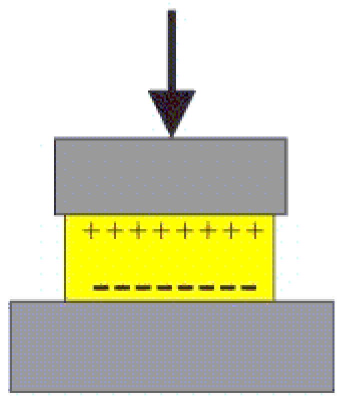
How does a piezo-electric accelerometer work?

Piezo-electric crystals are man-made or naturally occurring crystals that produce a charge output when they are compressed, flexed or subjected to shear forces. The word piezo is a corruption of the Greek word for squeeze. In a piezo-electric accelerometer a mass is attached to a piezo-electric crystal which is in turn mounted to the case of the accelerometer. When the body of the accelerometer is subjected to vibration the mass mounted on the crystal wants to stay still in space due to inertia and so compresses and stretches the piezo electric crystal. This force causes a charge to be generated and due to Newton law F=ma this force is in turn proportional to acceleration. The charge output is either is converted to a low impedance voltage output by the use of integral electronics (example: in an IEPE accelerometer) or made available as a charge output (Pico-coulombs /g) in a charge output piezo-electric accelerometer.



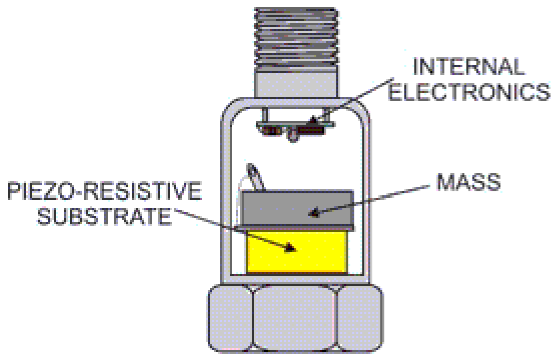
What are the different types of accelerometer?

There are many different type of accelerometers and each has unique characteristics, advantages and disadvantages. The different types include:

Different technologies	Piezo-electric accelerometers Piezo-resistive accelerometers Strain gage based accelerometers
Different output accelerometers	Charge output IEPE output (2-wire voltage) Voltage output (3 wire) 4-20mA output Velocity output accelerometers
Different designs of accelerometer	Shear type design Single ended compression design Isolated compression Inverted compression Flexural design

What is a single ended compression accelerometer?

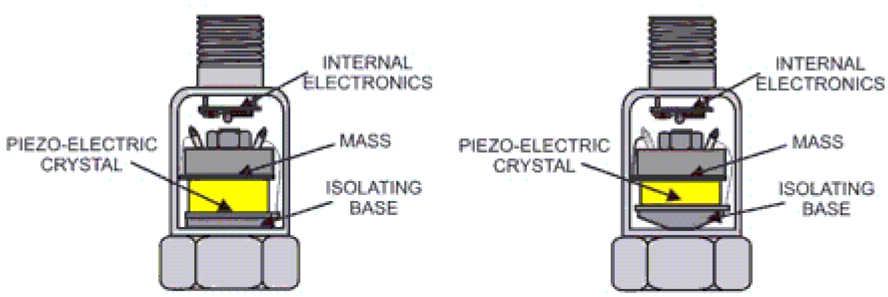
A single ended compression accelerometer is where the crystal is mounted to the base of the accelerometer and the mass is mounted to the crystal by a setscrew, bolt or fastener.



A single ended compression accelerometer

What is an isolated compression accelerometer?

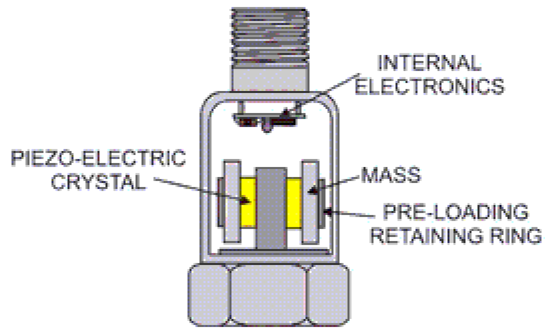
Single ended compression accelerometers can be susceptible to base strain and so to alleviate this problem the crystal is isolated from the base by mounting on an isolation washer or by reducing the mounting area by which the crystal is mounted to the base.



Isolated compression accelerometers

What is a shear type accelerometer?

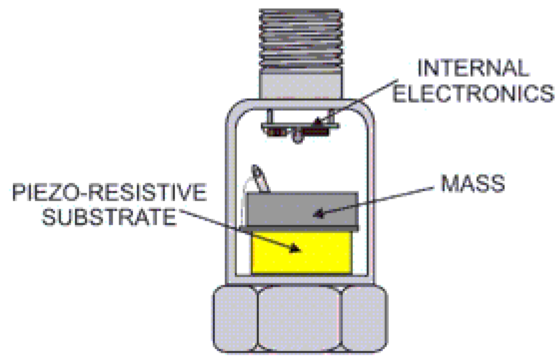
A shear type accelerometer is where the seismic mass is attached to the crystal so that it exerts a shear load on the crystal rather than a compressive load. Shear type accelerometers are designed for applications that are likely to encounter significant base distortion from thermal transients or where they are mounted onto flexible structures.



