993, we began to process the demodulated ultrasound signal of a UE Systems Ultraprobe 2000 through a CSI 2110 analyzer. The procedure is very simple. A connecting cable was built with a miniature phono plug that can be inserted into the audio output of the Ultraprobe. The other end of the cable terminates with a standard BNC connector. The cable connects to the CSI analyzer using the standard BNC adapter supplied by CSI. The CSI analyzer is set to receive a non-standard RMS signal. Sensor power is turned off. The calibration factor is set to 1. For a typical machine reading, data is taken in the Acquire Spectrum mode. The bandwidth is set from 400 CPM to 60,000 CPM (this will be adjusted, depending on the speed of the machine). Resolution is set to 800 lines. 6-10 averages are used.

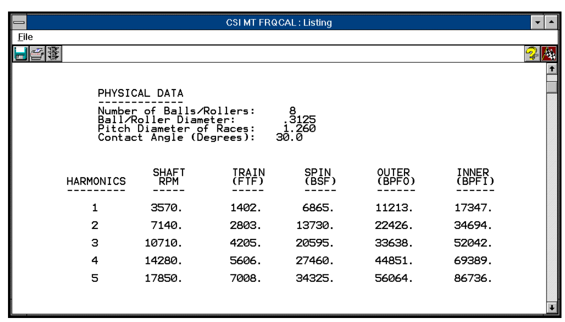
We have found that spectral analysis of the demodulated ultrasound signal provides a wealth of information about bearings, gears and various machine conditions. For some types of faults, spectral analysis of ultrasound signals provides better information than spectral analysis of lower frequency vibration data. As a result, the technique has become a critically important addition to our array of supplemental tests.

As a bearing begins to fail, spalls begin to develop in the races, rollers or balls. In any case, these spalls produce impacts. The impacts excite resonances within the bearing or the surrounding machine structures. During the early stages of the fault, high frequencies are excited. These excitations are easily monitored with the ultrasonic instrument.

The spectrum below shows the outboard bearing of a boiler feedwater pump. The bearing is a MRC5303 bearing. This bearing has a history of failures. The spectra below show comparative vibration for the current and a prior period. The only change is at pump speed vibration. There is no indication of a bearing fault. However, the bearing produced a distinctive buzzing noise that suggested a bearing fault might be developing. As a result of the buzzing noise, the bearing was checked with ultrasound. Audible ultrasound revealed that elevated ultrasound levels were produced in this bearing. Tests of identical adjacent pumps revealed low levels of ultrasound. The ultrasound signal was next fed into the spectrum analyzer. The following graph shows the results.






CSI MT FRQCAL : Listing

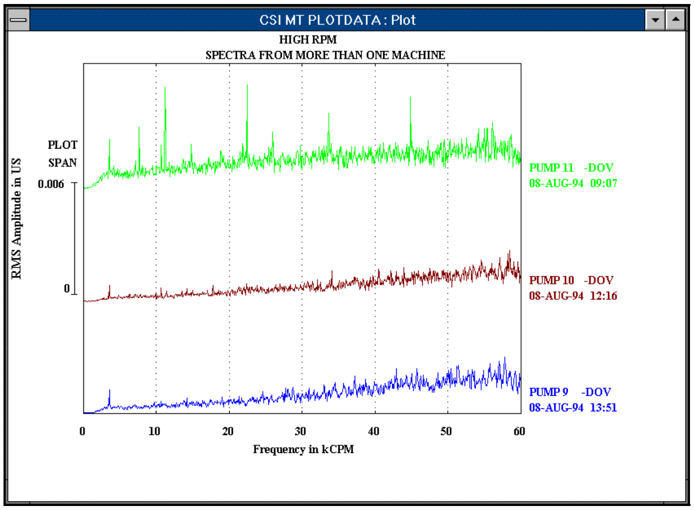
PHYSICAL DATA

Number of Balls/Rollers: 8
Ball/Roller Diameter: .3125
Pitch Diameter of Races: 1.260
Contact Angle (Degrees): 30.0

HARMONICS	SHAFT RPM	TRAIN (FTF)	SPIN (BSF)	OUTER (BPFO)	INNER (BPFI)
1	3570.	1402.	6865.	11213.	17347.
2	7140.	2803.	13730.	22426.	34694.
3	10710.	4205.	20595.	33638.	52042.
4	14280.	5606.	27460.	44851.	69389.
5	17850.	7008.	34325.	56064.	86736.

