How to select and install accelerometers

Over the past decade, trending vibration parameters has become the most widely used technology for monitoring machinery health. Industrial accelerometers have become the workhorse in the predictive maintenance market. These sensors are extremely rugged, provide a wide dynamic range, and are available in a variety of configurations to meet individual installation requirements.

Physical Design

Material Selection

Accelerometers are piezoelectric devices i.e., the primary sensing element is a piezoelectric element constructed in such a way that when stressed by vibratory forces, a proportional electrical signal is produced. Some materials are found to be naturally piezoelectric. Quartz is a natural material commonly used in accelerometers and exhibits unmatched long-term stability. Polycrystalline ceramic materials can be made to exhibit piezoelectric properties. Lead zirconate titinate (PZT) is a common material used in accelerometers after they have been "polarized." Polling PZT subjects the ceramic to very high DC voltages at high temperatures in an attempt to align the domains along the polling axis. PZT demonstrates a natural decay in output over time and will require frequent recalibration. Special efforts in artificially aging the units reduces this condition. High shock levels or high temperature installations may also cause shifts in the output of PZT based sensors.

In general Quartz and PZT are both used in the manufacture of accelerometers. Each material has certain advantages and disadvantages. As stated earlier, Quartz exhibits superior temperature stability and has no aging effects and is therefore extremely stable over time. Quartz sensors offer high voltage sensitivities and require voltage amplifiers to condition the signal. Voltage amplifiers, with large valued resistors, are normally inherently noisier and limit the minimum measurable signal but allow for very high levels of vibration to be monitored. PZT based sensors provide a high charge output and a high capacitance. Quieter microelectronic charge amplifiers are used, thus allowing the low level vibrations to be measured.

Other material selection to be considered in accelerometer design include the case material, connector choice and the method of sealing. Industrial accelerometers are required to operate in very adverse environmental conditions. Harsh chemicals are often present subjecting the sensor to corrosive and ultimately damaging conditions. Noncorrosive 316L stainless steel cases are required in harsh industrial environments to insure sensor survivability. 316L stainless steel is also used for its nonmagnetic properties which is important around large motors. Anodized aluminum cases will not stand up to extreme conditions. Some newer sensors are emerging that are composite in case design. Some composite materials exhibit similar corrosion resistance as stainless steel.

Connectors should also be equally rugged. Stainless steel connectors with hermetic seals are also required in harsh environments. Non-hermetic connectors such as BNC's, though convenient, will not survive industrial conditions. BNC connectors also tend to wear out with repeated use and under harsh vibrations. Contaminants may enter the sensor through epoxy seals and permanently damage the sensor. Hermetic connectors and hermetic laser or electron beam welds ensure that the sensor is sealed from outside contaminants.

Three basic structural designs are used in manufacturing of industrial accelerometers. They are flexural, compression and shear designs. All three designs contain the basic components of the piezoelectric element such as seismic mass, base, and housing.

In the flexural design the piezoelectric element is secured to the seismic mass in the form of a double cantilever beam. Figure 1 shows the sensing element/mass system being driven at the fulcrum or the base. Flexural designs have lower resonant frequency and are generally not well-suited for machinery monitoring applications. Because of their very high output (up to 100 V/g), flexural designs excel in low level, low frequency seismic applications. The flexural element is often epoxied which limits its application in high shock environments.

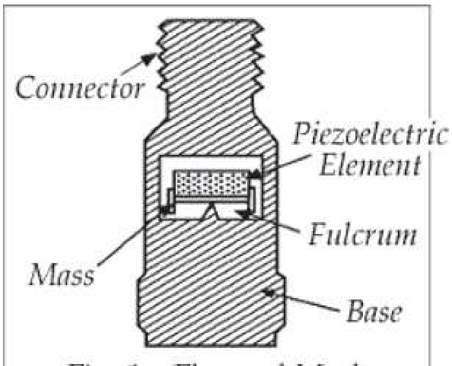

Fig. 1 – Flexural Mode

The compression design is generally the simplest and easiest to understand. The crystal, quartz or ceramic, is sandwiched between the seismic mass and the base with an elastic pre-load bolt. Motion (vibration) into the base squeezes the crystal creating an output. Compression designs are much more suited than flexural designs for industrial machinery monitoring applications because of their high resonance and more durable design. Compression designs generally have thick bases and should be used on thick walled structures because of base strain and thermal transient sensitivities.

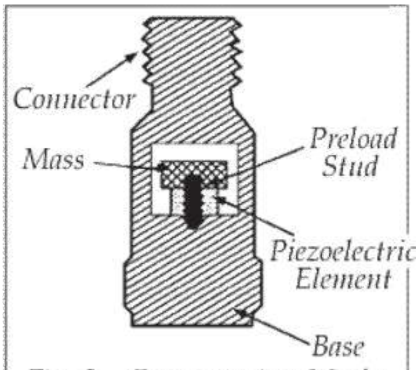

Fig. 2 – Compression Mode

The shear design subjects the sensing element to a shear stress. The piezoelectric sensing element and seismic mass are secured to a center post/base standing upright via a retaining ring as shown in figure 3. This preload produces a stiff structure with good frequency response and greater mechanical integrity. As the sensitive axis is not in-line with the mounting surface, adverse environmental conditions such as base strain and thermal transients do not produce false signals as in the other designs.