Shear type piezo-electric accelerometer

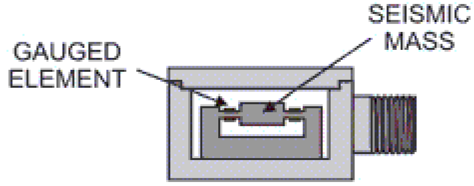
What is a piezo-resistive accelerometer?

A piezo-resistive accelerometer is an accelerometer that uses a piezo-resistive substrate in place of the piezo electric crystal and the force exerted by the seismic mass changes the resistance of the etched bridge network and a whetstone bridge network detects this. Piezo-resistive accelerometers have the advantage over piezo-electric accelerometers in that they can measure accelerations down to zero Hertz.



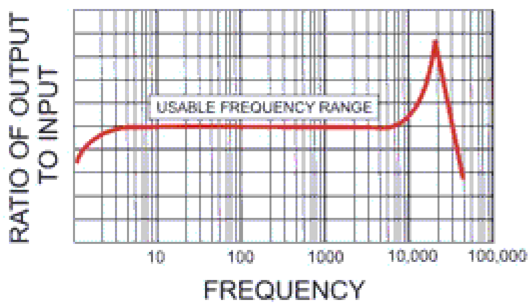
What is a strain gage based accelerometer?

A strain gauged based accelerometer is based on detecting the deflection of a seismic mass by using a silicon or foil strain gauge element. A whetstone bridge network detects the deflection. The deflection is directly proportional to the acceleration applied to the sensor. Like the piezo-resistive accelerometer it has a frequency response down to zero Hz.

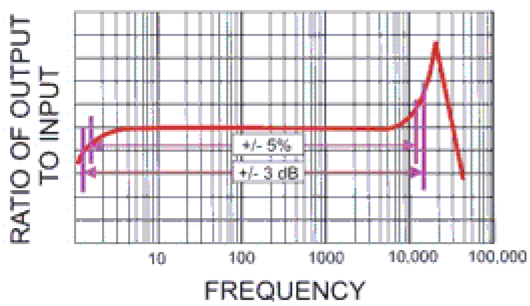


What is the useable frequency range?

For an accelerometer to be useful the output needs to be directly proportional to the acceleration that it is measuring. This fixed ratio of output to input is only true for a range of frequencies as described by the frequency response curve.



Typical Piezo-electric frequency response curve



The usable frequency response is the flat area of the frequency response curve and extends to approximately 1/3 to 1/2 of the natural frequency. The definition of flat also needs to be qualified and is done so by quoting the roll off of the curve in either percentage terms (typically 5% or 10%) or in dB terms (typically +/- 3db).

What is an IEPE accelerometer?

IEPE stands for Integrated Electronics Piezo Electric and defines a class of accelerometer that has built in electronics. Specifically it defines a class of accelerometer that has low impedance output electronics that works on a two wire constant current supply with an voltage output on a DC voltage bias. IEPE two wire accelerometers are easy to install, have a wide frequency response, can run over long cable lengths and are relatively cheap to purchase. The IEPE technology has generally replaced most 3 wire accelerometers and is broadly used for most applications except for specialist applications such as zero Hz accelerometers, high temperature applications or 4-20mA accelerometers used in the process industries.

What is an ICP accelerometer?

ICP is the trademarked PCB name for IEPE accelerometers. It stands for 'Integrated circuit-piezo electric'.

What is a charge output accelerometer?

All piezo-electric accelerometers work by measuring the charge generated by a crystal that is being compressed or shear loaded by a mass influenced by acceleration. In most applications this high impedance charge output is converted to a low impedance voltage output by the use of integral electronics. However in some applications integral electronics are not appropriate such as high temperature or high radiation applications. Charge output accelerometers are self-generating and would typically have amplifying electronics mounted several feet away from the local heat or local radiation source.

What is dynamic range?

The dynamic range of an accelerometer is the range between the smallest acceleration detectable by the accelerometer to the largest. A piezo-electric accelerometer produces a charge proportional the force applied to the crystal, which due to the seismic mass on the crystal is proportional to acceleration applied. The piezo electric effect can be detected for very small forces or accelerations all the way through to very large accelerations. In most cases the smallest acceleration is dictated by the amplifying electronics noise floor and for high g levels to the voltage rail used by the power supply. The design of the accelerometer will also play a part in what shock g levels an accelerometer can withstand before the crystal is irreparably damaged or the structure holding the crystal is distorted. Compression accelerometers are the most shock resistant design of accelerometer.

Accelerometers with integral electronics have a maximum output voltage determined by the circuit design and the input voltage. The maximum output for an IEPE accelerometer is typically 4-8 volts. An accelerometer with a sensitivity of 100mV/g with electronics that has a maximum output of 5V will obviously have a dynamic range of +/- 50g while an accelerometer of sensitivity of 10mV/g will have a dynamic range of +/- 500g.

What is amplitude linearity?

