Vibration sensor wiring and cabling

This technical note describes basic wiring and cabling installation techniques for accelerometers and other vibration sensors. It will allow qualified field technicians to connect vibration sensors in a variety of applications and environments. Some techniques will be general to all installations, whereas others may be specific to a particular application. If additional information is required, please consult Wilcoxon technical support.

The process of installation begins with verifying that the proper sensor was selected for the measurement point. Refer to the Wilcoxon technical note “Sensor selection guide” for assistance.

With a firm understanding of the sensor requirements, capabilities, and limitations the vibration analyst should have evaluated and determined the mounting location of the individual sensors based on the specific machine and vibration source to be monitored. Refer to Wilcoxon technical note, “Mounting considerations for vibration sensors” for assistance with proper sensor mounting.

After the sensors have been properly mounted, installation wiring can be accomplished. This technical note will address the issues involved in proper sensor wiring for permanently mounted sensors.

After wiring installation, verification of operation and troubleshooting the installation may be necessary to complete the process. Refer to the Wilcoxon technical note, “Troubleshooting accelerometer installations” for assistance. This technical note also contains a detailed explanation of sensor operation and powering.

Electrical powering requirements

Most internally amplified vibration sensors require a constant current DC power source. Generally, the power supply contains an 18 to 30 Volt source with a 2 to 10 mA constant current diode (CCD) (see Figure 1). If other powering schemes are used, consultation with the sensor manufacturer is recommended. A more thorough discussion of powering requirements follows.

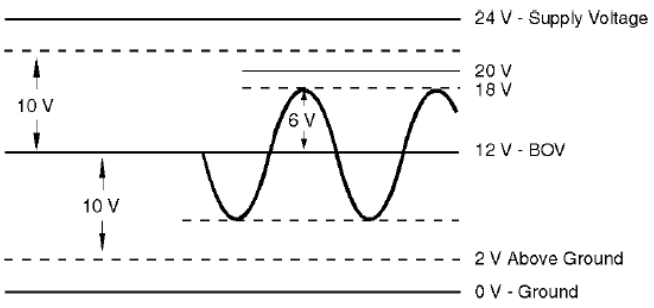

Figure 1: Amplitude range versus supply voltage

AC coupling and the DC bias voltage

The sensor output is an AC signal proportional to the vibration applied. 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 can be blocked by a capacitor thereby leaving the AC output signal. Most vibration data collectors, monitors, and sensor power units contain an internal blocking capacitor for AC coupling.

Amplitude range and the supply voltage

The sensor manufacturer usually sets the bias voltage at half the nominal 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 1). Thus an accelerometer with a sensitivity of 100 mV/g, and a peak output swing of 5 Volts, will have an amplitude range of 50 g peak. Some accelerometers may be able to achieve a larger voltage swing than the 5 Volts normally assumed. Consult with your sensor manufacturer for details of the voltage swing permitted for the sensor under consideration.
If a voltage source lower than 18 Volts is used, the amplitude range will be lowered accordingly. Custom bias voltages are available for lower or higher voltage supply applications.

Constant current diodes (CCD)

Virtually all internally amplified vibration sensors require power supplies that are regulated by a CCD. The CCD limits the current supplied to the sensor. The use of unlimited power supply current will damage most internally amplified sensors. For this reason, most commercially available data collectors and vibration monitors have power supply circuits that include a CCD to regulate the power supplied to the sensor. The power supplied is almost always in the 2 - 10 mA range. Most battery power supplies contain a 2 mA CCD to ensure long battery life. Line powered supplies (where power consumption is not a concern) should contain 6 to 10 mA CCDs to drive long cables. For operation above 100°C, limit the current to less than 6 mA to reduce overheating of the accelerometer’s internal amplifier. Common CCD’s used are the J500 Series (J507, J509) from Vishay Siliconix. The CCD should be placed in series with the voltage output of the supply while making sure that proper diode polarity is observed!

Cabling requirements

Cabling is one of the most important aspects of vibration sensor installation. Careful attention must be given to four major considerations: cable length and capacitance, routing, grounding, and anchoring.

Driving long cables

Modern industrial piezoelectric sensors are, typically, voltage mode devices. That is, they produce a voltage dependent on the vibration signal being measured. This vibration signal voltage is an Alternating Current (AC) voltage and, as such, is subject to all the limits of AC signals. High frequency AC signals are affected by the capacitance in AC circuits causing capacitive reactance. While many users may feel that vibration signals are not high frequency, compared to radio frequency signals, these signals are still affected by the capacitive reactance in circuits.

