Dytran by HBK
HOTTINGER BRÜEL & KJÆR

WHITE PAPER

Selection of amplifiers and hardline cables for high-temperature piezoelectric sensor

SELECTION OF AMPLIFIERS AND HARDLINE CABLES FOR HIGH-TEMPERATURE PIEZOELECTRIC SENSORS

High-temperature piezoelectric sensors are commonly utilized in harsh applications, where standard instrument electronics cannot operate or withstand extreme testing environments. To successfully retrieve vibration signals, it is necessary to use a high-temperature charge mode piezoelectric sensor along with a remote charge amplifier and rugged cable. A characteristic of high-temperature piezoelectric accelerometers and pressure sensors is that the insulation resistance (IR) of the charge mode sensors goes from a high insulative condition at room temperature, to a low output resistance when operating at the maximum specified high temperature. For example, a sensor like model 3316M3 with IR of 100 Mega Ohms at room temperature will turn into 250 Kilo Ohms at 1,000°F maximum operating temperature. This high-temperature piezoelectric sensor characteristic makes it imperative to select a proper charge amplifier and hardline cable combination that will retrieve good, useful, and valid data from a vibration test.

The construction of high-temperature piezoelectric sensors should employ materials that can survive the harsh test conditions created by extreme temperature, pressure, and chemical corrosion caused from exposure to oxidative environments. The sensor envelope should be made with high-strength metal alloys that are corrosion resistant at high operating temperatures. Commonly used high nickel alloys include alloy 600 and stainless-steel alloys like 304 or 316. All internal interconnects are typically made with nickel alloys connecting with electrodes that retrieve the electrical charge from the piezoelectric element of the sensor. Piezoelectric materials that can be used include single crystal and polycrystalline ceramics that are able to function to the maximum operating temperature without detrimental effects to their material structure, even after myriad cycles of temperature excursions.

There is a limited number of high-temperature piezoelectric materials available and most are highly dielectric. Hence, they are basically metal oxides in single crystal or polycrystalline form. The best known are tourmaline, lithium niobate, bismuth germanate, langatate, gallium orthophosphate, aluminum nitride, bismuth titanate, barium silicate titanate. Another commonly used element in the assembly, is the incorporation of an insulator, such as a dielectric material like alumina ceramic. This element is meant to isolate the piezoelectric stack from the signal ground, mostly on differential-ended instruments.

As previously mentioned, an important aspect of high-temperature piezoelectric materials, like single crystals and piezoceramics, is their capability to transition from a very high insulation resistance value at room temperature to a low insulation resistance value at maximum operating temperature (between 700°F and 1,600°F). This condition is attributed to the loss of oxygen as most piezoelectric materials are metal oxides. When the temperature reaches over 700°F, the loss of oxygen puts the material in a condition that is chemically reduced. The free reduced metal in the crystal structure causes it to be more electrically conductive, which lessens its insulation resistance properties. The reduction of insulation resistance can reach values at which standard commercial charge amplifiers cannot properly operate. Once the sensor temperature cools down, the phenomenon of oxygen depletion is reverted, and the sensor normally recovers its original IR value. It should be noted that in closed systems, like hermetically sealed sensors or in exposure to high vacuum, the oxygen depletion might become permanent and the structure of the piezoelectric material might be altered and even damaged.

The best solution to counter the drop in insulation resistance of piezoelectric materials is to hermetically seal the sensor using Dytran's patented Silver Window™ technology. The technology incorporates a patented metallic Silver Window™ that allows diffusion of oxygen from the exterior of the housing and forms an integral part of the metal housing of the sensor. The use of silver allows a constant supply of oxygen to the interior of the oxygen-depleted sensor housing that is activated only when operating at high temperatures. Additionally, silver operates perfectly in high-temperature environments, as the silver deoxidizes with exposure. A sensor made with the Silver Window™ technology is still hermetically sealed, as the silver allows diffusion only through the metal matrix and the sealing of the sensor is hermetic in nature. Dytran by HBK holds U.S. patent number 8,375,793 covering the Silver Window™ invention as applied to all types of high-temperature piezoelectric sensors.

Figure 1. Dytran by HBK's model 3683C triaxial 1,000°F accelerometer with Silver Window™ technology.

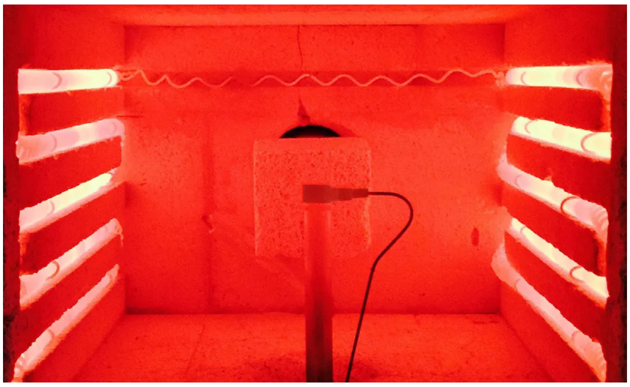

Figure 2. Dytran by HBK's model 3316M3 with Silver Window™ technology under test at 1,000°F.

To further enhance the performance of the sensors and address the intrinsic IR decrease, it is good practice to use a special charge amplifier. Selecting the right charge amplifier for high-temperature piezoelectric sensors requires matching the low input resistance of the instrument at maximum operating temperature. Typically, a charge amplifier for a high-temperature application can handle an input resistance of 100 Kilo Ohms, and as low as ten (or even one) Kilo Ohms. It is also important to know the input capacitance to the charge amplifier, as piezoelectric accelerometers made with piezoelectric ceramics inherently have a large capacitance value, which increases to double or triple the initial value at maximum operating temperature. Piezoelectric sensors made with single crystals have low capacitance and will not present any issues due to capacitance change during operation.

