This invention is a multiple channel high data rate pressure sensing device for use in wind tunnels, spacecraft, airborne, process control, automotive, etc., pressure measurements. This device offers data rates in excess of 100,000 measurements per second with inaccuracies from temperature shifts less than 0.25% (nominal) of full scale over a temperature span of 55°C. This device consists of thirty-two solid state sensors I1, signal multiplexing electronics to electronically address each sensor, and digital electronic circuitry to automatically correct the inherent thermal shift errors of the pressure sensors and their associated electronics.
**FIG. 3**

![Diagram of 32 CHANNEL MULTIPLEXER](image1)

**FIG. 2**

![Graph showing thermal zero shift](image2)
SELF-CORRECTING ELECTRONICALLY
SCANNED PRESSURE SENSOR

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government and may be used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

The invention relates generally to pressure sensors and more specifically concerns apparatus for correcting thermal errors in multiple pressure sensor systems.

The major impediment of the widespread use of semiconductor type pressure sensors in the past has been their sensitivity to temperature. This sensitivity to temperature manifests itself as errors that result from changes in zero offset (voltage offset at zero pressure) and in pressure sensitivity. The errors can be reduced by the use of compensating elements or through “in situ” calibration (U.S. Pat. No. 4,111,038), but only at the expense of size, cost, or complexity. The compensating elements are often larger than the pressure sensing elements and require extensive calibration of the pressure sensors before the proper compensating elements can be chosen, thus adding significantly to the cost. Also, because the thermal zero shift is often very non-linear with temperature, compensating elements generally only are able to reduce the errors to 0.5% full scale per 55°C. For pressure sensors that can be calibrated “in situ,” the calibration mechanism is as large as the pressure sensing module and requires pneumatic multiplexing and the generation and accurate measurement of the calibration pressures as well as automatic data processing equipment to compute and store the calibration coefficients.

It is the primary object of this invention to provide a pressure sensing device that largely overcomes the drawbacks of the above mentioned systems. Another object of this invention is to provide a pressure sensing device that will accommodate multiple pressures, have a high data rate, and high accuracy through the use of analog and digital electronic circuitry that will automatically correct for errors resulting from temperature changes.

Other objects and advantages will become apparent hereinafter in the specifications and drawings.

SUMMARY OF THE INVENTION

The invention consists essentially of a plurality of solid state pressure sensors, signal multiplexing electronics that allow each of the pressure sensors to be digitally addressed, and solid state memory components and their associated electronics that have stored in them a digital code that will correct for errors resulting from temperature changes (zero offset and pressure sensitivity) in each of the pressure sensors. Through the use of this invention, the errors resulting from temperature shifts can be reduced from typical values of 5% to less than 0.15% for a 55°C temperature range.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of an embodiment of the invention; FIG. 2 is a voltage versus temperature at zero pressure graph of the pressure sensors used; and FIG. 3 is a partial block diagram of an alternate embodiment of the invention that contemplates for the pressure sensitivity of the pressure sensors.

DETAILED DESCRIPTION OF THE INVENTION

Turning now to the embodiment of the invention selected for illustration in the drawings, the number 11 in FIG. 1 designates thirty-two different pressure sensors. Silicon diaphragm pressure sensors of the diffused Wheatstone Bridge type are used and connected in parallel with common excitation nodes—one connected to ground and the other connected to a voltage source V. Each of the sensors 11 produces a voltage at its output that is related to the pressure at its location. The outputs from all the sensors 11 are connected to a thirty-two channel multiplexer 12. A sensor address 13 including terminals A0, A1, A2, A3, A4 applies digital signals to multiplexer 12 to sequentially connect the sensors 11 to the output of the multiplexer and then to a sensor amplifier 14. If the voltage V at the output of sensor amplifier 14 were related to the pressure P applied to the different sensors 11 in accordance with the following equation:

\[ P = kV \]  

(1)

where \( k \) is a constant that is the same for all thirty-two sensors there would be no problem—the output of amplifier 14 would be proportional to the pressure at all thirty-two locations. Unfortunately, commercially available pressure sensors are not that uniform. The output of sensors 11 are related to the first order to the pressure applied to the sensors in accordance with the following equation:

\[ P = a(T) + b(T)V_i \]  

(2)

where \( i = 1, 2, \ldots, 32 \) corresponds to one of the thirty-two sensors 11 and where \( a(T) \) and \( b(T) \) are functions of the temperature T. It is the purpose of this invention to reduce the thirty-two curves defined by equation (2) to the straight lines defined in equation (1).

Consider first the \( a(T) \) term in equation (2). If zero pressure is applied to each of the sensors 11 and the voltage \( V \) is measured as the temperature \( T \) is varied, each of the sensors will have a \( V \) versus \( T \) curve similar to the one shown in FIG. 2. Inasmuch as \( a(T) \) does not change with pressure this curve will remain substantially the same for all values of pressure. If the \( a(T) \) is determined at the output of amplifier 14 for each sensor 11 and is subtracted from the corresponding equation (2) then the resulting outputs of these sensors will be related to the pressure applied to the sensors in accordance with the following equation:

\[ P = bV_i \]  

(3)

To implement the portion of this invention that eliminates the \( a(T) \) term note in FIG. 2 that at the minimum temperature in the temperature range (for example, 25°C to 80°C) the voltage \( V \) is not zero. That is, there is a zero offset voltage at minimum temperature. A digital code which when converted to analog is equal to the zero offset voltage at minimum temperature is programmed into a 32x8 programmable read only mem-
The sensor address is applied to PROM which sequentially applies the digital code in the form of an 8-bit digital output to a digital-to-analog converter. The analog output of converter 16 is applied to a summing node in sensor amplifier 14 which subtracts the offset voltage from the corresponding sensor output.