What does this mean to users of voltage-mode vibration sensors? When cables between the sensor power supply and the sensor are short (under 30 meters), circuit capacitance will usually have no noticeable effect upon the vibration data signals. But, long cables will likely introduce sufficient capacitance into the sensor circuit to allow the vibration signal to develop distortion and, hence, produce spurious signals. This additional capacitance creates a capacitive load on the output of the sensor’s amplifier. The amplifier has the ability to sink fairly large amounts of current, but cannot provide an indefinite amount of current for driving capacitance.

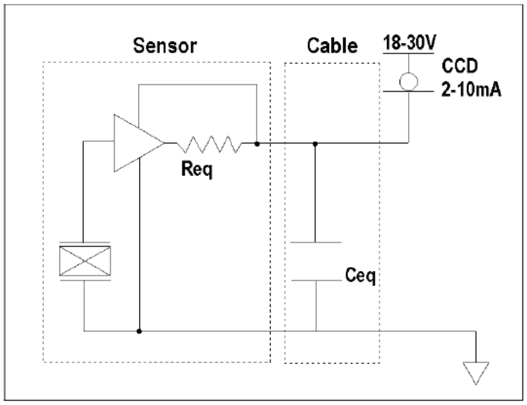

Figure 2: Sensor output equivalent circuit

In the circuit of figure 2, the CCD must provide all of the current to charge the capacitance of the cable when the signal voltage is positive. Each cycle of an AC signal being produced by the sensor's amplifier must have sufficient current available to adequately drive the cable capacitance. The amplifier itself needs approximately 1 mA of current available for its own use. When the current needs of the on-board amplifier combined with the current required to drive the cable are insufficient, the amplifier output voltage will become "slew rate limited." In a practical sense this means that the output signal, for an AC sinusoid, will not be able to accurately reflect the true signal.

Figure 3 is an illustration of a slew rate limited sinusoid. The positive-going part of the sine wave signal is being limited by the current available to drive the signal into the cable. It becomes a "straight" line because of the limited current available to drive the cable capacitance. During the negative-going portion of the sine wave, the amplifier must "sink" or "soak up" the current being discharged by the capacitor. The amplifier is far more capable at absorbing this discharge current, so the limiting factor in high frequency operation becomes the ability of the CCD to provide the necessary current to charge up the cable capacitance.

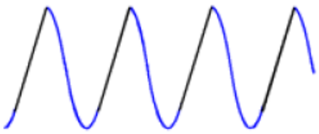

Figure 3: Slew rate limited signal

When the current limitation point is reached, it is only the positive going portion of the signal that is affected. The practical effect of this condition is that the signal actually becomes distorted and harmonics are generated. This could lead to vibration signals being misinterpreted as having strong harmonic components when they, in fact, do not have such harmonics present. In the extreme case, the signal waveform will actually start to resemble a triangle waveform. Triangle waveforms have strong harmonic components at all multiples of the fundamental frequency.

Computing the maximum frequency

The current through a capacitor is determined by the following differential equation:

$I = \frac{Cdv(t)}{dt}$, where $v(t) = V \text{ sine } \omega t$, and $\omega = 2\pi f$ with f being the frequency of interest and V the peak voltage.

Differentiating the $v(t)$ function yields:

$\frac{dv(t)}{dt} = V\omega \cos \omega t$, or $I = CV(2\pi f) \cos (2\pi f)t$

However, since we are only looking at the current required to meet the peak voltage we must evaluate this equation at the point where the value is at its peak. The voltage is at its peak when $\cos \omega t = 1$. Now the equation for determining the limiting frequency looks like this:

$I = CV(2\pi f)$, where I is the current required for the capacitor.

But the current required for the capacitor is only part of the total current. The equation for the total current in the circuit is expressed by the following:

$Iccd = I + 1 \text{ mA}$, where $Iccd$ is the current supplied by the constant current supply and 1 mA is needed for powering the on board electronics of the sensor.

Rearranging the equation yields:

I = Iccd – 1 mA

Combining these equations results in the following:

Iccd – 1 mA = CV (2πf)

By rearranging the terms to solve for the frequency f, we get this equation:

$$f = \frac{\text{Iccd} - 1\text{ mA}}{2\pi(C)(V)}$$

This is the equation that will yield the frequency limit. However, we will again rearrange these terms and add a scaling factor to allow the computation to be conducted in units typical for the application.

