CHAPTER 5

Acceleration, Shock and Vibration Sensors

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5.1 Introduction

Accelerometers are sensing transducers that provide an output proportional to acceleration, vibration[1] and shock. These sensors have found a wide variety of applications in both research and development arenas along with everyday use. In addition to the very technical test and measurement applications, such as modal analysis, NVH (noise vibration and harshness), and package testing, accelerometers are also used in everyday devices such as airbag sensors and automotive security alarms. Whenever a structure moves, it experiences acceleration. Measurement of this acceleration helps us gain a better understanding of the dynamic characteristics that govern the behavior of the object. Modeling the behavior of a structure provides a valuable technical tool that can then be used to modify response, to enhance ruggedness, improve durability or reduce the associated noise and vibration.

The most popular class of accelerometers is the piezoelectric accelerometer. This type of sensor is capable of measuring a wide range of dynamic events. However, many other classes of accelerometers exist that are used to measure constant or very low frequency acceleration such as automobile braking, elevator ride quality and even the gravitational pull of the earth. Such accelerometers rely on piezoresistive, capacitive and servo technologies.

5.2 Technology Fundamentals

Piezoelectric Accelerometer

Piezoelectric accelerometers are self-generating devices characterized by an extended region of flat frequency response range, a large linear amplitude range and excellent durability. These inherent properties are due to the use of a piezoelectric material as the sensing element for the sensor. Piezoelectric materials are characterized by their ability to output a proportional electrical signal to the stress applied to the material. The basic construction of a piezoelectric accelerometer is depicted in Figure 5.2.1.

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[1] For information on machinery vibration monitoring, refer to Chapter 13.

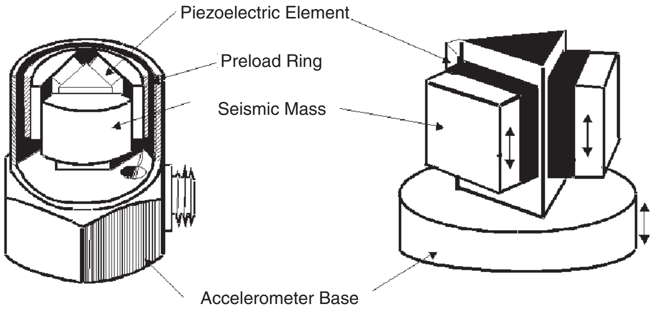


Figure 5.2.1: Basic piezoelectric accelerometer construction.

The active elements of the accelerometer are the piezoelectric elements. The elements act as a spring, which has a stiffness k, and connect the base of the accelerometer to the seismic masses. When an input is present at the base of the accelerometer, a force (F) is created on piezoelectric material proportional to the applied acceleration (a) and size of the seismic mass (m). (The sensor is governed by Newton's law of motion $F = ma$.) The force experienced by the piezoelectric crystal is proportional to the seismic mass times the input acceleration. The more mass or acceleration, the higher the applied force and the more electrical output from the crystal.

The frequency response of the sensor is determined by the resonant frequency of the sensor, which can generally be modeled as a simple single degree of freedom system. Using this system, the resonant frequency (ω) of the sensor can be estimated by: $\omega = \sqrt{k/m}$.

The typical frequency response of piezoelectric accelerometers is depicted in Figure 5.2.2.

Piezoelectric accelerometers can be broken down into two main categories that define their mode of operation. Internally amplified accelerometers or IEPE (internal electronic piezoelectric) contain built-in microelectronic signal conditioning. Charge mode accelerometers contain only the self-generating piezoelectric sensing element and have a high impedance charge output signal.

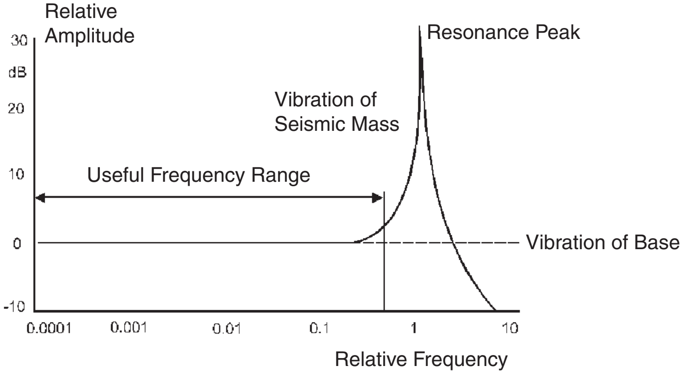


Figure 5.2.2 Typical frequency response of piezoelectric accelerometer.

IEPE Accelerometers

IEPE sensors incorporate built-in, signal-conditioning electronics that function to convert the high-impedance charge signal generated by the piezoelectric sensing element into a usable low-impedance voltage signal that can be readily transmitted, over ordinary two-wire or coaxial cables, to any voltage readout or recording device. The low-impedance signal can be transmitted over long cable distances and used in dirty field or factory environments with little degradation. In addition to providing crucial impedance conversion, IEPE sensor circuitry can also include other signal conditioning features, such as gain, filtering and self-test features. The simplicity of use, high accuracy, broad frequency range, and low cost of IEPE accelerometer systems make them the recommended type for use in most vibration or shock applications. However, an exception to this assertion must be made for circumstances in which the temperature at the installation point exceeds the capability of the built-in circuitry. The routine upper temperature limit of IEPE accelerometers is 250°F (121°C); however, specialty units are available that operate to 350°F (175°C).

