Design and Selection Considerations for High Temperature Aerospace Accelerometers

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Accelerometers used for shock and vibration measurement in extreme environments require special consideration during the design and manufacturing process. Specialised applications frequently require the use of a single model of accelerometer which must be capable of operation over significantly wider temperature ranges (–54degC to +649degC for example) than conventional laboratory accelerometers whilst at the same time providing high levels of accuracy, stability and reliability.

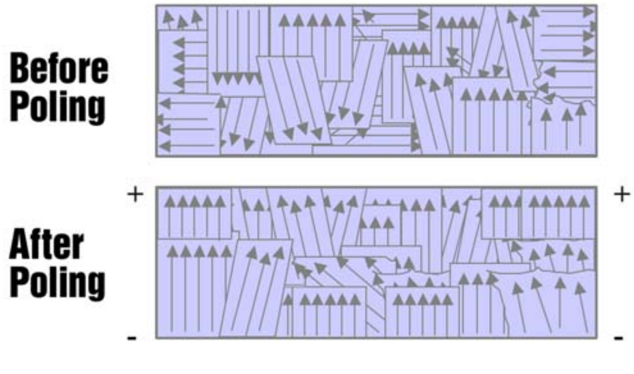
Typical applications for high temperature, aerospace accelerometers include the measurement of vibration on gas turbine engines – both in-flight and in test cells, rocket motors and thruster assemblies. The same accelerometers may also be required to function in environments of nuclear radiation - vibration monitoring in nuclear power plant generation and on space vehicles for example. Materials and construction must therefore be optimised, not only to enhance high-temperature performance, but also allow operation in the presence of gamma and neutron radiation without degradation.

The design and performance of a sensor varies depending upon the choice of piezoelectric material selected for the application (see fig 1). Both natural and man-made materials have unique features and advantages. Natural crystals tend to provide the highest temperature ranges and lowest pyroelectric outputs, however, ferroelectric ceramics offer extended frequency ranges and smaller sizes for the equivalent output.

Fig 1

Single, natural crystals such as quartz or tourmaline are inherently piezoelectric where as man made, ferroelectric ceramic crystals require polarisation before use. The polarisation process, during which a high voltage is applied to the material to align polar regions within the ceramic element thus resulting in a net piezoelectric effect is known as poling (see fig 2).

Fig 2



A design utilising ferroelectric ceramic material in compression mode will have a greater pyroelectric output than that of a shear design or one using a natural crystal. This is due to the direct coupling of the ferroelectric ceramic crystal stack to the accelerometers' base and the pyroelectric characteristics of the ferroelectric material which is sensitive to uniform temperature changes on those surfaces which are perpendicular to the axis of polarisation.

The pyroelectric output, which is very low frequency in nature, can be avoided by the use of high-pass filtering in the measurement system electronics.

There are design trade-offs with high temperature sensors that must also be considered, all affecting maximum temperature, bandwidth, and the sensors sensitivity.

Ferroelectric ceramics typically exhibit around twice the sensitivity obtained from some natural crystals, and around ten times that of Tourmaline, one of the more commonly used natural crystals. Bismuth Titanate - based ferroelectric material can be used to temperatures of +482°C. Various compounds can be added to alter sensor characteristics, but higher temperature ranges always come at the expense of sensitivity. Many so called "natural" crystals are actually grown in laboratories, rather than mined, resulting in higher, more consistent quality and enabling new variations to be developed with higher sensitivities. A single crystal allows processing in both shear and compression modes. Typically, shear mode configurations offer almost twice the sensitivity of that of compression mode configurations and this allows flexibility of design and performance optimisation (see fig 3A & 3B).

Fig 3a

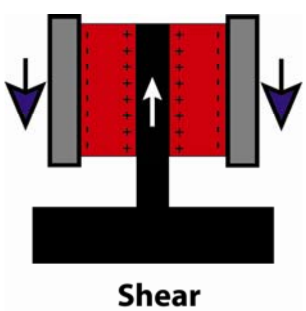
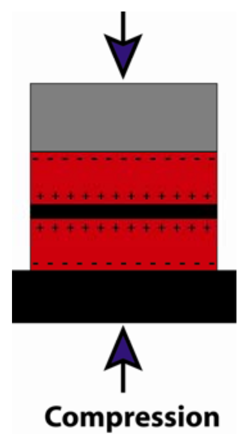


