Miniature Combination Pressure/Temperature Sensors with Redundant Capability

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Abstract

Combination pressure/temperature sensors with redundant capability are designed and built for high reliability/availability and extreme service environments. Previous technology required separate sensors for temperature and pressure measurement or redundant measurements. These sensors feature small size and minimum weight, critical features in automotive and other space limited applications. Thin film RTD temperature probes, packaged for harsh environments and redundant capability are presented. Pressure capsules using silicon on insulator technology for high temperature measurements in extreme environments are discussed. Various sensor header designs with single and multiple glass elements, and a dual silicon die for redundant measurement are discussed. Also presented are extensive test and analysis of the sensing capsule and RTD device to optimize the designs for service pressure exposure and RTD response time.

1. Introduction

Combination pressure/temperature sensors with redundant capability are designed and built for high reliability/availability and extreme service environments. These sensor feature small size and minimum weight, critical features in automotive and other weight and size limited applications. Combined pressure and temperature measurement give a better indication of process status or fluid health. Redundant sensors give an extra measure of reliability, and maintain process control in the event of a single sensor failure. Prior technology required separate sensors for pressure and temperature, and multiple sensors for redundant applications. The installation of redundant or multiple sensors in a single penetration or package makes engineering and installation easier. Reducing sensor penetrations and wiring harnesses also decreases installation and life cycle costs.

The combined temperature/pressure sensor was originally developed for the automotive engine test application. Great detail and engineering effort goes into designing the engine and associated systems for peak performance and efficiency. Monitoring may include brake fluid, engine coolant, fuel pressure, oil pressure, exhaust, and others. The miniature pressure/temperature sensor must penetrate the chamber or passage wall to measure the fluid during engine operation. As with any measurement system, anything introduced to measure the system, changes the system. This change must be minimized. The small size of the combination pressure/temperature sensor provides for minimal change and chamber or passage wall penetration.

Figure 1 - Miniature Pressure/Temperature Sensor

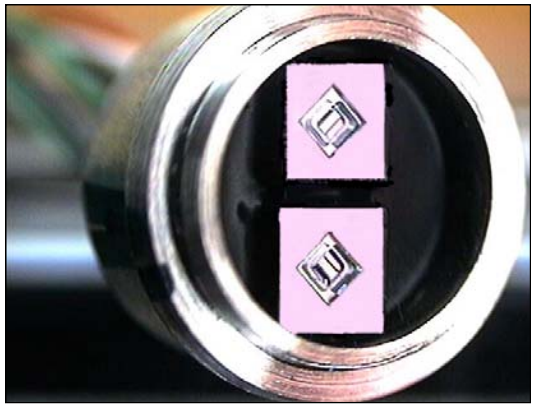

Figure 2 - Miniature sensor with screen removed, showing two pressure sensing dies

In high reliability systems, the redundant sensor has been used with multiple wire harnesses. If one sensor or wire harness is compromised, the other sensor is still available for measurement. Engine control systems or computers can determine the loss of signal from one sensor, and automatically switch to the second sensor. Sensors have been fabricated with combined pressure and temperature, with redundancy in both measurements. Applications include oil and fuel, combustion, hydraulic line pressure and temperature, braking systems pressure, coolant systems and others.

The single penetration feature allows easier mounting for redundant or combined sensors. With a single penetration, the mechanical strength and fatigue resistance of a pressurized chamber or passage can be improved. Also, fewer penetrations reduce potential leak points, and minimize installation errors. The single penetration will also allow designers to make smaller, lighter components.

Multiple sensors improve reliability by eliminating many of the body and port parts, while doubling the electrical portion of the component. As discussed earlier, the redundant feature, with the elimination of piece parts, makes for a more reliable system.

Applications for the redundant sensors include automotive test and measurement applications. Automotive applications can include test bed measurements, or "live" measurements on Formula-1 racecars. Fluid health, which is best described by pressure and temperature, especially thermodynamic fluids, include monitoring of coolants, oil and fuel.

2. The Kulite Combination/Redundant Sensor Design

    a. Temperature Probes

Temperature measurements are based on a thin film RTD technology. The thin film RTD uses a platinum film sputtered onto a ceramic substrate, allowing for a very small package. The bare RTD, shown in Figure 3, is on the order of 1.2 mm wide, and can be placed in a stainless steel package, to withstand harsh environments and pressure. Kulite has developed a packaging process to encapsulate the thin film RTD in thermally conductive epoxy, mounted in a steel sheath, to maintain the response time of the RTD. The RTD sheath, shown in figure 4, is as small as .065 inch diameter, with a length of about .6 inches long. The RTD is mounted on a variety of sensors, including aircraft sensors for oil and fuel measurement, or automotive sensors, for hydraulic, engine oil and coolant measurement.