IEPE is a generic industry term for sensors with built-in electronics. Many accelerometer manufacturers use their own registered trademarks or trade name to signify sensors with built-in electronics. Examples of these names include: ICP® (PCB Piezotronics), Deltatron (Bruel & Kjaer), Piezotron (Kistler Instruments), and Isotron (Endevco), to name a few.

The electronics within IEPE accelerometers require excitation power from a constant-current, DC voltage source. This power source is sometimes built into vibration meters, FFT analyzers and vibration data collectors. A separate signal conditioner is required when none is built into the readout. In addition to providing the required excitation, power supplies may also incorporate additional signal conditioning, such as gain, filtering, buffering and overload indication. The typical system set-ups for IEPE accelerometers are shown in Figure 5.2.3.

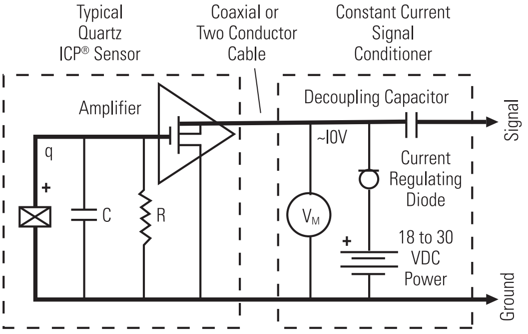


Figure 5.2.3: Typical IEPE system.

Charge Mode Accelerometers

Charge mode sensors output a high-impedance, electrical charge signal that is generated directly by the piezoelectric sensing element. It should be noted that this signal is sensitive to corruption from environmental influences and cable-generated noise. Therefore it requires the use of a special low noise cable. To conduct accurate measurements, it is necessary to condition this signal to a low-impedance voltage before it can be input to a readout or recording device. A charge amplifier or in-line charge converter is generally used for this purpose. These devices utilize high-input-impedance, low-output-impedance charge amplifiers with capacitive feedback. Adjusting the value of the feedback capacitor alters the transfer function or gain of the charge amplifier.

Typically, charge mode accelerometers are used when high temperature survivability is required. If the measurement signal must be transmitted over long distances, it is recommended to use an in-line charge converter, placed near the accelerometer. This minimizes the chance of noise. In-line charge converters can be operated from the same constant-current excitation power source as IEPE accelerometers for a reduced system cost. In either case, the use of a special low noise cable is required between the accelerometer and the charge converter to minimize vibration induced triboelectric noise.

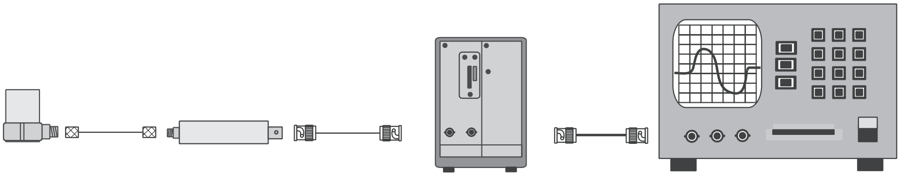


Figure 5.2.4: Typical in-line charge converter system.

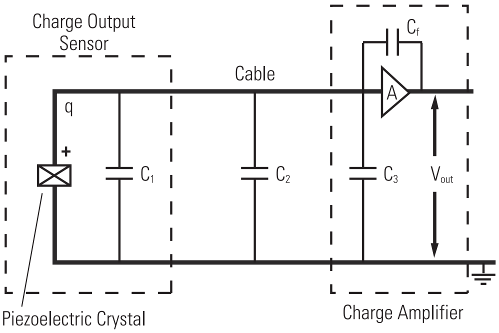


Figure 5.2.5: Laboratory charge amplifier system.

Sophisticated laboratory-style charge amplifiers usually include adjustments for normalizing the input signal and altering the feedback capacitor to provide the desired system sensitivity and full-scale amplitude range. Filtering also may be used to tailor the high and low frequency response. Some charge amplifiers provide dual-mode operation, which provides power for IEPE accelerometers and conditions charge mode sensors.

Because of the high-impedance nature of the output signal generated by charge mode accelerometers, several important precautionary measures must be followed. As noted above, always be attentive to motion induced (triboelectric) noise in the cable and mitigate by using specially treated cable. Also, always maintain high insulation resistance of the accelerometer, cabling, and connectors. To ensure high insulation resistance, all components must be kept dry and clean. This will help minimize potential problems associated with noise and/or signal drift.

Piezoelectric Sensing Materials

Two categories of piezoelectric materials that are predominantly used in the design of accelerometers are quartz and polycrystalline ceramics. Quartz is a natural crystal, while ceramics are man-made. Each material offers certain benefits. The material choice depends on the particular performance features desired of the accelerometer.

