MEASURING LOW FREQUENCY VIBRATION WITH CXB INSTRUMENT

Low frequency vibration monitoring is an integral part of the total predictive maintenance program. Failure of slow speed machinery can result in catastrophic machine damage, lost production, and worker safety hazards.

CXB and CXM FFT Analyzer are available now for off-route low frequency measurements.

Low frequency condition monitoring generally requires measurements within a 0.1 to 200 Hz bandwidth. Applications Include paper machines, cooling towers and slow speed agitators. Gearboxes, compressors and other higher speed machinery may also exhibit faults in this region. Many structural and geophysical measurements require very low frequency equipment and techniques.

Low frequency applications are <u>more complicated</u> than general machinery monitoring. The relationship between acceleration, velocity, and displacement with respect to vibration amplitude and machinery health redefines measurement technique and data analysis. Motion below 10 Hz (600 CPM) produces very little vibration in terms of acceleration, moderate vibration in terms of velocity, and relatively large vibrations in terms of displacement (Figure 1).

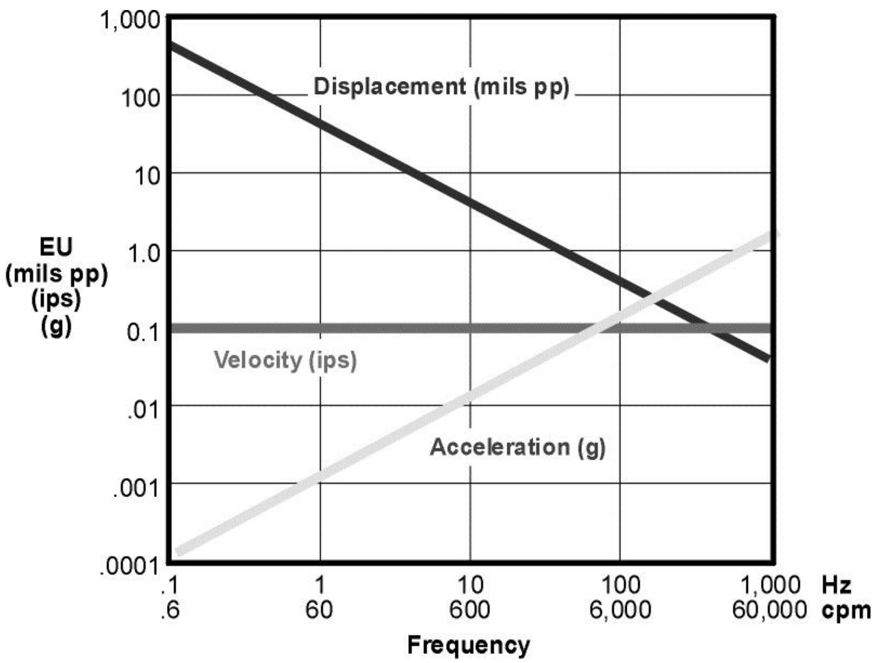


Figure 1 - Relationship between displacement, velocity, and acceleration at constant velocity

Low frequency readings are generally expressed in terms of velocity (mm/sec RMS), or displacement (μm peak to peak). Accelerometer measurements are converted by software. Vibration can be measured with velocity sensors and proximity probes; however these devices lack the versatility of piezoelectric accelerometers (Figure 2).

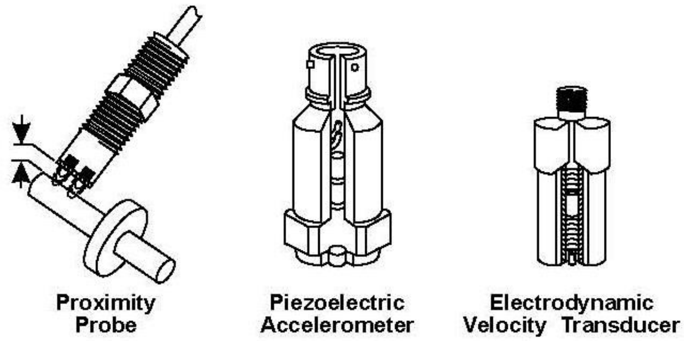


Figure 2 - Sensor types

An example pump measurement is shown in Figure 4. An accelerometer output is displayed in terms of acceleration (Fig.4c), velocity (Fig.4b), and displacement (Fig.4a). The displacement plot exhibits the strongest low frequencies, but attenuates the spectrum above 10,000 Cpm (167 Hz). The acceleration display provides the broadest frequency range.

