Practical understanding of key accelerometer specifications

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One of the most difficult aspects of selecting an accelerometer for a particular application is gaining an understanding and interpreting the accelerometer's specifications themselves. Often the user understands their test requirements well, but runs into difficulty matching these requirements with available accelerometer models. Manufacturers of accelerometers frequently contribute to this problem by engaging in a "game" of "specmanship" by positioning their products in the best light possible. This often obfuscates the accelerometer's set of specifications. There exists, then, a need for a comprehensive description and explanation of accelerometer specifications that manufacturers routinely use. What follows is a detailed explanation of the key specifications used to describe piezoelectric accelerometers.

Sensitivity

Sensitivity of the accelerometer, sometimes referred to as the "scale factor" of the accelerometer, is the ratio of the sensor's electrical output to mechanical input. [Note that a transducer is defined generally as a device that converts one form of energy to another. An accelerometer is simply a transducer that converts mechanical acceleration into a proportional electrical signal.] Typically rated in terms of mV/g or pC/g, it is valid only at one frequency, conventionally at 100 Hz. Since most accelerometers are influenced to some degree by temperature, sensitivity is also valid only over a narrow temperature range, typically 25 ±5°C. Additionally it is valid only at a certain acceleration amplitude, usually 5 g or 10 g. Sensitivity is sometimes specified with a tolerance, usually ±5% or ±10%. This assures the user the accelerometer's sensitivity will be within this stated tolerance deviation from the stated nominal sensitivity. In almost all cases, accelerometers are supplied with a calibration certificate stating its exact sensitivity (within measurement uncertainty limits).

Sensitivity is called the "reference sensitivity" when referring to the percentage or dB tolerance band of frequency response specifications. See frequency response below.

Sensitivity is called the "axial sensitivity" when discussing transverse sensitivity. See transverse sensitivity below.

Despite the tight constraints that surround the sensitivity specification, this is the number that is most frequently used for programming a signal conditioner or data acquisition system. A signal conditioner and/or DAQ system uses this number to process and interpret the signal from the accelerometer.

Frequency response

Similar to the sensitivity specification, frequency response also tells the user what the accelerometer's "scale factor" is, but with the additional variable of frequency added. Frequency response is the sensitivity specified over the transducer's entire frequency range. More properly referred to as "amplitude response", since the phase response is rarely specified. Frequency response is always specified with a tolerance band, relative to the 100 Hz sensitivity (or reference sensitivity). The tolerance band can be specified in percentage and/or dBs, with typical bands being ±10%, ±1 dB and ±3 dB. In this context, a dB is defined as:

$$\mathrm{dB} = 20\log\left(S_f/S_{ref}\right)$$

where: S_f **is the sensitivity at a particular frequency**
S_{ref} **is the reference sensitivity**

The frequency response specification enables the user to calculate how much the accelerometer's sensitivity can deviate from the reference sensitivity at any frequency within its specified frequency range. For example, assume an accelerometer model has a reference sensitivity of 10 pC/g (i.e. calibration results report this number, thus it is exact, within uncertainty limits). Assume its frequency response specification is ±10% from 1 Hz to 6 kHz. Over this frequency range, sensitivity can vary from 9 pC/g to 11 pC/g, or 10 ±1 pC/g (±10% of 10 pC/g). Recall again that at the reference sensitivity frequency of 100 Hz, sensitivity is exactly 10 pC/g, but at any other frequency, it can vary up or down by 1 pC/g.

Accelerometers often come with a calibration certificate stating the exact reference sensitivity. The certificates often do not show the frequency response in tabular form (i.e. stating sensitivities at various frequencies) but instead show a plot from the lowest rated frequency to the highest. The plot (see Figure 1) shows sensitivity deviation in percentage (or dB) from the reference sensitivity. Using the technique illustrated in the example above, users can estimate the sensitivity at any frequency using this plot. If the plot shows the sensitivity to up 2% at 1 kHz, for example, and the reference sensitivity is stated as 10 pC/g, a simple calculation shows the sensitivity at 1 kHz to be 10.2 pC/g.

Transverse sensitivity

Transverse sensitivity is the sensitivity of the accelerometer at 90 degrees to the sensitive axis of the sensor. See Figure 2. Stated another way, transverse sensitivity is the sensitivity at 90 degrees to the axial sensitivity. It is expressed as a percentage of the axial sensitivity. Ideally it would be 0%, but due to manufacturing tolerances, it can be as much as 5%. Values as low as 3% or lower are available on special request, but as the desired value goes lower, it becomes increasingly difficult (and thus more expensive) to achieve. Transverse sensitivity is sometimes referred to as "cross-axis sensitivity."