The amplitude linearity of an accelerometer is the degree of accuracy that an accelerometer reports the output in voltage terms as it moves from being excited at the smallest detectable acceleration levels to the highest. This accuracy is qualified by the linearity. Typically the amplitude linearity is 1%. The dynamic range describes the minimum to maximum accelerations that can be detected. The output of an IEPE accelerometer can typically go from 100 micro g to 500g. This dynamic range is dependent on the electronics used with the accelerometer either internal or external, as is the output linearity over the dynamic range.

When should I use a velocity output accelerometer?

Velocity output accelerometers are usually used in condition monitoring applications where velocity is a much better parameter for judging the health of a machine. Doubling of velocity vibration equates to a doubling of the deterioration of the health of the machine. Velocity can also be used in lower frequency applications where the acceleration amplitude of vibration is too small to measure and the velocity vibration maybe of a higher and more meaningful value. Velocity vibration accelerometers are only really effective if the frequency of vibration is higher than 2Hz but more ideally 5 Hz.

How do I choose the sensitivity of an accelerometer?

Accelerometers with integral electronics have a maximum output voltage determined by the circuit design and the input voltage. The maximum output for an IEPE accelerometer is typically 4-8 volts. An accelerometer with a sensitivity of 100mV/g with electronics that has a maximum output of 5V will obviously have a dynamic range of +/- 50g while an accelerometer of sensitivity of 10mV/g will have a dynamic range of +/- 500g If the maximum g levels likely to be experienced is known then dividing this number by 5 volts will give the maximum sensitivity that should be used to get this dynamic range

Example: Vibration expected to be seen is 300g. Sensitivity will be 5 divided by 200 which equals 16.6 mV/g. The nearest sensitivity would be a 10mV/g accelerometer.

What is condition monitoring?

Condition monitoring is where the health of a rotating machine is monitored using vibration levels. As the health of a machine (example becomes unbalanced, fan blades corrode, bearing surfaces degrade) deteriorates so the amplitude of the vibration the machine generates increases. By monitoring the vibration levels over a long period of time this gradual deterioration of the health of the machine can be assessed until the vibration levels get to a point where the machine needs to be taken out of service and overhauled. Analysis of the frequency content of the machine vibration signal will indicate not only that the health of the machine has deteriorated but also root causes can be attributed to the problem.

Example: An 8 bladed pump running at 6000 rpm (100Hz) will produce a vibration signal with 100 Hz frequency if it becomes unbalanced, 200 Hz if it becomes mis-aligned 800 Hz if the blades become corroded and 43-47 Hz if the bearings start to go into oil whirl.

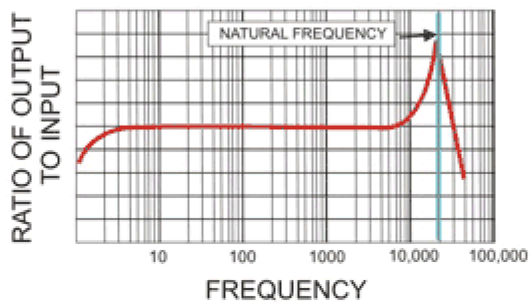
What is the natural frequency of an accelerometer?

The natural frequency of an accelerometer is the frequency where the ratio of output is at it highest. The natural frequency of an accelerometer is defined by the equation:

$$f_N = \frac{1}{2\pi}\sqrt{\frac{K}{M}}$$

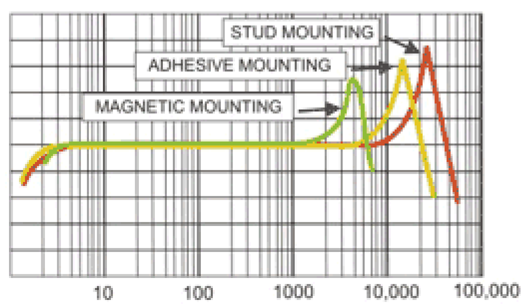
f_N = Natural frequency
K = Stiffness
M = Mass

From a frequency roughly 1/3 to 1/2 of the natural frequency the ratio of output to input becomes non-linear and therefore makes measurements from this region difficult to interpret. Therefore the higher the natural frequency of an accelerometer the higher frequencies where the output to input is linear and the higher the frequencies that can be measured.



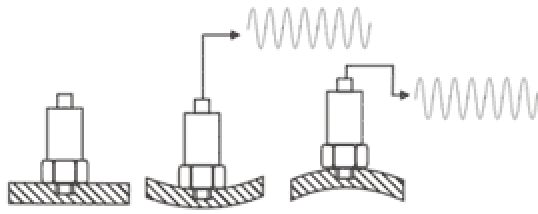
It can be seen from the formula for natural frequency that to increase the natural frequency the mass needs to be as small as possible and the stiffness needs to be as high as possible. A small mass usually means a lower sensitivity and this is true of most high frequency accelerometers.

What is the mounted natural frequency?



