Wilcoxon SENSING TECHNOLOGIES

Sensor selection guide

Global competition and pressure on corporate performance make productivity a primary concern for any business. Machinery vibration monitoring programs are effective in reducing overall operating costs of industrial plants. Vibration signals produced by industrial machinery are effective indicators of machinery health. Monitoring vibration levels over time records the machine's vibration history, allowing plant engineers to predict problems before serious damage or failure occurs. Machinery damage and costly production delays caused by machinery failure can be prevented – when problems are discovered early, there is an opportunity to schedule maintenance and thereby reduce downtime in a cost-effective manner. Vibration analysis is used as a tool to determine machine condition and the specific cause and location of machinery problems. This expedites repair and minimizes cost.

This technical note will cover the important factors to consider when choosing a vibration sensor. These include the type of machinery being monitored, environmental conditions in the plant, and the different types of vibration sensors. Sensor specifications and their relevance to industrial applications are discussed.

Common vibration sensors

Critical to vibration monitoring and analysis is the machine-mounted sensor. Three parameters representing motion detected by vibration monitors are displacement (in inches), velocity (in inches per second, or ips), and acceleration (in g's). These parameters are mathematically related and can be derived from multiple types of motion sensors. Selection of a sensor proportional to displacement, velocity or acceleration depends on the frequencies of interest and the signal levels involved. Figure 1 shows the relationship between velocity and displacement versus constant acceleration. Proper sensor selection and installation is crucial to accurately diagnosing machine condition.

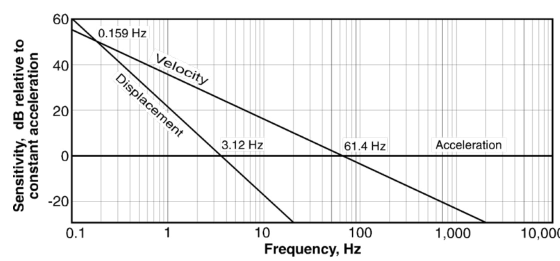

Figure 1. The Relationship of Velocity and Displacement to Acceleration

Displacement sensors

Displacement sensors are used to measure shaft motion and internal clearances. Monitors have used non-contact proximity sensors, such as eddy probes, to sense shaft vibration relative to bearings or other support structures. These sensors are best suited to measuring low frequency and low amplitude displacements typically found in sleeve bearing machine designs. Piezoelectric displacement transducers (doubly integrated accelerometers) have been developed to overcome problems associated with mounting non-contact probes, and are more suitable for rolling element bearing machine designs. Piezoelectric sensors yield an output proportional to the absolute motion of a structure, rather than relative motion between the proximity sensor mounting point and the target surface.

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Velocity sensors

Velocity sensors are used for low to medium frequency measurements. They are useful for vibration monitoring and balancing operations on rotating machinery. As compared to accelerometers, velocity sensors have lower sensitivity to high frequency vibrations, making them less susceptible to amplifier overloads. Overloads can compromise the fidelity of low amplitude, low frequency signals. Traditional velocity sensors use an electromagnetic (coil and magnet) system to generate the velocity signal. Now, hardier piezoelectric velocity sensors (internally integrated accelerometers) are gaining in popularity due to their improved capabilities. A comparison between the traditional coil and magnet velocity sensor and the modern piezoelectric velocity sensor is shown in Table 1.

Table 1: Coil and magnet vs. piezoelectric velocity sensors

	Coil and magnet	**Piezoelectric**
Flat frequency response 20 - 1,500 Hz 2 - 5,000 Hz	 Yes No	 Yes Yes
Phase fidelity 2 - 5,000 Hz	 Poor	 Excellent
Low off-axis sensitivity	No	Yes
Reduced noise at high frequencies	No	Yes
Linearity	Good	Good
Mounting in any orientation	No	Yes
Operation to 120°C	Yes	Yes
EMI resistance	Poor	Excellent
Mechanical durability	Fair	Excellent

Accelerometers

Accelerometers are the preferred motion sensors for most vibration monitoring applications. They are useful for measuring low to very high frequencies and are available in a wide variety of general purpose and application-specific designs. The piezoelectric accelerometer is unmatched for frequency and amplitude range. Accelerometers are versatile, reliable and the most popular type of vibration sensor for industrial machinery monitoring.

