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# Sensor Selection



## GENERAL SENSOR SELECTION

The goal of sensor selection is to ensure that the anticipated vibration signals fall within various constraints and that the type of sensor chosen is suitable for its intended environment. The usable range of a piezoelectric accelerometer is defined by four constraints: low frequency cut-off, high frequency cut-off, high amplitude limit and low amplitude limit. These ranges are graphically shown in figure 1 below.

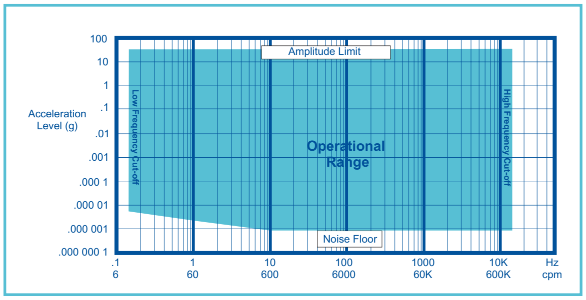


*Figure 1: Operational Range of Accelerometers*

## OUTPUT SENSITIVITY

Before discussing the usable range of an accelerometer, we must first understand its output sensitivity. The output sensitivity of an accelerometer indicates how much voltage will be produced for a given level of vibration excitation. The sensitivity is set when the sensor is manufactured and can't be changed. As discussed later, different sensitivities are appropriate for different applications. The most common output sensitivity for an industrial accelerometer is 100 mV/g. In other words, for each "g" of vibration sensed by the transducer, a signal level of 100 mV will be produced.

Each model sensor has a tolerance associated with the output sensitivity as noted on the specification sheet. If the sensitivity tolerance for a given sensor is ±5%, the buyer will be assured to receive a sensor between 95 mV/g and 105 mV/g measured at its reference frequency (usually 100 Hz). Many less costly sensors have a wider tolerance on sensitivity (±15% for example). In this case, the buyer may receive units between 85 mV/g and 115 mV/g. The exact sensitivity for every sensor is noted with its calibration data.

## FREQUENCY RANGE

The high and low frequency cut-off of an accelerometer defines its frequency range. Figure 2 shows a typical frequency response for an accelerometer. During calibration, the individual sensor sensitivity is obtained by dividing its output by the output of the reference standard at 100 Hz. The frequency response defines how much this sensitivity changes as the sensor vibrates at different frequencies. The flat portion of curve in Figure 2 is the usable frequency range of the sensor.

As the sensor vibrates at lower and higher frequencies, the curve will eventually begin to rise or fall. It will usually begin to decrease

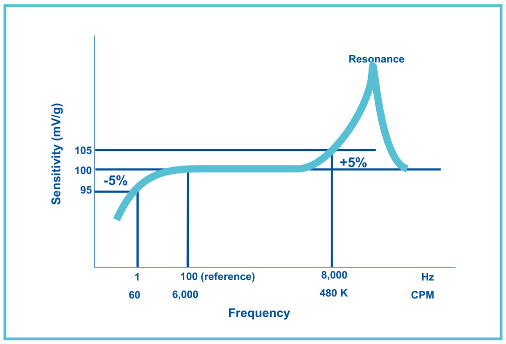


*Figure 2: Typical Accelerometer Frequency Response*

at low frequencies and typically increase at higher frequencies. The usable frequency range is then defined by the frequency values (low & high) that the sensitivity will change from its 100 Hz reference value (100mV/g in this case by a certain tolerance). In the example, if we set our tolerance at ±5%, the frequency range will be those frequencies, high and low, where the sensor drops below 95 mV/g (–5%) or rises above 105 mV/g (+5%). In Figure 2, these values correspond to 1 Hz and 8 kHz respectively. Many specification sheets will provide three ranges of tolerance: ±5%, ±10% and ±3dB. For most industrial applications, a wider tolerance is acceptable, and therefore ±3dB is often accepted as the operating range of the sensor.

Low frequency cut-off is usually determined by the characteristics of a high-pass filter used in the amplifier within the sensor. As we move to the left from our 100 Hz reference frequency, the frequency decreases and the sensitivity will eventually begin to decrease (see Figure 2). At some point, it will reach the tolerance value. The sensor drops to 95 mV/g (–5%) at 1 Hz. This is then the low frequency cut-off.

The high frequency cut-off is usually determined by the resonance of the sensor. As we move to the right from our reference frequency, the sensitivity will begin to increase. As we approach the resonance of the sensor, these values will increase rapidly. The point at which the sensitivity reaches the tolerance value will be the high frequency cut-off. In the example, at approximately 8 kHz, the sensor reaches 105 mV/g (+5%). The frequency range of our example sensor is then 1Hz to 8 kHz at ±5%. This sensor is usable to measure frequencies from 1 Hz to 8 kHz, with ±5% accuracy.




