Practical considerations of accelerometers noise

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This paper offers an overview of low-noise piezoelectric accelerometers and, specifically, noise generated by the electrical and mechanical components of the accelerometer, amplifier and cables. It includes the application conditions under which low-noise devices are commonly specified, as well as the engineering trade-offs associated with design of a low-noise accelerometer.

I. When is low-noise a factor?

Noise can be defined as any undesired signal. This paper will limit the discussion to noise generated by the electrical and mechanical components of the accelerometer, the amplifier and cables. There are other noise sources to be aware of such as ground loops, etc, covered in other technical papers.

Figure 1 below shows the relative noise spectra of various accelerometers from Endevco® product line. Model 86 is an ultra low-noise device used in very low noise applications. Model 5220 is an industrial accelerometer used when frequency response is of interest and low-noise is secondary.

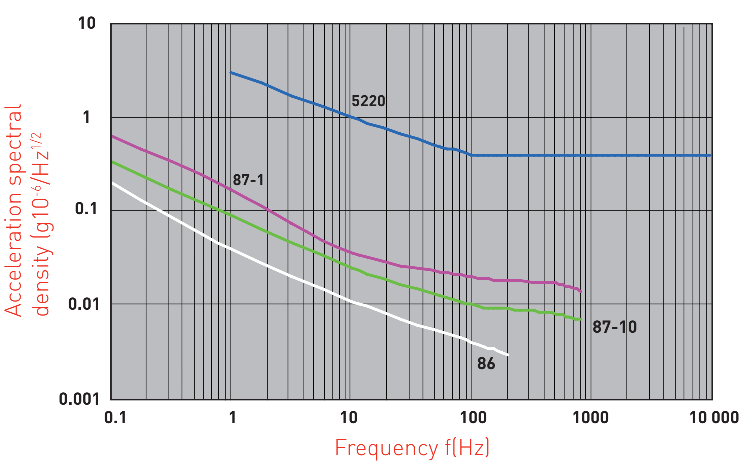

Figure 1 A comparison showing the acceleration spectral density of a typical industrial accelerometer vs. two low noise accelerometers.

Examples in which low-noise accelerometers and electronics are required

Seismic applications

This requires both a wide dynamic range and very low-noise to detect low level, low frequency vibrations in the presence of larger signals. For example, an event that has a displacement amplitude of +/- 1" (25.4 mm) peak to peak will produce only 0.5 mg (0.0035 m/sec^2) of acceleration. To measure these levels with any reasonable amount of accuracy, a very low-noise measurement system is required such as the Endevco 86 or 87 accelerometer.

Wide dynamic range

This might be an application in which a single accelerometer is used to measure both a high shock response and low levels of vibration. This application would call for the use of a relatively insensitive accelerometer with a low noise floor. In general terms, this is a device with a wide dynamic measuring range.

This type of measurement problem is often encountered in rocket and missile testing thus small lightweight devices are required. Depending on the requirements, the engineer will choose between an integral electronic piezoelectric (IEPE) or a charge-mode piezoelectric accelerometer.

Other low-noise applications

Some industrial applications require low-noise accelerometers to observe low frequency, low level events, calling for a threshold of 10 µg for a signal-to-noise level of 10 (20 dB).

Very low-level signals are often encountered in medical applications requiring low-noise sensors.

Low levels

When making low level measurements it is important to consider both the noise floor and the sensitivity of the accelerometer (see equation below). The noise specifications found on data sheets and are generally given in "equivalent g", where

$$\text{Threshold (in g rms)} = \frac{\begin{array}{c}\text{Noise in mV}\\ \text{(over a specified frequency range)}\end{array}}{\text{Sensitivity in mV/g}}$$

As an example, model 86 has a threshold of 0.1 ng rms based on a bandwidth of approximately 1 kHz.

Noise spectral density figures are also provided on data sheets and should be observed, especially when making low-noise measurements at low frequencies. The noise spectral density information provides noise information as a function of frequency. To quickly determine if the accelerometer selected has a low enough noise floor, use this rule-of-thumb: the lowest g level to be measured should be 10 times the threshold level.

There are instances where noise is of minimum interest (note, this is minimum interest, not NO interest). Generally speaking, low-noise devices are not required when measuring very high shock signals since maximum amplitude of the signal is of major importance. Also, when measuring high levels of vibration such as imbalance on a large rotating machine, no special consideration as to accelerometer noise is generally required.

II. Noise considerations in accelerometer design

There is no one accelerometer that "does it all." There are trade-offs that the designer must consider during the development of the device. For example, when making a subminiature device considerations such as small size and lightweight are balanced against low noise and high output.

There are several noise sources within the acceleration measurement chain. Noise originates from the transducer's electrical and mechanical properties, be they internal electronics (IEPE, Isotron®, etc.) or external charge amplifiers. Over the years, piezoelectric material sciences, including single crystal technology, have advanced to the point where the noise generated by the crystals is so low that, if implemented and installed correctly, it presents a very minimal amount of noise to the measuring chain. Crystal systems with higher charge sensitivity require less gain within the electronic system thus resulting in lower total system noise.

