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Accelerometer Selection Considerations

Charge and ICP® Integrated Circuit Piezoelectric

Written By
Jim Lally, PCB Piezotronics, Inc.

ACCELEROMETER SELECTION CONSIDERATIONS
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Jim Lally,
PCB Piezotronics, Inc. Depew, NY 14043

There is a broad selection of charge (PE) and Integrated Circuit Piezoelectric (ICP®) accelerometers available for a wide variety of shock and vibration measurement applications. Selection criteria should include accelerometer electrical and physical specifications, performance characteristics, and environmental and operational considerations. Comparing advantages and limitations of the two systems may be helpful in selecting an accelerometer and measurement system best suited for a specific laboratory, field, factory, underwater, shipboard or airborne application.

Introduction

This paper will review sensor selection considerations involving two general types of piezoelectric sensors. High impedance, charge output (PE) type and ICP® with a characteristic low impedance output. In addition to sensor electrical and physical characteristics, several factors play a role in the selection of an accelerometer for a specific application. These factors include environmental, operational, channel count and system compatibility.

PIEZO ELECTRIC (PE) TYPE ACCELEROMETERS

PE type accelerometers generate a high-impedance, electrostatic charge output in response to mechanical stress applied to its piezo ceramic, or crystal, sensing element. Because of its high charge sensitivity, piezo ceramics have found wide use in both charge and voltage mode accelerometers. Quartz, generally recognized as the most stable of all piezoelectric materials, is also commonly used in general purpose ICP® accelerometers, calibration transfer standards, and PE pressure and force sensors. Charge output systems have been available for about 40 years. PE accelerometers operate through low-noise cable into a high input impedance charge amplifier, which converts the charge signal into a usable low-impedance voltage signal for acquisition purposes. The charge amplifier provides for signal impedance conversion, normalization, and gain/range adjust. Options may include filtering, integration for velocity and/or displacement, and adjustment of the input time constant, which determines low frequency response. Modern charge amplifiers are designed with more effective low-noise circuits and may incorporate simplified LCD displays and digital controls. Some "dual-mode" models operate with both PE and ICP® accelerometers. The main advantage of the laboratory charge system is flexibility of adjusting and controlling the electrostatic charge output of the PE accelerometer. Miniature, solid-state charge amplifiers, generally with fixed characteristics, have been used historically for airborne applications. PE accelerometers can also operate to higher temperature than ICP® accelerometers with built-in electronics.

The main limitations of the PE charge system involve system complexity, difficulty operating, maintaining high impedance circuits in dirty adverse environments, and noise increase when operating through long input cables. High impedance circuits are generally more susceptible to electrical interference.

INTEGRATED CIRCUIT PIEZOELECTRIC (ICP®) ACCELEROMETERS

ICP® accelerometers incorporate a built-in microelectronic charge or voltage amplifier, which functions to convert high impedance electrostatic charge from the PE sensing element into a low impedance voltage signal. In hermetic welded designs, all high impedance circuitry is sealed and electrically shielded inside the accelerometer. ICP® accelerometers were first manufactured in the mid 1960's.

ICP® accelerometers operate from a low-cost, constant-current power source over a two-wire circuit with signal/power carried over one wire and the other wire serving as ground. The cable can be ordinary coaxial or ribbon wire. Low-noise cable is not required. Constant current to operate the accelerometer comes from a separate power unit or it may be incorporated inside a readout instrument such as an FFT analyzer or Data Collector. Integrated electronic accelerometers are available under several different trademark names such as ICP® (PCB Piezotronics), Isotron® (Endevco), Delta-Tron® (B&K), and Piezotron® (Kistler) to mention a few. Although built-in electronics is a "common thread," all integrated electronic accelerometers are not necessarily interchangeable or "compatible" with each other. Some contain MOSFET circuits, others JFETS. Some use hybrid, microelectronic, charge amplifiers, others voltage followers. Although most integrated electronic accelerometers operate from 2 to 4 mA constant current, some operate from as little as 0.5 mA for low power consumption and others operate up to 20 mA for driving long cables at high frequencies. It is recommended that ICP® sensor and power specifications be checked before assuming compatibility.

