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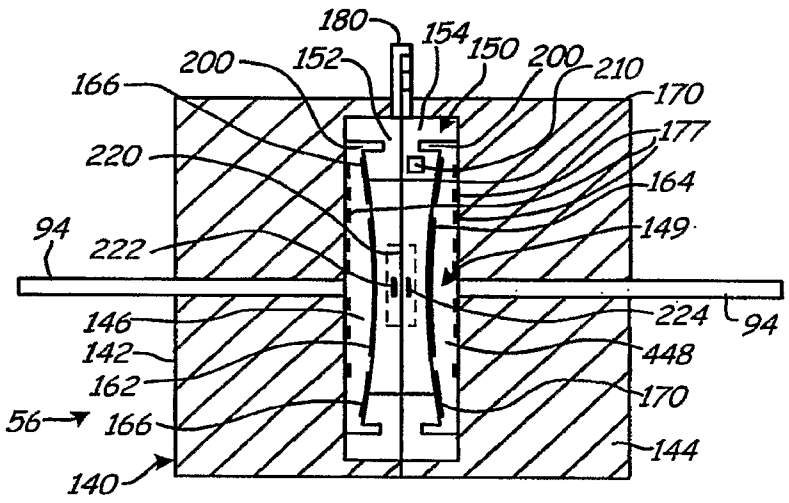
(54) **Title:** PRESSURE SENSOR WITH DEFLECTABLE DIAPHRAGM



(57) **Abstract:** A pressure sensor (5G) for sensing a pressure of a process fluid includes a sensor body (140) having a cavity (149) formed therein. A deflectable diaphragm (150) is positioned in the cavity (149) and deflects in response to a pressure applied to the cavity. An electrode (162) on the diaphragm forms a variable capacitor with the pressure sensor body (140). The capacitance varies in response to the applied pressure.

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PRESSURE SENSOR WITH DEFLECTABLE DIAPHRAGM

BACKGROUND OF THE INVENTION

The present invention relates to pressure sensors. More specifically, the present invention relates to pressure sensors of the type which use a deflectable diaphragm to measure a pressure.

Transmitters are used in process monitoring and control systems to measure various process variables of industrial processes. One type of transmitter measures pressure of process fluid in the process. Various techniques have been used in the pressure sensors used in such transmitters. One well known technique is to use a deflectable metal diaphragm. A capacitance is measured with respect to the diaphragm, with the metal diaphragm forming one of the capacitive plates of the capacitor. As the diaphragm is deflected due to applied pressure, the measured capacitance changes. In such a configuration, there are a number of sources of inaccuracies in pressure measurements.

One technique which addresses these inaccuracies is set forth in U.S. Patent No. 6,295,875 entitled, "PROCESS PRESSURE MEASUREMENT DEVICES WITH IMPROVED ERROR COMPENSATION" issued October 2, 2001 to Frick et al. which is incorporated herein by reference in its entirety. This patent describes a differential pressure sensor that includes an additional electrode for use in reducing measurement inaccuracies.

SUMMARY

A pressure sensor for sensing a pressure of a process fluid includes a sensor body having a cavity with a pressure connection through the cavity into the sensor body. A deflectable diaphragm in the cavity deflects in response to a pressure applied to the cavity through the pressure connection. An electrode on the diaphragm forms a variable capacitor with the pressure sensor body and provides a capacitance which varies in response to the applied pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a process measurement system with a process transmitter constructed in accordance with the present invention.

Figure 2 is schematic view of a transmitter of Figure 1.

Figure 3A is a side cross-sectional view of a pressure sensor in accordance with the present invention.

Figure 3B is a front plan view of a diaphragm of the pressure sensor shown in FIG. 3A.

Figure 3C is a perspective view showing half of the diaphragm of figure 3A and half of a sensor body of figure 3A.

Figure 4 is a simplified cross-sectional view of the pressure sensor positioned in a process transmitter.

DETAILED DESCRIPTION

The present invention provides a pressure sensor in which a deflectable diaphragm carries a capacitive plate to provide a capacitance which varies in response to an applied pressure. As discussed below, this configuration provides a number of advantages related to manufacturing, reduced errors and improved performance.