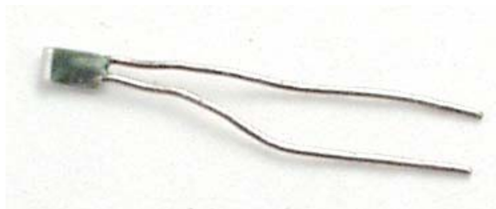

Figure 3 - Thin Film RTD

Figure 4 - Enlargement of RTD active sensing area

Figure 5 - RTD Probe Stainless Steel Sheath

For redundant RTD capability, two RTD devices can be packaged in a single tube. For full redundancy, each RTD can be packaged in a completely independent tube.

b. Pressure Measurements

Pressure measurements are based on the Kulite silicon on silicon technology (patent #5,286,671). The silicon die features a diaphragm on which four piezoresistive elements are placed, in a Wheatstone bridge configuration. Pressures will deflect the flexible membrane of the diaphragm, and cause stresses in the membrane to change the resistance of the four piezoresistors. This change in resistance will cause a change in output voltage corresponding to the pressure.

Figure 6 - Silicon Sensing Die with Wheatstone Bridge

The silicon die is mounted on a glass substrate, using Kulite leadless technology. This technology allows the diameter of the sensor to be minimized, and also eliminates gold wire bonds between the header pins and the sensing diaphragm. The elimination of the gold wire bonds eliminates eight connection points and four wires, increasing reliability, and improving robustness in the harsh temperature and vibration environment

Using multiple dies, a redundant sensor can be fabricated. For absolute or true delta-p pressure measurements, full bridges can be used. These dies can be mounted on independent glass headers, as shown in figure 6, or on a single glass substrate, as shown in figure 7. The single glass substrate uses a "domino" or "hex" die, which contains two full Wheatstone bridges and sensing dies. The hex die is shown in figure 8. Although the circuitry is on a single silicon substrate, each bridge is completely independent of the other. In addition, a groove is etched between the two circuits to maintain dielectric isolation of the silicon-on-silicon layer.

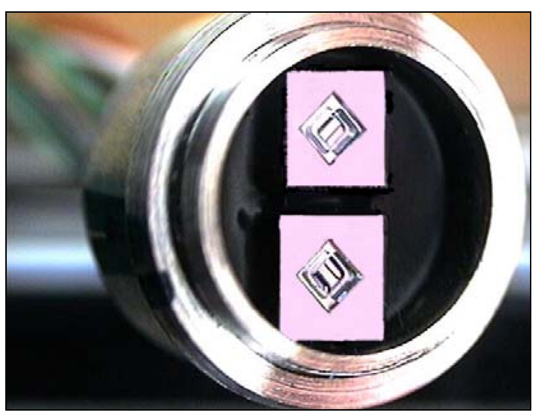

Figure 7 - Double Glass Header with Two Dice

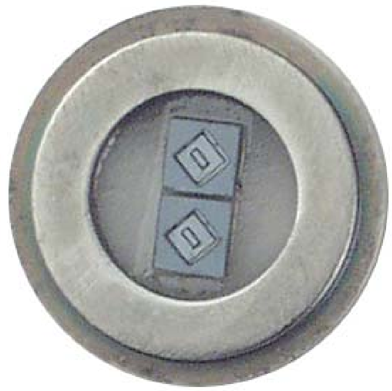

Figure 8 - Single Glass Header for dual Die

Figure 9 –Dual Die with two Sensing Elements

Variations of these designs have been fabricated using leaded technology, but the principles remain the same, using two bridges in single or multiple glass headers, with single or dual dice. In addition, the dual die can be extended to design a triple redundant die. Kulite has designed a triple redundant transducer.

The Kulite combined/redundant sensor can be supplied with various options such as amplifiers and protective screens. The basic transducer has a compensation network, to maintain pressure-sensing accuracy over a wide temperature range. The network is composed of a group of passive resistors, placed in series with the bridge. The compensation is required because of the temperature coefficient of the gage factor of the piezoresistors, and zero shift with temperature. An amplifier, external to the sensor, can be added, to provide a 5-volt DC output, instead of a millivolt output. Dual amplifiers for redundancy can be provided. High temperature amplifiers have been developed for extreme environments. Various screens or snubbers can be installed to protect the sensing dies or RTD probes from debris or handling.

3. Functional Testing - Temperature Sensor

The response time and accuracy of the RTD temperature-sensing element is highly dependent on the packaging of the bare device for survival in the service environment. The typical bare RTD, on the ceramic substrate has a response time of .2 sec, in water. When packaged in a steel sheath for robustness, and potted using thermally conductive materials, the response time is reduced, as an artifact of introducing thermal resistance in the path. In addition, the heat sinking of the very small RTD package by the relatively large flange or sensor body will further reduce response time. This can be compensated for by increasing the distance between the RTD element and the larger flange or sensor body mass.

Various tests and analyses have been performed to determine the best length of the RTD package to decrease response time and improve RTD accuracy. A typical response curve for the RTD is shown in Figure 10. The time constant (63.3%) is about 1.2 seconds. The RTD design is mainly driven by the inside diameter required to fit the RTD element, and the wall thickness driven by the service pressure in which the RTD operates. The sleeve OD is about .065 inches. Various lengths were tested, to minimize the heat transfer into the port or sensor body.