The main advantage of low-impedance operation is the capability of ICP® accelerometers to operate continuously in adverse environments, through long, ordinary, coaxial cables, without increase in noise or loss of resolution. Cost per channel is less, since low-noise cable and charge amplifiers are not required. The main limitation involves operation at elevated temperatures, above 325 °F. ICP® accelerometers, structured with quartz sensing elements and special electronics, operate well at cryogenic temperatures. Table 1 is a comprehensive list of advantages and limitations of PE and ICP® accelerometers. This list was reviewed and inputs provided by outside consultants with years of experience in shock and vibration technology. The list should be considered "dynamic", subject to additional inputs relative to advantages and limitations.

TABLE I

CONSIDERATIONS FOR SELECTING PE & ICP® ACCELEROMETERS

PE SENSOR

Advantages

Flexibility in adjusting accelerometers electrical output characteristics properly

Wide dynamic range

Higher temperature operation >500 °F

Interchangeability in existing charge systems

Extended low frequency response

Limitations

Requires training and expertise to understand and operate high impedance circuits

Capacitive effects from accelerometer and cable increases noise and reduces resolution

High impedance circuitry must be kept clean and dry. (Sensor, low-noise cable and charge amplifier)

Requires special purpose low-noise cable to minimize triboelectric noise

High impedance systems are more susceptible to electrical and RF interference

PE accelerometer size and sensitivity are directly related - A sensitivity/size/mass loading consideration

Higher cost per-channel than ICP® type (due to required low-noise cable and charge amplifier)

ICP® SENSOR

Advantages

Simplified operation-less operator attention, training and expertise

Uses standard coaxial cable or ribbon wire

Drives long cables without noise increase or loss of resolution

Operates from low-cost, constant-current power source

Connects directly to many readout instruments

High output miniature designs reduce mass loading

Low impedance systems have greater resistance to contamination and electrical interference

Better system reliability

Dynamic range typically >100,000 to 1 (>100 dB)

Range and resolution are data sheet specifications

Bias monitor detects cable faults - shorts or open circuits

Can incorporate self-identification "TEDS" circuit and steep filtering

Operates through slip rings

Lower cost per-channel than PE type

Limitations

Electrical characteristics, sensitivity, range, and discharge time constant are fixed within the sensor

Limited temperature range (-320 °F to + 325 °F)

May not be interchangeable in system if power requirement is not the same

Each of these considerations will now be reviewed in more detail for both PE and ICP® accelerometers.

ADVANTAGES OF PE ACCELEROMETERS

Flexibility- A laboratory "bench type" charge amplifier usually has controls for adjusting and modifying output signal from the PE accelerometer. At a minimum, there are controls for normalizing sensitivity, setting gain and full-scale range, and grounding. The charge amplifier may also have capability for filtering, integration, and adjustment of discharge time constant, which determines low-frequency response. Dual-mode charge amplifiers also provide constant current, which allows operation with both ICP®, and charge output PE sensors.

Dynamic Range- Typically, a high-sensitivity PE accelerometer may operate over a wide dynamic range (>100 dB.) When used with a laboratory charge amplifier, full-scale output can be set for any g level within maximum range. Dynamic range can be defined as the operating range from resolution to the maximum range that the sensor will remain in specification. However, neither dynamic range nor resolution is specified for most ceramic crystal structured PE accelerometers. Maximum range is sometimes determined by the maximum acceptable non-linearity associated with operating at a higher range. Non-linearity is often expressed as a percentage of "X" number of g's, e.g. 1% per 500 g's. Resolution is based on system noise, which is determined by amplifier gain and capacitive loading from the input cable and accelerometer on the charge amplifier input.

High Temperature Operation- Since the PE accelerometer does not contain built-in electronics, the operating temperature is limited only by the sensing element and materials used in the construction. PE accelerometers commonly operate to 500 °F. Special models are available to > 1000 °F. For best accuracy, the accelerometer should be calibrated at operating temperature.

Interchangeability- Virtually any PE accelerometer is interchangeable in a charge output system, with the exception of some models which may have very low insulation resistance at high temperatures. Special charge amplifiers are available for operation with low-resistance inputs.

Extended Low Frequency Response- Quartz force sensors are commonly used in force controlled shaker applications. When coupled into high input impedance electrostatic charge amplifiers (> 1012 ohm), quartz force sensors have discharge time constants in the order of hundreds, or thousands of seconds, imparting excellent low-frequency response and capability for static calibration.

LIMITATIONS OF PE ACCELEROMETERS

Expertise- Training and expertise are required to understand, operate and maintain charge output systems. Basic understandings of high-impedance circuitry, low-noise cables, sensor pC/g sensitivity, capacitive loading effects, system noise, setting charge amplifier controls, and keeping the system clean and moisture-free are required. Some newer charge amplifiers have digital controls, which simplify entering sensitivity and setting range.