Quartz is widely known for its ability to perform accurate measurement tasks and contributes heavily in everyday applications for time and frequency measurements. Examples include everything from wristwatches and radios to computers and home appliances. Accelerometers benefit from several unique properties of quartz. Since quartz is naturally piezoelectric, it has no tendency to relax to an alternative state and is considered the most stable of all piezoelectric materials. This important feature provides quartz accelerometers with long-term stability and repeatability. Also, quartz does not exhibit the pyroelectric effect (output due to temperature change), which provides stability in thermally active environments. Because quartz has a low capacitance value, the voltage sensitivity is relatively high compared to most ceramic materials, making it ideal for use in voltage-amplified systems. Conversely, the charge sensitivity of quartz is low, limiting its usefulness in charge-amplified systems, where low noise is an inherent feature.

A variety of ceramic materials are used for accelerometers, depending on the requirements of the particular application. All ceramic materials are man-made and are forced to become piezoelectric by a polarization process. This process, known as “poling,” exposes the material to a high-intensity electric field. This process aligns the electric dipoles, causing the material to become piezoelectric. If ceramic is exposed to temperatures exceeding its range, or large electric fields, the piezoelectric properties may be drastically altered. There are several classifications of ceramics. First, there are high-voltage-sensitivity ceramics that are used for accelerometers with built-in, voltage-amplified circuits. There are high-charge-sensitivity ceramics that are used for charge mode sensors with temperature ranges to 400°F (205°C). This same type of crystal is used in accelerometers that use built-in charge-amplified circuits to achieve high output signals and high resolution. Finally, there are high-temperature piezoceramics that are used for charge mode accelerometers with temperature ranges over 1000°F (537°C) for monitoring engine manifolds and superheated turbines.

Structures for Piezoelectric Accelerometers

A variety of mechanical configurations are available to perform the transduction principles of a piezoelectric accelerometer. These configurations are defined by the nature in which the inertial force of an accelerated mass acts upon the piezoelectric material. There are three primary configurations in use today: shear, flexural beam, and compression. The shear and flexural modes are the most common, while the compression mode is used less frequently, but is included here as an alternative configuration.

Shear Mode

Shear mode accelerometer designs bond, or “sandwich,” the sensing material between a center post and seismic mass. A compression ring or stud applies a preload force required to create a rigid linear structure. Under acceleration, the mass causes a shear stress to be applied to the sensing material. This stress results in a proportional electrical output by the piezoelectric material. The output is then collected by the electrodes and transmitted by lightweight lead wires to either the built-in signal conditioning circuitry of ICP® sensors, or directly to the electrical connector for a charge mode type. By isolating the sensing crystals from the base and housing, shear accelerometers excel in rejecting thermal transient and base bending effects. Also, the shear geometry lends itself to small size, which promotes high frequency response while minimizing mass loading effects on the test structure. With this combination of ideal characteristics, shear mode accelerometers offer optimum performance.

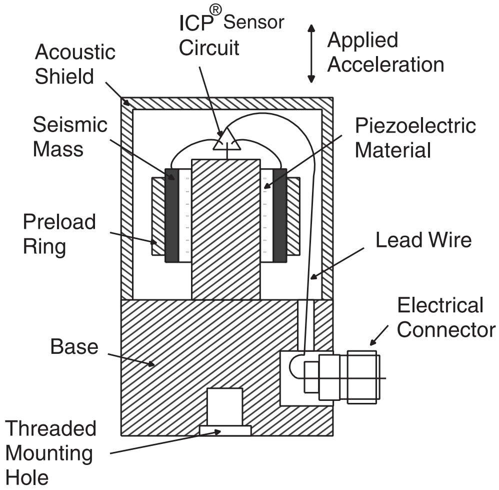


Figure 5.2.6: Shear mode accelerometer.

Flexural Mode

Flexural mode designs utilize beam-shaped sensing crystals, which are supported to create strain on the crystal when accelerated. The crystal may be bonded to a carrier beam that increases the amount of strain when accelerated. The flexural mode enables low profile, lightweight designs to be manufactured at an economical price. Insensitivity to transverse motion is an inherent feature of this design. Generally, flexural beam designs are well suited for low frequency, low gravitational (*g*) acceleration applications such as those that may be encountered during structural testing.

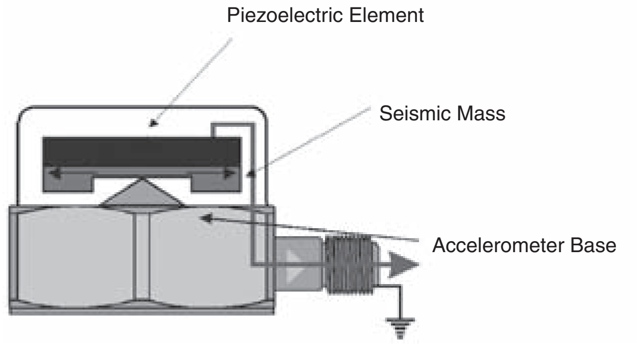


Figure 5.2.7: Flexural mode accelerometer.

