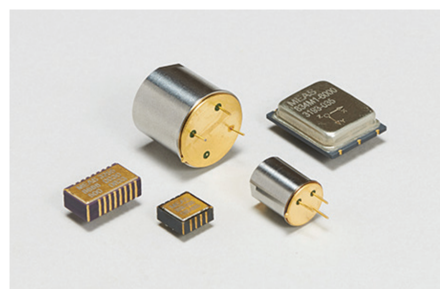
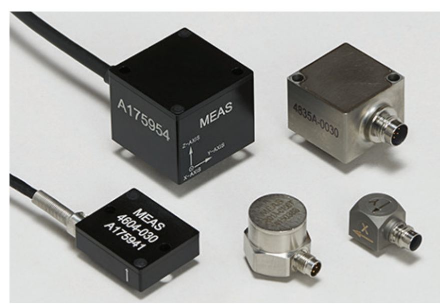
CHOOSING THE RIGHT TYPE OF ACCELEROMETER

As with most engineering activities, choosing the right tool may have serious implications on the measurement results. The information below may help the readers make the proper accelerometer selection. Let's start with the basic classifications and their technologies.

BASIC ACCELEROMETER TYPES





There are two classes of accelerometers in general:
AC-RESPONSE
DC-RESPONSE

In an AC-response accelerometer, as the name implies, the output is ac coupled. An AC coupled device cannot be used to measure static acceleration such as gravity and constant centrifugal acceleration, for example. It is only suitable for measuring dynamic events.

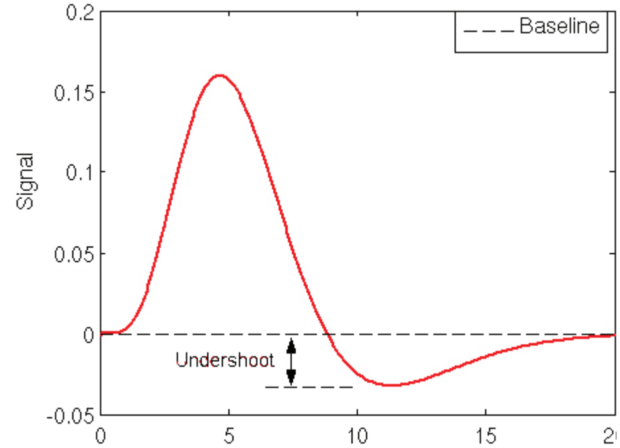
A DC-response accelerometer, on the other hand, is DC coupled, and can respond down to zero Hertz. It therefore can be used to measure static, as well as dynamic acceleration. Measuring static acceleration is not the only reason a DC-response accelerometer should be selected, however.

DESIGN REQUIREMENTS

ACCELERATION, VELOCITY, DISPLACEMENT

The majority of vibration studies require the knowledge of acceleration, velocity, and displacement - the important variables that engineers seek in designing or validating a structure. Generally speaking, the g value provides a good reference, but velocity and displacement are the variables needed in most design calculations. To derive velocity and displacement from the acceleration output, the signal from the accelerometer is integrated and double integrated respectively in the analog or digital domain. Here is where an AC-response accelerometer may run into trouble. To illustrate the problem, picture when an AC- response accelerometer is used to measure a long duration half-sine input pulse. The output of this device can never quite track the peak of the half-sine input because of the intrinsic limitation imposed by its RC time constant. At the end of the half-sine pulse, the output of the ac coupled accelerometer will produce an undershoot (offset) for the very same reason. The red trace in the figure below depicts the output of an AC coupled device following a long duration half-sine input.

These seemingly small amplitude deviations can result in significant errors during numerical integration. A DC-response device has no such problem because it can follow the slow-moving input accurately. In real day-to-day applications, physical inputs do not resemble half-sine impulses, but the basic problem remains whenever one needs to track slow motion with an AC coupled device. Now, let's look at the various popular accelerometer technologies.



AC ACCELEROMETERS

The most common AC-response accelerometers use piezoelectric elements for their sensing mechanism. Under acceleration, the seismic mass of the accelerometer causes the piezoelectric element to “displace” a charge, producing an electrical output proportional; to acceleration.

Electrically, the piezoelectric elements look like a source capacitor with a finite internal resistance, typically in the order of 10^9 ohms. This forms the RC time constant which defines the high-pass characteristics of the device. For this reason, piezoelectric accelerometer cannot be used to measure static events. Piezoelectric elements can be natural or man-made. They come with varying degrees of transduction efficiency and linearity characteristics.

Two types of piezoelectric accelerometer are available on the market: CHARGE OUTPUT TYPE and VOLTAGE OUTPUT TYPE.