Resolution- Although resolution for PE accelerometers may be considered infinite, resolution is not generally specified on a data sheet, since it is determined by system noise. Until capacitance values for the sensor and input cable length are determined and the amplifier gain set, resolution is not known. This can present uncertainties for low-level measurements involving long cables. Although increased cable length does not affect sensitivity, it does affect system noise and resolution. Lack of capability to drive long cables is one of the main limitations of the PE accelerometer charge output system. New, more modern charge amplifiers, with low-noise circuits, minimize this problem. "Triboelectric" noise generated as a result of input cable motion, can also degrade resolution.

Operating Environment- High-impedance PE accelerometers and charge amplifiers are best suited for operation in clean laboratory conditions. They do not operate well in adverse factory, shipboard or underwater environments. All high-impedance components, including the accelerometer, low-noise cable and charge amplifier must be kept clean and dry. Contamination of the high impedance circuit causes low resistance, loss of low frequency response, and baseline drift.

Cable and Connectors- PE accelerometers require the use of high insulation resistance, low-noise, coaxial cable. Low-noise cable has a graphite lubricant embedded in the dielectric layer to minimize friction and generation of "triboelectric" static electricity. The electrostatic charge generated by cable motion is the same as the charge generated from the piezo element. The charge amplifier cannot differentiate between the two. Cable connectors are commonly Microdot® 10-32 coaxial. Cable and connector selection are limited.

Size vs Sensitivity- Size, sensitivity, and frequency response of PE accelerometers are all directly interrelated. The larger the accelerometer, the higher the sensitivity, but lower the frequency response, and vice-versa. When a measurement application requires a miniature accelerometer for low-mass loading considerations, compromise may have to be made in selecting a larger accelerometer that provides adequate sensitivity.

Cost- PE accelerometer cost is essentially the same as an equivalent ICP® design. However, since the PE accelerometer requires the use of low-noise cable and charge amplifiers, cost per-channel is higher than an ICP® voltage output channel. Cables and amplifiers are major cost considerations in multi-channel measurement systems.

ADVANTAGES OF ICP® ACCELEROMETERS

Simplified Operation- ICP® accelerometer systems offer simplified operation requiring less operator expertise, training and attention. They provide a fixed, mV/g, low-impedance output signal that is virtually unaffected by cable type, length, and environmental operating conditions.

Resolution- The resolution of ICP® accelerometers is virtually unaffected by cable type or length. Resolution is a standard data sheet specification. Long cables can be used without increase in noise, loss of resolution, or signal attenuation. Input cables hundreds of feet long can act as an LP filter on ultra high-frequency data. However, this is usually only of concern with ICP® pressure sensors used for microsecond shock and blast wave pressure measurements.

Operating Environment- Hermetically sealed ICP® accelerometers operate well in adverse environments. They are resistant to contamination, since all the high impedance circuitry is safely sealed inside the accelerometer. Welded hermetic designs are generally more contamination resistant than epoxy sealed designs. Compatibility with adverse environments makes ICP® accelerometers the preferred choice for industrial machine health monitoring, underwater, shipboard, vehicular and field test applications.

Cable and Connectors- The low-impedance output of ICP® accelerometers allows complete flexibility in cable type and connectors. Cable and connector considerations can be important in certain applications involving high or low temperature, pressure, vacuum, corrosive fluids and where mass loading is a concern. Miniature ICP® accelerometer designs often incorporate solder terminal connections, allowing the use of lightweight flexible cable to minimize strain and mass loading effects. Industrial accelerometers use large, rugged connectors and/or vulcanized connections to achieve reliability in adverse environments. The use of standard cable and connectors in large channel-count systems promotes effective cable management and is a significant factor in cost reduction.

Size and Sensitivity- By incorporating gain in miniature ICP® accelerometers, it is possible to solve applications requiring accelerometers with low mass, high sensitivity, and high frequency response. Internal gain also improves the resolution of ceramic structured ICP® accelerometers incorporating hybrid charge amplifiers. Some ICP® accelerometers incorporate voltage gain circuits, and although signal level is boosted for recording and/or cable driving purposes, so is the noise level.

