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SELECTING ACCELEROMETERS FOR HIGH-FREQUENCY MEASUREMENTS

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Selecting Accelerometers for High-Frequency Measurements

Vibration data for high-speed equipment can be misleading when general-purpose accelerometers are used. Turbocompressor case shows importance of using the correct sensor and mounting technique.

By Eric Saller and Duane Brzezowski, Industrial Monitoring Instrumentation

As the field of predictive maintenance matures, most facilities are faced with expanding their programs to encompass more and more equipment. The implementation of this additional machinery can produce new and unique monitoring and analysis opportunities as well as some unforeseen difficulties.

However, before any additions can be made to the maintenance program, it is important to carefully evaluate each machine. Complex machines, such as high-speed turbocompressors, require a thorough understanding of their operation and design before potential faults can be detected with vibration analysis. One particular fault indicator on these machines occurs at very high frequencies and can be measured only by using specific monitoring tools such as high-frequency accelerometers.

Accelerometer types

General-purpose accelerometers, when used with data collectors, can handle 80 percent of the applications normally encountered in predictive maintenance programs. When used to monitor equipment such as motors, pumps, and fans, general-purpose sensors can

Technician uses a special high-frequency accelerometer to collect vibration data from a turbocompressor in a processing plant.

INDUSTRIAL HIGH-FREQUENCY SENSOR

GENERAL-PURPOSE SENSOR

LABORATOY-STYLE, HIGH-FREQUENCY SENSOR

Industrial high-frequency accelerometers (left) are smaller than general-purpose sensors (center); laboratory-style high frequency sensors (right) are even smaller.

detect faults such as imbalance and misalignment. These sensors also can detect bearing faults such as cracks on the inner and outer race as well as spalls or pits in the bearings themselves. Each of these faults manifests itself at a specific frequency where the frequency content of the vibration data is related to the type of fault, and the amplitude of the vibration at a specific fault frequency is related to the severity of the fault condition.

When these general-purpose sensors are mounted with industrial magnets during predictive maintenance routes, they have a limited frequency range up to 5 kHz. Unfortunately, many of the industrial machines that require vibration monitoring may have faults that generate fault frequencies outside of the bandwidth of these general-purpose sensors. To accurately monitor the remaining 20 percent of the industrial machinery that falls outside of the frequency range of these sensors, it may be necessary to incorporate either special low-frequency or high-frequency accelerometers.

Applications utilizing slow-speed equipment such as very large mixers, grinders, and cooling towers may require the use of low-frequency accelerometers. These sensors typically will be larger in size and will provide a higher sensitivity and a lower frequency response than general-purpose sensors. These characteristics better enhance the low-level, low-frequency vibrations generated by slow-speed equipment to supply more precise data on potential machinery faults.

At the other end of the spectrum, gearboxes and high-speed spindles demand high-frequency accelerometers capable of supplying a maximum frequency range which can match the faults being monitored. For example, the harmonics of bearing fault frequencies of high-speed spindles may be over 10 kHz, and particular types of turbomachinery produce gear mesh fault frequencies higher than 20 kHz. In both applications, the frequency range to be monitored is well beyond the capabilities of general-purpose accelerometers. To accomplish such measurements, high-frequency sensors are typically smaller and lighter in weight, have a higher mounted resonance, and have an output sensitivity that is lower than the general-purpose sensor.

Turbocompressors

The turbocompressor, one of the most widely used machines in industrial process applications, generally consists of three major mechanical components: motor, gearbox, and the compressor itself. There are also other components such as variable speed drives, solenoid valves, piping, oil coolers, heat exchangers, and others. All of these components together make analyzing a turbocompressor very complex, but it is the main three components that are most important to the analyst.

The most common drive mechanism for the turbocompressor is an electrical motor or some sort of internal combustion engine. Electrical motors are more versatile drives, and can be easily controlled with variable speed drives to match performance or energy conservation criteria. These motors can vary in size from 20 to 1500 hp, and larger ones are available for special applications.

The gearing system usually includes a motor-driven bull gear that is attached to a flywheel, or the bull gear may have enough mass itself to act as its own flywheel. The bull gear then drives usually two or more fixed pinion gears that correspond to each of the stages of the compressor. In most cases, the pinion gears for the rotors are different sizes to allow for different revolution rates. The variation in revolution rates is based on the particular volume rate and operation pressure required for an individual process.