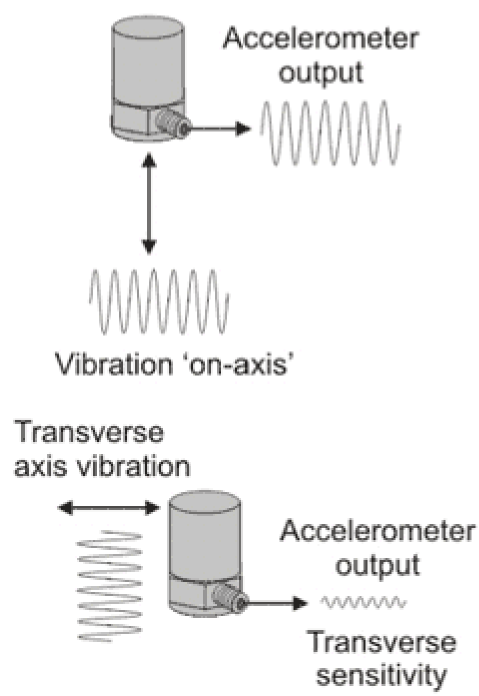
An accelerometer has a different natural frequency when it is in free space to that when it is mounted. The only frequency that is of interest to the user is of course the mounted natural frequency and is often the one quoted in the specifications. The mounted natural frequency is of course dependent on the stiffness of the mounting structure to which it is attached and is therefore quoted as the natural frequency of the accelerometer as installed according to manufacturers instructions. Gluing, magnetically mounting or loose bolting down to a surface will significantly reduce the mounted natural frequency.

What is base strain sensitivity?



Base strain sensitivity is the erroneous signal that is generated by an accelerometer when the base is subjected to bending, torque or distortion either by mechanical movement or thermal stressing. The relative movement of the base of the accelerometer squeezes the crystal in an accelerometer and the seismic mass mounted on the crystal. Base strain is where the base distorts the mass while acceleration causes the seismic mass to distort the crystal. These two forces on the crystal are indistinguishable and so reduction of the base strain is vital for good signals only to be generated. The more indirectly that a crystal is mounted to the base under strain the less sensitive the accelerometer is to base strain. Single ended compression sensors are the most prone to base strain sensitivity and shear type accelerometers the least. Isolated compression accelerometers are a good compromise between have good base strain immunity and the disadvantages that shear type accelerometers bring in terms of sensitivity an robustness.

What is cross sensitivity or transverse sensitivity?



Cross Axis Sensitivity

An accelerometer produces a charge output when the crystal is compressed. That same crystal also produces a charge, albeit a much smaller one, when a shear load is exerted on the crystal. The accelerometer therefore produces a charge when it is vibrated in the axis 90 degrees to the main axis of measurement, which is indistinguishable from acceleration in the main axis. Conversely shear type accelerometers produce an erroneous signal when they experience cross axis acceleration only this time it loads the crystal in compressive mode.

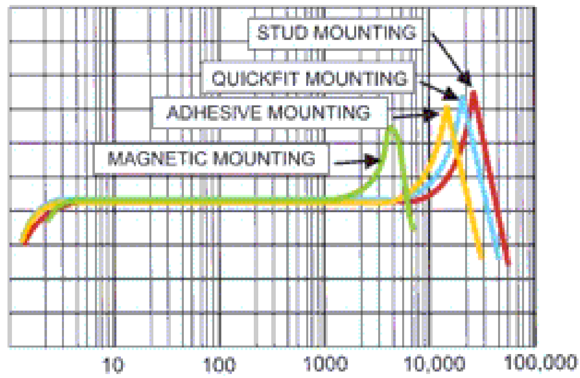
The sensitivity of the accelerometer to a transverse vibration is known as the transverse sensitivity and is typically less than 5% of the sensitivity to an "on axis" acceleration.

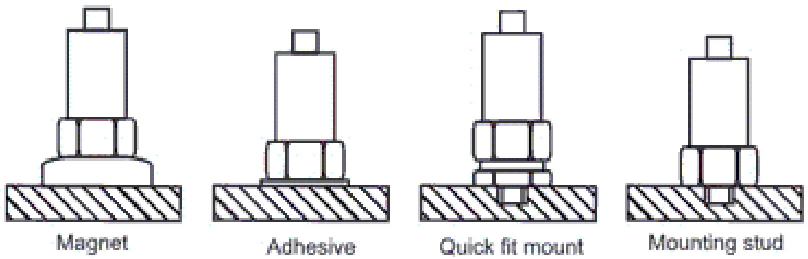
What are the differences between quartz crystal based and ceramic crystal based accelerometers?

Ceramic Crystals	Quartz Crystals
Man made piezo electric crystals	Natural piezo electric crystals
Higher output sensitivity	Lower output sensitivity
Less expensive	More expensive
Higher pyro-electric effect at elevated temperatures	Lower pyro-electric effect at elevated temperatures
Higher crystal decay rates at elevated temperatures	No crystal decay rates with time or temperature
Lower temperature of operation	Higher temperature operation

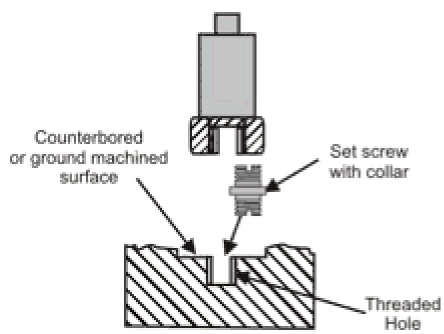
How do I mount an accelerometer?