Compression Mode

Compression mode accelerometers are simple structures which provide high rigidity. They represent the traditional or historical accelerometer design.

Upright compression designs sandwich the piezoelectric crystal between a seismic mass and rigid mounting base. A pre-load stud or screw secures the sensing element to the mounting base. When the sensor is accelerated, the seismic mass increases or decreases the amount of compression force acting upon the crystal, and a proportional electrical output results. The larger the seismic mass, the greater the stress and, hence, the greater the output.

This design is generally very rugged and can withstand high-*g* shock levels. However, due to the intimate contact of the sensing crystals with the external mounting base, upright compression designs tend to be more sensitive to base bending (strain). Additionally, expansion and contraction of the internal parts act along the sensitive axis making the accelerometer more susceptible to thermal transient effects. These effects can contribute to erroneous output signals when used on thin sheet-metal structures or at low frequencies in thermally unstable environments, such as outdoors or near fans and blowers.

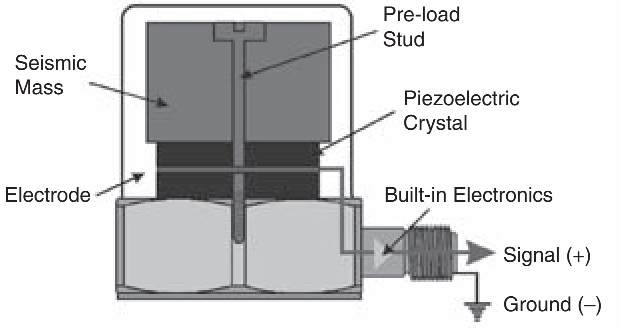


Figure 5.2.8: Compression mode accelerometer.

Piezoresistive Accelerometers

Single-crystal silicon is also often used in manufacturing accelerometers. It is an anisotropic material whose atoms are organized in a lattice having several axes of symmetry. The orientation of any plane in the silicon is provided by its Miller indices. Piezoresistive transducers manufactured in the 1960s first used silicon strain gages fabricated from lightly doped ingots. These ingots were sliced to form small bars or patterns. The Miller indices allowed positioning of the orientation of the bar or pattern with respect to the crystal axes of the silicon. The bars or patterns were often bonded directly across a notch or slot in the accelerometer flexure. Figure 5.2.9 shows short, narrow, active elements mounted on a beam. The large pads are provided for thermal power dissipation and ease of electrical and mechanical connections. The relatively short web avoids column-type instabilities in compression when the beam bends in either direction. The gages are subsequently interconnected in a Wheatstone bridge configuration. This fact that the gages are configured in a bridge indicates that piezoresistive accelerometers have response down to DC (i.e., they respond to steady-state accelerations).

Since the late 1970s we have encountered a continual evolution of microsensors into the marketplace. A wide variety of technologies are involved in their fabrication. The sequence of events that occurs in this fabrication process are: the single crystal silicon is grown; the ingot is trimmed, sliced, polished, and cleaned; diffusion of a dopant into a surface region of the wafer is controlled by a deposited film; a photolithography process includes etching of the film at places defined in the developing process, followed by removal of the photoresist; and isotropic and anisotropic wet chemicals are used for shaping the mechanical microstructure. Both the resultant stress distribution in the microstructure and the dopant control the piezoresistive coefficients of the silicon.

Electrical interconnection of various controlled surfaces formed in the crystal, as well as bonding pads, are provided by thin film metalization. The wafer is then separated into individual dies. The dies are bonded by various techniques into the transducer housing, and wire bonding connects the metallized pads to metal terminals in the transducer housing. It is important to realize that piezoresistive accelerometers manufactured in this manner use silicon both as the flexural element and as the transduction element, since the strain gages are diffused directly into the flexure. Figures 5.2.10 and 5.2.11 show typical results of this fabrication process.

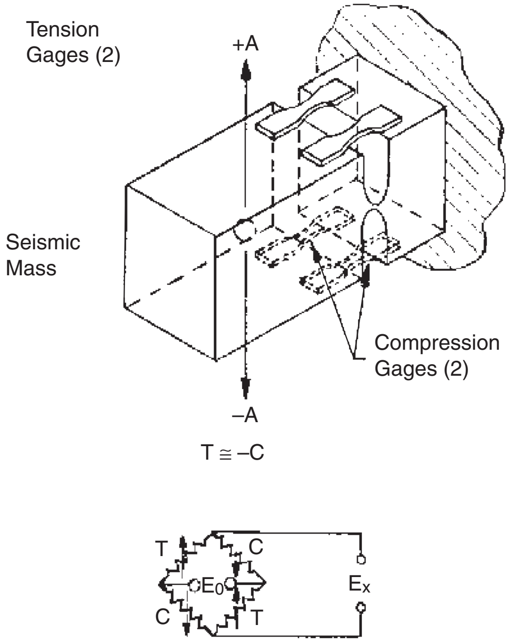


Figure 5.2.9: Bulk silicon resistors bonded to metal beam accelerometer flexure.