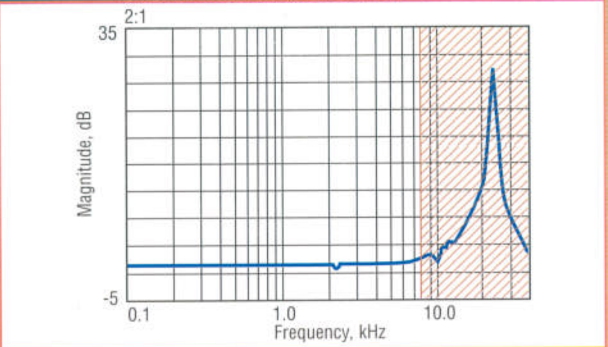
The gas is brought in from an outside source and pushed into the first stage where it is compressed. It is then forced into any following stages where the volume of gas is continually reduced and the pressure rises. Each stage has a compression chamber and rotor, vane, or screw that further compresses the gas. The gas is fed from stage to stage, and finally fed directly into some on-going process or into an accumulator tank for storage.

Failure modes

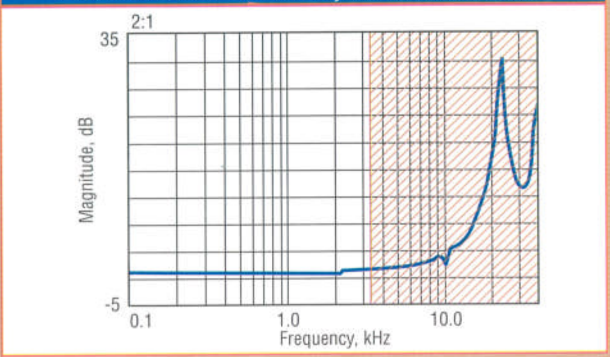
The turbocompressor system can have

CALIBRATION CURVES FOR SIX COMBINATIONS OF ACCELEROMETERS AND MOUNTINGS

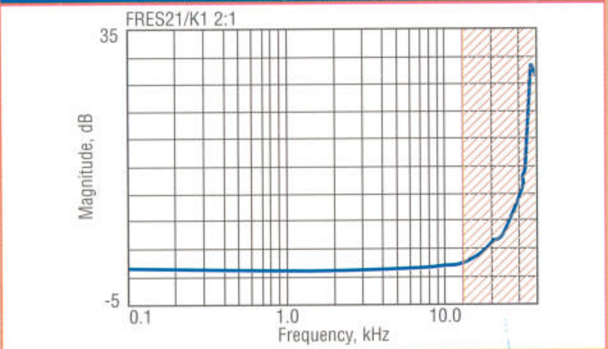
GENERAL-PURPOSE SENSOR, STUD MOUNTED, OK BELOW 8 KHZ