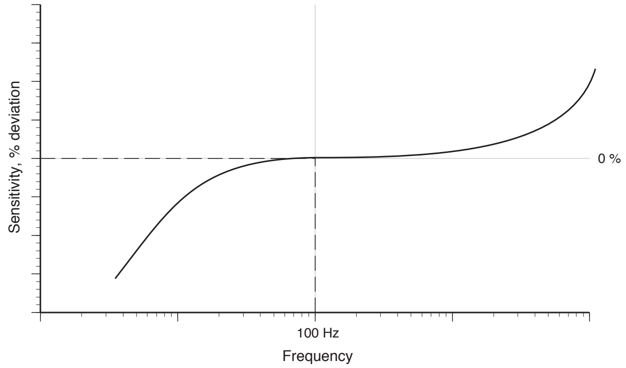

Figure 1: Frequency response plot

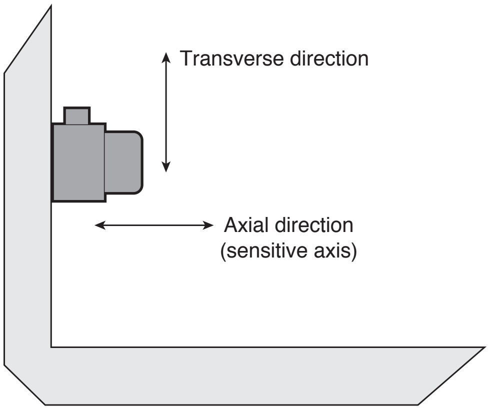

Figure 2: Transverse sensitivity

Why be concerned about transverse sensitivity? As a user, you want to be assured that the measurement you are taking is only due to acceleration in one direction. If not, making sense of your data would be difficult, if not impossible. (Note that triaxial accelerometers are available for measuring acceleration in 3 orthogonal directions from the same point.) When an accelerometer is stimulated on a calibration class shaker, every effort is made to ensure the motion is in one direction, with very little transverse motion. In this situation, you may not care that the accelerometer has a high transverse sensitivity, since the sensor does not see any motion in that direction. However, in a real test on a real structure (or even on a less than ideal shaker); we know that the motion is in all directions. In this case, a low transverse sensitivity accelerometer is crucial, as you want to be assured that the measurement you are getting is only from one direction. In this sense, the contribution of transverse sensitivity to a measurement can be thought of as a "noise" contributor to the measurement.

Mounted resonant frequency

Mounted resonant frequency is the point in frequency in the accelerometer's frequency response where the accelerometer outputs maximum sensitivity. See Figure 3. It is specified in units of hertz (Hz). Typical accelerometers exhibit a mounted resonant frequency above 20 kHz, although some show as high as 90 kHz. As the name implies, it is the result of the natural resonance of the mechanical structure of the accelerometer itself. [Certainly if the resonance of the accelerometer were measured in "free space" it would be different than if mounted to a structure. However, this is an impractical application for a piezoelectric accelerometer, thus the designation "mounted" is added.] It is not a design goal of manufacturers to produce an accelerometer that has a mounted resonant frequency within a certain tolerance. Instead, mounted resonant frequency is specified as a minimum, ensuring to the user that this resonant point will not occur below the minimum. As such, mounted resonant frequency is a rough "figure-of-merit" that sets the upper limit of the frequency bandwidth of the accelerometer.

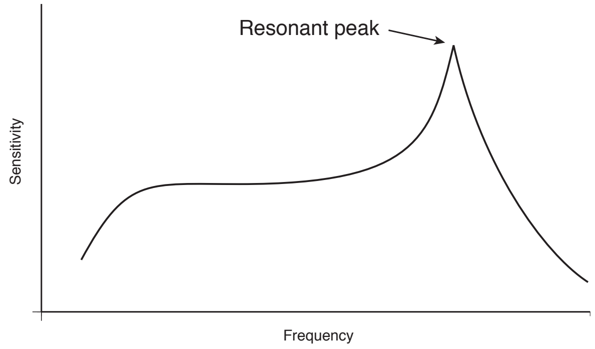

Figure 3: Mounted resonant frequency

For piezoelectric accelerometers, whose mechanical structure is almost completely undamped, the amplitude of the resonant peak can be quite high, resulting in a sensitivity many times higher than the specified reference sensitivity. As such, any vibration at or near the frequency of the resonant peak will be highly amplified, resulting in distorted measurements and corrupted data. A design goal of manufacturers, then, is to push the mounted resonant frequency point as high as possible in the accelerometer's structure, with the intent that the point be well beyond any vibration frequencies in the user's measurement application. The user also has to ensure that no vibration frequency components are at or near the mounted resonant frequency point.

Note that mounted resonant frequency is specified assuming ideal accelerometer mounting conditions. Just as the manufacturer can influence the mounted resonant frequency point with the accelerometer's mechanical structure itself, so too can external structural factors (which the user controls). As mechanical resonance characteristics in general are dependent on material stiffness and damping, it is critical the accelerometer be mounted correctly and as stiff as possible. Improper mounting generally decreases stiffness and increases damping, causing the resonant peak to decrease in frequency and the width of the resonant rise to increase (i.e. mechanical Q is lowered). The ultimate result of this will, if allowed to degrade enough, affect the frequency response of the accelerometer. Proper mounting techniques are beyond the scope of this article, but much literature can be found on this subject.