CHARGE MODE PIEZOELECTRIC

The majority of the piezoelectric sensors are based on lead zirconate titanate ceramics (PZT) which offer very wide temperature range, broad dynamic range, and wide bandwidth (usable to >10kHz). When housed in a hermetic, welded metal case, a charge mode accelerometer can be considered one of the most durable sensors because of its ability to tolerate hostile environmental conditions. Due to its high impedance characteristics, a charge mode device must be used with a low-noise shielded cable, preferably in a coaxial configuration. Low noise refers to low triboelectric noise[2], a motion induced spurious output from the cable itself. These noise- treated cables are commonly available from the sensor manufacturers. A charge amplifier is generally used to interface with charge mode accelerometers to avoid problems associated with parallel cable capacitance. With a modern charge amplifier, the broad dynamic range (>120 dB) of the charge mode sensors can be easily realized. Due to the wide operating temperature range of piezoelectric ceramics, some charge mode devices can be used from -200°C to +640°C and beyond. They are especially suitable for use in vibration measurements at temperature extremes, such as in turbine engine monitoring.

VOLTAGE MODE PIEZOELECTRIC

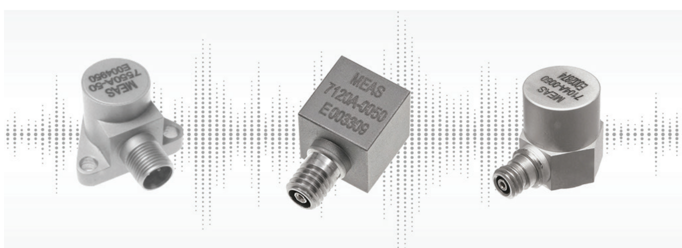
The other type of piezoelectric accelerometer provides voltage output instead of charge.

This is accomplished by incorporating the charge amplifier inside the housing of the accelerometer. Voltage mode devices feature 3-wire (Signal, Ground, Power) mode or 2- wire (Power/Signal, Ground) mode. The 2- wire mode is also known as Integral Electronics PiezoElectric (IEPE). IEPE is most popular due to its convenient coaxial (two-wire) configuration in which the ac signal is superimposed on the dc power line. A blocking capacitor is needed to remove the dc bias from the sensor signal output. Many modern signal analyzers provide the IEPE/ICP[3] input option which allows a direct interface to IEPE accelerometers. If the IEPE power option is not available, a signal conditioner/power supply with constant current power is required to interface with this type of device. The 3-wire mode device requires a separate dc power supply line for proper operation.

Unlike a charge mode device that only contains ceramic sensing element(s), voltage mode device includes a microelectronic circuit which limits the operating temperature of the device to the maximum operating temperature of the electronics, usually tops at +125°C. Some designs push the limit to +175°C, but they come with compromises elsewhere in the performance envelope.

A word on usable dynamic range - Due to the exceptionally wide dynamic range in piezoelectric ceramic elements, charge mode accelerometers are most flexible in terms of scalability because the system full scale range can be adjusted from the remote charge amplifier at the user’s command. Voltage mode devices, on the other hand, have their full scale range pre-determined by the internal amplifier at the factory and cannot be altered.

Piezoelectric accelerometers are available in very small footprint. They are therefore suited for dynamic measurements in lightweight structures.



DC-ACCELEROMETERS

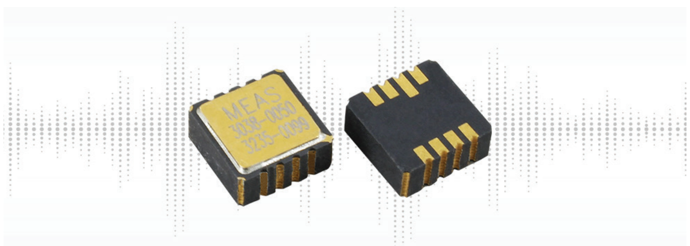
Two popular sensing technologies are used in making DC-accelerometers: CAPACITIVE and PIEZORESISTIVE

CAPACITIVE

Capacitive type (based on the capacitance changes in the seismic mass under acceleration) is the most common technology used for accelerometer today. They are made popular by large commercial applications such as air-bag and mobile devices. They employ Micro-Electro-Mechanical Systems (MEMS) fabrication technology which brings economy of scale to high volume applications, hence lower manufacturing cost. But this class of low-price capacitive accelerometers typically suffers from poor signal to noise ratio and limited dynamic range. One inherent characteristic with all capacitive devices is its internal clock. The clock frequency (~500kHz) is an integral part of the current detection circuit, which is invariably present in the output signal due to internal leakage. The high frequency noise may well be outside of the acceleration measurement range of interest, but it is always there with the signal. Due to its built-in amplifier/IC, its 3-wire (or 4- wire for differential output) electrical interface is straight forward, requiring only a stable DC voltage source for power.

Bandwidth of capacitive accelerometer is mostly limited to a few hundred Hertz's (some designs offer up to 1500Hz) partly due to its physical geometry and its heavy gas damping. Capacitive sensor structure also favors the lower range of acceleration measurement. Maximum range is typically limited to less than 200g's. Other than these restrictions, modern capacitive accelerometers, especially the instrument grade devices, offer good linearity and high output stability.

Capacitive type accelerometers are most suitable for on-board monitoring applications where cost may be the driving factor. They are suited for measuring low frequency motion where the g level is also low, such as vibration measurements in civil engineering.