Computing the maximum length for a cable

$$\text{fmax} = \frac{10^9}{2\pi(C)(V)/(\text{Iccd} - 1\text{ mA})}$$

, where fmax = maximum frequency (Hz), C = cable capacitance (pF), V = peak signal output from sensor (volts), Iccd = constant current from signal conditioner, and 10^9 is the scaling factor to equate units.

This equation illustrates that when cable capacitance increases, either the constant current value must increase or the maximum usable frequency must decrease to keep the equation in balance and avoid signal distortion.

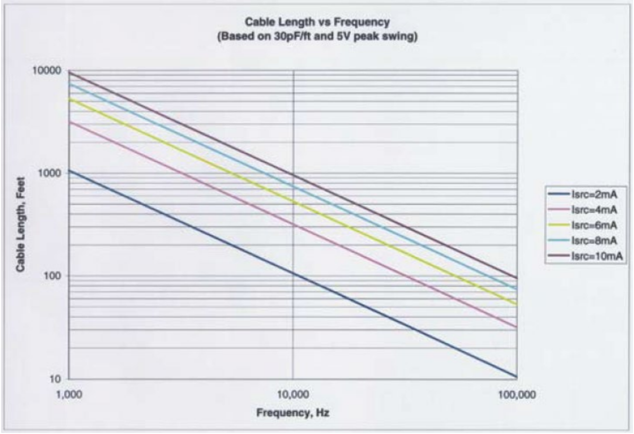

Figure 4: Cable length limits vs. frequency for various current drive levels

The chart in figure 4 illustrates, graphically, the results of applying the formula for cable length limits. In this graph the maximum voltage swing was assumed to be 5 Volts and the cable capacitance 30 picoFarads (30 pF) per foot. 5 Volts is one generally accepted swing used for computation of accelerometer dynamic range while 30 pF/foot is a fairly common capacitance for Wilcoxon cables. As an example, if the user wished to use an accelerometer with a 100 mV/g sensitivity, measuring vibration at up to 50g levels (50g x 100mV/g = 5 Volts), powering the accelerometer with a 4 mA constant-current source, and wanting to be able to measure signals at 10,000 Hz, how long could the cable be?

Starting at the 10,000 Hz location at the chart bottom we can move up until we get to the 4 mA line. At that point we are just over 300 feet of cable length. Therefore, under the conditions described above, the user could have up to 300 feet of cable and make reliable vibration measurements.

Amplitude overload

The previous technical discussion basically means that high frequency high amplitude signals can produce signal distortion and cause false signals to appear at low frequencies. Other sources of high frequency overload could be gear impacts or the broadband hiss of a steam release valve. Most Wilcoxon sensors are protected from moderate high frequency overloads by a washover filter.

Powering sensor in higher temperatures

In environments where sensor temperatures are at or above 100°C (212°F), the current should be no more than 6 mA to prevent overheating damage to the accelerometer's internal amplifier.

Cable routing and electromagnetic interference

Walkie-talkies, power lines, and electrical sparks are sources of signal interference. The following guidelines will eliminate many measurement errors due to electromagnetic interference (EMI) and electrostatic discharge (ESD).

Assure that high quality, well-shielded cables are used. If cable splices are made, complete shielding should be maintained. Proper cable routing is also recommended. Avoid routing sensor cables alongside AC power lines; cables should cross AC power lines at right angles. Where possible, provide a separate grounded conduit to enclose the sensor cable. In addition, route the cable away from radio transmission equipment, motors, generators, and transformers. Finally, avoid routing the cable through areas prone to ESD. Even though the sensor is protected against ESD failure, temporary signal distortion may occur as the result of severe ESD.

When running cables near electric motors, always have the cable approach the motor perpendicular to the motor rotor axis. The cables should always run directly away from the monitoring point and be maintained at the maximum distance from the motor case to avoid influence from the stator winding magnetic field. On DC motors, the cable runs should be kept as far away from the brushes as is practical to avoid the broadband radio frequency noise generated by the motor brushes.

Cable grounding and ground loops

In instrumentation circuits, grounding performs a different function than in electrical power wiring circuits. Electrical power wiring grounds are primarily for safety, to prevent electrical shock by providing a barrier between high potential wires and personnel. Electrical grounds also carry a portion of the current in many installations. For electrical purposes, any proper ground is a good ground for protection.