Figure 1 shows generally the environment of a process measurement system 32. Figure 1 shows process piping 30 containing a fluid under pressure coupled to the process measurement system 32 for measuring a process pressure. The process measurement system 32 includes impulse piping 34 connected to the piping 30. The impulse piping 34 is connected to a process pressure transmitter 36. A primary element 33, such as an orifice plate, venturi tube, flow nozzle, and so on, contacts the process fluid at a location in the process piping 30 between the pipes of the impulse piping 34. The primary element 33 causes a pressure change in the fluid as it passes past the primary element 33.

Transmitter 36 is a process measurement device that receives process pressures through the impulse piping 34. The transmitter 36 senses a differential process pressure and outputs a standardized transmission signal that is a function of the process pressure.

A process loop 38 provides both a power signal to the transmitter 36 from control room 40 and bidirectional communication, and can be constructed in accordance with a number of process communication protocols. In the illustrated example, the process loop 38 is a two-wire loop. The two-wire loop is used to transmit all power to and all communications to and from the transmitter 36 during normal operations with a 4-20 mA signal. A computer 42 or other information handling system through modem 44, or other network interface, is used for communication with the transmitter 36. A remote voltage power supply 46 powers the transmitter 36. The invention is not limited to environments which implement a loop 38. Other communication techniques can be used including other communication media such as wireless and different wireless techniques, as well as different communication protocols and in standalone devices.

Figure 2 is a simplified block diagram of pressure transmitter 36. Pressure transmitter 36 includes a sensor module 52 and an electronics board 72 coupled together through a databus 66. Sensor module electronics 60 couples to pressure sensor 56 which received an applied differential pressure 54. The data connection 58 couples sensor 56 to an analog to digital converter 62. An optional temperature sensor 63 is also illustrated along with sensor module memory 64. As discussed below, the temperature

sensor 63 can be formed integral with pressure sensor 56. The electronics board 72 includes a microcomputer system 74, electronics memory module 76, digital to analog signal converter 78 and digital communication block 80.

One technique for measuring different pressure is set forth in U.S. Patent No. 6,295,875 to Frick et al. However, the present invention is not limited to such a configuration.

Figure 3A is a side cross-sectional view showing pressure sensor 56 in accordance with the present invention. Pressure sensor 56 includes a pressure sensor body 140 which is formed by half bodies 142 and 144 which have recessed regions 146 and 148 formed therein, respectively, which form a cavity 149 therebetween. A deflectable diaphragm 150 is mounted in the cavity 149 and the cavity 149 couples to impulse piping 94. Diaphragm 150 is formed of two half diaphragms 152 and 154. Center capacitor plates or electrodes 162 and 164 are carried on diaphragm halves 152 and 154, respectively. Similarly, diaphragm half 152 carries outer capacitor plate or electrode 166 while diaphragm half 154 carries outer capacitor plate or electrode 172. Capacitor plates 162, 164, 166, 168, 170 and 172 for 6 respective electrical capacitors with sensor body 140. A contact protrusion 180 extends from center diaphragm 150 and carries electrical contacts 182 thereon. Electrical contacts 182 connects to each of

the six capacitor plates or electrodes 162 through 172.

Figure 3B is a front plan view showing deflectable diaphragm 150 including the arrangement of capacitor plates 162 and 166 in greater detail. Figure 3C is a side perspective view showing half diaphragm 154 and half sensor body 144. Figure 3C also illustrates electrical connections 192 and 196 which electrically connect capacitor plates or electrodes 170 and 164, respectively, to contacts 182 on protrusion 180. Figures 3A and 3B also show annular notches 200 which can be formed in the diaphragm 150 to increase the amount of deflection of diaphragm 150 for a given pressure.

During operation, a differential pressure is applied to either side of diaphragm 154 through impulse piping 94. This causes deflection of diaphragm 150 within cavity 149. As diaphragm 150 deflects, the distance between capacitor plates 162, 164, 166, 168, 170, 172 changes with respect to the sides of cavity 149 formed by sensor body halves 142 and 144. The electrical capacitance between each capacitor plate 162, 164, 166, 168, 170, 172 can be measured with respect to the sensor body 140 and correlated with the applied differential pressure. The amount of deflection of diaphragm 154 is a function of the applied pressure as well as the material used in diaphragm 154 and the dimensions of diaphragm 154. Figures 3A through 3B also show

annular notches 200 which can be formed in the diaphragm 150 to increase the amount of deflection of diaphragm 150 for a given pressure.