The calculated fault frequencies for this bearing correspond precisely to the peak frequencies shown in the demodulated ultrasound spectrum.

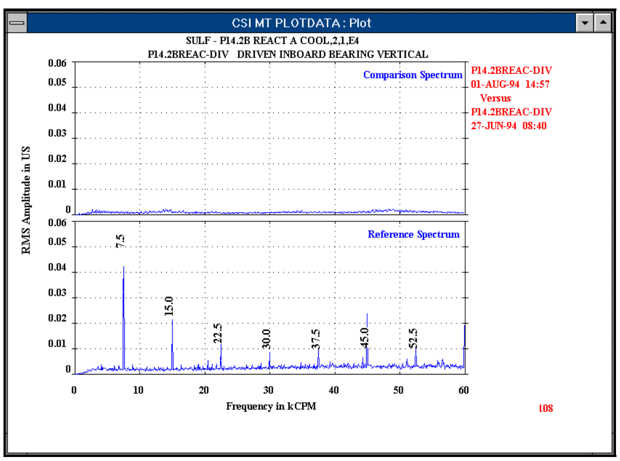
The following graph shows the demodulated ultrasound spectrum for this pump as well as and two identical adjacent pumps.

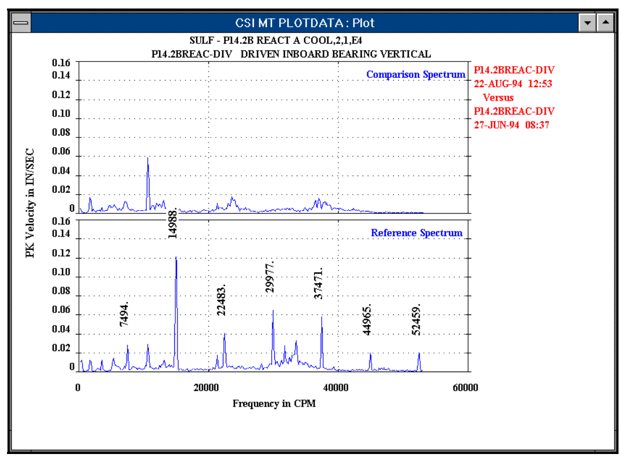


These spectra show that no bearing fault frequencies are visible in the adjacent pumps. Once the pump bearing was changed, the audible buzz disappeared.

The next example shows another pump bearing. The bearing model was unknown. The spectra below show the demodulated ultrasound and vibration spectra before and after the bearing was replaced.

The left graph is demodulated ultrasound. The right graph shows vibration. Both graphs show suspected fault frequencies. These frequencies disappeared after the bearings were replaced.