Amplitude linearity

Amplitude linearity is a measure of how linear the output of an accelerometer is over its specified amplitude range. It is sometimes called amplitude non-linearity, since it specifies the deviation from perfect linearity. Ideally, an accelerometer would have exactly the same sensitivity at any amplitude point within its specified amplitude range. But with a real accelerometer, this is not the case. So amplitude linearity specifies the limits to how far the accelerometer's output will differ from this perfect linearity. Note that amplitude linearity is only valid at a (usually undisclosed) single frequency.

There are several ways to specify amplitude linearity. The most restrictive is to specify percentage of reading, typically ±1% over the entire full scale range. This is a close tolerance specification, as it means the accelerometer's sensitivity cannot vary by more than ±1% at any point in the amplitude range. A much less restrictive way is to specify linearity in a piecewise manner, such as this example: sensitivity increases 1% per 500 g, 0 to 2000 g. This means that at the top end of the amplitude range, sensitivity can vary as much as 4% from that at the low end of the amplitude range.

Amplitude linearity errors cause signal distortion, particularly in high amplitude accelerations. In environments where multiple vibration frequencies are present, intermodulation distortion can result, creating frequencies in the instrumentation that were not present mechanically at the accelerometer. A full discussion of intermodulation distortion is well beyond the scope of this article.

Output polarity

Output polarity describes the direction of the accelerometer's output signal (whether it is positive or negative going), given a particular direction of the input acceleration. By convention, most accelerometers are specified such that if the acceleration is directed into the mounting surface of the sensor, the output signal will be positive going. See Figure 4. If in doubt, the user can easily test and verify this. While holding the accelerometer in hand, and with it connected to all proper signal conditioning, tap the mounting surface with a finger (orientation of the accelerometer is irrelevant). Observe which direction the resulting signal goes. If it is a conventional accelerometer, the signal should go positive.

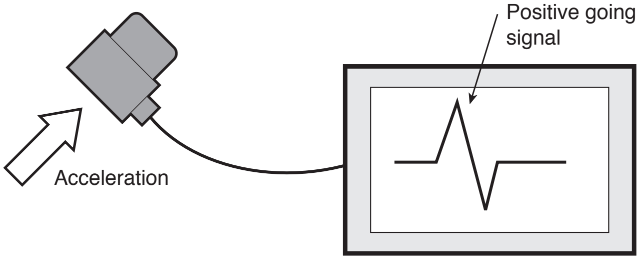

Figure 4: Output polarity

Output polarity of a triaxial accelerometer is slightly less straightforward. In most cases, however, the manufacturer will mark arrows for each orthogonal direction (X, Y and Z), indicating the direction the acceleration would have to be for a positive going signal to result.

Interpreting output polarity correctly is critical in some applications. For example, in a modal test on a large structure, it is essential to understand the directions and phase relationships of the acceleration vectors the structure is exhibiting during vibration excitation. Without correct polarity understanding in the accelerometers, this would be impossible, and incorrect (or no) understanding of the behavior of the structure would be gained.

Grounding (or ground isolation)

Accelerometers, being an electrical device, must have a signal ground return back to a signal conditioning device. How this signal ground is handled mechanically (and therefore electrically) within the sensor must be understood by the user, for proper operation. This is therefore specified by the manufacturer. Without this understanding by the user, the potential exists for an improper grounding system in the instrumentation, resulting in ground loops and erroneous data.

There are a number of ways a grounding system can be realized in the design of an accelerometer by the manufacturer, often dictated by expected use and market pricing. One of the least expensive methods is to simply connect the system ground to the accelerometer's casing. This method is often found in laboratory grade accelerometers using miniature coaxial connectors.

To prevent ground loops, manufacturers offer isolated mounting adapters that install between the accelerometer and structure mounting location. The next method is again to connect the accelerometer casing to ground, but isolate the mounting surface on the accelerometer itself. This is usually done with an isolating material applied to the surface, such as a hard anodized layer. In essence, the isolated adapter is built-in to the accelerometer. The ultimate ground isolation method is where the outer accelerometer casing and connector are completely isolated from the internal system ground. This method is often found in rugged industrial class accelerometers used on jet engines, gas turbines or industrial process machine monitoring.

Conclusion

Accelerometer users are often confused over accelerometer specifications, particularly when they are trying to select an appropriate sensor for a specific application or test. It is essential that users have a clear understanding of these specifications and what the limits and implications of these are to their test situation. Without this understanding, there exists a great potential for errors to enter the test data, and the time and expense of a test wasted. This article has covered some of the key specifications for users to consider. Manufacturers too have a responsibility to present their product's specifications in a clear and unambiguous manner.