In one preferred configuration, diaphragm 150 is formed of an insulating crystal material such as silicon, quartz, sapphire, or spinel. The electrodes can comprise a metal and be deposited or implanted on diaphragm 150. The sensor body 140 is formed of a conductive material such as metal. This configuration allows the diaphragm 150 to be assembled and subsequently mounted into body halves 142 and 144. In another configuration, body 140 is of a non-conductive material and include a conductive material for the electrical capacitors with respect to capacitor plates 162, 164, 166, 168, 170, 172. In contrast, some prior art configurations in which the capacitor plates are carried on the walls of the cavity formed in the sensor body. This requires the sensor body to be filled with an insulating material such as glass. In such a configuration, a conductive diaphragm used.

In one optional configuration, features 177 are provided on an internal wall of cavity 146 or on diaphragm 150. Features 177 are configured to distribute forces if an over pressure occurs in which diaphragm 150 is pressed against one of the internal walls of cavity 146.

The pressure sensor 56 of the present invention can be assembled using any appropriate

technique. For example, the two diaphragm halves 152 and 154 can be fused together to form the complete diaphragm 150. Additional features such as the diaphragm shape and hinge point can be fabricated as desired. In some embodiments, a temperature sensor 210 is fabricated in diaphragm 150 for use in measuring temperature of the pressure sensor 56. The temperature can be used to compensate for temperature related errors in pressure measurements. The temperature signal can also be used to determine other information about the process fluid, such as for use in a flow rate calculation.

In one embodiment, the completed diaphragm 150 is welded between the two metal sensor body halves 142 and 144 with protrusion 180 extending from the cavity 149 through the sensor body 140 to the outside of body 140. The region where protrusion 180 meets the two sensor half bodies 142 and 144 can be sealed using, for example, a brazing technique. This configuration provides a solid state sensor with electrodes that can be mounted on a solid state material rather than a glass such as used in some prior art configurations. This reduces hysteresis and provides improved stability. Further, the capacitor electrodes on the high and low pressure sides of the diaphragm 150 remain in close proximity which can also provide improved performance over temperature extremes. The center diaphragm 150 can be fabricated using standard solid state fabrication techniques

which allow simplified manufacturing, reduced costs and greater tolerance control. Sensor features such as the hinge point, cavity shape, electrodes, electrode lead wires and temperature sensor are etched, deposited or otherwise formed in a solid state center diaphragm structure rather than on a glass/metal pressure sensor half cell as used in prior art designs. This simplifies manufacturing, lowers manufacturing cost and provides greater tolerance control which leads to improved performance.

Referring back to figure 3A, an optional internal cavity 220 is illustrated which is located within diaphragm 154 between diaphragm halves 150 and 152. Capacitive plates or electrodes 222 and 224 are positioned on the sides walls of internal cavity 220. Internal cavity 220 is configured such that the spacing between capacitive plates 222 and 224 changes as a function of the applied line pressure. This optional configuration allows both the differential pressure applied to diaphragm 150 through impulse piping 94 to be measured along with the line pressure. In such a configuration, electrical contacts are provided on and protrusion 180 which connect to capacitor plates or electrodes 222 and 224.

Figure 4 is a simplified cross-sectional view of one embodiment of a sensor module 52 showing pressure sensor 56. Pressure sensor 56 couples to a

process fluid through isolation diaphragms 90 which isolate the process fluid from cavities 92. Cavities 92 couple to the pressure sensor module 56 through impulse piping 94. A substantially incompressible fill fluid fills cavities 92 and impulse piping 94. When a pressure from the process fluid is applied to diaphragms 90, the pressure is transferred to the pressure sensor 56 through the fill fluid in the impulse piping 94.