Piezoelectric sensors

The rugged, solid-state construction of industrial piezoelectric sensors enables them to operate under most harsh environmental conditions. They are unaffected by dirt, oil and most chemical atmospheres. They perform well over a wide temperature range and resist damage due to severe shocks and vibrations. Most piezoelectric sensors used in vibration monitoring today contain internal amplifiers.

The piezoelectric element in the sensor produces a signal proportional to acceleration. This small acceleration signal can be amplified for acceleration measurements or electronically integrated within the sensor into a velocity or displacement signal. The piezoelectric velocity sensor is more rugged than a coil and magnet sensor, has a wider frequency range, and can perform accurate phase measurements.

Piezoelectric materials

The two basic piezoelectric materials used in vibration sensors today are piezoelectric ceramics and quartz. While both are adequate for successful sensor design, differences in their properties allow for design flexibility. For example, quartz has lower charge sensitivity and exhibits a higher noise floor than modern piezoceramic materials. Most vibration sensor manufacturers now use piezoceramics developed specifically for sensor applications. Special formulations yield optimized characteristics to provide accurate data in extreme operating environments. The exceptionally high output sensitivity of piezoceramics allows for the design of sensors with increased frequency response when compared to quartz.

Much has been said of the thermal response of quartz versus piezoceramics. Both materials exhibit an output during a temperature change (known as the pyroelectric effect) when the material is not mounted within a sensor housing. Although this effect is much lower in quartz, when properly mounted within the sensor housing the elements are isolated from fast thermal transients. The difference in materials then becomes insignificant. The dominant thermal signals are caused by metal case expansion strains reaching the base of the crystal. These erroneous signals are then a function of the mechanical design, rather than of the sensing material. Proper sensor designs isolate strains and minimize thermally induced signals. (See the section “Temperature range” on page 5.)

High quality piezoceramic sensors undergo artificial aging during the production process. This ensures stable and repeatable output characteristics for long term vibration monitoring programs. Theoretical stability advantages of quartz over ceramic designs are eliminated as a practical concern.

The development of advanced piezoceramics with higher sensitivities and capability to operate at higher temperatures is anticipated.

Choosing an industrial sensor

When selecting a piezoelectric industrial vibration sensor (acceleration, velocity or displacement), many factors should be considered to make sure the selection is the best one for the application. The user who addresses application-specific questions will become more familiar with sensor requirements.

Typical questions include:

- What is the vibration level?
- What is the frequency range of interest?
- What is the temperature range required?
- Are any corrosive chemicals present?
- Is the atmosphere combustible?
- Are intense acoustic or electromagnetic fields present?
- Is there significant ESD present in the area?
- Is the machinery grounded?
- Are there sensor size and weight constraints?

Related questions concerning the connectors, cables and associated electronics:

- What cable lengths are required?
- Is armored cable required?
- To what temperatures will the cable be exposed?
- Does the sensor require a splash-proof connector?
- What are the power supply requirements?

Primary sensor considerations

Two of the main parameters of a piezoelectric sensor are the sensitivity and the frequency range. In general, most high frequency sensors have low sensitivities and, conversely, most high sensitivity sensors have low frequency ranges. It is therefore necessary to compromise between the sensitivity and the frequency response.

The sensitivity range

The sensitivity of industrial accelerometers typically ranges between 10 and 100 mV/g; higher and lower sensitivities are also available. To choose the correct sensitivity for an application, it is necessary to understand the range of vibration amplitude levels to which the sensor will be exposed during measurements.

As a rule of thumb, if the machine produces high amplitude vibrations (greater than 10 g rms) at the measurement point, a low sensitivity (10 mV/g) sensor is preferable. If the vibration is less than 10 g rms, a 100 mV/g sensor should generally be used. In no case should the peak g level exceed the acceleration range of the sensor. This would result in amplifier overload and signal distortion, generating erroneous data. Higher sensitivity accelerometers are available for special applications such as low frequency/low amplitude measurements. In general, higher sensitivity accelerometers have limited high frequency operating ranges. One of the excellent properties of the piezoelectric sensor is its wide operating range. It is important that anticipated amplitudes of vibration fall reasonably within the operating range of the sensor. Velocity sensors with sensitivities from 20 to 500 mV/ips are available. For most applications, a sensitivity of 100 mV/ips is satisfactory.

The frequency range

In order to select a sensor with the appropriate frequency range, it is necessary to determine the frequency requirements of the application. This range is often already known from vibration data collected from similar systems or applications. The plant engineer may have enough information on the machinery to calculate the frequencies of interest. Sometimes the best method to determine the frequency content of a machine is to place a test sensor at various locations on the machine and evaluate the data collected.