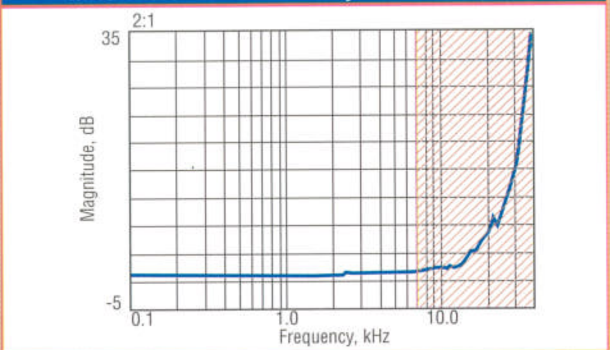
GENERAL-PURPOSE SENSOR, MAGNETICALLY MOUNTED, OK BELOW 3.5 KHZ



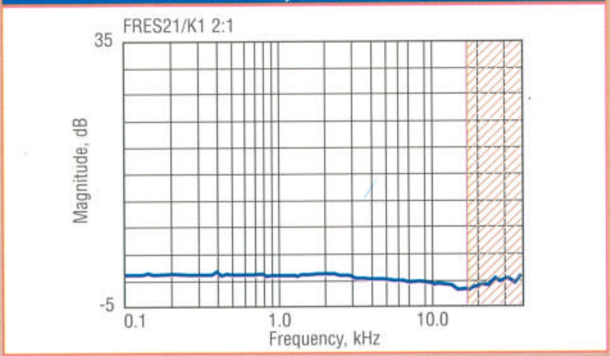
HIGH-FREQUENCY INDUSTRIAL SENSOR, STUD MOUNTED, OK BELOW 15 KHZ



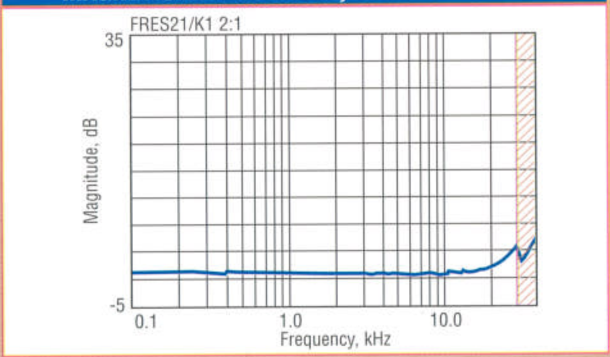
HIGH-FREQUENCY INDUSTRIAL SENSOR, MAGNETICALLY MOUNTED, OK BELOW 7 KHZ



HIGH-FREQUENCY LABORATORY-STYLE SENSOR, STUD MOUNTED, OK BELOW 18 KHZ

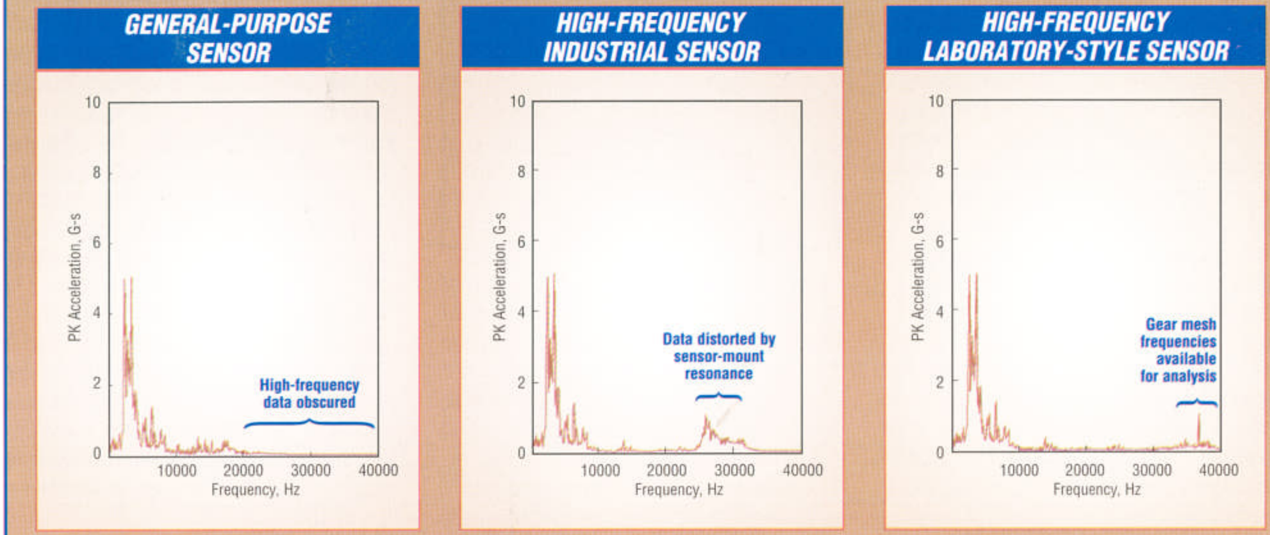


HIGH-FREQUENCY LABORATORY-STYLE SENSOR, MAGNETICALLY MOUNTED, OK BELOW 30 KHZ



Calibration curves of frequency response of accelerometers with stud and magnet mounts show their relative suitability for high-frequency measurements. Signal distorting resonance of each accelerometer-mounting combination becomes visually apparent at higher frequencies. Stud-mounted units generally allow higher response, except for laboratory unit with low pass filtering internal to the sensor, which obtains an upper frequency response to 30 kHz when magnetically mounted.