Dynamic Range- ICP® accelerometers have a very wide dynamic range. "Limited or Fixed Dynamic Range" is sometimes cited as a "limitation" of ICP® accelerometers. Most ICP® accelerometers have greater than 100,000 to 1 (>100 dB) dynamic range. Some seismic models incorporating special low-noise circuits have >500,000 to 1 range. Both dynamic range and resolution of an ICP® sensor are known data sheet specifications. Even more significant, the ICP® system does not lose dynamic range, due to added cable length and system configuration.

Powering ICP® Accelerometers- Depending on the specific model, ICP® accelerometers may operate from 0.5 mA to 20 mA constant current at anywhere from 3 to 30 VDC. For extended dynamic range, some special models have been supplied to operate from as high as 35 VDC. As cautioned earlier, all ICP® accelerometers do not contain the same internal electrical circuit and consequently, they are not necessarily compatible with all constant current power sources. Sensor bias and supply voltage both affect dynamic range. Supply current affects cable driving capability, especially when driving high-voltage signals at high frequencies. Constant current power units are available today with battery or line power, with or without gain, and manual or computer controlled operation. ICP® sensor line power units generally supply 2 to 4 mA current. However, they are usually adjustable to 20 mA, which may be required when driving long cables at high frequencies. Many commercial readout instruments, such as FFT analyzers and Vibration Data Collectors, incorporate constant current power input for direct connection to ICP® accelerometers. Dual-mode charge amplifiers incorporate constant-current power to provide for operation with both PE and ICP® accelerometers.

Cable Fault Monitor- In ICP® two-wire sensor circuits, signal/power is carried over one wire and signal return (ground) over the other. By monitoring the characteristic DC "bias" voltage that exists on the signal/power wire, it is possible to detect cable open or short circuits. ICP® sensor power units commonly incorporate red, green, yellow color-coded meters, or LED's, to indicate normal operation or cable faults.

Operation Through Slip Rings- Certain vibration measurement applications on rotating machinery require operation through slip rings. The characteristic low-impedance output voltage from ICP® accelerometers is compatible with operation through slip rings.

"TEDS" Transducer Electronic Data Sheet- Incorporation of a "TEDS" memory circuit in ICP® accelerometers allows storing self identification information such as manufacturer's name, sensor type, model, serial number, sensitivity, calibration date, channel ID, sensor location, and other information. TEDS accelerometers operate in a "mixed" analog or digital mode. A TEDS signal conditioner is used to access digital memory over the same wires normally used for analog measurements. Once the memory data has been accessed, the digital memory circuit can be switched out and the accelerometer can be used for normal analog operation.

Cost- Although most ICP® and PE accelerometers essentially cost the same, the per-channel cost of the ICP® system is substantially lower since special low-noise cables and charge amplifiers are not required. Savings can be substantial when comparing costs of multi-channel systems. From an operational perspective, less care, attention, and effort is required to operate and maintain low impedance systems.

LIMITATIONS OF ICP® ACCELEROMETERS

Fixed Output- Electrical characteristics, such as sensitivity, range, resolution and discharge time constant, are fixed within the ICP® accelerometer. Fixed discharge time constant is less of a limitation with accelerometers than with quartz pressure and force sensors, which can be operated in the long time constant mode for quasi-static calibration purposes.

Temperature Range- Most general purpose ICP® accelerometers have limited temperature range from about -65 °F to +250 °F. Special cryogenic models operate down to -320 °F and high temperature designs to +325 °F.

SUMMARY

Charge amplifier systems benefit from the very wide dynamic range of PE accelerometers by offering flexibility in adjusting the electrical output characteristics such as sensitivity and range. They are well-suited for operation at high temperatures. Modern charge systems feature improved low-noise operation, simplified digital controls, and dual output operation for operation with charge or ICP® voltage mode sensors. High-impedance circuitry is not well suited for operation in adverse field or factory environments. PE accelerometer resolution may not be specified or known since noise is a system consideration determined by cable length and amplifier gain. ICP® accelerometers operate from a constant current power source, provide a high-voltage, low-impedance, fixed mV/g output. They operate through long, ordinary, coaxial cable in adverse environments without degradation of signal quality. They have limited high temperature range. ICP® sensors are simple to operate. Both resolution and operating range are defined specifications. Cost per-channel is lower compared to PE systems, since low-noise cable and charge amplifiers are not required.

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PCB PIEZOTRONICS
AN AMPHENOL COMPANY

3425 Walden Avenue, Depew, NY 14043 USA

pcb.com | info@pcb.com | 800 828 8840 | +1 716 684 0001