The mounting of an accelerometer affects its frequency response. The mounted natural frequency is dependent directly on the stiffness of the mounting. The higher the stiffness the more the mounted natural frequency approaches its maximum. The least stiff mounting of an accelerometer is magnetic mounting and the highest stiffness is using a high tensile setscrew tightened to the correct torque mounted on a hard flat surface. Other mounting methods come in between these two extremes.



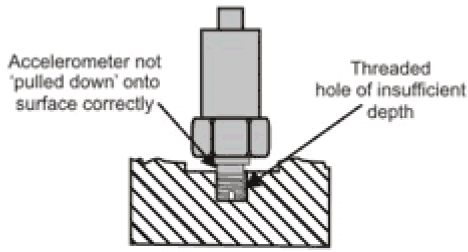


It is important to ensure that the site chosen for the accelerometer is ground flat for at least an area larger than the base of the accelerometer. A slight smear of Silicone grease will ensure a stiff bond between accelerometer and structure.



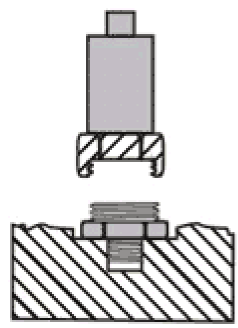
Surface preparation and set screw installaion

When using a mounting stud it is important to ensure that the stud does not bottom out in either the base of the accelerometer or the drilled location hole. High tensile strength set screws that have a shoulder will prevent this eventuality from happening.



Incorrect mounted accelerometer

What is a quickfit mount?

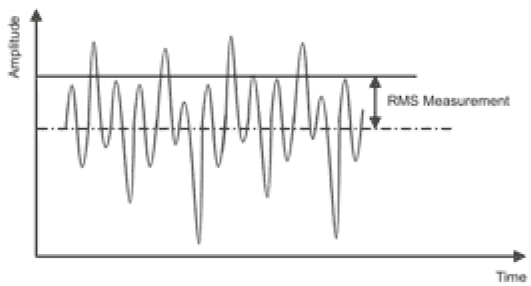

Quickfit mounting for an accelerometer

A quickfit mount is used in installations where the accelerometer will be removed between monitoring the acceleration or velocity vibration yet will be repeatedly place back in the same location. Such installations include machine health monitoring using data collectors.

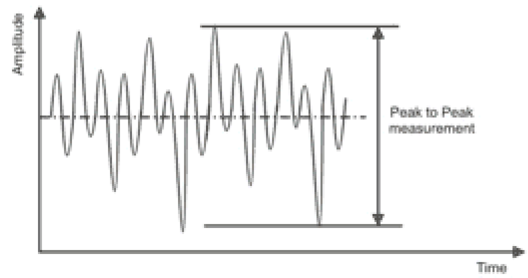
What signal conditioning do I need for my accelerometer?

All internally amplified accelerometers need a power supply be it a constant current IEPE supply, a 4-20mA loop, a 10V bridge excitation or a bipolar +/- 15V supply for a three wire accelerometer. The output of the accelerometer is now conditioned to an AC voltage whose amplitude is proportional to the amplitude of vibration with a frequency the same as the frequency of the vibration. An AC voltage signal needs further signal conditioning to retrieve any useful data. This signal conditioning takes three main forms:

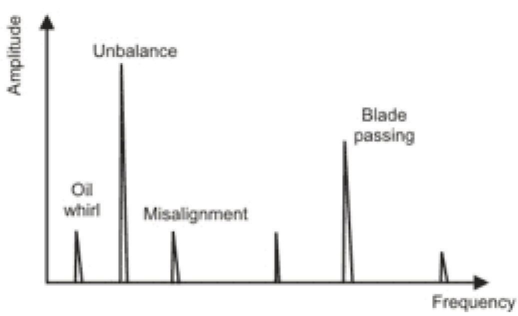
- a) Overall voltage levels in either RMS or peak to peak
- b) Spectral content analysis
- c) Snap shot time domain analysis



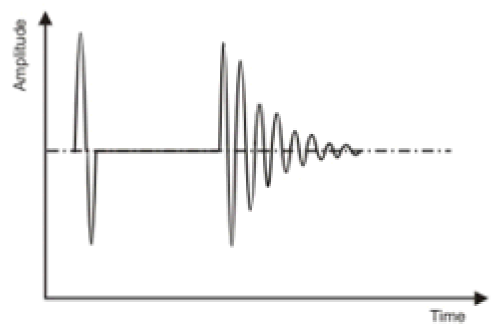
Overall acceleration levels in RMS terms