VIBRATION DATA FROM TURBOCOMPRESSOR GEARBOX COLLECTED WITH MAGNETICALLY MOUNTED ACCELEROMETERS



High-frequency gearbox vibration data is obscured above the mounted resonance of the general-purpose sensor (first curve), so that high-frequency gear mesh vibration data is not available with this setup. High-frequency industrial sensor with a smaller magnet (second curve) may increase the frequency range of the measurement, but resonance obscures vibration data above 25 kHz. Modified high-frequency laboratory-style sensor (third curve) has a flat linear response to 30 kHz, which makes vibration data in the gear mesh frequency range more pronounced than in the other plots. Gear mesh frequencies and their side bands can be analyzed with this data.

many different vibration signatures that indicate failures. These failures can occur in the drive mechanism, the gearing mechanism, the compressor, or in the coupling mechanism between each of these components.

In the drive mechanism for an electric motor, the problems detected by vibration analysis are the standard problems encountered in everyday analysis. These include bearing problems, rotor dynamics, and electrical phasing problems. These problems are as typical for compressors as they are for any other electric motor-driven machine.

The next area on the turbocompressor to analyze would be the gearbox and its components. Usually the gearing between the drive gear and the driven gears for the different stages is analyzed for failures. These failures are often at very high frequencies due to the speed of the motor and the number of gear teeth used in the calculation of the gear mesh frequency. Failure usually will show high amplitudes of 2 to 3 times gear mesh frequency. It is also important to examine the ball or roller pass frequency of the standard bearings used to mount the drive gears for each stage of the compressor.

The analysis of the actual compressor for the system can yield failure modes of different responses. The most prevalent would be a bearing- or bushing-related problem for the screws or vanes, depending on the design of the compressor. These failures can be seen as a raised noise floor with harmonics of the turning speed of the rotor stage. Also, flow turbulence of the individual stages of the compressor could be present and would be shown as raised low-frequency amplitude, not necessarily at a frequency corresponding to the rotation speed of the particular stage in question. There also would be an excitation of frequencies greater than the ball pass frequency of the bearing for the rotor shaft. Some of the larger compressors may use tilt-pad bearings and the standard analysis of these bearings should be observed. One other common failure mode could be rotor rub, characterized by a truncated waveform and raised amplitudes at harmonics of running speeds.

The standard soft-foot condition, coupling wear, and misalignment also should be taken into account during the analysis. These can be seen from elevated amplitudes of 1, 2, and 3 times running speed of the motor. Since most of the components have been individually balanced, balance is not usually a major concern.

Sensor selection

As stated previously, general-purpose sensors, when used with data collectors and mounted with industrial magnets, provide an upper frequency range of approximately 5 kHz. To accommodate applications requiring vibration monitoring of slow-speed equipment, special low-frequency sensors are designed to be larger in size and weight than general-purpose sensors. The additional mass is necessary to produce greater stress on the piezoelectric element, mechanically gain the vibration signal, and provide a greater output. By increasing the internal seismic mass, the natural resonance of the sensor decreases, thereby limiting the upper frequency that the sensor can measure.

High-frequency sensors are just the opposite. The internal seismic mass is made smaller to increase the resonance frequency of the sensor. This broadens the frequency range and allows the unit to measure higher frequency vibrations. Incorporating a smaller seismic mass, high-frequency accelerometers are typically smaller in size than general-purpose sensors. To provide the ruggedness and durability required in industrial predictive maintenance applications, these smaller, high-frequency sensors are equipped with larger, hermetically sealed military-style connectors. For applications requiring measurements beyond 20 kHz, very high-frequency accelerometers are even smaller and may require microdot, laboratory-style connectors.

To obtain the broadest frequency response and the most accurate data, high-frequency accelerometers should be stud mounted directly to the machinery's surface. However, most portable data collection involves periodically mounting the vibration sensors to the machinery with an industrial, magnetic mounting base. Unfortunately, these mounting bases will induce a mounted resonance earlier than the resonance generated from a stud-mounted sensor. This will result in a reduction of the upper frequency range of the sensor. Another factor to consider when mounting high-frequency sensors is the preparation of the machinery surface itself. In order to maintain the highest frequency response possible, it is critical that the mounting surfaces be as clean and smooth as possible.

