ACCELEROMETER SELECTION CONSIDERATIONS
Charge and Integral Electronic Piezo Electric

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There is a broad selection of charge (PE) and Integral Electronic Piezo Electric (IEPE) accelerometers available for a wide variety of shock and vibration measurement applications. Selection criteria should include accelerometer electrical and physical specifications, performance characteristics, as well as environmental and operational considerations. Comparing the 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 mode (PE) type and Integral Electronic Piezo Electric (referred to as IEPE) 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 considerations.

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 IEPE accelerometers, calibration transfer standards, and PE pressure and force sensors. Charge mode 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 IEPE 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 IEPE 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.

INTEGRAL ELECTRONIC PIEZOELECTRIC ACCELEROMETERS (IEPE)

IEPE accelerometers incorporate a built-in microelectronic charge or voltage amplifier, which functions to convert the 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. IEPE accelerometers were first manufactured in the mid 1960's.

IEPE 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. IEPE 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-electronics is a "common thread," all IEPE 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 IEPE 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 IEPE sensor and power specifications be checked before assuming compatibility.

The main advantage of low impedance operation is the capability of IEPE 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 degree F. IEPE 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 IEPE 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 & IEPE ACCELEROMETERS

PE TYPE

Advantages

- Flexibility in adjusting accelerometers electrical output characteristics properly
- Wide dynamic range
- Higher temperature operation >500 deg. F
- Interchangeability in existing charge systems
- Extended low frequency response

Limitations

- Requires training & 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 IEPE type (due to required low-noise cable and charge amplifier)

IEPE TYPE

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, & 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 IEPE accelerometers.

ADVANTAGES OF PE ACCELEROMETERS

Flexibility- A laboratory "bench type" charge amplifier usually has controls for adjusting and modifying the output signal from the PE accelerometer. As a minimum, there are controls for normalizing sensitivity, setting the 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 IEPE, and charge mode PE sensors.

Dynamic range- Typically, a high sensitivity PE accelerometer may be operated over a wide dynamic range greater than 100 dB. When used with a laboratory charge amplifier, full-scale output can be set for any g level within its 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 deg F. Special models are available to > 1000 deg. F. For best accuracy, the accelerometer should be calibrated at operating temperature.

Interchangeability- Virtually any PE accelerometer is interchangeable in a charge mode 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 ($> 10^{12}$ 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 mode systems. A basic understanding 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 is required. Some newer charge amplifiers have digital controls, which simplify entering sensitivity and setting the range.

Resolution- Although resolution for PE accelerometers may be considered as 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 is 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 mode system. New, more modem 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 and the charge amplifier cannot differentiate between the two. Cable connectors are commonly Microdot® 10-32 coaxial. Cable and connector selection is limited.

Size vs sensitivity- The size, sensitivity, and frequency response of PE accelerometers are all directly interrelated. The larger the accelerometer, 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 in order to provide adequate sensitivity.

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

ADVANTAGES OF IEPE ACCELEROMETERS

Simplified Operation- IEPE 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 IEPE 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 IEPE pressure sensors used for microsecond shock and blast wave pressure measurements.

Operating environment- Hermetically sealed IEPE 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 IEPE accelerometers the preferred choice for industrial machine health monitoring, underwater, shipboard, vehicular and field test applications.

Cable and Connectors- The low impedance output of IEPE accelerometers allows complete flexibility in the type of cable and connectors used. Cable and connector consideration can be important in certain applications involving high or low temperature, pressure, vacuum, corrosive fluids and where mass loading is of concern. Miniature IEPE 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 IEPE 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 IEPE accelerometers incorporating hybrid charge amplifiers. Some IEPE accelerometers incorporate voltage gain circuits and although the signal level is boosted for recording and/or cable driving purposes, so is the noise level.

Dynamic Range- IEPE accelerometers have a very wide dynamic range. "Limited or Fixed Dynamic Range" is sometimes cited as a "limitation" of IEPE accelerometers. Most IEPE 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 IEPE sensor is a known data sheet specification. Even more significant, the IEPE system does not lose dynamic range due to added cable length and system configuration.

Powering IEPE Accelerometers- Depending on the specific manufacturer's model, IEPE 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 IEPE 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 a 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 IEPE accelerometers.

Cable fault monitor- In IEPE 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 IEPE accelerometers is compatible with operation through slip rings.

"TEDS" Transducer Electronic Data Sheet- Incorporation of a "TEDS" memory circuit in IEPE 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 the 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 then be used for normal analog operation

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

LIMITATIONS OF IEPE ACCELEROMETERS

Fixed output- Electrical characteristics such as sensitivity, range, resolution and discharge time constant are fixed within the IEPE accelerometer. Fixed discharge time constant is less of a limitation with accelerometers than it is 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 IEPE 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 mode operation for operation with charge or IEPE voltage mode sensors. High impedance circuitry is not well suited for operation in adverse field or factory environments. The resolution of a PE accelerometer may not be specified or known since noise is a system consideration determined by cable length and amplifier gain. IEPE 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. IEPE 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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