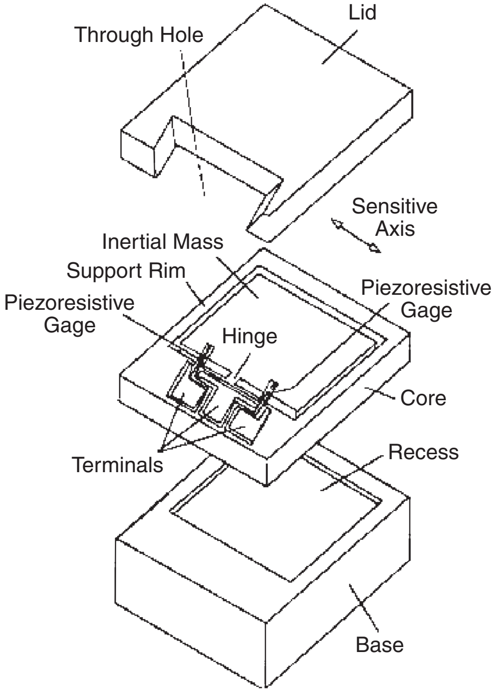


Figure 5.2.10: MEMS piezoresistive accelerometer flexure.

The advantages of an accelerometer constructed in this manner include a high stiffness, resulting in a high resonant frequency (ω) optimizing its frequency response. This high resonant frequency is obtained because the square root of the modulus-to-density ratio of silicon, an indicator of dynamic performance, is higher than that for steel. Other desirable byproducts are miniaturization, large signal amplitudes (semiconductor strain gages have a gage factor 25 to 50 times that of metal), good linearity, and improved stability. If properly temperature compensated, piezoresistive accelerometers can operate over a temperature range of –65 to +250°F. With current technology, other types of piezoresistive sensors (pressure) operate to temperatures as high as 1000°F.

Figure 5.2.11: Multiple MEMS accelerometer flexure containing diffused and metallized piezoresistive gages in Wheatstone bridge configuration.

Capacitive Accelerometers

Capacitive accelerometers are similar in operation to piezoresistive accelerometers, in that they measure a change across a bridge; however, instead of measuring a change in resistance, they measure a change in capacitance. The sensing element consists of two parallel plate capacitors acting in a differential mode. These capacitors operate in a bridge configuration and are dependent on a carrier demodulator circuit or its equivalent to produce an electrical output proportional to acceleration.

Several different types of capacitive elements exist. One type, which utilizes a metal sensing diaphragm and alumina capacitor plates, can be found in Figure 5.2.12. Two fixed plates sandwich the diaphragm, creating two capacitors, each with an individual fixed plate and each sharing the diaphragm as a movable plate.

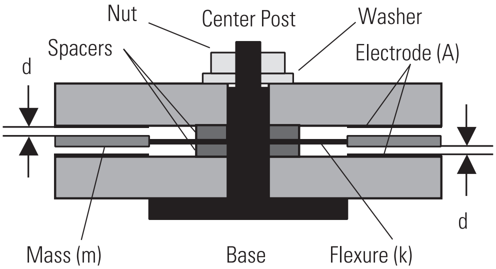


Figure 5.2.12: Capacitive sensor element construction.

When this element is placed in the Earth's gravitational field or is accelerated due to vibration on a test structure, the spring-mass experiences a force. This force is proportional to the mass of the spring-mass and is based on Newton's Second Law of Motion.

$F = ma$ where F = inertial force acting on spring-mass Eq. 5.2.1
m = distributed mass of spring-mass
a = acceleration experienced by sensing element

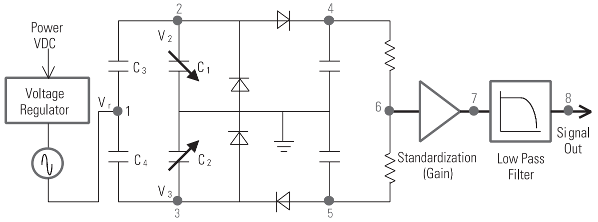
Consequently, the spring-mass deflects linearly according to the Spring Equation.

$X = F/k$ where X = deflection of spring-mass Eq. 5.2.2
k = stiffness of spring-mass

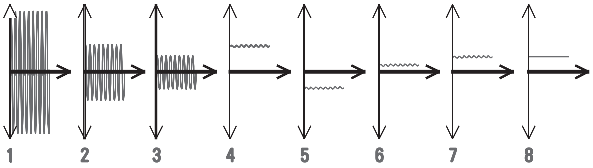
The resulting deflection of the spring-mass causes the distance between the electrodes and the spring-mass to vary. These variations have a direct effect on each of the opposing capacitor gaps according to the following equation.

$C_2 = A_E\,[\varepsilon / (d + X)]$ and,
$C_2 = A_E\,[\varepsilon / (d - X)]$ where C = element capacitance Eq. 5.2.3
A_E = surface area of electrode
ε = permittivity of air
d = distance between spring-mass and electrode

A built-in electronic circuit is required for proper operation of a capacitive accelerometer. In the simplest sense, the built-in circuit serves two primary functions: (1) allow changes in capacitance to be useful for measuring both static and dynamic events, and (2) convert this change into a useful voltage signal compatible with readout instrumentation.



