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Accelerometer Selection Based on Applications

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ACCELEROMETER SELECTION BASED ON APPLICATIONS

Selecting the right accelerometer starts with determining whether you need to measure motion or vibration. This technical note guides you through choosing the most suitable accelerometer for a range of applications and measurement environments.

Applications include:

1. Measuring motion
2. Measuring high frequency vibration
3. Measuring low frequency vibration
4. Measuring shock
5. Measuring micro-G vibration
6. Measuring vibration on small objects
7. Measurement in high temperature environments
8. Measurement in low temperature environments
9. Measurement in radiation environments
10. Measurement in machine health monitoring
11. Measurement in multi-channel applications

Principal acronyms used:

IEPE = Integrated Electronics Piezoelectric
PE = Piezoelectric
PR = Piezoresistive
VC = Variable Capacitance
SERVO = Force-Balance Servo
TZS = Thermal Zero Shift
TEDS = Transducer Electronic Data Sheet

1. MEASURING MOTION

When selecting an accelerometer, it is important to determine whether the goal is to measure motion or vibration. In vibration measurement, the focus is on the vibratory responses of the object under test. In motion measurement, the aim is to capture the speed or the displacement of the rigid body (or part thereof).

Using an accelerometer to measure motion (i.e. the speed of a slow-moving robotic arm, or the movement of an elevator) accurately, the measured acceleration data must not contain any zero offset error. A very small amount of zero offset in the acceleration output can lead to gross amount of velocity or displacement errors after numerical integrations. Since all piezoelectric based accelerometers and other AC-coupled designs will produce zero offset errors when trying to follow a slow motion, they should not be considered for motion measurements.

Selection considerations in this application are:

DC Response: For reasons discussed above, DC-response accelerometers, such as PR or VC types, are more suitable for measuring motion.

Resolution: Since the results of the integration (velocity or displacement) are highly dependent on the quality of the acceleration signal, it is important to have a healthy amount of output from the accelerometer to begin with. However, it is not just the sensitivity of the accelerometer that one should consider, but the actual resolution or signal-to-noise ratio of the device.

Thermal Zero Shift (TZS): Drift of the zero baseline in a DC-response accelerometer produces the same kind of error as the zero offset would in AC-coupled devices. Depending on the operating temperature range, a low TZS specification may be critical.

High resonance designs usually mean very low output sensitivity.

Applications such as modal analysis, building and bridge monitoring, require accelerometers with exceptional low frequency characteristics.

2. MEASURING HIGH FREQUENCY VIBRATION

Applications such as gear noise analysis, turbine or high-speed rotating machinery monitoring, require accelerometers with exceptional high frequency characteristics. Therefore, high accelerometer resonance is a prerequisite. But high resonance designs usually mean very low output sensitivity. This is just a physical constraint in any given spring-mass type transducer design.

Selection considerations in this application are:

Resonance frequency: Since most of the high frequency accelerometers are undamped, high frequency harmonics from the structure can excite the resonance, causing overload condition in downstream electronics. Resonance of the accelerometer should be sufficiently high so that it can stay above the high frequency signals that are present in the structure.

Mounting method: High frequency signal transmissibility varies widely with different mounting methods. Care must be taken in mounting the accelerometer. Stud mounting is the most reliable method for measurement above 10kHz. Couplant (i.e. silicone based grease) should be used between the accelerometer and the mounting surface whenever possible.

Calibration: The capabilities to perform calibration above 10 kHz is essential for broadband accelerometers. We provide frequency response calibrations up to 40kHz for most lightweight accelerometers.

There are PE and IEPE accelerometers with very high (>70 kHz) resonance frequency and sufficiently high output sensitivity that will satisfy these requirements. There are also PR accelerometers with resonance higher than 1 MHz, but their very low sensitivities may preclude their use in most of these applications.

3. MEASURING LOW FREQUENCY VIBRATION

Applications such as modal analysis, building and bridge monitoring, require accelerometers with exceptional low frequency characteristics. In modal testing, channel-to-channel phase deviation between the accelerometers is a key concern to the analyst. The ideal accelerometer therefore should have no phase shift in the frequency range of interest. DC-coupled designs have the advantage over AC-coupled designs in this area.

For acceleration measurements from a few Hertz and up, AC-coupled devices with sufficient low-end response may be used.

An accidental drop of a cellular phone from standing height can produce peak acceleration levels well over 10,000 g's. PR devices designed for high-g shock are typically immune from zero shift.

Accelerometer selection considerations in this application are:

Low-end frequency response: For very low frequency measurements (near DC), DC-coupled devices, such as PR, VC, or SERVO, are the obvious choices. In addition to having no phase shift at low frequency, DC-coupled accelerometers are also suitable for measuring slow motions of an object (see Motion Measurement above). For acceleration measurements from a few Hertz and up, AC-coupled devices with sufficient low-end response may be used.