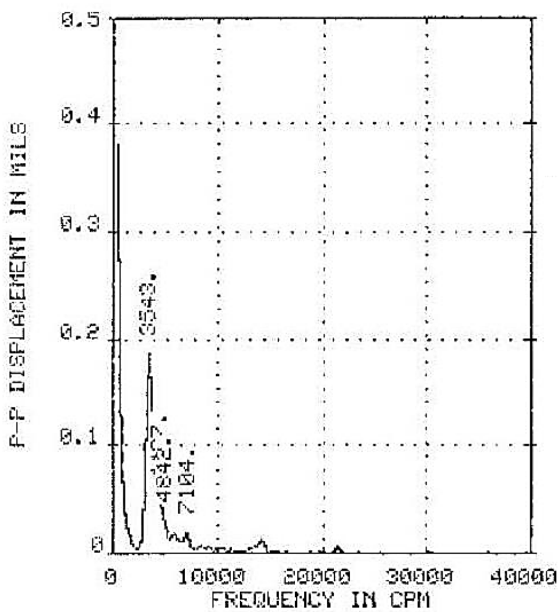


Figure 4a

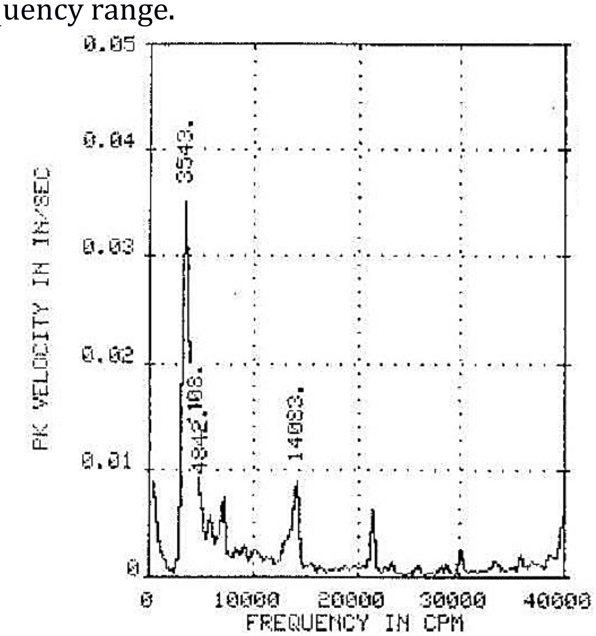


Figure 4b

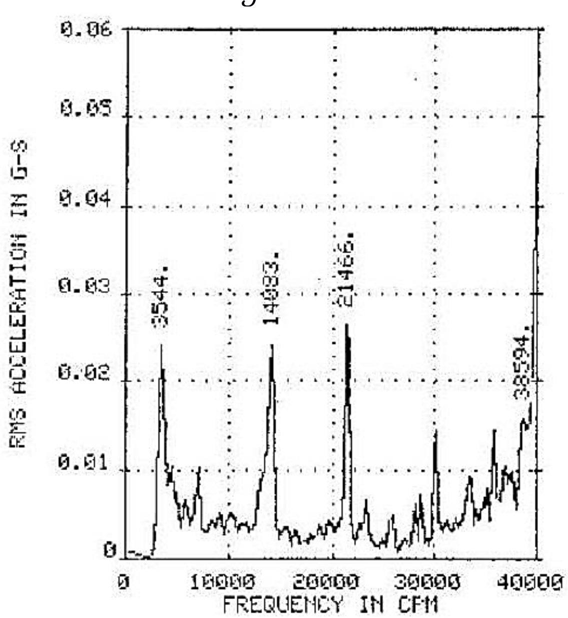


Figure 4c

Piezoceramic accelerometers are used for most low frequency measurement applications. If properly selected, they generate sufficient signal strength for very low amplitude use and integration to velocity or displacement. Compared to other sensors, accelerometers exhibit the broadest dynamic range in terms of frequency and amplitude.

There are several potential problems that must be considered when attempting to measure low frequency vibration using digital instruments that typically utilize accelerometers:

(a) Reduced sensitivity at low frequencies: The sensitivity of standard accelerometer/ instrument combinations used today is significantly reduced at frequencies below the 2 - 10 Hz range (Fig.5).