Circuit Schematic



Response from Circuit due to applied +1g Static Acceleration
(x-axis = time and y-axis = voltage)

Figures 5.2.13 and 5.2.14: Operation of built-in circuit for capacitive accelerometer.

A representative circuit is shown in Figure 5.2.13 and Figure 5.2.14, which graphically depicts operation in the time domain, resulting from static measurand input.

The following explanation starts from the beginning of the circuit and continues through to the output, and describes the operation of the circuit.

To begin, the supply voltage is routed through a voltage regulator, which provides a regulated dc voltage to the circuit. The device assures “clean” power for operating the internal circuitry and fixes the amplitude of a built-in oscillator, which typically operates at >1 MHz. By keeping the amplitude of the oscillator signal constant, the output sensitivity of the device becomes fixed and independent of the supply voltage. Next, the oscillator signal is directed into the capacitance-bridge as indicated by Point 1 in Figure 5.2.13. It then splits and passes through each arm of the bridge, which each act as divider networks. The divider networks cause the oscillator signal to vary in direct proportion to the change in capacitance in C_2 and C_4. (C_2 and C_4 electrically represent the mechanical sensing element.) The resulting amplitude-modulated signals appear at Points 2 and 3. Finally, to “demodulate” these signals, they are passed through individual rectification/peak-picking networks at Points 4 and 5, and then summed together at Point 6. The result is an electrical signal proportional to the physical input.

It would be sufficient to complete the circuit at this point; however, additional features are often added to enhance its performance. In this case, a “standardization” amplifier has been included. This is typically used to trim the sensitivity of the device so that it falls within a tighter tolerance. In this example, Point 7 shows how this amplifier can be used to gain the signal by a factor of two. Finally, there is a low pass filter, which is used to eliminate any high frequency ringing or residual affects of the carrier frequency.

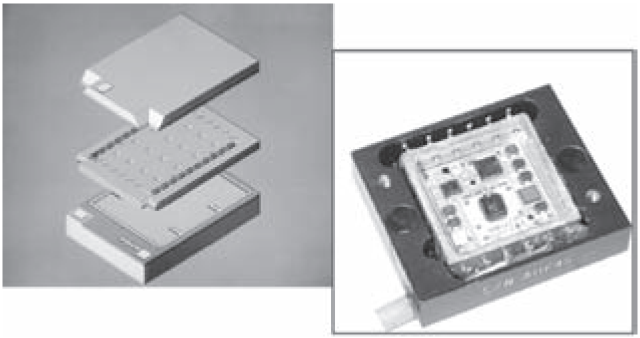


Figure 5.2.15: MEMS capacitor plates and completed accelerometer with top lid off.

If silicon can be chemically machined and processed as the transduction element in a piezoresistive accelerometer, it should similarly be able to be machined and processed into the transduction element for a capacitive accelerometer. In fact, MEMS technology is applicable to capacitive accelerometers. Figure 5.2.15 illustrates a MEMS variable-capacitance element and its integration into an accelerometer. As with the previously described metal diaphragm accelerometer, the detection of acceleration requires both a pair of capacitive elements and a flexure. The sensing elements experience a change in capacitance attributable to minute deflections resulting from the inertial acceleration force. The single-crystal nature of the silicon, the elimination of mechanical joints, and the ability to chemically machine mechanical stops, result in a transducer with a high over-range capability. As with the previous metal diaphragm accelerometer, damping characteristics can be enhanced over a broad temperature range if a gas is employed for the damping medium as opposed to silicone oil. A series of grooves, coupled with a series of holes in the central mass, squeeze gas through the structure as the mass displaces. The thermal viscosity change of a gas is small relative to that of silicone oil. Capacitive MEMS accelerometers currently operate to hundreds of g's and frequencies to one kHz. The MEMS technology also results in accelerometer size reduction.

Most capacitive accelerometers contain built-in electronics that inject a signal into the element, complete the bridge and condition the signal. For most capacitive sensors it is necessary to use only a standard voltage supply or battery to supply appropriate power to the accelerometer.

One of the major benefits of capacitive accelerometers is to measure low level (less than 2 g's), low frequency (down to dc) acceleration with the capability of withstanding high shock levels, typically 5,000 g's or greater. Some of the disadvantages of the capacitive accelerometer are a limited high frequency range, a relatively large phase shift and higher noise floor than a comparable piezoelectric device.