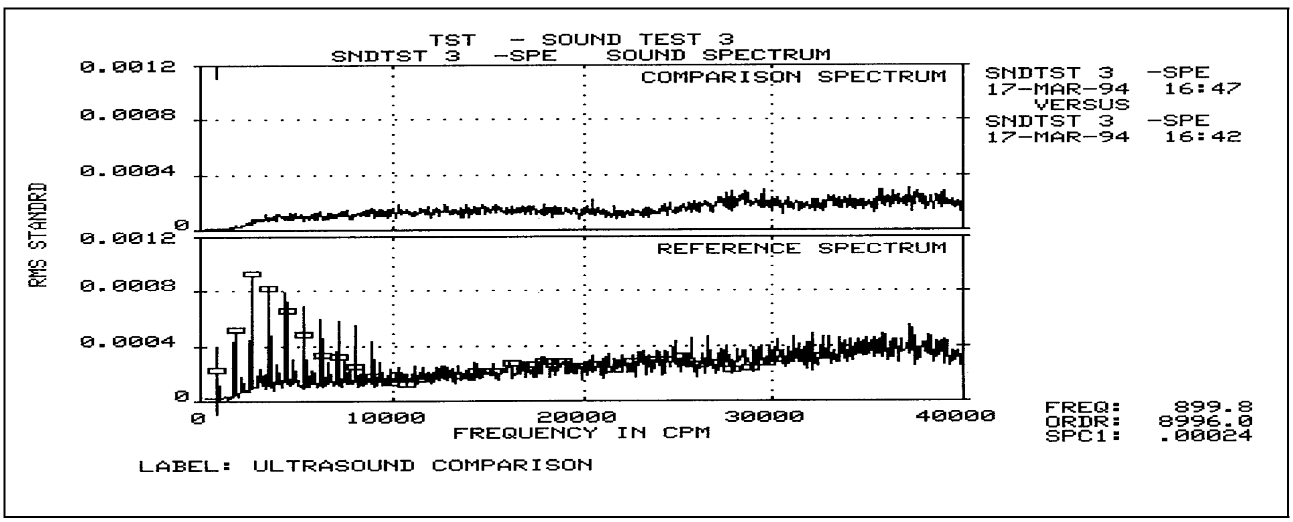
Comparing the vibration and ultrasound graphs, it is easier to see the suspected bearing fault frequencies in the ultrasound plot. This is typically the case since the unrelated vibration frequencies do not show up in the ultrasound plot. In many cases, the fault frequencies are present in the vibration spectrum. However, they can be difficult to distinguish when many other frequencies are present. The demodulated ultrasound spectrum provides an immediate indication of the likely fault frequencies. They may be used to guide evaluation of the vibration spectrum to locate the bearing fault frequencies.

There are other uses for ultrasound besides bearing evaluations. Any mechanical phenomenon that produces a rub or impact will produce ultrasound. This means that gear faults and mechanical looseness can be detected with ultrasound.

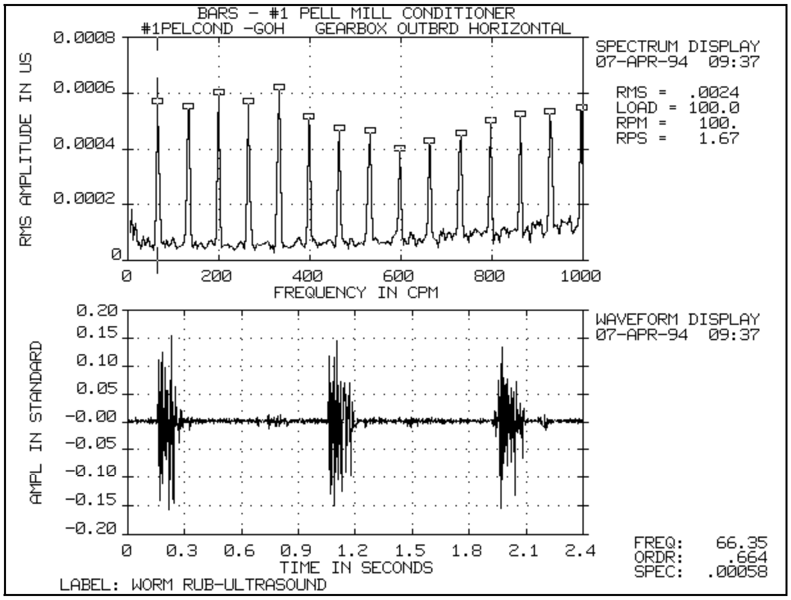
The graph below is from a brand new gear box. The input gear box speed is 899 CPM. The output speed is 6 CPM. Plant personnel complained that the gearbox was producing an unusual noise. The vibration and sound test revealed a spectrum with numerous harmonics of input shaft speed. However, the vibration and sound were fairly uniformly distributed around the gearbox and clutch assembly. We assumed there was looseness at the input shaft or clutch, but we could not determine the location with sound or vibration measurements. We utilized demodulated ultrasound. The results are seen in the plot below.