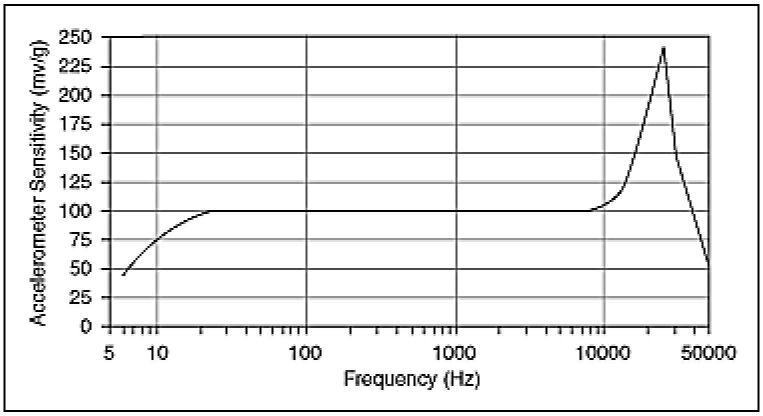


Figure 5 - Accelerometers sensitivity vs. frequency

(b) Instrument integration errors: As previously mentioned, it is usually recommended that velocity units to be used for measuring low frequency vibration. However, a potential problem arises when very low frequencies are received by accelerometers and converted from velocity through single integration, or displacement through double integration. Integration can cause errors on the vibration spectrum. These errors are evident as large "spikes" that occur at the lowest frequencies, usually within the first three lines of resolution (sometimes called "spectral bins"). Sometimes, the amplitude is high enough to force the instrument to auto-range to a higher scale to the detriment of other higher frequencies on the spectrum. The effect is usually worse when using displacement units due to the "double integration error."

To verify whether the indicated peak is real or not, retake the spectrum in acceleration units (which disconnects the integration circuits) and the questionable peak should disappear.

(c) Signal to noise ratio: Signal noise is the primary consideration when performing low frequency measurements. Noise can obscure spectral data, alter amplitude information and render measurements useless. When integrated, low frequency noise is amplified to produce the familiar "ski slope" response.

The first law of low frequency analysis is to *"maximize the signal to noise ratio of the vibration measurement"*. The vibration signal is analogous to a ship on an ocean, where sea level is equivalent to the noise floor of the measurement. The higher the ship rides in the water, the more information about it will be available and the easier it is to detect on the horizon - submerged ships go undetected.

Signal noise results from a combination of three sources: sensor electronic noise, instrument electronic noise and environmental noise. The electronic noise of the sensor is directly related to the charge output of the piezoelectric sensing element and amplifier design. The instrument noise is determined by electronic design, integration method, and the voltage input from the sensor. Environmental noise can result from a variety of external sources, electrical and mechanical in nature.

All amplifiers contain a variety of electronic noise sources including resistors, diodes, and transistors. Resistors create Johnson (white) noise - this is the familiar “crackle” on a low-fidelity stereo system. Johnson noise governs the high frequency noise floor of the measurement. Transistors and other active devices produce Schottky (1/f) noise. Schottky noise increases with decreasing frequency and determines the low frequency measurement limit as demonstrated in Figure 6. The low frequency noise of an accelerometer is proportional to the gain (amplification) of the circuit and inversely proportional to the charge sensitivity of the piezoelectric sensing element.

This is caused by electronic noise which becomes a significant component of the total low frequency signal as the very small acceleration signals diminish with frequency. Many instruments use filters to minimize the noise, but this can mask the true signals as well. The instrument supplier should be able to supply calibration charts that accurately indicate the frequency range of the particular instrument or transducer, but remember that the actual working range will also be affected by operating conditions such as mounting method, temperature and stabilization time. Special accelerometers and instruments are capable of measuring down to 0.25 Hz, but these are usually reserved for special applications due to their expense.