Figure 3. Recommended inline charge amplifier for low insulation resistance in high-temperature HBK's piezoelectric sensors, Dytran by HBK model 4754B.

While the high-temperature piezoelectric sensor might operate within a wide frequency response range, and up to the limit imposed by the resonance frequency, it is an intrinsic limitation of the same amplifier that the low input resistance will affect the low frequency response of the instrument. The lower value of the insulation resistance of the sensor will limit how low in frequency response it can measure with meaningful data. The corner frequency on the low end will be determined by the formula below:

$$Fcorner = \frac{1}{2\pi TC}$$

Where TC is:

$$\frac{1}{TC} = \frac{1}{TCa} + \frac{1}{TCc} + \frac{1}{TCdaq}$$

TCa is the discharge time constant of the charge amplifier (found in the data sheet)

TCc is the coupling discharge time constant calculated as following:

$$TCc = IR * Cc$$

IR is the insulation resistance of the sensor at operating temperature

Cc is the coupling capacitor of the amplifier (typical value 0.1 Microfarads)

TCdaq is the discharge time constant of the DAQ (if used AC coupled). This value is usually fairly small compared to the rest so it can be omitted from the equation.

Another important consideration in the selection of a high-temperature vibration system, is the use of a high-temperature hardline cable that complements the sensor and amplifier. The design of hardline cables for single-ended sensors, like model 3316M3, is typically comprised of a center conductor made of high nickel alloys or stainless steel that is surrounded by a mineral insulator made with silicon dioxide or magnesium oxide; and a metal sheath envelope of high nickel alloy or stainless steel. Silicon dioxide is the preferred mineral insulator as it is not hygroscopic or deliquescence, like magnesium oxide (MgO must be sealed hermetically and heat treated to achieve proper insulation resistance). Additionally, a fiber-glass sleeving is applied on top of the cable sheath to prevent electrical ground loops from distorting the data.

In order for the hardline cable to successfully operate in extreme conditions, it must be robust and have an adequate connector termination that matches the sensor. Cable terminations are typically made with ceramic brazing or a high-temperature glass composition. Common materials used for brazing solutions include alumina or sapphire, which are specified for operation at maximum temperature of 900°F. However, this technique might suffer from oxidation of the manganese molybdenum (Mo-Mn) layer used to bond the brazing alloy onto the alumina ceramic preform. There are special techniques using active brazing alloys with titanium or zirconium, mixed with a gold-copper brazing alloy that can bond sapphire and does not require a Mo-Mn layer interface. This is more expensive, but they can survive temperatures up to 1,200°F.

A preferred solution for achieving proper cable termination is the use of high-temperature glass on the connector. Glass, like other dielectric materials, suffers from low insulation resistance when operating at high temperatures. This effect is more pronounced in glass, which would lead one to believe that ceramics are more appropriate. However, there are certain high-temperature glasses that can maintain a high insulation resistance when operating up to 1,200°F. Glasses are made with metal oxides and therefore, they do not suffer further oxidation. They are optimal for hardline cables and hightemperature connectors. A strain relief is incorporated onto the hardline cable to avoid excessive bending of the cable near the welded areas. The optimal hardline cable on a single-ended application must be terminated in such a way to be able to apply torque to secure the cable, like using a Hex nut with lockwire holes. Some manufacturers utilize a knurled termination for hand tightening, which is not secured in a harsh environment (see figure 4).

Figure 4. Examples of hardline cable terminations on the market, optimal cable on top, model 60016A, with Hex termination and complete fiberglass covering, rated at 1,000°F. At bottom, an underperforming hardline cable with knurled termination, no fiberglass coverage, and lower temperature rating of 900°F.

Another aspect that it is important in the selection of a hardline cable, or any high-temperature cable for that matter, is a lower capacitance per foot specification. The higher capacitance of a cable is a major contributor to the overall noise figure of the system. As a rule of thumb, every 1000 pF in capacitance adds 0.008 pC rms of noise. Dytran hardline cables have a value of approximately 30 pF/ foot and other similar cables in the market are 100 pF/ foot or more, which means up to three times higher noise or less resolution of the measurement. It is important to avoid cables with high triboelectric noise, like flexible solutions. Additionally, the center conductor must be a good electrical conductor, display low resistivity, and stay within such value at operating temperature. All metals (conductors) will raise in resistivity at temperature, but there are materials that have little change in resistivity while in operation. It is disturbing to see other hardline cables on the market with high resistivity at maximum operational temperature, as this new feature of electrical resistance will be another contributor to the limited low frequency response.

Figure 5. Example of proper selection of charge amplifier and hardline cable.

SUMMARY

1. Determine which charge mode high-temperature accelerometer, or piezoelectric sensor, best fits the application. Read and understand the latest revision of the data sheet for the instrument. Every parameter on the specification sheet has some importance and might be limiting the scope of your test.
2. Match the high-temperature piezoelectric sensors to an adequate charge amplifier that can handle the change in insulation resistance and the change in capacitance of the sensor at maximum operating temperature.
3. Select a hardline cable with the robustness required for the harsh testing environment. Ensure the cable characteristics are impervious to damage when operating in extreme environments where temperature excursions might arise. Furthermore, the cables should have a low capacitance specification to exhibit a minimal contribution to the overall noise of the system.

Dytran by HBK is the ideal provider of high-temperature sensors and ancillary electronics and cables. For more information, visit www.dytran.com or consult a technical specialist by calling (818) 700-7818. We have worldwide representation.