The high frequency range of the sensor is constrained by its increase in sensitivity as it approaches resonance. The low frequency range is constrained by the amplifier roll-off filter, as shown in Figure 2. Many sensor amplifiers also filter the high end of the frequency range in order to attenuate the resonance amplitude. This extends the operating range and reduces electronic distortion.

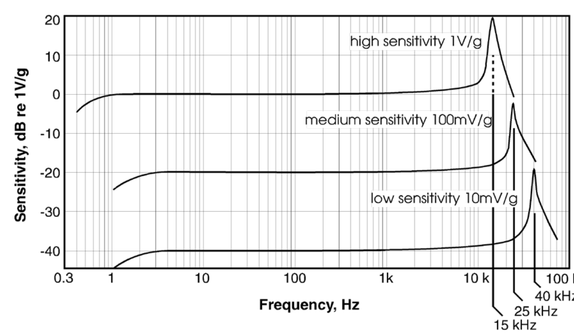

Figure 2. Typical Frequency Response Curves for Various Sensitivities

Most vibrations of industrial machinery contain frequencies below 1,000 Hz (60,000 CPM), but signal components of interest often exist at higher frequencies. For example, if the running speed of a rotating shaft is known, the highest frequency of interest may be a harmonic of the product of the running speed and the number of bearings supporting the shaft. The user should determine the high frequency requirement of the application and choose a sensor with an adequate frequency range, while also meeting sensitivity and amplitude range requirements. (Note that sensors with lower frequency ranges tend to have lower electronic noise floors. Lower noise floors increase the sensor's dynamic range and may be more important to the application than the high frequency measurements.)

High amplitude vibration signals

The sensor operating environment must be evaluated to ensure that the sensor's signal range not only covers the vibration amplitude of interest, but also the highest vibration levels that are present at that measurement point. Exceeding the sensor's amplitude range can cause signal distortion throughout the entire operating frequency range of the sensor.

Temperature range

Sensors must be able to survive temperature extremes of the application environment. The sensitivity variation versus temperature must be acceptable to the measurement requirement. Temperature transients (hot air or oil splash) can cause metal case expansion, resulting in erroneous output during low frequency (<5Hz) measurments. A thermal isolating sleeve should be used to eliminate these errors.

Humidity

All vibration sensors are sealed to prevent the entry of high humidity and moisture. In addition, cable connectors and jackets are available to withstand high humidity or wet environments.

Hazardous areas

Vibration sensors certified as being intrinsically safe should be used in areas subjected to hazardous concentrations of flammable gas, vapor, mist, or combustible dust in suspension. Intrinsic safety requirements for electrical equipment limit the electrical and thermal energy to levels that are insufficient to ignite an explosive atmosphere under normal or abnormal conditions. Even if the fuel-to-air mixture in a hazardous environment is in its most volatile concentration, intrinsically safe sensors are incapable of causing ignition; this greatly reduces the risk of explosions.

Electrical powering requirements

Most internally amplified vibration sensors require a constant current DC power source. Generally, the power supply contains an 18 to 30 V source with a 2 to 10 mA constant current diode (CCD) (see Figure 3). When other powering schemes are used, consultation with the sensor manufacturer is recommended. A more thorough discussion of powering requirements follows.

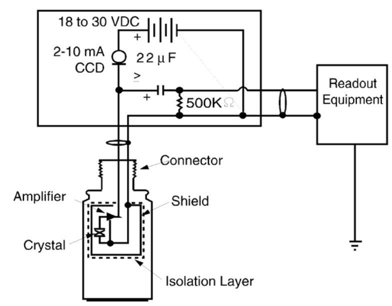

Figure 3. Powering Schematic

AC coupling and the DC bias voltage

The sensor output is an AC signal proportional to the vibration of the structure at the mounting point of the sensor. This AC signal is superimposed on a DC bias voltage, also referred to as bias output voltage (BOV) or rest voltage. The DC component of the signal is blocked by a capacitor. This capacitor, however, passes the AC output signal to the monitor. Most monitors and sensor power supply units contain an internal blocking capacitor for AC coupling. If not included, a blocking capacitor must be field-installed.

Amplitude range and supply voltage

The sensor manufacturer usually sets the bias voltage halfway between the lower and upper cutoff voltages (typically 2 V above ground and 2 V below the minimum supply voltage). The difference between the bias and cutoff voltages determines the voltage swing available at the output of the sensor. The output voltage swing determines the peak vibration amplitude range (see Figure 4). Thus, an accelerometer with a sensitivity of 100 mV/g and a peak output swing of 5 V will have an amplitude range of 50 g peak.