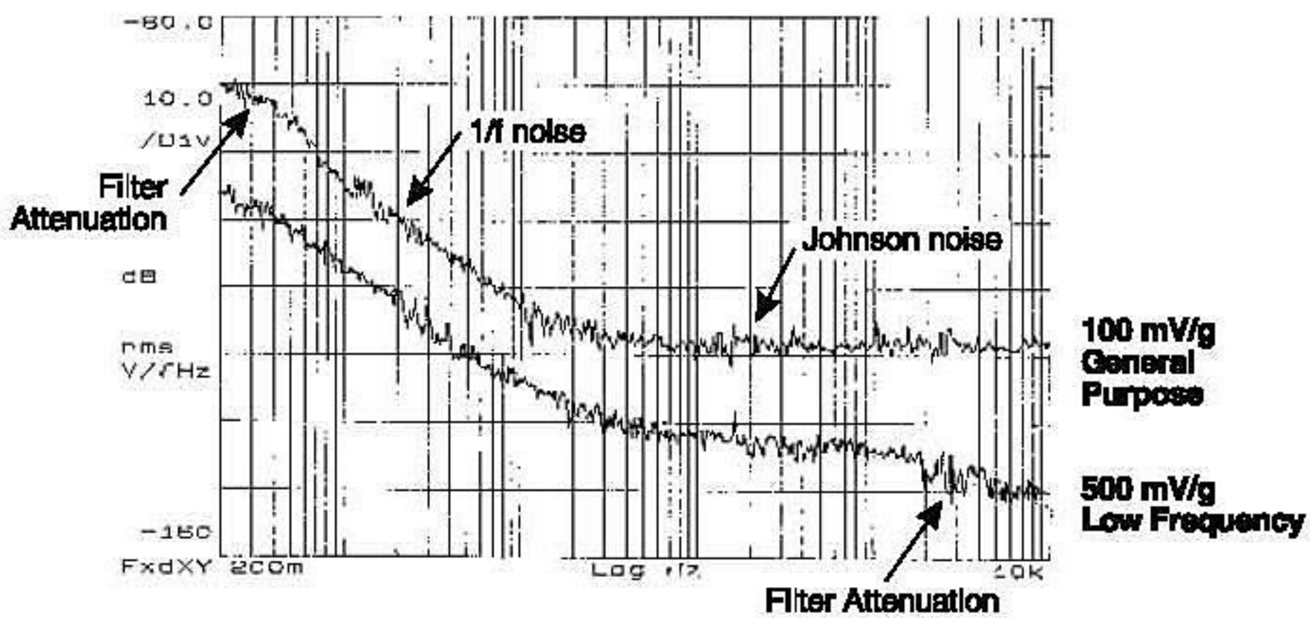


Figure 6 - Noise plot of 100 mV/g and 500 mV/g sensors

Increasing gain to increase the voltage sensitivity will reduce the contribution of instrument noise, but will not change the signal to noise ratio at the sensor. Returning to our analogy above - if the ship were in a canal, increasing the water level in a lock will make it easier to view from the levee, however, the amount of ship that can be seen above the water remains unchanged.

Increasing the charge output of the sensing element (output before the amplification) reduces the need for gain and increases signal to noise. The charge sensitivity can only be increased by adding more seismic mass or using a more active sensing material. In low frequency applications piezo-ceramics should be used to maximize the charge output of the sensing assembly.

(d) Instrument noise: Instrument contribution to system noise depends on electronic design, dynamic range and set up. Instrument components create both Johnson and Schottky noise as described above. Dynamic range considerations require matching the sensor output with instrument processing requirements. Set up factors to be considered are integration, resolution, and averaging.

Analog integration within the monitoring instrument usually increases low frequency noise and lowers signal to noise. The integration circuit converts acceleration to velocity by amplifying low frequency signals and attenuating high frequencies. Low frequency gain also amplifies and accentuates low frequency noise of both the accelerometer and instrument. Double integration from acceleration to displacement requires more amplification and introduces more noise. Integration of low frequency noise is the primary cause of "ski slope". Higher input voltage improves signal to noise by reducing the monitor noise contribution.

Finer instrument resolution improves signal fidelity by reducing spectral amplifier noise. Since electronic amplifier noise is random in nature, spectral sensor noise is determined by measuring the average power of the noise over a specified bandwidth. Spectral amplifier noise is written in terms of volts (or equivalent units) per square root of the measured frequency band; the frequency band used for most specification tests is 1 Hz. If resolution is increased so that the linewidth (measured band) is less than 1 Hz, noise will decrease.