A high-frequency sensor can be designed to have a very high frequency stud-mounted resonance, and at the same time, have a tailored frequency response to broaden the frequency range when it is magnetically mounted. In order to maintain a clean high-frequency response, the magnetically mounted sensor needs to be mounted on a smooth and clean surface coated with a light lubricant such as silicone vacuum grease. With the application of this lubricant, the higher frequencies of the vibration data will be transmitted cleaner and with greater accuracy.

High-frequency accelerometers should be stud mounted directly to the machinery's surface.

Three different sensors were used to compare the vibration data collected on a high-frequency gearbox in a gas turbocompressor. The first sensor was a general-purpose accelerometer mounted with an industrial magnet, which is the set-up as would be expected on most predictive maintenance routes. The second sensor, an industrial high-frequency accelerometer, was magnetically mounted as well, and featured a higher frequency response and a rugged industrial connector. The third sensor was a laboratory-style accelerometer with a very high-frequency response and a smaller, more fragile connector.

Calibration data

The accompanying curves show frequency response of the three sensors used to gather high-frequency data from the turbocompressor gearbox.

The first sensor, the general-purpose accelerometer, shows an upper frequency response to 8 kHz (±3dB) when stud mounted, and an upper frequency response to 3.5 kHz when magnetically mounted.

The second sensor, the industrial high-frequency accelerometer, shows an upper frequency response to 15 kHz (±3dB) when stud mounted, and an upper frequency response to 7 kHz when magnetically mounted.

The third sensor, the high-frequency, laboratory-style accelerometer, shows an upper frequency response to 18 kHz (±3dB) when stud mounted, and due to low pass filtering internal to the sensor, obtains an upper frequency response to 30 kHz when magnetically mounted.

Field data

Each sensor (the general purpose, the industrial high frequency, and the laboratory-style high frequency) was tested in the field. Each unit was magnetically mounted at exactly the same location on the gearbox of the gas turbocompressor. The accompanying plots represent the high-frequency data that was collected on a portable FFT analyzer.

Normal data collected on predictive maintenance routes is provided by a general-purpose industrial accelerometer with a large dual rail magnet. This combination results in a linear frequency response to only 3 or 4 kHz. High-frequency gearbox vibration data is obscured above the mounted resonance of the sensor-magnet mounting combination. Gathering high-frequency gear mesh vibration data is not possible with this setup.

Using a high-frequency industrial sensor with a smaller magnet may increase the frequency range of the measurement, but high-frequency gearbox vibration data again is obscured above 25 kHz.

The vibration data of the turbocompressor collected with a modified high-frequency laboratory-style sensor. shows a flat linear response to 30 kHz. The high-frequency gearbox vibration data in the gear mesh frequency range is more pronounced than in the other plots. Gear mesh frequencies and their side bands can be analyzed with this data.

Key factors

The predictive maintenance of rotating equipment using vibration monitoring is a very effective technique for diagnosing machinery faults. Typical faults such as oil whip, misalignment, and imbalance all occur at the lower frequencies, less than a few hundred hertz.

Bearing faults manifest themselves at higher frequencies; however, they are often less than 1 kHz. High-frequency equipment such as high-speed spindles and turbocompressor gearboxes generate fault frequencies at much higher levels, usually above 20 kHz. Gathering very high-frequency vibration data with general-purpose accelerometers and industrial magnets will not provide accurate information at the higher frequencies of interest. Amplitudes may be exaggerated due to the amplification of the signals occurring at the mounted resonance or may be obscured if the vibrations are above the mounted resonance.

When performing vibration monitoring, it is critical that the application be thoroughly reviewed. The frequency range of the sensor needs to be considered, particularly the response of the accelerometer with respect to its mounting.

Sensor selection for the measurement is dependent upon the individual fault frequencies that are anticipated.

Sensor selection for the measurement is dependent upon the individual fault frequencies that are anticipated.

By matching the accelerometer's mounted high-frequency response with that of the upper fault frequencies of the apparatus, more accurate data can be collected and analyzed.

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