The following sections are brief reviews of three major noise sources within the acceleration measurement system.

Sources of accelerometer noise

Noise sources are broken down in terms of mechanical-thermal noise and electrical-thermal noise. The noise power spectral density of the sensor is

where a^2_{nm} = mechanical noise
a^2_{ne} = electrical noise

$$P_{sD} = \sqrt{a^2_{nm} + a^2_{ne}}$$

Mechanical noise can be related to the mass and spring constant and mechanical resistance of the sensor's seismic system. Mechanical noise can be reduced by increasing the mass and quality factor (Q) or by decreasing the resonance frequency. One can easily see that these factors represent tradeoffs in terms of frequency response. Mechanical-thermal noise is dominant over electrical-thermal noise above 10 kHz.

Electrical-thermal noise is in addition to noise contributed by any internal or external electronics used in the measurement system. Electrical noise is a function of the sensing materials loss factor which is the inverse of the materials quality factor. When selecting and processing material for low-noise applications, materials with few defects and impurities are selected. Loses are increased by the addition of capacitance and thus an increase in the electrical noise. This noise source is generally dominant at frequencies below 10 kHz.

Many low-noise accelerometers include internal electronics. This design approach improves signal-to-noise ratios since the extremely short distance between the sensor and charge amplifier reduces the capacitance thus eliminating a source of noise.

Figure 2 **Note the larger size of model 86, the ultra low-noise unit.**

However, the internal electronics represent an additional noise source. Field-effect transistors have been used at the input stage of the internal electronics due to their high input impedance. Junction gate field-effect transistors are generally the transistor of choice, but the semiconductor manufacturers are reluctant to publish noise specifications thus sensor designers must use their experience to choose the best components.

One can generally expect lower noise devices to be larger in size and mass than accelerometers with higher residual noise specifications, as the result of a higher mass. Figure 2 shows two low-noise accelerometers and their relative size difference. The crystal sensor assemblies are typically larger in order to produce a higher output level. Also keep in mind that as the mass is increased, the resonance frequency is reduced thus lowering the accelerometer's frequency response.

III. User actions

Up to this point, we have covered what the manufacturer does to decrease accelerometer noise. There are many actions that the user can do, and in some cases must do, to ensure a clean noise free sensor output. Most of the emphasis will be on charge mode accelerometers since they are the most susceptible to noise, compared to IEPE accelerometers.

Cable problems

Cables should be as short as possible, especially with charge mode accelerometers.

Capacitance (when using a charge-mode accelerometer) will add to the noise floor of the accelerometer's output signal. A cable looks like a capacitor and a typical cable has a capacitance of approximately 30 pF/foot. It is easy to see that the longer the cable, the more the capacitance, thus more noise. In addition, a long cable acts as an antenna and will pick-up electromagnetic signals.

Only cables with low-noise treatment should be used with charge mode accelerometers. Cable motion will cause self-generated noise, referred to as the Triboelectric effect. The low-noise treatment is the solution to minimizing this effect, as is limiting the motion of cables.

IEPE accelerometers can use ordinary coaxial cable and are less susceptible to noise pickup due to their low impedance characteristics. Again, long cables act like antennas thus length should be limited. It is often necessary to increase the excitation current as cables length is increased which will result in increased noise generation.

Care must be taken in making sure that all cable connections are as clean and dry as possible.

Connectors must be cleaned with alcohol and then dried with a lint-free wipe. This is of paramount importance on charge-mode piezoelectric accelerometers and, while cleaning is not as critical on IEPE devices, it is always a best practice to ensure precision measurements.

Charge converters and amplifiers

A technique to reduce cable noise is the use of an in-line charge converter (Figure 3). In-line charge converters are joined to a charge mode accelerometer with a short length of low-noise cable. The charge converter provides a low impedance voltage output, desirable for long cable runs. Charge converters are powered by conventional IEPE current sources and look like an IEPE accelerometer to the measurement electronics. The short cable between the accelerometer and charge converter provides for a low-capacitance load, resulting in a lower noise acceleration signal.

Figure 3 **Endevco 2771C low-noise charge converter with 10-32 accelerometer connector and BNC for the conventional two wire IEPE output/power**

With the introduction of the Endevco 2771C charge converter, the signal-to-noise ratio has been improved up to a factor of five times that of most other charge converters.

Lastly, the user should be aware of the noise characteristics of subsequent voltage amplifiers in the measurement chain.

IEPE current sources are found in many data acquisition systems and FFT analyzers. These built-in sources of power are convenient and work well in most applications. When making low-noise measurements, it is advisable to know the noise characteristics of the internal power source. Many internal current sources use voltage converters that produce noise that can be introduced into the accelerometer's output signal. If the built-in current source noise is a problem, use an external power supply such as Endevco model 133.

References

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