Piezo sensors Characteristics

Sensitivity

A piezoelectric accelerometer with charge output can be regarded as either a charge source or a voltage source with very high impedance. Consequently, charge sensitivity or voltage sensitivity are used to describe the relationship between acceleration and output. In the individual characteristics sheet Metra states the charge sensitivity at 80 Hz and room temperature in picocoulombs per g or perms $^{-2}$ (1 g = 9.81 m/s²).

The sensitivity of accelerometers with IEP/LIVM output is stated as voltage sensitivity in millivolts per g or per ms^{-2}.

The total accuracy of this calibration is 2 %, valid under the following conditions:

f = 80 Hz, T = 21 °C, a = 10 m/s², C_{CABLE} = 150 pF, I_{CONST} = 4 mA.

The stated accuracy should not be confused with the tolerance of nominal sensitivity which is specified for some accelerometers, for instance, has ± 5 % nominal sensitivity tolerance. Standard tolerance window for sensitivity, if not otherwisely stated, is bestween ± 10-20 %. Hence the exact sensitivity of production accelerometers may vary from the nominal sensitivity within the specified tolerance range.

Charge sensitivity decreases slightly with increasing frequency. It drops about 2 % per decade. For precise measurements at frequencies differing very much from 80 Hz a recalibration in the desired frequency range should be performed.

Before leaving the factory each accelerometer undergoes a thorough artificial aging process. Nevertheless, further natural aging can not be avoided completely. Typical are -3 % sensitivity loss within the first 3 years. For a high degree of accuracy recalibration should be performed (see section 4.2.5).

Frequency Response

Measurement of frequency response requires mechanical excitation of the transducer. Metra uses an especially-designed calibration shaker which is driven by a sine-wave generator swept over a frequency range from 20 or 80 Hz to 40 000 Hz. Acceleration is kept nearly constant at 3 m/s² over the entire frequency range by means of a feedback signal from a reference accelerometer. Most accelerometers are supplied with an individual frequency response curve. It shows the deviation of sensitivity in dB. For example the upper 3 dB limit can be derived from this curve. The 3 dB limit is often used in scientific specifications. It marks the frequency where the measuring error becomes 30 %. It is usually at about 50 % of the resonance frequency (compare Figure 3). The 1 dB limit marks an error of approximately 10 %. It can be found in the range of 1/3 the resonance frequency. The mounted resonance frequency, which is the largest mechanical resonance, can be identified as well from this curve. Usually there are sub-resonances present at lower frequencies.

Frequency response measurements are given under optimum operating conditions with the best possible contact between accelerometer and vibration source practical. In practice, mounting conditions will be less than ideal in many cases and often a lower resonance frequency will be obtained. The lower frequency limit of IEP/LIVM accelerometers can be found in the linear frequency range given in the data sheet. It is stated for limits of 5 %, 10 % and 3 dB (see also page 5). For accelerometers with charge output we do not state a lower frequency limit since it is mainly determined by the external electronics.

The frequency response of IEP/LIVM transducers can be altered by long cables.

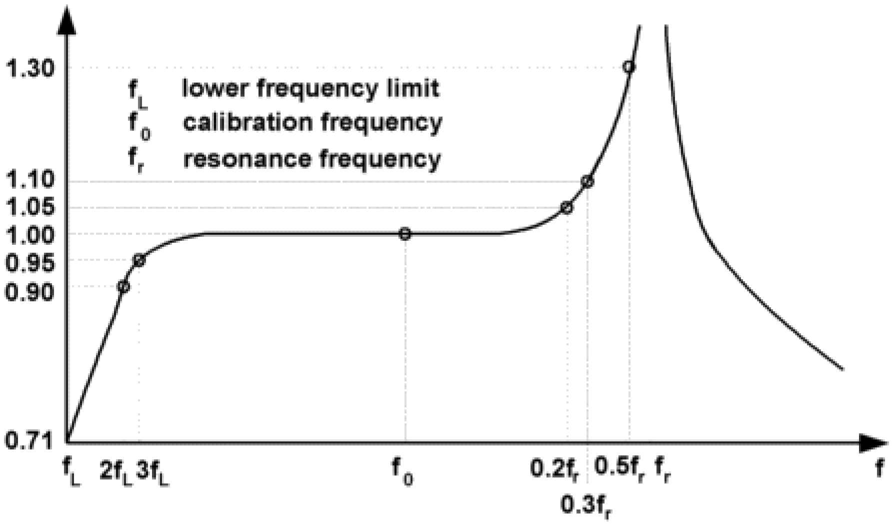

Figure 3: Typical frequency response of accelerometers

Transverse Sensitivity

Transverse sensitivity is the ratio of the output caused by acceleration perpendicular to the main sensitivity axis divided by the basic sensitivity in the main direction. The measurement is made at 40 Hz sine excitation rotating the sensor around a vertical axis. A figure-eight curve is obtained for transversal sensitivity. Its maximum deflection is the stated value. Typical are <5 % for shear accelerometers and <10 % for compression and bending models.