Overall acceleration levels in Peak-Peak terms



Breaking the acceleration signal into its frequency components

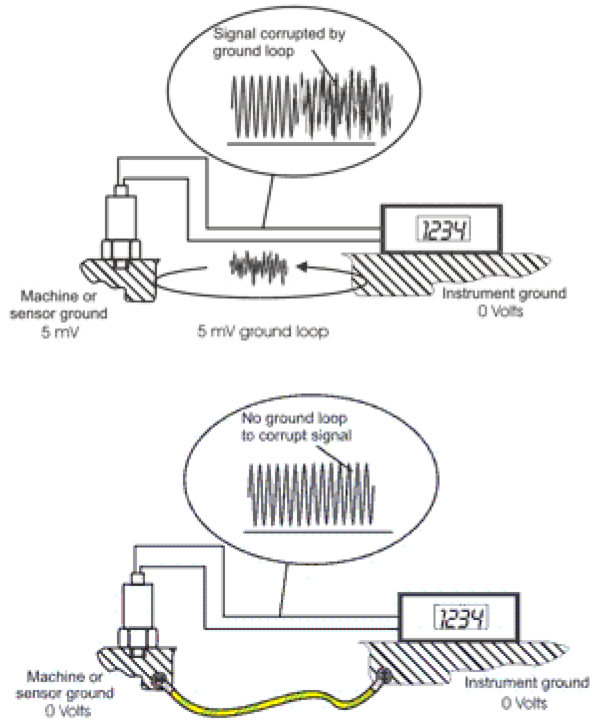


Viewing the acceleration signal on a storage scope or transient recorder

What are ground isolated accelerometers?

Ground loops can be a significant problem to all type of sensors where the signal is un-amplified or the signal levels are low. Ground loops occur when different parts of the structure lab or building have different electrical grounds. These grounds may only differ by a few milli-volts or less. When areas with different grounds are connected by sensor cables then unless measures are taken to prevent it a ground loop are set up in the cable that can be significant when compared to low level voltage signals that come from the sensor.

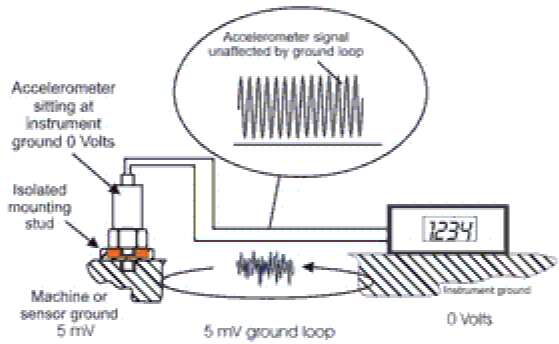
Ground loops are often very difficult to detect so it is prudent to take precautions to prevent their effects. There are a number of ways that ground loops can be prevented. The first is to hard wire different parts of the structure to ensure that each area has exactly the same ground.



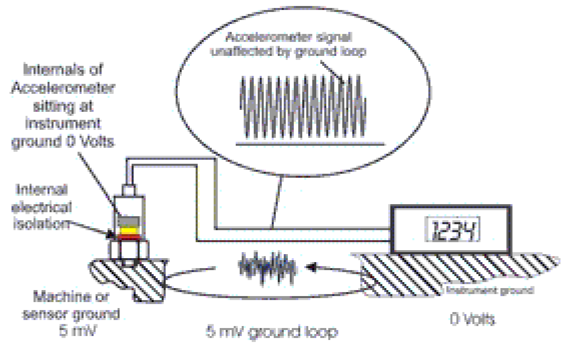
Preventing ground loops by ensuring all parts of structure have same ground

Ensuring different parts of a plant have the same ground may not be so easy particularly when long distances are involved or structures carry noise generating machinery. In these cases it may be better not to eliminate ground loops but to prevent their effects influencing the sensor output. This can be achieved by mounting the accelerometer on an electrically isolated mounting stud. In this way the accelerometer sits on a locally constructed instrument ground and ensures that now ground loop exists between this and the measuring instrument.

The same effect as mounting the accelerometer on an electrically isolated mounting base can be achieved by isolating the accelerometer internals from the outer case of the accelerometer. This is done by the manufacturer. Mounting the accelerometer on an isolating base or internally isolating the accelerometer does reduce the stiffness of the accelerometer and therefore reduces the mounted natural frequency. It is for this reason that not all accelerometers come automatically with internal isolation.



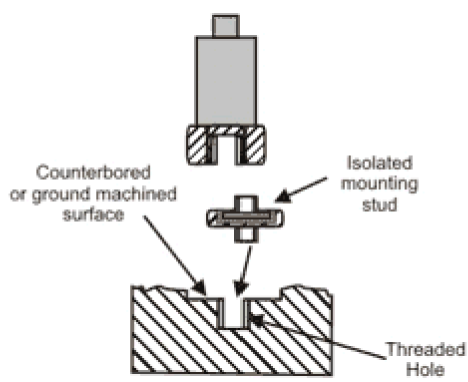
Isolated mounting bases
eliminate problems with ground loops



Internally isolated accelerometers can prevent ground loops
but have a reduced frequency response as a result

What is an isolated stud?

An accelerometer isolated stud is used in application where the possibility for ground loops exists which can corrupt the output of the sensor. Isolated studs do reduce the frequency response of the accelerometer somewhat so caution should be taken if high frequency data needs to be measured.



How do I install a charge amplifier?