The lower graph shows demodulated ultrasound at the inboard bearing cap. The upper graph shows demodulated ultrasound at the outboard bearing cap. Note the harmonics of shaft speed in the lower graph.

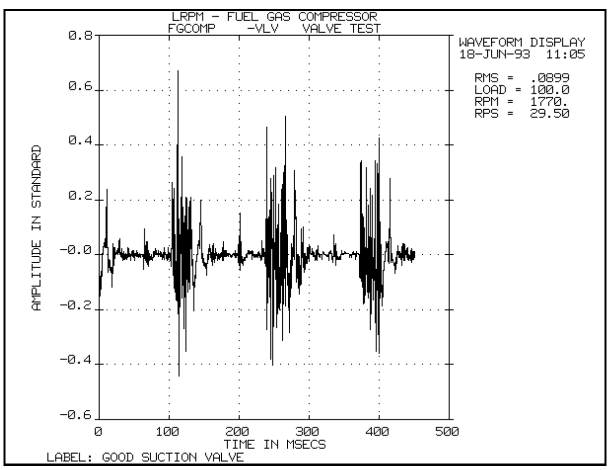
The signal was very strong at the drive side input shaft bearing and diminished rapidly as distance from the bearing increased. This bearing was replaced and the noise was eliminated.

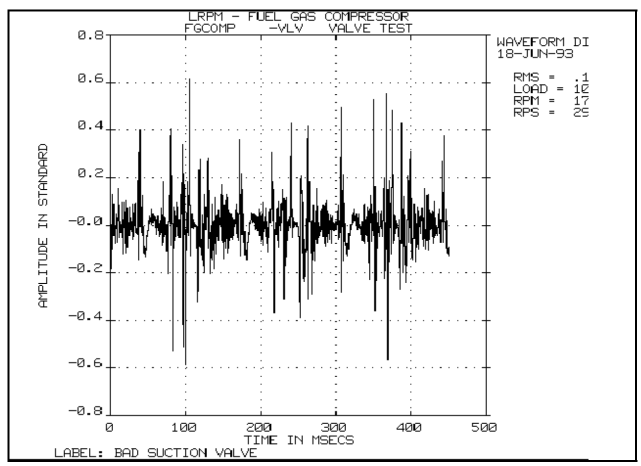


The next case was produced from a screw conveyor. The rotational speed of the conveyor was 66 CPM. The conveyor produced an audible grind. The demodulated ultrasound spectrum shows an impact occurring once per revolution. The worn drive sheave on the conveyor was replaced, thereby correcting the problem.



Another useful application of demodulated ultrasound analysis is valve testing in reciprocating compressors. Properly functioning inlet and outlet valves on reciprocating compressors snap smartly shut after each operation. As valve seats wear, gasses begin to leak by the valve. The valve begins to rattle in its seat as wear progresses. An easy way to monitor compressor valve condition is by observing the ultrasound signal as a waveform display on the analyzer. This is accomplished by placing the stethoscope probe of the ultrasonic instrument on the compressor valve. The output signal is observed on the spectrum analyzer in oscilloscope mode. The left trace, below, shows a good valve. The right trace shows a leaking valve.





These examples demonstrate that spectral analysis of demodulated ultrasound signals is a powerful analytical tool for a variety of mechanical faults. The supplemental data provided by the ultrasonic signal provides an additional level of problem definition or verification. As a result, spectral analysis of demodulated ultrasound has become an indispensable tool in the arsenal of tests used during our daily testing activities.