For example, given a sensor with a specified spectral noise of 2.0 $\mu g/\sqrt{Hz}$ at 2 Hz, and an instrument setup for 1,600 lines of resolution over a 0÷200 Hz bandwidth, the linewidth of the measurement is:

(200 Hz – 0 Hz) / 1600 lines = 0.125 Hz

The spectral noise improvement of the sensor is:

$(2.0\mu g/\sqrt{Hz})(\sqrt{0.125}Hz = 0.707\mu g$

Like resolution increases, the down side is longer data collection time (e).

(e) <u>Signal acquisition time</u>: Low frequency measurements are inherently slow. In order to obtain a correct FFT spectrum, theoretically, an acquisition time equal to or greater than the lowest useful frequency period is required. In practice, it was found that the acquisition time should be at least 4-5 times higher than this period. For example, to measure a vibration frequency of 0.25Hz (with a period of 4 seconds), the acquisition time must be at least 16 seconds, plus the time required for processing (filtering and calculating the FFT transform).

The second law is that *"post processing cannot reproduce signals that were not recorded in the first place."* To continue the analogy, if a picture is taken of the sea once the ship is submerged, no amount of photographic enhancement will reproduce its image.

Low frequency signals and noise may vary in amplitude and increase also the auto-ranging time.

Settling time can be a much greater problem in "route" applications. Settling is the time it takes the amplifier bias voltage to recover from shock overload; low frequency accelerometer recovery may vary from 2 seconds to 5 minutes! The problem is most obvious when using magnets at low frequency. Sensors with overload protection circuitry recover from mounting shock much faster than unprotected sensors. Due to the high sensitivity of low frequency sensors, unprotected amplifiers are also at risk of permanent damage from shock overload. This is not the case for "standard" sensitivity accelerometers.

(f) <u>Environmental noise</u>: Environmental noise can be caused by any external signal that directly or indirectly interferes with the measurement. Noise sources can be caused by electrical or mechanical signals originating from the machine under test, nearby machinery, or the plant structure and environment. Very low frequency vibration measurements are much more susceptible to environmental noise than general monitoring.

(g) Indirect sources: Indirect noise originates at high frequency and interacts with the measurement system to produce low frequency interference. Several common examples of indirect mechanical noise include pump cavitation, steam leaks on paper machine dryer cans, and compressed air leaks. These sources produce high amplitude, high frequency vibration noise (HFVN) and can overload the sensor amplifier to produce low frequency distortion. This type of interference is a form of intermodulation distortion commonly referred to as “washover” distortion; it usually appears as an exaggerated “ski slope”.

Pump cavitation produces HFVN due to the collapse of cavitation bubbles. The spectra in Figure 7 show measurements from identical pumps using a 500 mV/g low frequency accelerometer. The first plot displays expected readings from the normal pump; the second shows ski slope due to pump cavitation and washover distortion. Although cavitation overload can mask low frequency signals, it is a reliable sign of pump wear and can be added to the diagnostic toolbox.