With the sensor of the present invention, features such as the hinge point, cavity shape, electrodes, electrode lead wires and the temperature sensor can be etched, deposited or otherwise formed in a solid state structure rather than in the glass/metal half cell used in some designs. This reduces manufacturing costs and provides greater tolerance control which allows improved performance. Further, the outside of the pressure sensor is formed of a metal body which can easily contain excessive over pressures. The structure can be formed and mounted using any appropriate technique such as laser welding or brazing. The measurement circuitry used to determine the applied pressure based upon the changing capacitance can be mounted in close proximity to the protrusion 180. This to reduces errors due to stray capacitance from the electrical connections to the capacitor plates. In some configurations, the circuitry is carried directly on protrusion 180. In such a configuration, measurement

circuitry can be mounted to protrusion 180, or fabricated directly on protrusion 180.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. Pressure measurements may be made using the pressure sensor discussed above using any appropriate technique. One example technique is described in U.S. Patent application Serial No. 11/140,681, Line Pressure Measurement Using Differential Pressure Sensor, filed May 27, 2005 which is incorporated herein by reference. The particular configuration illustrated in the Figures in which four different capacitors are formed can be used to compensate for errors as discussed in application Serial No. 11/140,681. In one embodiment, any number of capacitors are used including a single capacitor, two capacitors, etc. The present invention is not limited to any particular number of capacitors or configuration of capacitor plates. Although the above description discusses an oil fill fluid, other fill fluids may be used, including an air or gas fill. The diaphragm can be configured to deflect as desired. In one configuration, the diaphragm deflection may be less than one angstrom. The center diaphragm structure can have any shape and/or feature as desired for particular implementation. For example, the diaphragm can have hinge features to promote bending at certain

points, ceiling features, etc. This allows the diaphragm to be optimized for performance of the sensor in a particular environment, such as a differential pressure sensor. These features and shapes can be formed using any appropriate method including both additive techniques in which additional structures are added to a sub straight, or subtractive techniques in which material is removed from a sub straight to form a desired shape or feature.

WHAT IS CLAIMED IS:

1. A pressure sensor for sensing a pressure of a process fluid:

a sensor body having a cavity formed therein;

a pressure connection extending through the cavity into the body;

a deflectable diaphragm in the cavity configured to deflect in response to a pressure applied to the cavity through the pressure connection;

an electrode on the diaphragm configured to form a variable capacitor with the pressure sensor body having a capacitance which varies in response to the applied pressure; and

an electrical connection to the electrode which extends to outside of the pressure sensor body.

2. The apparatus of claim 1 wherein the deflectable diaphragm comprises a rigid material.

3. The apparatus of claim 1 wherein the deflectable diaphragm comprises a crystal material.

4. The apparatus of claim 1 wherein the deflectable diaphragm comprises a material selected from the group of materials consisting of silicon, quartz, sapphire and spinel.

5. The apparatus of claim 1 wherein the sensor body comprises a conductive material.

6. The apparatus of claim 1 wherein the sensor body comprises a metal.

7. The apparatus of claim 1 wherein the sensor body is formed from two sensor body halves.

8. The apparatus of claim 1 wherein the diaphragm is formed from two diaphragms halves.

9. The apparatus of claim 1 including a second electrode on the diaphragm configured to form a second variable capacitor with the pressure sensor body.

10. The apparatus of claim 9 wherein the electrode and the second electrode are on opposite sides of the diaphragm.

11. The apparatus of claim 1 wherein two electrodes are positioned on one side of the diaphragm and two electrodes are positioned on an opposite side of the diaphragm.

12. The apparatus of claim 1 wherein the diaphragm includes an internal diaphragm cavity configured to deform in response to a line pressure applied to the cavity of the sensor body.

13. The apparatus of claim 12 wherein the internal diaphragm cavity includes electrodes configured to form a variable capacitance which changes based upon the applied line pressure.

14. The apparatus of claim 1 wherein the cavity of the sensor body receives a differential pressure and deflection of the diaphragm is based upon the differential pressure.

15. The apparatus of claim 1 including a temperature sensor configured to measure a temperature of the sensor body or diaphragm.

16. The apparatus of claim 1 including a protrusion from the diaphragm which carries the electrical connections from the diaphragm to outside of the pressure sensor body.