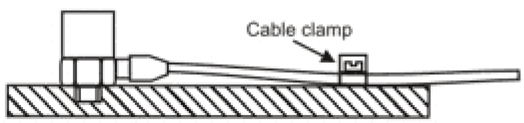
Charge output accelerometers are used in applications where:

a. High temperatures environments are encountered

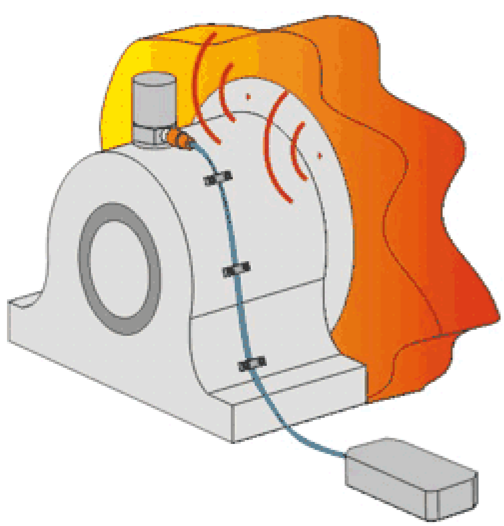
b. High radiation environments are encountered

c. Very high frequency accelerometers are used where no room exists for internal electronics

Charge output accelerometers are self-generating and so no excitation is required but a local charge amplifier is used to convert the charge output to a voltage. The charge output accelerometers do however have high output impedance. This high output impedance makes them susceptible to noise, cable movement (tribo-electric effect) and low insulation resistance. To minimize these effects it is important to have; a charge amplifier-impedance converter mounted as close to the accelerometer as possible, prevent cable movement, use low noise co-axial cable and ensure all surfaces are kept clean and dry.

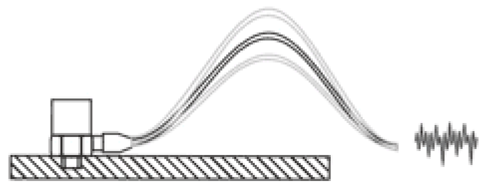


Installing a charge output accelerometer and clamping low noise co-axial cable



Charge amplifier is located as close to accelerometer as possible but away from the hostile environment

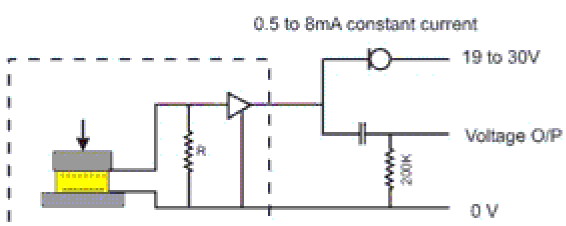
What is the tribo-electric effect?



Tribo-electric effect

Tribo-electric effect is when a spurious signal is generated by a charge output accelerometer by the movement of the co-axial cable. To prevent the tribo-electric effect the low noise cable needs to be clamped down as close to the accelerometer as possible. See [How do I install a charge amplifier?]

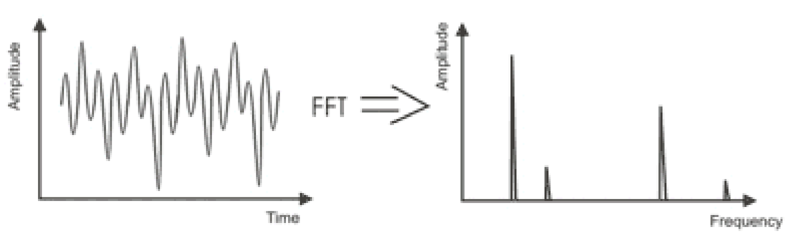
What is the output of an IEPE accelerometer?



An IEPE accelerometer is a two-wire sensor that requires a constant current supply and outputs an AC voltage output on a DC voltage bias. The DC bias is often removed by the use of a decoupling capacitor.

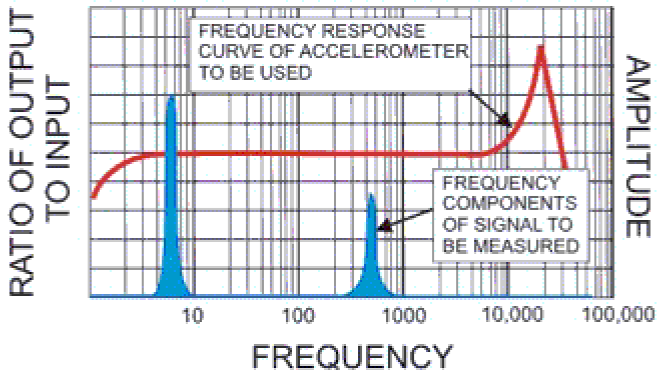
What is an FFT?

An FFT is short for Fast Fourier Transform and is an algorithm that is used to obtain frequency content data from time domain signal. Spectral analysis, frequency analysis are terms also used to describe obtaining frequency content data from time domain signals.