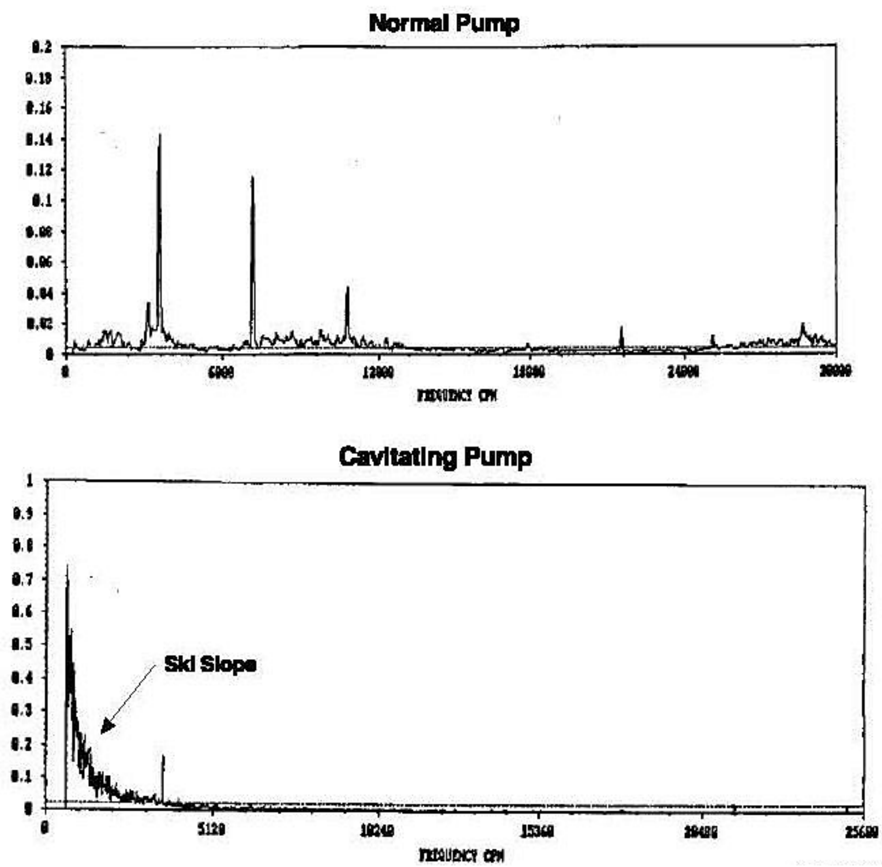


Figure 7 - Low frequency signal overloaded from high frequency pump cavitation

Gas leaks are another common source of HFVN. Paper machines contain steam heated dryer cans fitted with high pressure seals. When a seal leak develops, steam exhaust produces very high amplitude noise. Similar to cavitation, the “hiss” overloads the accelerometer amplifier to produce low frequency distortion. Again, this represents a real problem with the machine that must be repaired.

Low frequency accelerometers are generally more susceptible to HFVN and washover distortion than general purpose accelerometers. This is due to their lower resonance frequency and higher sensitivity.

(h) Indirect sources, electrical noise: Indirect electrical events from electromagnetic radiation and electrostatic discharge can induce noise directly into the measurement system. When mounting or cabling the sensor near radio equipment, ignition wires, or machinery with high voltage corona discharge, low frequency interference becomes a concern. Unless properly protected, the sensor amplifier can rectify very high frequency signals to produce low frequency distortion products. It is very important that overload reduction circuitry be used to prevent the sensor amplifier from operating as an AM radio detector. Anyone who has noticed automobile radio static increase with engine speed has experienced this problem.

(I) Direct noise sources: Direct environmental noise is caused by low frequency mechanical events within the measurement region. Primary sources include thermal transient pickup and interference from unwanted low frequency vibration sources.

Thermal transients cause low frequency expansion of the sensor housing. Often mistaken for the pyroelectric effect, the resultant mechanical strain signal is transmitted to the piezoelectric sensing element. Susceptibility to false signals from thermal transients is directly related to the strain sensitivity of the sensor and filter corner frequency. Low frequency sensors must be designed for low strain sensitivity to prevent thermal transient disturbances.

Direct vibration noise from the rumble of nearby machinery and equipment can limit low frequency measurement in many plant environments. Low frequency energy propagates easily through most structures. At very low frequencies, passing vehicular noise will produce measurement interference. Even advanced noise isolation structures employed in laboratories can be insufficient in traffic prone areas. Some very low frequency measurements must be performed in the middle of the night!