Base strain sensitivity: As mentioned previously, base strain sensitivity cannot be easily distinguished from vibration signals, especially at low frequency where the displacement amplitude is large. The ideal accelerometer should have very low strain sensitivity. Adhesive mounting can reduce this problem to a large degree if the application allows.

Thermal transient sensitivity: Since the error induced by external thermal transient occurs at low frequency, it combines with the low frequency acceleration signal and becomes indistinguishable. Use of thermal protective boots can effectively reduce this problem in accelerometers that have high thermal transient sensitivity.

Low-pass filtering: In many applications where the desired information is in the low frequency range, high level, high frequency components may reduce the usable dynamic range of the system. The use of an external or internal low-pass filter can minimize the problem.

4. MEASURING SHOCK

Applications such as package drop-testing, automotive crash-testing, and pyroshock/simulation, require accelerometers with special capabilities. An accidental drop of a cellular phone from standing height can produce peak acceleration levels well over 10,000 g's. Many novices in shock testing make the wrong assumption that the shock measurements of an object can be approximated using a rigid body model, and forget about the localized material responses. In a high-g shock test where structural responses are often nonlinear and difficult to characterize, choosing the right accelerometers can be critical.

Basic accelerometer selection considerations in this application are:

Zero shift: Zero shift or DC-offset, a sudden change of baseline level during a high-g event, is a type of error usually associated with, but not limited to, PE/IEPE accelerometers. There is no universal standard for this parameter, so it cannot be found in the Performance Specifications. PR devices designed for high-g shock are typically immune from zero shift.

Survivability: In lower-level shock applications, most accelerometers can survive the environment without causing internal damage. But in high-g testing, physical damage to the sensor is often a reality. It is suggested to overestimate the maximum shock level when selecting the range of a shock accelerometer. A general rule-of-thumb: the closer the accelerometers are to the source (explosive or impact), the higher the input g level. Survivability extends to cables and connections. In high-g shock, a small amount of unrestrained mass would translate into large force, causing connector failures (or bad contacts) and generating triboelectric noise with ordinary coaxial cable. An accelerometer may only have to measure 100g full scale, but it may be required to survive an initial shock of 10,000g.

High sensitivity and low noise floor are a prerequisite to micro-g vibration measurement.

The effects of environmental sensitivities, such as base strain, thermal transients, and acoustic noise may be significant.

Range: Usable output range should not be confused with survivability. An accelerometer may only have to measure 100g full scale, but it may be required to survive an initial shock of 10,000g preceding the lower-level event. Another distinction should be made between the maximum expected level from a Shock Response Spectrum and the actual input spectrum the accelerometer is likely to experience.

Low-pass filtering: Low-pass filters can be used at the input of an amplifier to prevent overload condition due to unexpected input spikes.

DC Response: When measuring long duration shock or measuring rigid body motion of the structure (i.e. ship shock), accelerometers with DC response are required to capture the low frequency information accurately. If the acceleration data is be integrated to yield velocity or displacement information, DC response is an absolute necessity.

5. MEASURING MICRO-G VIBRATION

Measuring vibration in space on the Hubble telescope or monitoring noise in a nuclear submarine requires accelerometers that are extremely sensitive. The electronic noise floor and the dynamic range of these devices must be exceptional. Noise specifications of accelerometers are usually given in broadband rms terms, which is fine in most applications. But in some cases, the noise specification is more useful if depicted as a root power spectral density (root PSD), given in equivalent g per root Hertz. In addition, noise of the transducer system (including the necessary signal conditioner/power supply) is more relevant than the noise specification of the transducer alone. In most cases, a battery-operated power supply is the preferred choice. Whenever possible, use the accelerometer with its recommended signal conditioner so that the noise performance of the system can be maximized.

Accelerometer selection considerations in this application are:

Signal-to-Noise Ratio: High sensitivity and low noise floor is a prerequisite to micro-g vibration measurement. High sensitivity and good S/N however, may come at the expense of size and weight. In this respect, given the same weight/size package, the ISOTRON type has the fundamental advantage in S/N over the PE, PR, and VC types.

Environmental Sensitivities: As with all extremely high output transducers, the effects of environmental sensitivities, such as base strain, thermal transients, and acoustic noise may be significant. Some form of environmental barrier should be used with a micro-g sensor.

There are several PE, ISOTRON, VC, and SERVO accelerometers which are specifically designed for low-g measurement. Cost of these devices varies significantly, as do their sizes, weights and signal conditioning requirements.

Attention should be paid, when measuring low-g acceleration using DC response accelerometers (PR, VC, SERVO) to the direction of earth's gravity. The highly sensitive transducer might run out of range (saturate), owing to the high output response to ±1 g of the earth's gravity. With an open-loop design, such as a PR accelerometer, very little can be done to alleviate this problem. With a close-loop design, such as SERVO accelerometer, the DC offset may be electrically nulled, but the limitation on dynamic range still remains. A PE accelerometer does not have this problem due to its AC coupled characteristic.