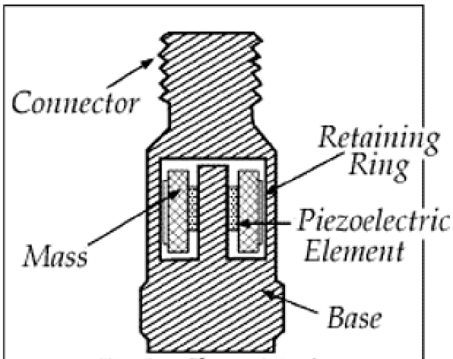

Fig.3 – Shear Mode

Selection Criteria

When selecting accelerometers, the vibration specialists must consider three main areas: amplitude range, frequency range, and environmental considerations.

Amplitude Range

Accelerometers used in predictive maintenance applications are internally amplified, ICP® sensors. These sensors are powered with a constant current DC supply. Supply voltage is regulated between 18 and 28 volts DC and current limited, via a constant current diode, between 2 and 20 mA. The signal output of ICP® sensors is a DC biased AC signal. The vibration signal, typically 100 mV/g AC, is superimposed on the DC bias. This DC bias is normally blocked by a decoupling capacitor so the read-out equipment can be AC coupled. If a normal bias level of 12 VDC is used with an 18 volt DC power supply and the accelerometer signal is 100 mV/g, the maximum measurable signal would be 50 g's or 5VAC. This maximum level can be increased by either increasing the supply voltage level or decreasing the sensitivity of the accelerometer. By using a 10 mV/g accelerometer with the same 5VAC maximum output, the vibration limit increases to 500 g's.

The other criteria to consider when reviewing the amplitude range is the lowest measurable vibration level. This is specified as either the noise floor or the resolution of the sensor. The resolution of the sensor is determined by two factors: electrical noise of the internal amplifier and mechanical gain of the mass/piezoelectric system. The larger the seismic mass, the larger the output of the sensor prior to amplification. This high mechanical gain improves low level measurements by producing substantial electrical signals without the use of amplifier gain. Ceramic sensing elements typically provide greater signal to noise ratios, allowing small levels of vibration to be measured without electrical noise interfering with analysis.

Frequency Response

The frequency response of an internally amplified ICP® accelerometer is described as the frequency range over which the sensor will provide a linear response. The upper end of the frequency response is governed by the mechanical stiffness and the size of the seismic mass in the sensing element while the low frequency range is controlled by the amplifier roll-off and the discharge time constant. Figure 4 shows a typical frequency response.

High End Frequency Response

The upper end frequency response is determined by the formula $w=\sqrt{k/m}$, where w is the resonant frequency (2pf), k is the stiffness of the sensing structure, and m refers to the size of the seismic mass. With a given stiffness a sensor with a large seismic mass will have a low resonance. A large seismic mass will also produce higher mechanical gain and thereby result in a lower noise accelerometer with greater sensitivity. A smaller seismic mass will produce less signal but will result in a sensor with a higher resonant frequency. Output signal may be low using a smaller seismic mass but the frequency range will be wider allowing for measurements to be made at higher frequency.

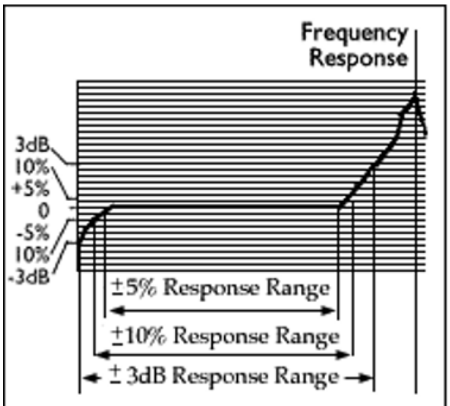

FIG. 4 – FREQUENCY RESPONSE CURVE

Sensitivity Deviation vs. Frequency

Stiffness, the second variable in the $w=\sqrt{k/m}$, equation is dependent on the sensing structure. Flexural designs as stated earlier provide significant mechanical gain, but the stiffness is very low. Flexural designs typically have high output, low resonance and limited shock resistance. Compression accelerometers, by virtue of the pre-load compression screw, exhibit a higher stiffness than flexural units and therefore have a higher resonance and a wider frequency ranges. As stated earlier, other environmental factors such as base strain and thermal transients may limit their use. Shear mode sensors, when mechanically secured, exhibit a high stiffness and thus a high resonance. Insensitivity to environmental factors of strain and thermal shifts places the shear design at the top of the list.