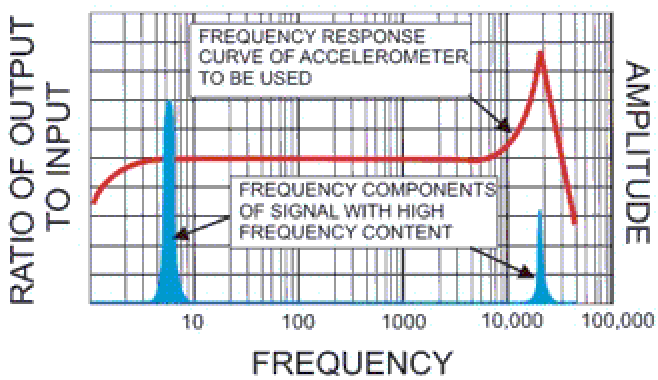
What frequency response do I want from my accelerometer?

The frequency response of the accelerometer needed for testing depends on what frequencies of vibration are required to be measured. An accelerometer should have a high enough natural frequency as to capture all the frequencies required to be measured.



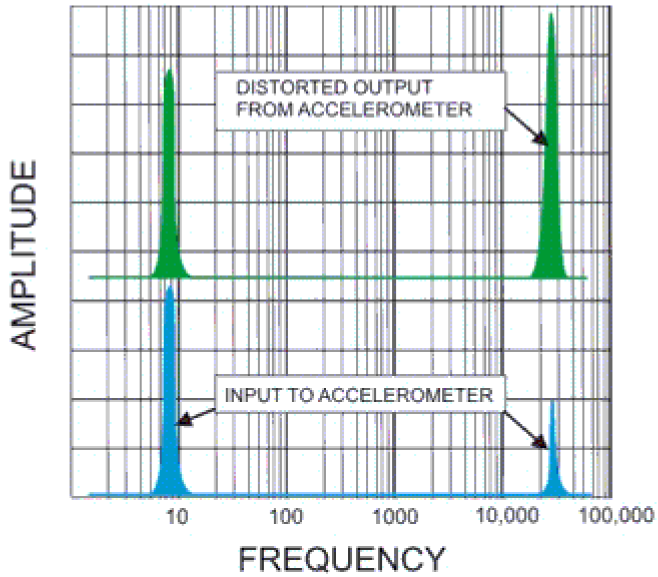
Natural frequency sufficiently high to capture all frequencies in signal

Problems start to arise however when the vibration content of the acceleration to be measured gets close to the natural frequency of the accelerometer.



Frequencies to be measured approach the natural frequency of the accelerometer

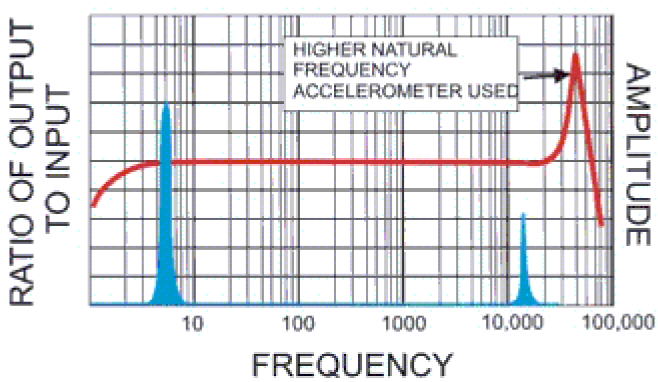
In these instances distortion of the acceleration by the high gains seen near the natural frequency can give a false picture of the reported acceleration amplitudes at high frequencies.



Acceleration signal is misrepresented by non-unity gain of the higher frequencies

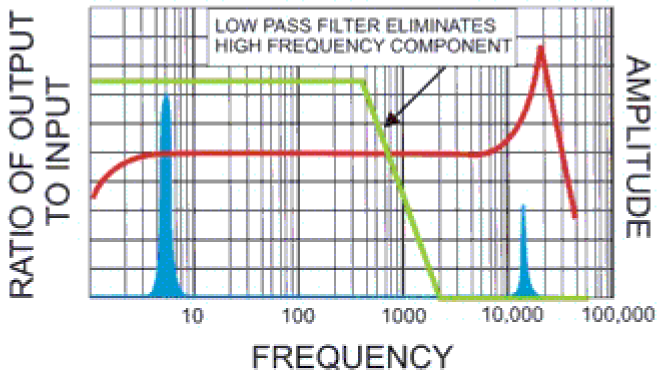
To overcome this problem one of two things needs to happen:

a) a higher frequency accelerometer needs to be used



A higher natural frequency accelerometer solves the problem of measuring high frequency accelerations

b) If the higher frequencies are not required to be measured then using a low pass filter should filter them out.



A low pass filter removes high frequency components of the measured signal

What type of accelerometer best suits my application?

Accelerometer Type	Advantages	Disadvantages
Single ended compression	1. Robust 2. Highest natural frequency 3. High shock resistance	1. Poor base strain characteristics
Isolated base compression	1. Robust 2. High natural frequency	1. Better base strain performance
Shear	1. Best base strain performance 2. Best temperature transients immunity 3. Smallest size	1. Less robust 2. Lower shock resistance
Charge output	1. High temperature operation 2. Suitable for radiation environments 3. Small size	1. Requires local charge amplifier 2. Susceptible to tribo-electric effect
Piezo-resistive	1. Measures down to zero Hz	1. Limited high frequency response
Strain Gage based	1. Measures down to zero Hz 2. High shock resistance	1. Limited high frequency response