Dytran by HBK
HOTTINGER BRÜEL & KJÆR

WHITE PAPER

Nuclear and radiation hardened sensors

NUCLEAR AND RADIATION HARDENED SENSORS

Sensors intended for applications in high radiation environments, like the ones encountered in nuclear power plants, space vehicles and assets deployed for long term outside the Earth's atmosphere, are required to operate and provide reliable signals and measurements during their life cycle. Sensors used in those harsh environments are exposed to high radiation fluxes, very high temperatures, [as well as very cold temperatures in space], and high corrosion or degradation of materials used in their fabrication. Operators of nuclear power plants, [humans and/or automatic control systems] must be able to make decisions that are based in true measurement of vibration and pressure, that correspond with actual environmental conditions. Many of the safety postulates in nuclear power plants are based in measurands, reaching a certain established threshold; high precision and accuracy of the measurements are, therefore, very important for proper and safe operation.

When utilized in nuclear power plants, stationary, or in propulsion systems, the sensor is typically located in a harsh environment, and is not easily retrievable or removable for recalibration. In most occasions, the sensor is practically inaccessible. The same situation is presented in space applications, in which a vehicle or assets are deployed for long term, and sensors are not retrievable. This additional factor of a sensor that cannot be retrieved, recalibrated, or removed and replaced, forces the sensor designer to plan for enhanced longevity of the instrument.

The terminology for nuclear qualified sensors needs some clarification. Procurement agents, engineers, operators, installers, etc, tend to confuse or mix the different terms utilized in reference to nuclear or radiation resistance sensors. The semantics are very important, especially regarding the meaning of the radiation terms in both the intention and extension of the words. There are three terms associated with radiation resistance sensors, the first one is "radiation hardened", the second one is "radiation tolerant", and the third is "radiation shielded". Each one has different performance and costs associated.

RADIATION HARDENED SENSORS

"Radiation hardened" sensors are instruments that were exposed to radiation to a specific required level to improve the features that might drift, age or change during radiation exposure in the intended application. In radiation hardening, it is common to use material modifications to enhance the stability of the sensing element. Examples include the irradiation of PZT ceramics to reduce their aging and make them more stable in piezoelectric sensitivity, and the sweeping of quartz, which is an electro diffusion process in solid state to remove impurities on the crystal lattice and improve frequency stability and/or piezoelectric sensitivity in high radiation environments. Any treatment that removes dislocation on the crystal, or impurities, will make the material less susceptible to radiation damage. Every single lot of sensors is irradiated with gamma radiation and neutrons to the required levels, and only sensors that pass this screening are accepted. Radiation hardening is the most expensive process because it requires actual exposure and/or material modification or special treatments. However, it is the preferred process for long-term deployment or missions, as well as for nuclear power plants, where the instrument is inaccessible for repair and replacement. Radiation hardening has higher reliability and longer life cycles than any other method.

RADIATION TOLERANT SENSORS

There are also "radiation tolerant" sensors that have an intrinsic resistance to radiation. This type can be immune to the effects of radiation, or, as the word indicates, the radiation damage can be tolerated within certain limits. Typically, instruments are tested to established radiation levels, and after testing the sensors, a passing grade indicates that the type of sensor is qualified as radiation tolerant and no further test is necessary. The design of the sensor is locked, as the qualification is only valid for the same set of parts and construction that was previously qualified. This option is cheaper than hardening which requires a 100% screening of every lot.

RADIATION-SHIELDED SENSORS

The last type of nuclear qualified sensors are "radiation shielded" sensors. These are sensors that do not have an intrinsic or enhanced resistance to radiation and have to be made from high-density metals. They are typically DC accelerometers with MEMS devices and embedded electronics, and they are shielded against radiation by the use of high-density metals, like tantalum, platinum, gold, or tungsten. The instruments have no other defense against radiation except for the thickness of the shielding material. Like radiation tolerant sensors, shielding design and construction must be qualified with the sensor in order to prove that they do protect against radiation. A passing grade of a sensor with shielding qualifies the shield design to the radiation levels tested. Implementing a shield against radiation appears to be an easy solution for commercial sensors, but the high density and raw materials, as well as their processing, are costly. Also, the addition of a shield makes them intrinsically heavier, which adds weight to the instrument. This might not be too important in a nuclear power plant, but it is a concern for payload limitation in space applications. The shielding can be applied in thin film at the component level of a particularly radiation susceptible device, but the shielding depends on the thickness, so the magnitude of radiation is also limited.

Industry standards and regulatory agencies have accepted levels of minimum radiation exposure tolerance in a nuclear power plant, depending on the location of the sensor inside the reactor. Typically, for vibration sensors the specification is a minimum cumulative exposure of 100 megarads in gamma radiation by cobalt-60 isotope; and a flux of 1010 neutrons/cm^2. Those accepted levels are for sensors that usually do not have any electronics inside, also called charge mode sensors, and are intended for locations that are typically not accessible and have a higher magnitude of radiation flux. For low impedance sensors, signal conditioners, or charge amplifiers with internal electronics, the radiation specification is lower, 1 megarad cumulative.

Only a few manufacturers are qualified to make vibration and pressure sensors for the nuclear and aerospace industries. Environmental screening and quality controls are mandatory by proceedings of the nuclear Regulatory Commission, and industry standards specific to the Nuclear operator, Department of Defense, and the aerospace industry. Dytran by HBK qualified several charge mode accelerometers and two inline charge amplifiers as radiation tolerant. The qualified sensors include: 3235C Series, 3316 Series and the 3443C. Qualified amplifiers include the 4754B Series and 4753B Series.