Instrumentation circuits use grounds for shielding and protecting the sensitive instrumentation equipment from accidentally measuring noise and stray electromagnetic fields as part of the signal being analyzed. In instrumentation, the only proper ground is one that has no ground loops, that is, there exists one, and only one, path to ground from any grounded point in the instrumentation ground system. This is often referred to as a ground tree, as it has the characteristic structure of a tree with no limbs crossing or touching. Instrumentation circuits also have all their wires encased in a shield to protect them from electromagnetic pickup. The shield should never be allowed to come into contact with conduit walls or junction boxes, otherwise an inadvertent ground loop will be created.

When ground loops exist in instrumentation circuits, they allow currents to flow through the ground system. Any time there is a loop circuit in instrumentation wiring, current will be induced in that wire by any of the many sources of electromagnetic fields found around industrial equipment. These loop currents flowing in the shield will cause electromagnetic coupling into the vibration measurement circuit, as shown in figure 5. Power lines, motor stator fields, motor rotor fields, and radio frequency equipment are the normal sources within industrial installations.

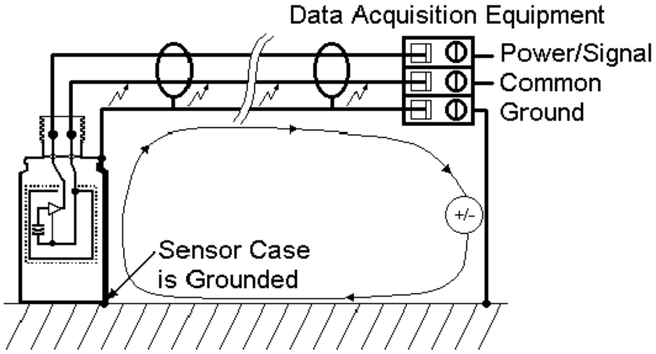

Figure 5: Illustration showing improper grounding in an accelerometer installation

All on-line monitoring systems and other permanently connected instrumentation systems have their own connection to the plant instrumentation ground. Instrumentation grounds should never be used for electrical power circuit grounding. If used, they will generally result in compromising the integrity of the instrumentation ground and inducing noise into the entire instrumentation system. The best cabling to use for vibration monitoring installations is shielded, twisted pair. These cables have two conductors that are twisted around each other for the length of the cable. The conductors are twisted creating alternating wireloops, which when exposed to magnetic fields cancel the induced currents in the wires, reducing magnetic pickup. This same technique is used by the telecommunication industry for telephone wiring. High voltage power transmission lines are also twisted for similar reasons.

Instrumentation shields used in vibration monitoring systems should be connected only at one end of the cable run. Figure 6 illustrates a shield connected at the data acquisition equipment end of the cable, while being isolated at the sensor end of the connection.

Another grounding possibility for the instrumentation wiring would be to ground the shield at the sensor end of the cable. This option is illustrated in figure 7. Do not connect the shield to the ground at the data acquisition equipment if the sensor end of the cable is grounded.

When portable data collectors are used to gather data from permanently mounted vibration sensors, the ground issue is not as critical. The portable data collector has its own internal reference that is used for the circuit common. Since the data collector runs from battery power, there is no connection to earth ground from the data collector power system. Any connection to earth ground would only be through the sensor wiring. Since the connection to ground would only exist via one path, no ground loop can be created.