Examples of current accelerometer models for this application: Endevco Models 86, 7754A-1000, 7752-1000, 7290A-2.

Mass-loading effect can change the dynamic responses of the measurement. Size and weight of the accelerometer must not be out of proportion with the test article. The rule-of-thumb is not to exceed 10:1.

Care should be taken to provide a flat surface for the accelerometer.

In test environments over 200°C, the only choice is a PE accelerometer.

Temperatures as high as 400°C+ are common for engine vibration monitoring. The accelerometer should survive and operate under these conditions continuously without degradation in sensitivity or resonance characteristics.

6. MEASURING VIBRATION ON SMALL OBJECTS

There are many applications where the test articles are no bigger than a tennis ball. Making shock and vibration measurements under such conditions require sensors with unique physical characteristics.

Accelerometer selection considerations in this application are:

Mass-Loading Effect: Mass-loading effect can change the dynamic responses of the measurement. Size and weight of the accelerometer must not be out of proportion with the test article. The rule-of-thumb is not to exceed 10:1. There are PE, IEPE and PR accelerometer models that are very small and light-weight (as low as 0.14 gm) which help minimize mass-loading problems.

Mounting Method: Drilling threaded holes for stud-mount type sensors in a small test article is impractical. Adhesive mounting is the only logical method. Adhesive mounting/removal instructions should be followed religiously to prevent damage to the accelerometer body..

Surface Curvature: Care should be taken to provide a flat surface for the accelerometer. This might require manufacturing special mounting blocks with matched curvature of the lower surface.

Resonance: Small structures usually have high frequency modes. Accelerometers with higher resonance (>50 kHz) may be required.

Cable: When the test structure is very small and lightweight, even the stiffness of the cable can affect the dynamic responses. Small-gauge, flexible cable should be used in these situations.

7. MEASUREMENT IN HIGH TEMPERATURE ENVIRONMENTS

Shock and vibration testing performed on jet engines, propulsion systems, and power generators requires transducers that can withstand the inherent high temperature environment. In test environments over 200°C, the only choice is a PE accelerometer. Below 200°C, there are obvious advantages in using IEPE accelerometers designs offer a low impedance out-put, which has better noise immunity in noisy environments. The downside of using IEPE in this application, however, is imposing the same temperature environment on the internal amplifier, which would otherwise be sitting outside at room-temperature. The consequences of exposing the electronics to high temperature are shorter operating life, reduced electrical performance, and lower mean time between failure (MTBF). One is advised to balance the pros and cons when making a selection.

Selection considerations in this application are:

Survivability: Temperatures as high as 400°C+ are common for engine vibration monitoring. The accelerometer should survive and operate under these conditions continuously without degradation in sensitivity or resonance characteristics.

Temperature Response: The performance of a transducer at its temperature limits must be well defined. It is important that the sensitivities at the higher temperatures are repeatable and without hysteresis. Some PE models feature special output sensitivity compensation over a defined range of temperature, resulting in a fairly “flat” temperature response. Most PE transducers show a drastic drop in internal resistance at very high temperature, rendering the signal conditioner (charge amplifier) inoperable

Sensitivity of many transducer designs drops off drastically when approaching absolute zero.

Most cables become very brittle at cryogenic temperature. Careful selection of the correct cable type is critical in a fairly “flat” temperature response. Most PE transducers show a drastic drop in internal resistance at very high temperature, rendering the signal conditioner (charge amplifier) inoperable.

Cable Survivability: Can the connector and cable assemblies survive the hot environment? The output cable must have a similar temperature rating as the transducer. Most high temperature hardline cables use ceramics as their dielectric, which are usually brittle and not very flexible.

8. MEASUREMENT IN LOW TEMPERATURE ENVIRONMENTS

Measurements performed near cryogenic conditions, such as cooling systems on rocket engines or spacecraft components, require transducers that can operate at temperatures near absolute zero. Most accelerometer designs can operate satisfactorily to -100°C, but below this point, only those built with specific design objectives can be recommended. In these sub-zero test environments, one also needs to assess the pros and cons of using accelerometers with internal electronics. (See High Temperature Environment Measurement.)

Selection considerations in this application are:

Temperature Response: Sensitivity of many transducer designs drops off drastically when approaching absolute zero. Quartz based PE designs are most linear and predictable at lower temperature extremes, and are more suitable for cryogenic applications.

Thermal Transient Sensitivity: Sudden temperature changes in sub-zero applications can change the boundary condition in the sensing element due to thermal expansion, which in turn generates unwanted output. When the measurement environment presents a very steep temperature gradient (i.e., sudden liquid nitrogen blasts), good low-temperature accelerometers should produce limited responses from such environmental stimulus. Review carefully the thermal transient sensitivity specifications of the device to match your applications.