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## AMPLITUDE RANGE

Each accelerometer has a maximum operational vibration range (measured in g's) which it can sense without overloading the electronics within the sensor. This maximum is closely related to the output sensitivity of the sensor. The sensitivity (usually mV/g) defines how much voltage (or mV) the sensor generates per unit of vibration (g's). This characteristic is pre-set within the sensor and cannot be adjusted. Many industrial accelerometers have an output sensitivity near 100 mV/g.

As discussed later in the section on "Power and Signal Conditioning," the supply power (usually 18-30 VDC) and the sensor bias voltage (commonly 12VDC) determine the maximum change in voltage the sensor can experience. For most industrial sensors and monitoring systems, this "voltage swing" will be at least 5 volts. By dividing the available voltage swing by the sensitivity of the sensor (5V/100mV/g) or (5000 mV/100 mV/g), we get the amplitude range. In this case 50 g's. This means that the usable range of the sensor is up to 50 g's of total vibration across frequency range of the sensor.

## NOISE

The low amplitude limit is defined by the noise floor of the sensor. Due to the electronics and the piezoelectric crystals, electrical noise exists within accelerometers. Except for the case of very low frequency measurements, the level of noise (measured in µg's or $10^{-6}$g's) is typically lower compared to the level of the vibration signal. If the vibration signal of interest is significantly greater than the noise of the sensor, the signal can be discerned. The ratio of these levels, known as signal to noise ratio or SNR, is usually recommended to be at least equal to 10. Therefore, if the vibration levels of interest are at least 10 times greater than the noise levels of the sensor, the sensor is usable for the intended measurement. In addition to the noise from the sensor, the noise level of the data acquisition equipment must be considered.

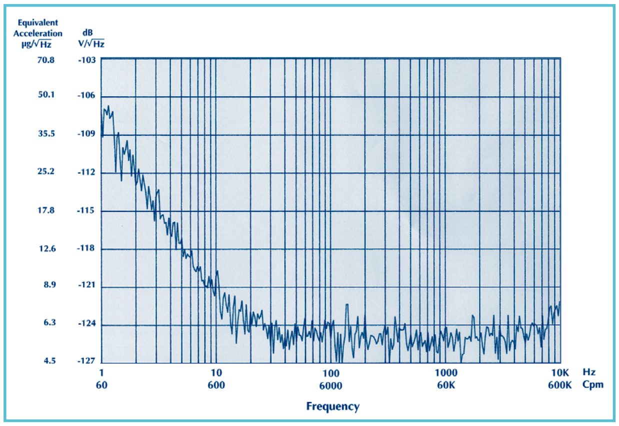


*Figure 3: Sensor Noise Floor*

| Frequency | Noise Level (µg /√ Hz) |
|---|---|
| 1 Hz | 35.0 |
| 10 Hz | 8.0 |
| 100 Hz | 5.0 |
| 1000 Hz | 5.0 |
| 10 kHz | 7.0 |

*Figure 4: Table of Sensor Spectral Noise Levels*

TECH TIP

## UNDERSTANDING NOISE SPECIFICATIONS

Manufacturers of accelerometers occasionally give noise levels in terms of broadband noise or resolution. These figures are the total noise of a sensor (measured in g's) over a given frequency range (2.5 Hz to 25 kHz, for example). The usefulness of broadband noise specification is limited.

Modern signal analysis now divides signals into individual frequency (spectral) components. The ability to observe vibration signals in these narrow frequency bands, disregarding all other frequencies (broadband), makes the sensor noise in the "narrow band" the specification to use.

Because vibration signals (in terms of acceleration) increase significantly as frequency increases, noise levels (even relatively high noise levels) will not be a factor at high frequencies. In other words, at higher frequencies (over 100 Hz) the SNR will usually be much greater than 10 for industrial applications. It is only at low frequencies that noise becomes a consideration where, even in industrial applications, vibration levels (acceleration) can be very low. Noise levels, unfortunately, tend to increase at these low frequencies. In order to compare vibration levels to the noise, noise levels are best expressed in terms of frequency.

It is possible to have vibration signals at low frequencies, which are not 10 times greater than the sensor noise level. In order to avoid this situation, we must evaluate noise levels at various frequencies (not broadband or resolution levels). The best technique to evaluate noise levels is with a graph of noise vs. frequency (see figure 3) or a table of noise levels at discrete frequencies (see figure 4).