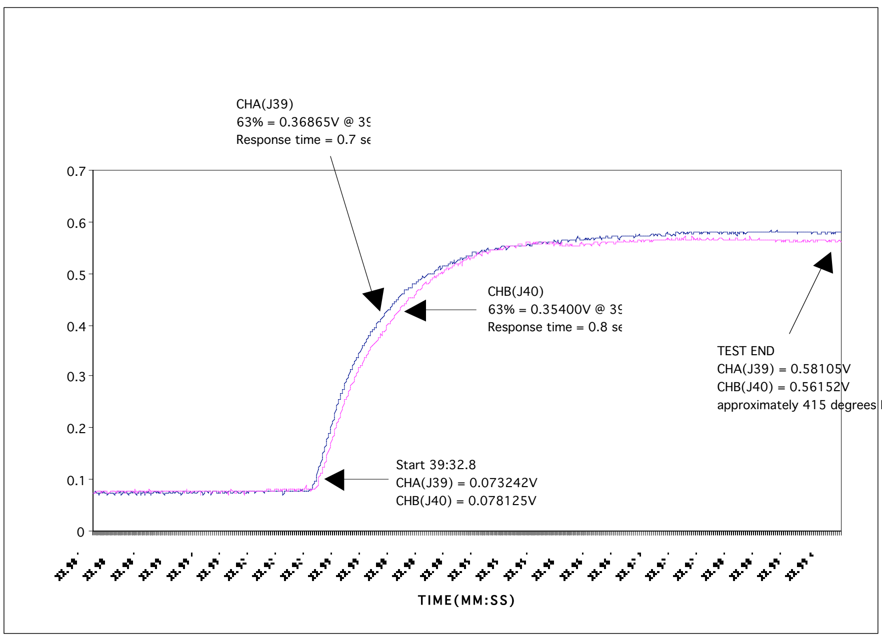

Figure 10 - RTD Response time

4. Analysis – Pressure Sensor Header

The dual glass and single glass header designs were checked using finite element analysis. The challenge with the single glass/domino die header is to withstand service pressures while the diameter of the glass is increased to accommodate the domino die. Using FEA, for a given pressure, the glass thickness was varied, to keep the stresses below design limits. The glass can withstand great stresses in compression, while failures are initiated by tensile stresses. As a guideline, the design limit for tensile stresses is below about 5,000 psi. A FEA model, and the stress tensor results in the XX direction are shown in Figure 11. As shown, the stress tensors, with 10,000 psi applied to the front face of the glass, are below about 4000 psi.

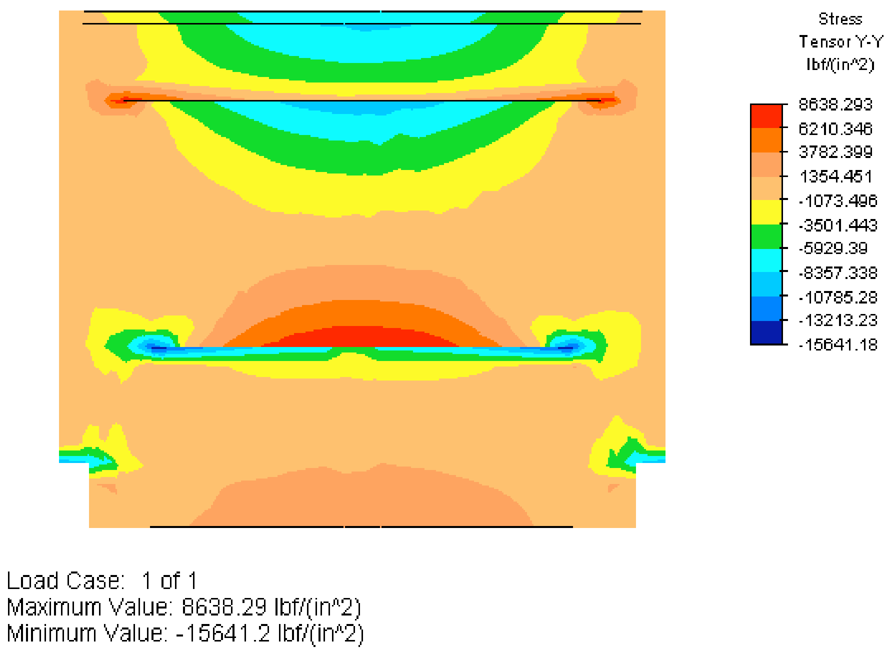

Figure 11 - FEA Analysis of Dual Die Header

5. Conclusion

In conclusion, a combination redundant pressure and temperature sensor has been developed for various critical applications. The combined sensor offers great weight and cost savings by eliminating several packages, while combining sensors. In addition, installation is made easier, by minimizing housing penetration and separate wiring harnesses. Redundant sensors, required for high reliability or race critical applications can be design with minimal size or weight penalties. The dual redundant design can even be extended to a triple redundant die design, which has been fabricated at Kulite. Test and analysis of the sensing capsule and RTD device have optimized designs for service pressure exposure and RTD response time.