PIEZORESISTIVE

Piezoresistive is the other commonly used sensing technology for DC-response accelerometers. Instead of sensing the capacitance changes in the seismic mass (as in a capacitive device), a piezoresistive accelerometer produces resistance changes in the strain gages that are part of the accelerometer's seismic system. Most engineers are familiar with strain gage and know how to interface with its output. The output of most piezoresistive designs is generally sensitive to temperature variation. It is therefore necessary to apply temperature compensation to its output internally or externally. Modern piezoresistive accelerometers incorporate ASIC for all forms of on board signal conditioning, as well as in- situ temperature compensation.

Bandwidth of piezoresistive accelerometers can reach upwards of 7,000 Hz. Many of the piezoresistive designs are either gas damped (MEMS types) or fluid damped (bonded strain gage type). Damping characteristics can be an important factor in choosing an accelerometer. In applications where the mechanical input may contain very high frequency input (or excite high frequency response), a damped accelerometer can prevent sensor ringing (resonance) and preserve or improve dynamic range. Because the piezoresistive sensor output is differential and purely resistive, signal to noise performance is generally outstanding; its dynamic range is limited only by the quality of the DC bridge amplifier. For very high g shock measurements, some piezoresistive designs can handle acceleration levels well above 10,000g's.

Due to its broader bandwidth capability, piezoresistive type accelerometers are most suitable for impulse/ impact measurements where frequency range and g level are typically high. Being a DC-response device, one can accurately derive from its acceleration output the desired velocity and displacement information without integration error. Piezoresistive accelerometers are commonly used in automotive safety testing, weapons testing, and higher shock range measurements beyond the usable range of VC accelerometers.

SUMMARY

Each accelerometer sensing technology has its advantages and compromises. Before making a selection, it's important to understand the basic differences of the various types and the test requirements.

First and foremost, choose only DC-response accelerometers to measure static or very low frequency (<1Hz) acceleration, or if velocity and displacement information are to be extracted from the acceleration data. Both DC and AC-response accelerometers are capable of measuring dynamic events. When dealing only with dynamic measurement, the choice between a DC or AC response device is really a matter of preference. Some users don't like to deal with the zero offset of a DC-response sensor and prefer the ac coupled, single-ended output of the piezoelectric types. Others don't mind dealing with the zero offset and four wires (or 3-wire if in single-ended mode) and like the shunt calibration and built- in functional test (2g turnover) capabilities of DC-response accelerometers. In summary:

Charge mode piezoelectric design is the most durable accelerometer type due to its simple construction and robust material properties.

For high temperature (>150°C) dynamic measurement applications, charge mode piezoelectric is an obvious choice; or in most cases, the only choice. With charge mode device, a low-noise coaxial cable should be used due to its high impedance output, and a remote charge amplifier (or an inline charge converter) to condition its charge output.

Voltage mode piezoelectric is the most popular type of accelerometer for dynamic measurements. It offers small size, broad bandwidth and a built-in charge converter which allows direct interface with many modern signal analyzers and data acquisition systems (those that offer integrated IEPE/ICP power source). Voltage mode piezoelectric is typically limited to <125°C applications, but it is no longer necessary to use a low-noise coaxial cable due to its low impedance output.

Capacitive design features critically damped to overdamped response which lends itself to low frequency measurements. The low cost, SMD class of devices is suited for high volume automotive and consumer applications where ultimate accuracy is not a priority. The more expensive instrumentation grade silicon MEMS capacitive accelerometers have good bias stability and very low noise. Capacitive accelerometers have low impedance output and ±2V to ±5V full scale output. Most designs require a regulated dc voltage for power.

Piezoresistive accelerometers are versatile in terms of their frequency and dynamic range capabilities. Being a DC-response device, it can handle static acceleration and produce accurate velocity and displacement data. Its broad bandwidth also covers most dynamic measurement needs. Piezoresistive designs offer various degree of damping (from ζ =0.1 to 0.8) response which makes it suitable for use in a variety of test conditions, including shock testing. Plain piezoresistive accelerometers (without electronics) are small and lightweight, with a ±100 to ±200mV full scale output. The amplified models (with built-in ASIC) feature low output impedance (<100Ω) and ±2V to ±5Vfull scale output.

REFERENCES

1. A. G. Piersol, T.L. Paez, Harris' Shock and Vibration Handbook 6th Ed., p.10.9, McGraw-Hill, 2010
2. A. G. Piersol, T.L. Paez, Harris' Shock and Vibration Handbook 6th Ed., p.15.19, McGraw-Hill, 2010
3. ICP is a registered trademark of PCB. Other popular trade names from various suppliers exist

te.com/sensorsolutions

Measurement Specialties, Inc., a TE Connectivity company.

CHOOSING THE RIGHT TYPE OF ACCELEROMETER 07/17 Original

TE CONNECTIVITY

For More Information Contact
TE Connectivity

te.com/sensorsolutions-contact

www.te.com