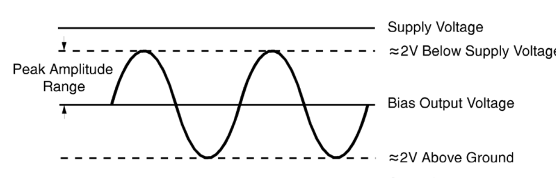

Figure 4. Range of Linear Operation

If a higher supply voltage is used (22 to 30 VDC), the amplitude range can be extended to 100 g peak. If a voltage source lower than 18 V is used, the amplitude range will be lowered accordingly. Custom bias voltages are available for lower or higher voltage supply applications.

Constant current diodes

Constant current diodes (CCDs) are required for two-wire internally amplified sensors. In most cases, they are included in the companion power unit or monitor supplied. Generally, battery powered supplies contain a 2 mA CCD to ensure long battery life. Line powered supplies (where power consumption is not a concern) should contain a 6 to 10 mA CCD when driving long cables. For operation above 100°C, where amplifier heat dissipation is a factor, limit the current to less than 6 mA.

If the power supply does not contain a CCD for sensor powering, one should be placed in series with the voltage output of the supply. It is important to ensure that proper diode polarity is observed.

High temperature piezoelectric vibration sensors

High temperature industrial sensors are available for applications up to 1,400°F. Currently, high temperature sensors are not internally amplified above 170°C (350°F). Above this temperature, sensors are unamplified (charge mode). Charge mode sensors usually require a charge amplifier. The sensitivity of unamplified sensors should be chosen to match the amplitude range of the amplifier selected. The unit of sensitivity for charge mode accelerometers is expressed in picoCoulombs/g (pC/g). It is necessary to use special low noise, high temperature cables with charge mode sensors to avoid picking up triboelectric noise–erroneous signals caused by cable motion.

It is recommended that a custom thermal isolation mount be used with amplified sensors for applications where the frequency of interest is less than 5 kHz and the temperature is below 170°C.

Triaxial sensors

Many industrial customers use triaxial vibration sensors for multi-directional machine monitoring and balancing. These devices contain three mutually perpendicular sensors which give the user more information about machine health than conventional single-axis units. A triaxial sensor is also easier to mount than three separate single-axis sensors.

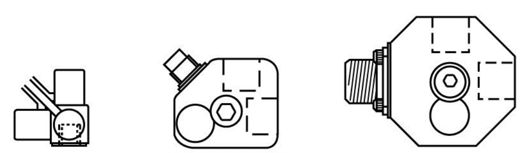

Figure 5. Triaxial Accelerometers

Handprobes

Handprobes are handheld sensors used to measure vibration. Requiring no mounting, they are quick, easy to use, and provide a good introduction to machine health monitoring. Though their frequency response is limited compared to stud mounted sensors, the information they provide can be very useful. In conjunction with portable data loggers, handprobes are versatile instruments for basic vibration analysis and trend monitoring.

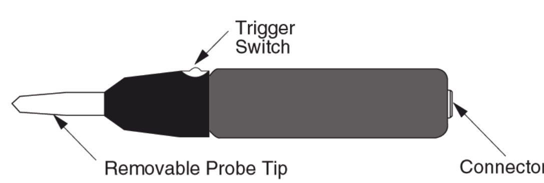

Figure 6. Model HA8 Handprobe

Summary

Vibration sensors are the initial source of information about machine condition, upon which productivity, product quality and personnel safety decisions are based. It is crucial that sensors be properly selected and installed to ensure reliable signal information. This technical note outlined some of the critical parameters that should guide the selection of industrial vibration sensors. Following this process will increase the effectiveness of your vibration monitoring program and improve productivity of plant personnel and equipment. The attached checklist may be used to aid in the process of sensor selection.

Once the correct sensors have been chosen, they must be mounted on plant machinery. With a firm understanding of the sensor requirements, capabilities, and limitations, the vibration analyst should have evaluated and determined the mounting location of each sensor based upon the specific machine and vibration source to be monitored, as well as the cabling requirements. Refer to Wilcoxon's technical notes "Mounting considerations," "Installation of vibration sensors" and "Vibration sensor wiring and cabling" for more information on these topics.