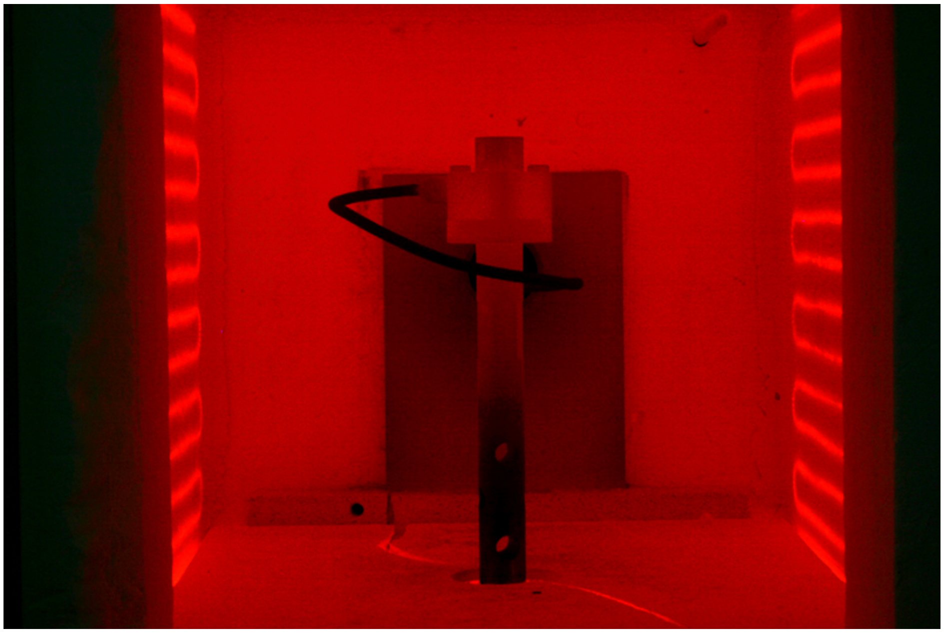
Fig 3b



The maximum operating temperature of an accelerometer is a function of the properties of the piezoelectric crystal material and specifically that of the "Curie temperature". That is the temperature at which the material looses its piezoelectric properties. Another area of concern is that of the accelerometers "source resistance" (also known as the insulation resistance) as this will significantly decrease with temperature. This parameter is of particular importance in relation to the signal conditioning equipment to which the accelerometer is to be connected. Charge amplifiers and charge converters that are not specifically designed to operate with low values of source resistance will not function correctly. PCB® has developed in-line charge converters specifically for this purpose.

Whenever a sensor is exposed to temperature changes, several key parameters, such as sensitivity, source resistance, and sensor capacitance, will change. These changes should be predictable and repeatable. PCB® tests every high temperature sensor they manufacture at its maximum operating temperature, in order to ensure consistency and quality.

Figure 4 below shows a +650degC accelerometer under test.



The design of cabling and electrical connections is also critical to the acquisition of good quality data. A loose connector, for example, can result in a high-level, low frequency signal unrelated to the measurement in question, a source of error within the data. In general, reliability of all connectors degrade at temperatures over +492degC, therefore to overcome this, PCB® accelerometers designed for temperatures of up to +649degC are fitted with integral cables. These integral cables are designed to be mechanically isolated from the seismic system to avoid base and cable strain effects. The cables provided by PCB® use silicon dioxide insulation, which, due to its non-hygroscopic nature, exhibit excellent high temperature, electrical characteristics. Careful selection of the cable material, and the use of a protective over braid, facilitates ease of handling and allows bend forming during installation whilst maintaining a rugged solution.

Where accelerometers are used for shock and vibration measurements in nuclear radiation environments, it is necessary to examine transient and steady state radiation effects. This allows the determination of a tolerable radiation dose before degradation of accelerometer performance. An adverse reaction to radiation would be the reduction of crystal output and the deterioration of various materials that are intolerant to radiation such as Teflon, for example. Generally, higher temperature crystals are more resistant to radiation effects. PCB® ensures that all crystal and component materials used for their high temperature accelerometers have been tested for Gamma and Neutron radiation exposure.

High temperature accelerometers manufactured by PCB® use both natural crystals and ferroelectric ceramics. For products designed to operate up to +482 °C ferroelectric crystals are used, however for products for use up to +650dgC PCB® use natural crystals. All PCB® high-temperature sensors are hermetically sealed and are tested to ensure they survive sustained harsh environments, with a long mean time between failures.

The PCB +482degC family consists of the Model 357C7X differential sensor, with sensitivity options of 10, 50 and 100 pC/g while the Model 357B61 is a high frequency single ended design with 10 pC/g sensitivity. The recently introduced lightweight Model 357B69 is a lower profile, single ended design offering a high frequency response with 3 pC/g sensitivity. The Model 357B67 has the same low profile design and high frequency characteristics as the 357B69 but with the added versatility of either 10-32 stud mounting or flange mounting.

The PCB® family of accelerometers designed to operate in temperatures of up to +649°C make use of a unique natural crystal specially grown to maximise their temperature and output characteristics. The PCB® Model 357B90 is a single ended design with a single point mounting designed for locations where space is minimal. The Model 357B91 is a similar sensor, but with the sensitive axis offset by 90 degrees. These sensors have 5 pC/g sensitivity and ±1 dB response to 5 kHz. The integral cable supplied with these sensors is both rugged and yet uniquely flexible to allow ease of installation.

Other additions to this family are the 357B66 which is the same size as the Model 357B69 but with 2pC/g sensitivity and an integral hardline cable. The Model 357B68 has the same profile and performance characteristics of the 357B66 with the same mounting flexibility as Model 357B67.

For more information on PCB Piezotronics high temperature accelerometers, please visit our website at www.pcb.com