Using these methods, noise values are often given in µg/√Hz or $10^{-6}$ g/ √Hz. For example, the table of noise levels in Figure 4 lists noise at 10 Hz = 8 µg/√Hz. For a frequency bandwidth of 1 HZ (for example 9.5 Hz to 10.5 Hz), √Hz Value becomes "1" and the level of noise at 10 Hz +/-0.5Hz is 8 µg or 0.000008 g's. Only vibration signals 10 times greater than this level can be reliably obtained. A sensor designed to measure low frequency vibration data needs to have low noise levels at low frequencies. Sensor noise evaluation is now done with narrowband (spectral) specifications in line with today's signal analysis.

TECH TIP

## SENSOR OVERLOADING

A common problem in industrial vibrations monitoring application is sensor overload. As discussed elsewhere for a given sensor sensitivity and powering there is a limit to the total amount of vibration (usually 50g to 80g for a 100 mV/g sensor) that can be measured. When the total vibration limit is exceeded, erroneous data will be produced. As shown in Figure 5, the time wave data will exhibit a clipped signal and the frequency data will show excessive low frequency vibration commonly known as a "ski-slope" effect. This erroneous data will confuse data analysis and possibly lead to improper fault diagnosis. To test for sensor overload, a lower sensitivity sensor could be substituted. Use of a 10mV/g sensor versus a 100mV/g unit will provide 10 times the vibration range (500 g's vs. 50 g's). The additional range will allow the user to accurately measure the total vibration present and select the most suitable sensitivity for the application. Another test method is to use a "mechanical filter," such as a piece of rubber or even a business card which can be temporarily placed between the sensor and machine. This type of mechanism will filter out much of the high frequency vibration which may be overloading the sensor. If the clippings and ski-slope are no longer present, the original sensor was most likely overloaded. Using an accelerometer with a lower sensitivity will provide enough range for the application. Beware, however, that a lower sensitivity accelerometer will give less output for a given vibration level (and lower signal to noise ratio) which may impair acquisition of low amplitude data. Also note that sensor overload is one of many causes of ski slope data.

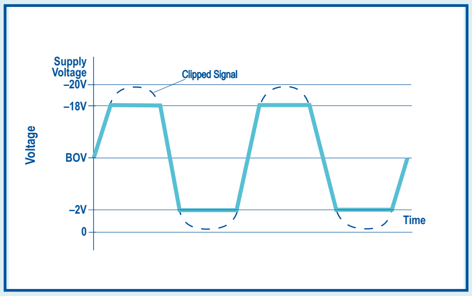


*Figure 5: Signal Overload, Clipping*

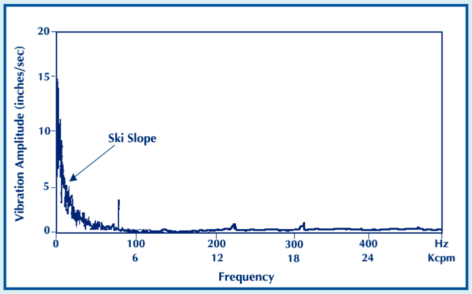


*Figure 6: Low Frequency Distortion, Ski-Slope*

## ENVIRONMENTAL CONSIDERATIONS

Whether an industrial sensor is permanently mounted to a machine or used with a portable analyzer, it must be suitable for the intended environment. Furthermore, the environment must be considered when choosing cables and connectors. Refer to Connectors & Cables for more information.

Case material and sealing are critical considerations to insure long-term sensor survival. The case material which has proven to be the most durable in industrial applications is 316L stainless steel. Other materials such as plastic or aluminum do not provide adequate protection against chemicals, radiation and heat found on paper machines, cooling towers, refineries or even seemingly benign outdoor installations.

Proper sealing is also critical for long sensor life. Besides heat, contamination is the biggest enemy of the electronics within piezoelectric sensors. A quality sensor is built with extra attention to circuit cleanliness and leaves the factory only after all contamination has been removed from within the sensor.

Inadequate sealing of the sensor will allow contaminants such as moisture and chemicals to enter the transducer during its use and will eventually lead to sensor failure. The best type of sealing is hermetic – metal to metal welds or metal to glass fusion. Other seals such as epoxy or mechanical couplings are not appropriate for sensors in harsh industrial installations.