Survivability: Not only is the accelerometer required to operate at a steady sub-zero temperature, it should also survive multiple cycles of thermal shock. Most microelectronic circuits (chip and wire or surface mounted types) suffer from reliability problems after multiple cycles of thermal shock due to thermal expansion problems. In this respect, transducer designs that do not have internal electronics have proven to be more reliable.

Cable Survivability: Most cables become very brittle at cryogenic temperature. Careful selection of the correct cable type is critical. Low impedance output devices allow a wider selection of cables in terms of cable material.

9. MEASUREMENT IN RADIATION ENVIRONMENTS

PE accelerometers have the highest radiation resistance, while designs with internal electronics offer the lowest survivability.

Most cable materials, including the common ETFE dielectric, fail after long term radiation exposure.

Measurements performed near radioactive sources, such as a nuclear reactor and its pumping system, require radiation-proof transducers. Since the radiation levels vary depending on the measurement location, there are different grades of radiation-proof accelerometers. As a rule of thumb, PE accelerometers have the highest radiation resistance, while designs with internal electronics offer the lowest survivability.

Selection considerations in this application are:

RAD Rating: PE transducers are the preferred choice in a nuclear environment. PE accelerometers that have RAD ratings from 1E8 to 6E10 integrated gamma flux are available. Radiation-proof inline charge converters can be used to drive long cables in applications where the control room is far away.

Cable Survivability: Most cable materials, including the common ETFE dielectric, fail after long term radiation exposure. Cable assemblies for nuclear applications must have properties suitable for extended usage. We offer special cable assemblies designed for radiation environments.

Industry Standard: Although there are a number of PE accelerometer models that carry radiation ratings, only a few models are routinely used in the nuclear power industry.

10. MEASUREMENT IN MACHINE HEALTH MONITORING

Vibration measurements performed in an industrial environment have different needs than those in a standard laboratory environment. Many applications require the transducer to have intrinsic safety certifications.

Selection considerations in this application are:

Ruggedness: The physical environment inside a manufacturing plant necessitates a rugged transducer design. Cable connector, cable, and mounting should be able to withstand the normal day-to-day use in an industrial environment.

Hermetically Sealed: Industrial environments routinely involve moisture and other liquid contaminants. A hermetically sealed design will keep the sensor in proper operating condition for an extended period of time.

Low cost: Although not a technical consideration, cost of the accelerometer can be an important factor in this application where hundreds of sensors are being used at one time.

There are many PE/IEPE transducers designed specifically for industrial applications, although IEPE types are more widely used due to their lower cost and the ability to operate in very dirty environments.

11. MEASUREMENT IN MULTI-CHANNEL APPLICATIONS

In most cases, over half of the time consumed in a multi-channel testing is related to set-up and configuration control.

With TEDS built into the transducers, connection tracking can be eliminated. The identity of the transducer is always known to the system regardless of how the connections are made.

Measurements performed on large structures, such as satellites and automobiles, tend to require many channels of sensors. In most cases, over half of the time consumed in a multi-channel testing is related to set-up and configuration control – keeping track of sensor ID, cable ID, channel ID, and entering sensor database into the analysis software. With TEDS (Transducer Electronic Data Sheet) technology much of these time-consuming efforts may be minimized.

Advantages of using transducers with TEDS are:

Eliminate Sensor Look-Up Table: All up-to-date information about the transducer is stored in the TEDS memory chip. There is no need, for example, to generate a separate database for transducer sensitivity from the manufacturer's calibration certificates. Current calibration data is downloaded to the TEDS memory chip (EEPROM) at the time of re-calibration.

Eliminate Cable Connection Errors: In a typical multi-sensor test set-up, valuable time is spent unnecessarily on matching transducer serial numbers to their connecting cables, and keeping track of the subsequent connections throughout the system. The process is prone to human errors as the number of channels increase. With TEDS built into the transducers, connection tracking can be eliminated. The identity of the transducer is always known to the system regardless of how the connections are made.

Location Identification: In modal testing, for example, the location of the transducer is of prime interest to the user. Information such as position ID, orientation, and polarity of the accelerometer, is typically recorded on a piece of paper, and manually entered into the analysis software. With TEDS sensors, these application specific parameters can be stored in the TEDS along with all other parameters, and output to the destination file as required. In short, all information about the device and its whereabout is known to the system once the location information has been entered into the TEDS chip.

Instant Transducer Substitution: Since the TEDS in the transducer contains all the device parameters, such as sensitivity and correction coefficients, one can substitute transducers on the fly without worrying about system set-up changes. An intelligent signal conditioner at the receiving end notices the transducer change and makes gain or transfer characteristics adjustments automatically – a true plug-and-play scenario.

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