17. A method of sensing pressure of a process fluid, comprising:

providing an electrode on a deflectable diaphragm;

placing the deflectable diaphragm in a sensor body;

applying a pressure to the deflectable diaphragm through the sensor body to thereby cause deflection;

measuring changes in a capacitance between the electrode on the deflectable diaphragm and the sensor body; and

determining pressure based upon changes in the measured capacitance.

18. The method of claim 17 wherein the deflectable diaphragm comprises a rigid material.

19. The method of claim 17 wherein the deflectable diaphragm comprises a crystal material.

20. The method of claim 17 wherein the deflectable diaphragm comprises a material selected from the group of materials consisting of silicon, quartz, sapphire and spinel.

21. The method of claim 17 wherein the sensor body comprises a conductive material.

22. The method of claim 17 wherein the sensor body is formed from two sensor body halves.

23. The method of claim 17 wherein the diaphragm is formed from two diaphragms halves.

24. The method of claim 17 including providing a second electrode on the diaphragm configured to form a second variable capacitor with the pressure sensor body.

25. The method of claim 17 including forming a diaphragm internal cavity in the diaphragm configured to deform in response to a line pressure applied to the cavity of the sensor body.

26. The method of claim 25 including providing electrodes in the diaphragm internal cavity configured to form a variable capacitance which changes based upon the applied line pressure.

27. The method of claim 17 including providing a temperature sensor configured to measure a temperature of the sensor body or diaphragm.