Maximum Acceleration

Usually the following limits are specified:

- â+ maximum acceleration for positive output direction
- â- maximum acceleration for negative output direction

The maximum acceleration is given for frequencies within the operating frequency range and at room temperature. At higher temperatures it may be lower.

For charge output accelerometers these limits are determined solely by the construction. If one of these limits is exceeded accidentally, for example, by dropping the sensor on the ground, the sensor will usually still function.

However, we recommend recalibrating the accelerometer after such incidents. Continuous vibration should not exceed 25 % of the stated limits to avoid wear. When highest accuracy is required, acceleration should not be higher than 10 % of the limit.

If the accelerometer is equipped with built-in LIVM/IEP electronics, the limits â+ and â- are usually determined by the output voltage span of the amplifier.

Linearity

The mechanical sensing elements of piezoelectric accelerometers have very low linearity errors. Within the stated measuring range the linearity error will be less than 1 % usually. Another issue is the linearity of IEPE transducers. The sensor electronics will contribute additional errors, particularly at higher output voltages. Typically the linearity error will be less than 1 % at within 70 % of the maximum output voltage.

Operating Temperature Range

The maximum operating temperature of a charge transducer is limited by the piezoelectric material. Above a specified temperature, called Curie point, the piezoelectric element will begin to depolarize causing a permanent loss in sensitivity. The specified maximum operating temperature is the limit at which the permanent change of sensitivity is 3 %. Other components may also limit the operating temperature, for example, adhesives, resins or built-in electronics. Typical temperature ranges are -35 to 150 °C and -10 to 80 °C. Accelerometers with built-in electronics are generally not suitable for temperatures above 120 °C.

Temperature Coefficients

Apart from permanent changes, some characteristics vary over the operating temperature range. Temperature coefficients are specified for charge sensitivity and inner capacitance. For sensors with built-in LIVM/IEP electronics only the temperature coefficient of voltage sensitivity is stated is stated.

There is a simple way to reduce the temperature coefficient of charge mode accelerometers. Since the temperature coefficients of B_{qa}, B_{ua} and C_i are different, the temperature behavior can be compensated by a serial capacitor at charge amplification or a parallel capacitor in case of high impedance voltage amplification. This capacitor is calculated to:

$$C = C_i \frac{TK(C_i) - TK(B_{qa})}{TK(B_{qa})}$$

This can be a useful improvement in case of very changeable temperatures. Please consider, that the total sensitivity will become lower by this measure.

Temperature Transients

In addition to the temperature characteristics mentioned above, accelerometers exhibit a slowly varying output when subjected to temperature transients, caused by the so-called pyroelectric effect. This is specified by temperature transient sensitivity b_{aT}. Temperature transient errors have frequencies below 10 Hz. Where low frequency measurements are made this effect must be considered. To avoid this problem, shear type accelerometers should be chosen for low frequency measurements. In practice, they are approximately 100 times less sensitive to temperature transients than compression and bending sensors.

Bending systems are midway between the other two systems in terms of sensitivity to temperature transients. When compression sensors are used, the amplifier should be adjusted to a 3 or 10 Hz lower frequency limit.

Base Strain

When an accelerometer is mounted on a structure which is subjected to strain variations, an unwanted output may occur as a result of strain transmitted to the piezoelectric material. This effect can be described as base strain sensitivity b_{as}. The stated values are determined by means of a bending beam oscillating at 8 or 15 Hz. Base strain output usually occurs at frequencies below 500 Hz. Shear type accelerometers have extremely low base strain sensitivity and should be chosen for for strain-critical applications.

Magnetic Fields

Strong magnetic fields often occur around electric machines at 50 Hz and multiples. Magnetic field sensitivity b_{aB} has been measured at B=0.01 T and 50 Hz for some accelerometers. It is very low and can be ignored under normal conditions.

Generally, accelerometers with stainless steel cases provide better protection against magnetic fields than accelerometers with aluminum cases.

Stray signal pickup can be avoided by proper cable shielding. This is of particular importance for sensors with charge output.

Adequate isolation must be provided against ground loops. They can occur when a measuring system is grounded at several points, particularly when the distance between these grounding points is long. Ground loops can be avoided using accelerometers with insulated bases (for instance

Sound Pressure

If an accelerometer is exposed to a very high noise level, a deformation of the sensor case may occur which can be measured as an output under extreme conditions. Acoustic noise sensitivity b_{ap} as stated for some models is measured at an SPL of 154 dB which is beyond the pain barrier of the human ear. Acoustic noise sensitivity should not be confused with the sensor response to pressure induced motion of the structure on which it is mounted.

Noise and Resolution

A piezoelectric sensing element can be regarded as purely capacitive source. Therefore, the sensor itself is free of intrinsic noise. The only noise contribution is caused by the temperature motion of electrons in the built-in the LIVM/IEP charge converter. Consequently, a noise specification makes only sense for IEPE compatible sensors.

The intrinsic noise determines the resolution limit of the sensor. Signals below the noise level cannot be measured.