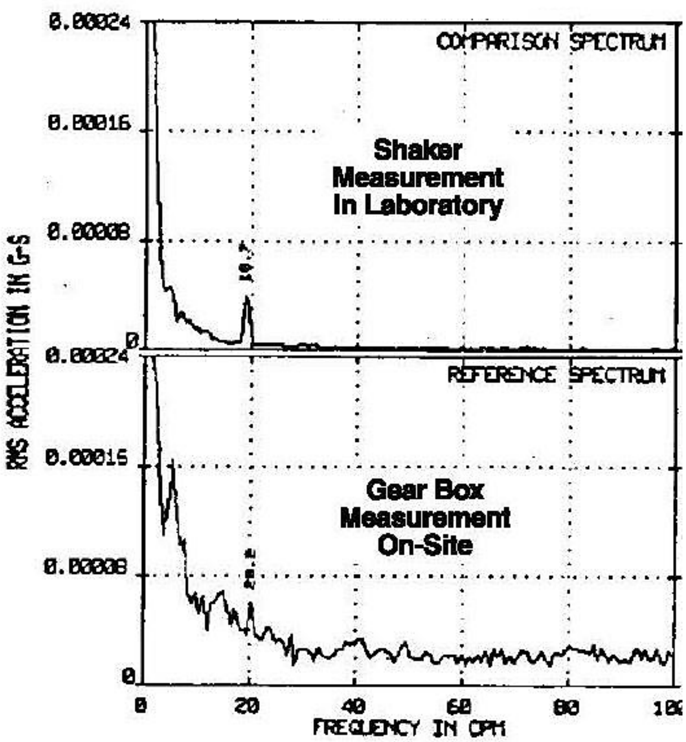


Figure 8 - Comparison spectra of laboratory vs. on-site measurements

The spectra in Figure 8 show the influence of environmentally noise on low frequency measurements. Using a 500 mV/g accelerometer, vibration measurements were made on an agitator gear reducer at a soap factory. The reducer vibration was then simulated in a laboratory on a low frequency shaker. The output shaft vibration was measured to be 2.4 mil pp at 19 Cpm

(0.32 Hz), integration to displacement was implemented by software after the measurement. Comparison of the laboratory and plant spectra clearly shows increased noise due to the plant environment. In this application, the instrument and sensor system noise was not a measurement factor.

(j) Transducers mounting: Stud mounts are recommended for low frequency measurements. Use of magnets and probe tips allow the sensor to move at low frequency and disturb the measurement. Handheld measurements can be disturbed by movement of the operators hand (the coffee factor) and cable motion. Stud mounts firmly attach the sensor to the structure and ensure that only vibrations transmitted through the machine surface are measured. Handheld mounts also exhibit lower mounting resonances and may be more susceptible to HFVN distortion.

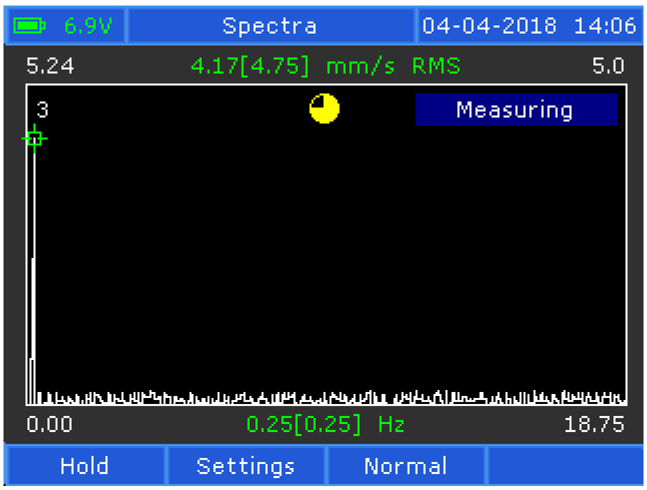
Measure low frequency with CXB and CXM FFT Analyzer

These instruments has a new low frequency range: 0.2 Hz to 200 Hz with a resolution of 0.0625 Hz. Total time for a single measurement is optimize to be around 16-18 seconds (not taking in consideration the auto-ranging, if required), no averaging and without overlapping.

Hanning window is recommended.

Measurements average can be used, but the total acquisition time will increase.

Below is a screen-shot for a low frequency measurement for a very low amplitude signal (0.05 mV from a standard accelerometer) with a frequency of 0.25 Hz. The time-signal is simple-integrated to obtain velocity results. A small yellow progress bar appears in the middle of the spectrum plot to show the measurement progress.



The measurements can be done with standard accelerometers, but better results can be obtained with high sensitivity accelerometers (500 mV/g).

Use of magnets and probe tips is not recommended.

On very low frequencies, attenuation occurs (due to transducer characteristics but also due to instrument hardware). Still the measurements can be used successfully for diagnosis purpose.

Conclusion

Low frequency condition monitoring requires strict attention to selection and use of vibration measurement equipment. The low acceleration amplitudes on slow speed machinery are beyond the measurement limits of general instrumentation and techniques. Concerted efforts to improve the signal to noise ratio of the measurement are required to best utilize data collection time and effort.

Specially designed low frequency piezoceramic sensors are recommended in most applications. Piezoceramic transducers provide superior performance over the broad frequency and amplitude ranges required in industrial applications.

They employ low noise electronics, provide high outputs to the instrument, and resist environmental effects. Instruments must be chosen with low frequency input capability and ample dynamic range. Proper instrument design and set up lowers system noise and speeds data collection time. Special techniques can be used to further improve data reliability. A systematic approach toward low frequency condition monitoring helps ensure that program goals are met.

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