Sensor selection checklist

For assistance in selecting a vibration sensor, specific application and measurement requirements should be provided to the application engineer. Completing the checklist below will help ensure that the proper sensor is chosen.

I) Describe the vibration measurement application (check all that apply):

- ☐ Pulp and paper
- ☐ Petrochemical
- ☐ Power plant
- ☐ Oil exploration
- ☐ Mining
- ☐ Other _________
- ☐ Automotive
- ☐ Laboratory research
- ☐ Microelectronics
- ☐ Civil engineering
- ☐ Military

II) Please describe the dynamic measurement requirements of the application:

What is the approximate vibration amplitude level to be measured?
_________g peak, ______in/sec peak, ______mil peak
What is the maximum vibration amplitude level expected to be present?
_________g peak, ______in/sec peak, ______mil peak
What is the minimum vibration amplitude level of interest?
_________g peak, ______in/sec peak, ______mil peak
What is the maximum frequency of interest?
___________Hz, _________RPM
What is the minimum frequency of interest?
___________ Hz, _________RPM

III) Mechanical and chemical environment of the application:

What is the continuous temperature range? (min. to max.)
__________ to _________ ºC, __________ to _________ ºF
What is the intermittent temperature range? (min. to max.)
_________ to _________ ºC, __________ to _________ ºF
What is the expected humidity level? ________ % relative
What fluids contact the accelerometer? ____
If submerged, what fluid pressure will be present? _________ psi
What high amplitude mechanical signals present? (i.e. steam valve release, gear chatter, impacts) __________________
____
What is the highest shock level expected to be present? ______________ g peak

What chemicals or gases contact the accelerometer or cable? (Check all that apply)

- ☐ Water (i.e. salt water, heavy water, steam) Describe: ________________________________
- ☐ Halogens (i.e. chlorine, fluorine, halogenated compounds) Describe: ____________________
- ☐ Gases (i.e. ozone, chemical fumes) Describe: ______________________________________
- ☐ Acids (i.e. hydrochloric, sulfuric, nitric) Describe: ____________________________________
- ☐ Bases (i.e. ammonia, caustic soda) Describe: ______________________________________
- ☐ Solvents (i.e. MEK, Freon, Alcohol) Describe: ______________________________________
- ☐ Fuels (i.e. gasoline, kerosene) Describe: ____
- ☐ Oil (i.e. lubricating, crude) Describe: ____
- ☐ Other chemicals Describe: ____

IV) Electrical requirements and electrical environment of the sensor:

Is Intrinsically Safe operation required? (i.e. explosive environments) ____ yes (or) ____ no
What Power supply will be used? (18 - 30 Volt, 2 - 10 mA is usually recommended):
Manufacturer ______________________________
Model #______________________________
Voltage Source ______________________________
Constant Current Source ______________________________(mA)
Is the machine grounded? ____ yes (or) ____ no
Is the sensor located near areas with electrostatic discharges? ____ yes (or) ____ no
Physical parameters and features of the sensor:
Sensor output: __ Acceleration __ Velocity __ Displacement
Physical design: __ Single axis __ Triaxial __ Ring shear mode
__ Handprobe
Special features: __ Temperature output __ Calibration circuit
Other:________________________
Housing material: __ 316 stainless steel __ Titanium
__ Other________________________
Desired characteristics:
Axial sensitivity _______________________mV/g
Frequency range to _______________________Hz
Resonance frequency _______________________kHz
Internal filtering requirements____
Maximum weight _______________________grams
Size limitation: h _______________ , l _______________ , w _______________

VI) Cabling requirements:

What cable lengths will be driven?
Cable length ________ft
Cable capacitance ________ pF/ft
Will the cable be near electromagnetic interference sources? (i.e. AC power lines, radio equipment, motors, and generators) ____ no (or) yes, describe:___________________________
Electrical connection: __ Connector __ Splash-proof __ Integral cable
Electrical connection location: __ Axial/top exit __ Radial/side exit
Cable type: __ Coaxial __ Two-conductor __ Dual shielded
Other________________________
Other cable requirements:____
Reinforced cable:
Cable pull strength _____ lbs
Cable shielding _____ %
Other_______________

VII) Mounting requirements (check request):

Mounting type: __ Detachable stud __ Integral stud __ Captive bolt
__ Adhesive __ Magnetic base

Thread size: __ 10-32 UNF __ 1/4-28 UNF
__ Other________________________

VIII) Other specific requests or requirements: ____
____
____
____