If the case of the accelerometer is made of rugged 316L stainless steel and has a qualified hermetic seal, the most significant environmental threat to sensor longevity is exposure to elevated temperatures. It is widely known that high temperatures and electronics are generally not compatible. The circuitry of internally amplified sensors is no different. While nearly all Wilcoxon industrial sensors are rated to 250ºF (120ºC), exposures to higher temperatures will lead to amplifier failures. A sensor which fails due to excessive heat will generally have a drop in bias output voltage. Wilcoxon's Fire*FET*® sensors (793-6 and 797-6) and charge mode sensors are designed to operate at temperatures beyond 250ºF. (Refer to the High Temperature Sensor section)

TECH TIP

## HERMETIC SEALING AND TEST METHODS

Loosely defined as a "metal to metal weld, braze, solder or metal to glass fusion," hermetic sealing is a vague (and often abused) term. Even a porous weld would qualify as hermetic even though its ability to prevent contamination would be negligible. Epoxy sealed sensors are not considered hermetic. In order to quantify and compare levels of hermetic sealing, we can use an example leakage scale (see table below) where the leakage rate of helium is stated in cc/second at 1 atmosphere of pressure. Wilcoxon industrial sensors have the highest hermetic seal rating in the industry. Wilcoxon uses the Helium Leak Test (HLT) to qualify the sealing of all sensor designs and maintains a continuous monitoring program to insure the proper sealing of all hermetically rated accelerometers.

| Leakage Rate (cc/sec) | Example | Time for 1 cc to Leak (@1 atm.) | Suitable Test Method |
|---|---|---|---|
| $10^{-4}$ | Poorly Built Accelerometers | 2.78 hours | Bubble Test |
| $10^{-6}$ | Beverage Cans | 11.57 days | HLT |
| $10^{-7}$ | Vacuum Process Systems | 3.86 months | HLT |
| $10^{-8}$ | Typical Wilcoxon Industrial Accelerometers | 3.22 years | HLT |
| $10^{-9}$ | Pacemaker | 32 years | HLT |

### Bubble Testing (simplified description)

A bubble test is performed by subjecting units to be tested to a pressurized atmosphere. 50 to 100 Pounds per Square Inch (PSI) would be typical of the pressure used. The units are exposed, typically, for thirty minutes to one hour. At the end of the pressure soak the units are submerged under water and observed to see if bubbles form on the surface, bubbles are continuously formed and break free, or a stream of bubbles emanate from the unit under test. The lowest leak rates detectable by bubble testing are around 1 x $10^{-5}$ cc/second.

### Helium Leak Test (simplified description)

HLT is performed by placing units to be tested in a chamber and then pressurizing that container with Helium. Pressures of 90 to 120 PSI are typical of the exposure for standard leak tests. Wilcoxon uses 120 PSI. After an appropriate time of exposure, the units are removed and, one at a time, placed in a test chamber. A vacuum is drawn and, when the vacuum is low enough, the remaining escaping gasses are sent to a mass spectrometer tuned to detect Helium. The HLT equipment can detect leak rates to 1 x $10^{-9}$ and below. Units with leak rates above about 1 x$10^{-3}$ will saturate the detector and are usually considered "gross leakers." A "gross leaker" is not considered hermetic, even though it is welded and may look sealed!

### Wilcoxon Quality

All accelerometers rated as "hermetic" on the data sheet are qualified using HLT. Wilcoxon uses the results of HLT in setting parameters for welding equipment to insure consistent hermetic qualified welds. Since all hermetically rated accelerometer designs have been subjected to pressure testing of 120 PSI, they are rated to withstand 100 PSI of pressure from submersion. Since Helium molecules are very tiny compared to water molecules, passing an HLT insures surviving underwater submersion for an indefinite period of time.

TECH TIP

## OTHER ENVIRONMENTAL CONSIDERATIONS INCLUDE SHOCK OVERLOAD PROTECTION, RADIO FREQUENCY (RF) INTERFERENCE SUSCEPTIBILITY AND INTERMODULATION OR WASHOVER DISTORTION.

Sensors used with a magnet in a walkaround program need to incorporate shock protection to protect against the very high acceleration levels associated with "snapping" the magnet onto equipment. Because tests at Wilcoxon have shown shock levels due to magnet mounting can reach several thousand g's, a protection level of 5,000 g was built into all industrial accelerometers.

High levels of RF signals in the area of an accelerometer have potential to introduce spurious signals which can be mistaken for machinery vibration. To protect against these false signals, Wilcoxon uses an internal shield within the sensor and employs the highest level RFI protection circuitry in the industry. (Refer to Junction Boxes for more information).

Very high frequency signals can generate "washover" in the usable band of an accelerometer. Washover shows up as false signals that could be misinterpreted as vibration data. Also known as intermodulation, generation of these signals is common in high noise environments. Many Wilcoxon industrial sensors protect against washover distortion with the use of special filtering techniques.