The signal-to-noise-ratio Sn is a measure of the error caused by noise. It is the logarithm of the ratio of the measured signal level (U) and the noise level (Un_n):

$$S_n = 20 \log \frac{u}{u_n}$$

The intrinsic noise of IEPE compatible accelerometers mainly depends on the frequency.

Below about 100 Hz it has the typical 1/f characteristics. Above 100 Hz the noise level is nearly independent of the frequency. The following picture shows a typical noise spectrum of an IEPE compatible accelerometer:

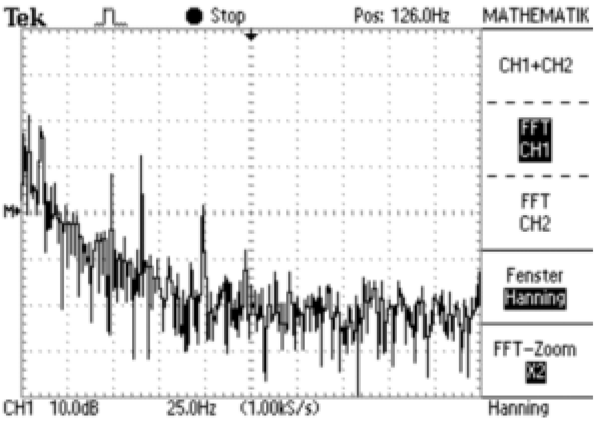

Figure 9: Typical noise spectrum of an IEPE compatible accelerometer

It is useful to state the noise of an accelerometer as equivalent acceleration level. For this purpose, the noise voltage (u_n) is divided by transducer sensitivity (B_{ua}) yielding the equivalent noise acceleration (a_n):

$$a_n = \frac{u_n}{B_{ua}}$$

While un only depends on the electronic circuit which is similar for all sensor types, the sensitivity of the piezoelectric sensing element will directly influence the equivalent noise acceleration. It can be seen that a transducer equipped with a very sensitive piezo system will provide the highest resolution.

The characteristics of most accelerometers show the wide-band noise (RMS) over the linear frequency range and noise densities at selected frequencies.

Example of a noise statement:

Wide-band noise (RMS)	$a_{n\ wide\ band}$	< 14 µg (0.5 to 1000 Hz)
Noise density 0.1 Hz	a_{n1}	3 µg/sqrt(Hz)
Noise density 1 Hz	a_{n2}	1 µg/sqrt(Hz)
Noise density 10 Hz	a_{n3}	0.3 µg/sqrt(Hz)
Noise density 100 Hz	a_{n4}	0.1 µg/sqrt(Hz)

To obtain the RMS noise acceleration within a certain frequency range, choose the noise density of the lowest frequency within the considered range and multiply it by the square root of the difference between the upper and the lower frequency limit.
For the evaluation of the intrinsic noise of an entire measuring chain the noise of all components including signal conditioners and other instruments has to be considered.

Inner Capacitance

The inner capacitance is stated in the individual calibration sheet only for accelerometers with charge output. It can be relevant if the transducer is used with a high impedance voltage amplifier. The stated value includes the capacitance of the sensor cable which was used for calibration. This cable capacitance is stated separately in the calibration sheet. Its value has to be deducted from the sensor capacitance to obtain the actual inner capacitance.

Protection Grades

The IP protection grades to IEC 529 and DIN 40050 characterize the suitability of a product for given environmental conditions. The first digit of the IP number means the shielding from the insertion of objects and dust. The second digit marks the protection against humidity.

Number	First	Second
0	No protection against hand or body contact	No protection
1	Maximum object dimension which can be inserted is 50 mm	Equipment is protected against vertical drops fall
2	Maximum object dimension which can be inserted is 12 mm	Equipment is protected against drops falling with 15° slope regarding the vertical axis
3	Maximum object dimension which can be inserted is 2.5 mm	Equipment is protected against spraying water falling with 60° slope regarding the vertical axis
4	Maximum object dimension which can be inserted is 1 mm	Equipment is protected against splashing water coming from any direction
5	Inserted dust may not overlay equipment parts	Equipment is protected against water jetting (IP65)
6	Full protection against dust insertion	Equipment is protected against powerful water jetting (IP66)
7	-	Equipment is protected against temporary immersion for a given time duration (IP67)
8	-	Equipment is protected against permanent immersion in given pressure (IP68)
9k	-	Protection against water for high pressure and steam jet cleaning (IP69k)

ATEX Certificates

For applications in explosive environments, we can supply for some of our products an ATEX certificate of type

"II 3G EEx nA II T6"

which means:

II - equipment group: electrical equipment for all explosive environments, except mining

3 - equipment category: for zone 2
(explosive condition unlikely, if occur, only rarely for short time)

G - for gas-explosive endangered areas

EEx - per directive 94/9/EC (ATEX)

n - equipment cannot ignite an explosive atmosphere under normal operating conditions

A - no sparks

II - equipment group: electrical equipment for all explosive environments, except mining

T6 - maximum surface temperature 85 °C