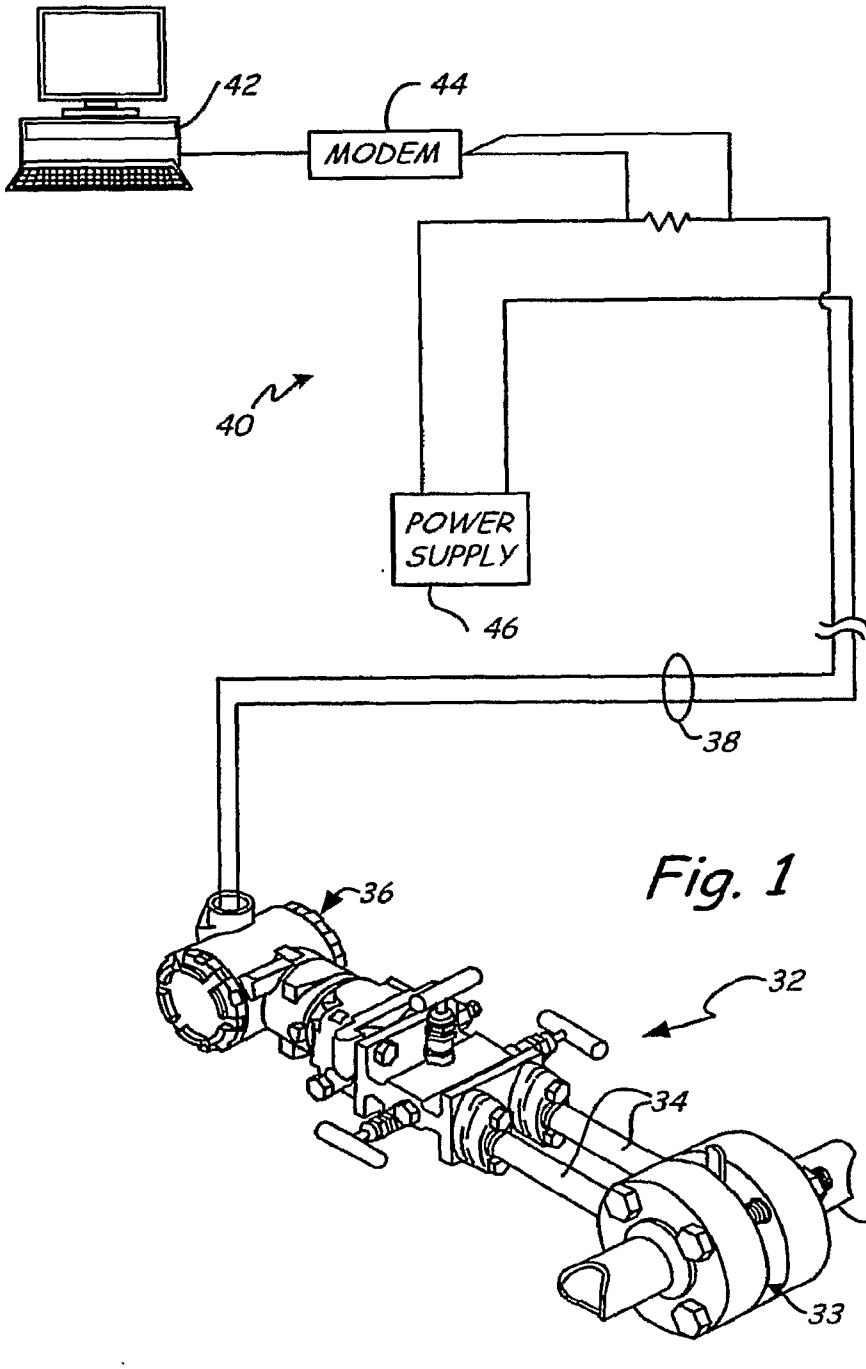
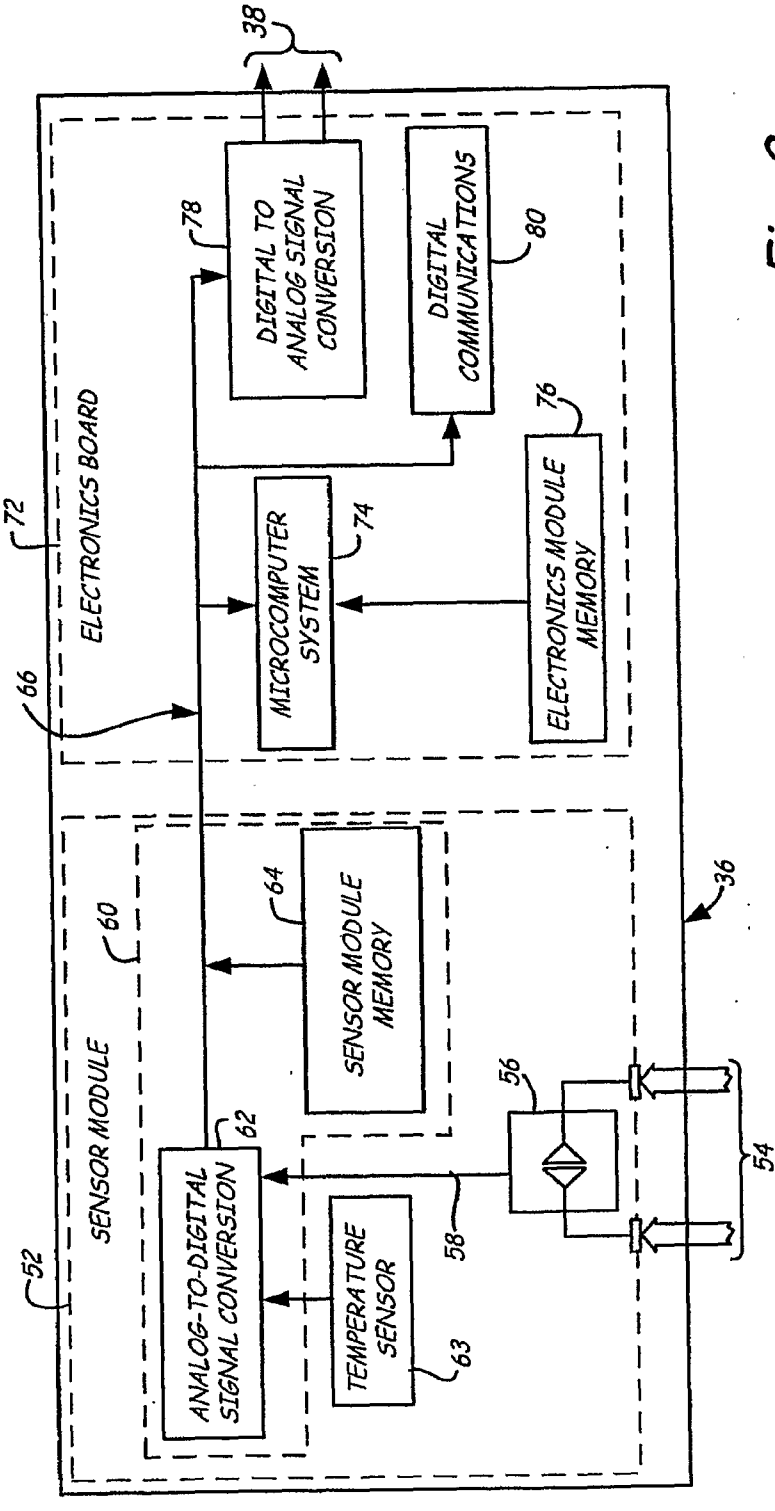