Servo or (Force Balance) Accelerometers

The accelerometers described to date have been all "open loop" accelerometers. The deflection of the seismic mass, proportional to acceleration, is measured directly using either piezoelectric, piezoresistive, or variable capacitance technology. Associated with this mass displacement is some small, but finite, error due to nonlinearities in the flexure. Servo accelerometers are "closed loop" devices. They keep internal deflection of the proof mass to an extreme minimum. The mass is maintained in a "balanced" mode virtually eliminating errors due to nonlinearities. The flexural system can be either linear or pendulous (C2 and C4 electrically represent opposite sides of the mechanical sensing element.) Electromagnetic forces, proportional to a feedback current, maintain the mass in a null position. As the mass attempts to move, a capacitive sensor typically detects its motion. A servo circuit derives an error signal from this capacitive sensor and sends a current through a coil, generating a torque proportional to acceleration, keeping the mass in a capture or null mode. Servo or "closed loop" accelerometers can cost up to ten times what "open loop accelerometers" cost. They are usually found in ranges of less than 50 g, and their accuracy is great enough to enable them to be used in guidance and navigation systems. For navigation, three axes of servo accelerometers are typically combined with three axes of rate gyros in a thermally-stabilized, mechanically-isolated package as an inertial measuring unit (IMU). This IMU enables determination of the 6-degrees of freedom necessary to navigate in space. Figure 5.2.16 illustrates the operating principal of a servo accelerometer. They measure frequencies to dc (0 Hertz) and are not usually sought after for their high frequency response.

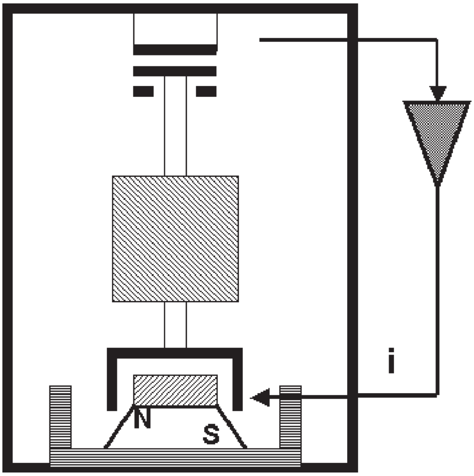


*Figure 5.2.16:
Typical servo accelerometer construction.*

5.3 Selecting and Specifying Accelerometers

Table 5.3.1 summarizes the advantages and disadvantages of different type of accelerometers along with some typical applications.

Table 5.3.1: Comparison of accelerometer types.

Accelerometer Type	Advantages	Limitations	Typical Applications
IEPE Piezoelectric Accelerometer	Wide Dynamic Range Wide Frequency Range Durable (High Shock Protection) Powered by Low Cost Constant Current Source Fixed Output Less Susceptible to EMI and RF Interference Can be Made Very Small Less Operator Attention, Training and Installation Expertise Required High Impedance Circuitry Sealed in Sensor Long Cable Driving without Noise Increase Operates into Many Data Acquisition Devices with Built-in Constant Current Input Operates across Slip Rings Lower System Cost per Channel	Limited Temperature Range Max Temperature of 175°C (350°F) Low Frequency Response is Fixed within the Sensor Built in amplifier is exposed to same test environment as the element of the sensor	Modal Analysis NVH Engine NVH Flight testing Body In White Testing Cryogenic Drop Testing Ground Vibration Testing HALT/HASS Seismic Testing Squeak and Rattle Helmet and Sport Equipment Testing Vibration Isolation and Control
Charge Piezoelectric Accelerometer	High operating temperatures to 700°C Wide dynamic Range Wide Frequency Range (Durable) High Shock Protection Flexible Output Simpler Design fewer parts Charge Converter electronics is usually at ambient condition, away from test environment	More Care/attention is required to install and maintain High impedance circuitry must be kept clean and dry Capacitive loading from long cable run results in noise floor increase Powered By Charge Amp which can be complicated and expensive Need to use Special Low Noise Cable	Jet Engine High Temperature Steam Pipes Turbo Machinery Steam Turbine Exhaust Brake

Table 5.3.1: Comparison of accelerometer types (continued).

Accelerometer Type	Advantages	Limitations	Typical Applications
Piezoresistive Accelerometer	DC Response Small Size	Lower Shock Protection Smaller Dynamic Range	Crash Testing Flight testing Shock testing
Capacitive Accelerometer	DC Response Better Resolution than PR Type Accelerometer	Frequency Range Average Resolution	Ride Quality Ride Simulation Bridge Testing Flutter Airbag Sensor Alarms
Servo Accelerometer	High Sensitivity Highest Accuracy for Low Level Low Frequency Measurements	Limited Frequency range, High Cost Fragile, Low Shock Protection.	Guidance Applications Requiring little or no DC Baseline Drift

Table 5.3.2 lists some of the *typical* characteristics of different sensors types.

Table 5.3.2: Typical accelerometer characteristics.

Accelerometer Type	Frequency Range	Sensitivity	Measurement Range	Dynamic Range	Size/weight
IEPE Piezoelectric Accelerometer	0.5 Hz to 50 000 Hz	.05 mV/g to 10 V/g	0.000001 g's to 100,000 g's	~120 dB	.2 Gram to 200 + grams
Charge Piezoelectric Accelerometer	0.5 Hz to 50 000 Hz	.01 pC/g to 100 pC/g	0.00001 g's to 100,000 g's	~110 dB	.14 grams to 200 + grams
Piezoresistive Accelerometer	0 to10000 Hz	0.0001 to 10 mV/g	0.001 to 100000 g's	~80 dB	1 to 100 grams
Capacitive Accelerometer	0 to 1000 Hz	10 mV/g to 1 V/g	0.00005 g's to 1000 g's	~90 dB	10 grams to 100 grams
Servo Accelerometer	0 to 100 Hz	1 to 10 V/g	<0.000001 g's to 10 g's	>120 dB	>50 grams

In order to select the most appropriate accelerometer for the application, you should look at a variety of factors. First you need to determine the type of sensor response required. The three basic functional categories of accelerometers are IEPE, Charge Mode and DC responding. The first two categories of accelerometers, the IEPE and Charge Mode type of accelerometers, work best for measuring frequencies starting at 0.5 Hz and above. The IEPE is a popular choice, due to its low cost, ease of use and low impedance characteristics, whereas the Charge Mode is useful for high temperature applications. There are advantages of each design.