The thermal zero shift values are programmed into a 2Kx8 PROM 17. These thermal zero shift values can be measured at sixty-four equally spaced temperature levels throughout the temperature range or the values can be measured at a smaller number of locations and interpolations made to determine the values at the other locations. A temperature transducer 18 produces a voltage proportional to temperature which is applied through a temperature sensor amplifier 19 to a 6-bit analog-to-digital converter 20. A strobe is applied to converter 20 to produce a 6-bit thermal address. The thermal address and the sensor address are applied to PROM to select the appropriate thermal zero shift data which is connected to an 8-bit temperature shift digital-to-analog converter 21. The resulting analog signal is applied to the negative input of a differential input programmable gain output amplifier 22 where it is subtracted from the output of sensor amplifier 14. Note that if the gain of amplifier 22 is constant (for example, one), the output of amplifier 14 is fitted to equation (3) to the resolution of the electronic correction circuitry. That is, the change in the output of the circuit is given by: 

$$\Delta V = k(T)$$

where the thermal sensitivity of the different sensors which varies with temperature. Hence, the sensitivities of the different sensors 11 are determined over the temperature operating range and the sensitivity correction values are programmed into a 2Kx8 PROM 23. The different sensitivities are selected by the sensor address and the temperature address and applied to a digital-to-analog converter 24. The analog output of converter 24 is applied to amplifier 22 to adjust its gain such that the product of the gain and the sensitivity is exactly equal to 1 or to some other constant k. Values corresponding to the reciprocals of the sensitivities could be stored in the PROM 23 and applied to a digital-to-analog converter 25. The analog output would be in accordance with equation (1).

$$V = k(T)$$

In a multiple pressure sensor system, means for converting said pressure voltage proportional to temperature; analog-to-digital converter means for converting said pressure voltage proportional to temperature to a digital temperature address; digital storage means for storing the thermal shift correction values generated by each of said pressure sensors through the temperature operating range of said pressure sensor system and responsive to said digital sensor address and digital thermal address for selecting the digital thermal shift value corresponding to the temperature and the pressure sensor connected to said output terminal; digital-to-analog converter means for converting the selected digital thermal shift value to an analog thermal shift signal; means for combining said analog thermal shift signal with the output of the corresponding pressure sensor to compensate for the thermal shift of the pressure sensor; and means for providing thermal sensitivity compensations for the different pressure sensor outputs.

2. In a multiple pressure sensor system according to claim 1 including a digital storage means for storing the zero offset values of each of said pressure sensors and responsive to said digital sensor address for selecting the zero offset corresponding to the pressure sensor connected to said output terminal; digital-to-analog converter means for converting said pressure voltage proportional to temperature to a digital temperature address; digital storage means for storing the thermal shift correction values generated by each of said pressure sensors through the temperature operating range of said pressure sensor system and responsive to said digital sensor address and said digital thermal address for selecting the digital thermal shift value corresponding to the temperature and the pressure sensor connected to said output terminal; digital-to-analog converter means for converting the selected digital thermal shift value to an analog thermal shift signal; means for combining said analog thermal shift signal with the output of the corresponding pressure sensor to compensate for the thermal shift of the pressure sensor; and means for providing thermal sensitivity compensations for the different pressure sensor outputs.
5. In a multiple pressure sensor system according to claim 1 or claim 2 wherein said means for providing thermal sensitivity compensations includes a digital storage means for storing values related to the sensitivities of the pressure sensors throughout the temperature operating range of said pressure sensor system and responsive to said digital sensor address and said digital thermal address for selecting the digital value corresponding to the sensitivity of the pressure sensor connected to said output terminal; digital-to-analog converter means for converting the selected digital value to an analog signal; and means responsive to said analog signal for applying a gain to the signal at said output terminal so that the product of the gain and the sensitivity is a constant.

4. In a multiple pressure sensor system according to claim 1 or claim 2 wherein said means for producing a voltage proportional to temperature is a temperature transducer.

5. In a multiple pressure sensor system according to claim 1 or claim 2 wherein said means for providing thermal sensitivity compensations is the pressure sensors having a thermal coefficient of resistance of the same magnitude and opposite sign of the thermal coefficient of sensitivity and a constant current source connected to said pressure sensors whereby whenever there is a change in temperature the resulting change in the output of a sensor offsets the change in sensitivity with temperature thereby resulting in a nearly constant pressure sensitivity with temperature.

6. In a multiple pressure sensor system according to claim 1 or claim 2 wherein said means for producing a voltage proportional to temperature is a temperature transducer and means for applying a gain to the signal at said output terminal so that the product of the gain and the sensitivity is a constant; said pressure sensors have a thermal coefficient of resistance of the same magnitude and opposite sign of the thermal coefficient of sensitivity; and a constant current source connected to said pressure sensors.

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