Low End Frequency Response

The low end is governed electrically by a resistive capacitive circuit that determines the discharge time constant ($t=R*C$). The higher the DTC, the slower the signal is bled off and hence the better the low end frequency response (see table 1). The DTC can be compared to a funnel. The smaller the opening in the bottom of the funnel (or the higher the time constant), the less water (signal) flows out. A sensor with a higher DTC means a better low end frequency response. A low frequency application will often be unmanageable without a sensor which has the proper DTC. The DTC however not only determines low end frequency response but is a major factor in determining settling time as well. The higher the DTC, the longer the settling time. (Note: A conservative rule of thumb to follow is that a settling time of 10 times the discharge time constant will allow the signal to decay to within 1% of the output bias.) A settling time of a few seconds or more might not seem to be significant to someone working in a laboratory environment with one or two points, but a person taking point to point data out in the field will certainly think otherwise. Therefore, a compromise must often be made between low frequency response and settling time.

Environmental

Material

Industrial accelerometers are intended to be permanently installed in very harsh environments. Earlier discussions concerning material selection directly affect the sensors ability to survive harsh environments. Sensors should be made of 316L stainless steel and the connectors should be hermetic military-style connectors. Outer cases should also be hermetically sealed. Aluminum cased accelerometers will not survive the rough industrial installation. BNC's and 10-32 coaxial connectors will not last in industrial applications. The internal crystal structure should be mechanically secured and not glued together.

Cable assemblies must also be as industrially rugged as the sensor. Mating connectors should be sealed if contamination is expected. Cable jacket materials should also be studied to be sure chemicals or temperature ranges do not exceed the useful range of the cable. Too often installations are compromised because not enough attention is given to the connectors and the cables. The sensor may be industrially rugged, but failure occurs in the cables and the connectors.

Sensor Mounting Techniques

Four main methods are used for attaching sensors to monitoring locations in predictive maintenance. They are stud mounted, adhesive mounted, magnetically mounted and the use of probe tips, or stingers. Each method affects the high frequency response of the accelerometer. Stud mounting provides the widest frequency response and the most secure and reliable attachment. Figure 5 shows ideal surface preparation for stud mounting sensors.

When choosing a mounting method, both the advantages and disadvantages of each technique should be closely considered. Characteristics such as location, ruggedness, amplitude range, accessibility, temperature and portability may be extremely critical. However, often the most important and overlooked consideration is the effect the mounting technique will have on the high frequency operating range of the accelerometer. Shown are six possible mounting techniques and their effect on the response of a typical piezoelectric accelerometer. (Note that not all the mounting methods may apply to your sensor.) By examining the mounting configurations and corresponding graph, the high frequency response of the accelerometer may be compromised as mass is added to the system and/or the mounting stiffness is reduced.

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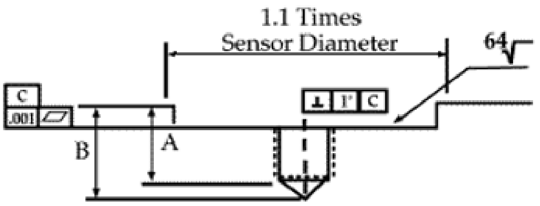

	1/4 – 28 Stud	1/4 – 28 Captive Screw
A. (in.)	.250	.250
B. (in.)	.350	.350
Torque (in. lbs.)	26	30

Fig. 5 – Stud Mounting Surface Preparation

Note: The low frequency response is unaffected by the mounting technique. This roll-off behavior is typically fixed by the built-in sensor electronics. However, when operating AC coupled signal conditioners with readout devices that have an input impedance of less than 1 megohm, the low frequency range may be affected.

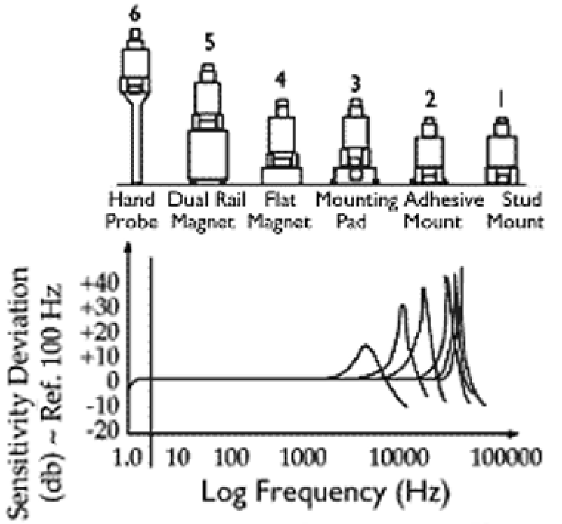

Fig. 6 - Mounted Resonance Change

One last point worth noting regarding mounting involves surface preparation. In addition to surfaces being as flat as possible, clean and free of debris, and the mounting holes to be perpendicular, the mounting surfaces should be lightly coated with a lubricant. This coating aids in the transmissibility of the higher frequency vibrations and improves high frequency response of sensors. Silicone vacuum grease, heavy machine oil, or bees wax are commonly used.

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