When looking at uniform acceleration, as may be required for tilt measurement, or extremely low frequency measurements below 1 Hz, capacitive or piezoresistive accelerometers are a better choice. Both accelerometer types have been designed to achieve true 0 Hz (DC) responses. These sensors may contain built-in signal conditioning electronics and a voltage regulator, allowing them to be powered from a 5–30 VDC source. Some manufacturers offer an offset adjustment, which serves to null any DC voltage offset inherent to the sensor. Capacitive accelerometers are generally able to measure smaller acceleration levels.

The most basic criteria used to narrow the search, once the functionality category or response type of accelerometer has been decided, includes: sensitivity, amplitude, frequency range and temperature range. Sensitivity for shock and vibration accelerometers is usually specified in millivolts per g (mV/g) or picocoulombs per g (pC/g). This sensitivity specification is inversely proportional to the maximum amplitude that can be measured (g peak range.) Thus, more sensitive sensors will have lower maximum measurable peak amplitude ranges. The minimum and maximum frequency range that is going to be measured will also provide valuable information required for the selection process. Another important factor for accelerometer selection is the temperature range. Consideration should be given not only to the temperatures that the sensor will be exposed to, but also the temperature that the accelerometer will be stored at. High temperature special designs are available for applications that require that specification.

Every sensor has inherent characteristics, which cause noise. The broadband resolution is the minimal amount of amplitude required for a signal to be detected over the specified band. If you are looking at measuring extremely low amplitude, as in seismic applications, spectral noise at low frequency may be more relevant.

Physical characteristics can be very important in certain applications. Consideration should be given to the size and weight of the accelerometer. It is undesirable to place a large or heavy accelerometer on a small or lightweight structure. This is called “mass loading.” Mass loading will affect the accuracy of the results and skew the data. The area that is available for the accelerometer installation may dictate the accelerometer selection. There are triaxial accelerometers, which can be utilized to simultaneously measure acceleration in three orthogonal directions. Older designs required three separate accelerometers to accomplish the same result, and thus add weight and require additional space.

Consideration should be given to the environment that the accelerometer will be exposed to. Hermetically sealed designs are available for applications that will be exposed to contaminants, moisture, or excessive humidity levels. Connector alternatives are available. Sensors can come with side connections or top connections to ease cable routing. Some models offer an integrated cable. Sensors with field-repairable cabling can prove to be very valuable in rough environments.

Accelerometer mounting may have an effect on the selection process. Most manufacturers offer a variety of mounting alternatives. Accelerometers can be stud mounted, adhesively mounted or magnetically mounted. Stud mounting provides the best stiffness and highest degree of accuracy, while adhesive mounts and magnetic mounting methods offer flexibility and quick removal options.

There are a wide variety of accelerometers to choose from. More than one will work for most applications. In order to select the most appropriate accelerometer, the best approach is to contact an accelerometer manufacturer and discuss the application. Manufacturers have trained application engineers who can assist you in selecting the sensor that will work best for your application.

5.4 Applicable Standards

In order to verify accelerometer performance, sensor manufacturers will test various characteristics of the sensor. This calibration procedure serves to help both the manufacturer and the end user. The end user will obtain a calibration certificate to confirm the accelerometer's exact performance characteristics. The manufacturer uses this calibration procedure for traceability, and to determine whether the product meets specifications and should be shipped or rejected. It can be viewed as a built-in quality control function. It provides a sense of security or confidence for both the manufacturer and the customer.

However, be aware that all calibrations are not equal. Some calibration reports may include terms such as "nominal" or "typical," or even lack traceability, or accredited stamps of approval. With the use of words like "nominal" or "typical," the manufacturer does not have to meet a specific tolerance on those specifications. This helps the manufacturer ship more products and reduce scrap, since fewer measured specifications means fewer rejections. While this provides additional profit for a manufacturer, it is not a benefit to the end customer. Customers have to look beyond the shiny paper and cute graphics, to make sure of the completeness of the actual measured data contained in each manufacturer's calibration certificate.

Due to the inconsistency of different manufacturer's calibration techniques and external calibration services, test engineers came up with standards to improve the quality of the product and certification that they receive. MIL-STD-45662 was created to define in detail the calibration system, process and components used in testing, along with the traceability of the product supplied to the government. The American National Standards Institute (ANSI) came up with its own version of specifications labeled ANSI/NCSL Z540-1-1994. This ANSI standard along with the International Organization for Standards (ISO) 10012-1, have been approved by the military as

References and Resources

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