### INTRINSIC SAFETY PROTECTION

Many applications require Intrinsic Safety (IS) protection. In some industries, machinery operates in the presence of hazardous and flammable gases. Any electrical equipment used or installed in these areas require protection to insure that they do not pose any potential of causing ignition of the gases. Commonly known as IS protection, the requirements vary depending on certifying agency and environment ratings. A list of Wilcoxon IS certified sensors and the certifying agencies can be found on pages 128 and 129. On specification sheets, products with IS certification will display the certifying agencies logo under "Options".

Often a barrier strip is required to be used for sensors permanently mounted in hazardous areas. These zener devices act as a fuse to limit the amount of energy that can be sent to the sensor. Wilcoxon offers two barrier strips, refer to the Mounting & Accessories section on page 121. For more information on Intrinsic Safety, consult Wilcoxon Customer Service .


### 1 IS A WIDER SENSITIVITY TOLERANCE BAD, SUCH AS ±15%?

Not necessarily, if trending on vibration levels then wider tolerances, such as ±15%, provides adequate, cost effective information for a successful monitoring program. Also, nearly all data collection boxes, analyzers and acquisition systems have the ability to enter the exact sensitivity of a sensor. In these cases, purchasing a sensor with a wide tolerance is acceptable as long as its sensitivity is appropriately noted. However, if the user is unable to enter the exact sensitivity and the acquisition equipment assumes a nominal sensitivity, then a precise measure of the vibration level may not be possible. For example, if the acquisition equipment assumes the vibration signal is obtained from a 100mV/g sensor and the actual sensor being used is 85 mV/g, the vibration readings will be 15% low. In this case, a tighter tolerance (±5%) may be more appropriate. If possible, enter the exact sensitivity of the sensor into the acquisition system to obtain the most precise measurements.

### 2 WILL A WIDE SENSITIVITY TOLERANCE (±15% VS. ±5%) MEAN A NARROWER FREQUENCY RESPONSE?

No. Sensor frequency response is based on sensitivity variation relative to the sensitivity at the 100 Hz reference point. Whether the reference sensitivity is 105 mV/g or 85mV/g, the frequency at which the sensor sensitivity increases/decreases by a specified amount (ie. 10% or 3dB) remains constant.

### 3 HOW OFTEN SHOULD AN INDUSTRIAL SENSOR BE RE-CALIBRATED?

With proper handling and usage, Wilcoxon industrial accelerometers do not need frequent re-calibration. Wilcoxon's proprietary crystal preparation stabilizes the ceramic crystals used within the sensors to minimize output drift due to aging. Maximum sensitivity drift is less than 1% over the life of the sensor. If exact accuracy of vibration levels is necessary, the sensors should be re-calibrated annually. Otherwise, Wilcoxon sensors need to be re-calibrated only if exposed to mistreatment (overshock, extremely high temperatures) or if required by regulations (ISO 9000, Nuclear Regulatory Commission). Wilcoxon offers calibration and testing services for any make sensor.

### 4 HOW LONG DO PIEZOELECTRIC SENSORS LAST?

Piezoelectric sensors are solid state sensors with no internal moving parts to wear or fatique. Mean Time Between Failure (MTBF) analysis for typical industrial sensors predicts a life of 12 years. However, many sensors returned to Wilcoxon for re-calibration are more than 30 years old and still operating. While many sensors do indeed last beyond a decade, empirical data suggests an average life of approximately 7 years. If a sensor is continuously operated to the full limits of their environmental specifications, then their life span can be decreased. Sensors exposed to high temperatures (> 200ºF) and rough handling are candidates for earlier failures than those permanently mounted in benign environments.

### 5 IS A SHEAR MODE SENSOR SUPERIOR TO COMPRESSION MODE?

What about flexure mode sensors? In recent years, shear mode sensors have gained popularity, while compression mode are often considered to be "old technology." Meanwhile, flexure mode sensors, once considered too fragile for industrial applications, are now making a comeback by incorporating special design techniques. Each construction method has inherent advantages and disadvantages. The construction method of a sensor is less important than its performance.

For each model, characteristics such as base strain and shock limits are quantified on the specification sheet and can be compared. For example, a well-designed compression mode sensor may have a lower base strain rating than a shear mode sensor. While this may be contrary to intuition, it can be verified by comparing the values of the 793 (compression) versus the 787A (shear). In today's advanced designs, the right sensor for an application is determined by the performance yielded by different design techniques.




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