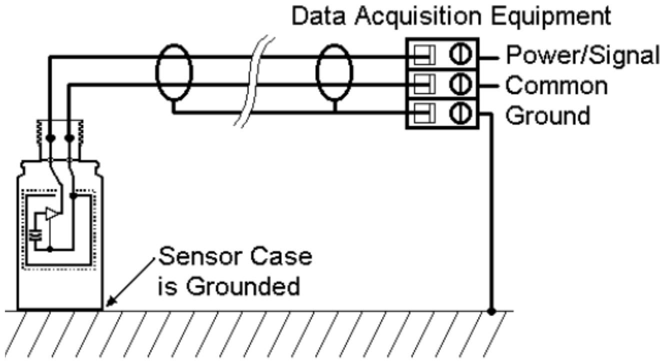

Figure 6: Grounded at the instrumentation, isolated at the accelerometer

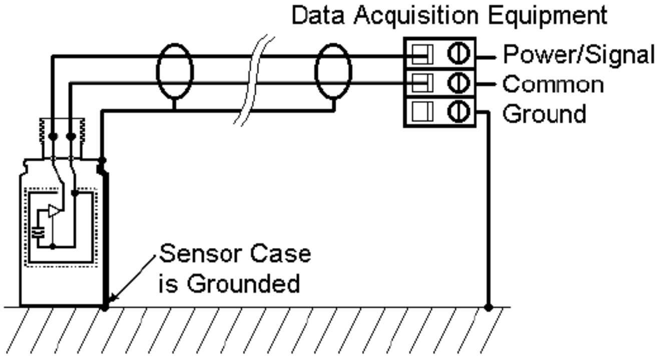

Figure 6: Isolated at the instrumentation, grounded at the accelerometer

Types of cables

The optimum cable to use for permanently installed vibration sensors is shielded, twisted pair. Shielded, twisted pair cable is also generally used in wiring plant instrumentation for process controls. It provides two wires for the power/signal of the vibration sensors and also the circuit common connection for completing the instrumentation circuit. Around the outside of this twisted pair is the shield. Braided shield is the optimum type of shielding for vibration sensors, as it has slightly better low frequency shielding capabilities over a foil type of shield. Foil is often used where RF shielding is necessary.

Coaxial cable is sometimes used for temporary or portable applications. Coaxial cable should never be used in permanent installations through conduit or other enclosed cable runs where the cable must be pulled. If the cable jacket insulation is ever pulled off, the shield can contact a piece of grounded conduit or tray and will immediately cause a ground loop. Since the coaxial shield is actually part of the sensing circuit, the noise pickup in the vibration measurement equipment will be severe. The most prominent frequency picked up will be the power line frequency and it will likely swamp the vibration signal and render all data as useless.

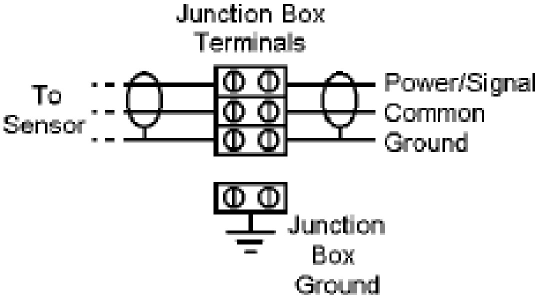

Figure 8: Illustration of junction box wiring, keeping shield isolated

When wiring permanently mounted sensors through junction boxes, always carry the shield through the box without connecting to ground. The shield must remain isolated from any ground connection between either end of the sensor circuit. Figure 8 illustrates the proper wiring for junction boxes. The only ground connection should occur at either the sensor or the measurement equipment.

Cable anchoring

After mounting the sensor, the cable should be anchored to reduce stress at the cable terminations and to prevent false signals due to cable vibration and slapping. Cables that are allowed to have excessive motion will eventually result in cable metal and insulation fatigue. The fatigue causes wire strand breakage, insulation failure, and results in noisy or broken connections. When securing the cable, leave enough slack to allow free movement of the accelerometer on the vibrating machinery (see figure 9.) These techniques for cable anchoring are extremely important for machinery with high displacement amplitudes.

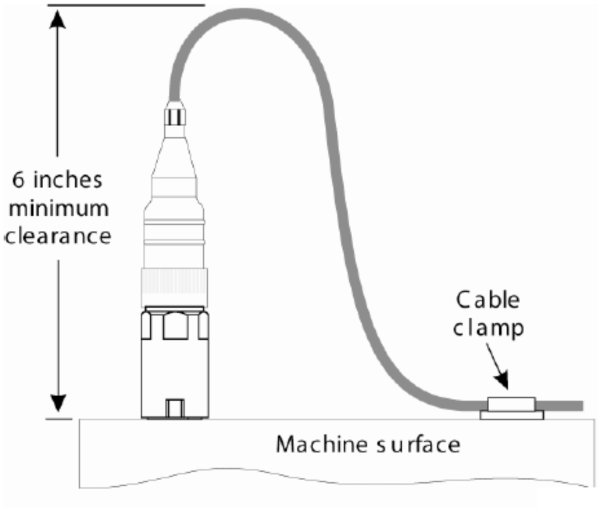

Figure 9: Illustration of proper cable anchoring

Summary

Cable installations for vibration monitoring must be planned carefully to minimize undesirable noise in the vibration signal measurements. The location of the cable runs should avoid potential sources of electromagnetic interference. When the length of cables exceeds 200 feet, or if vibration signal amplitudes are large, the effect of cable length must be examined more closely. Shielded, twisted pair wire is recommended for all vibration sensor installation wiring. Coaxial cable should be used only for temporary or portable data collection purposes.