Fig. 1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ELECTRONICS MODULE MEMORY
72
ELECTRONICS BOARD
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MICROCOMPUTER SYSTEM
74
64
SENSOR MODULE MEMORY
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SENSOR MODULE
62
ANALOG-TO-DIGITAL SIGNAL CONVERSION
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TEMPERATURE SENSOR
63
58
56
54
36

Fig. 2

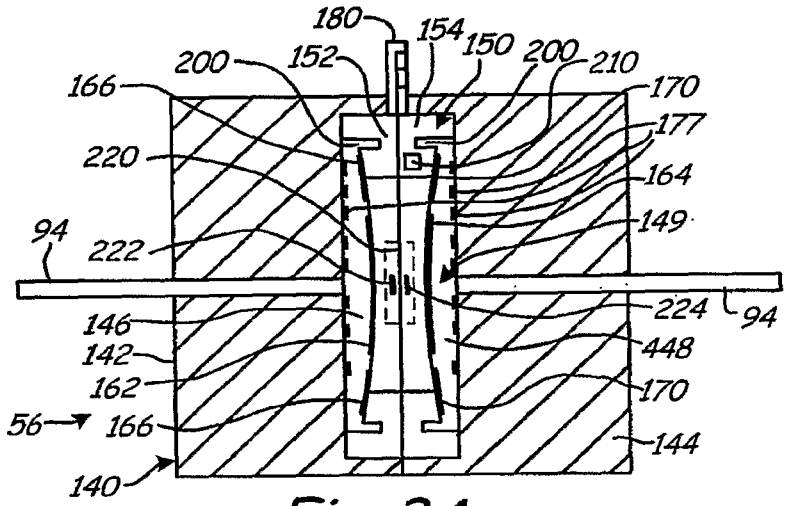

Fig. 3A

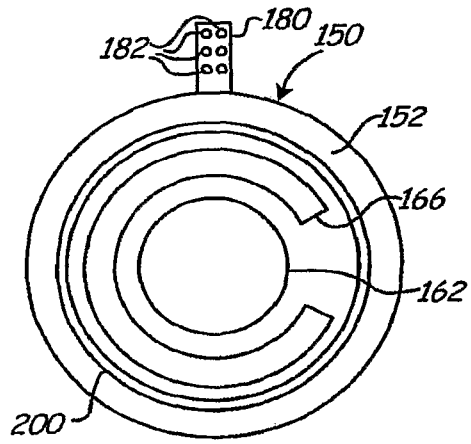

Fig. 3B

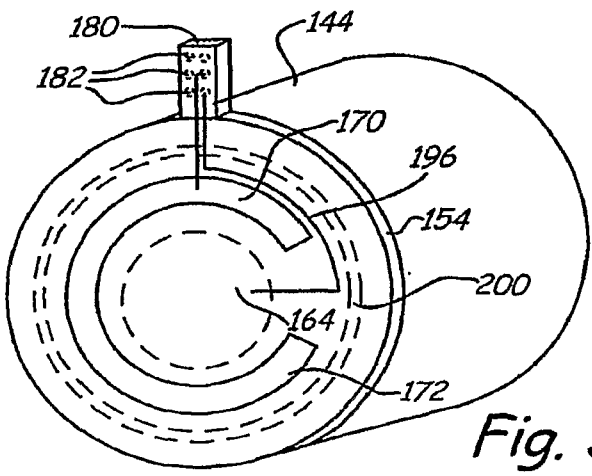

Fig. 3C

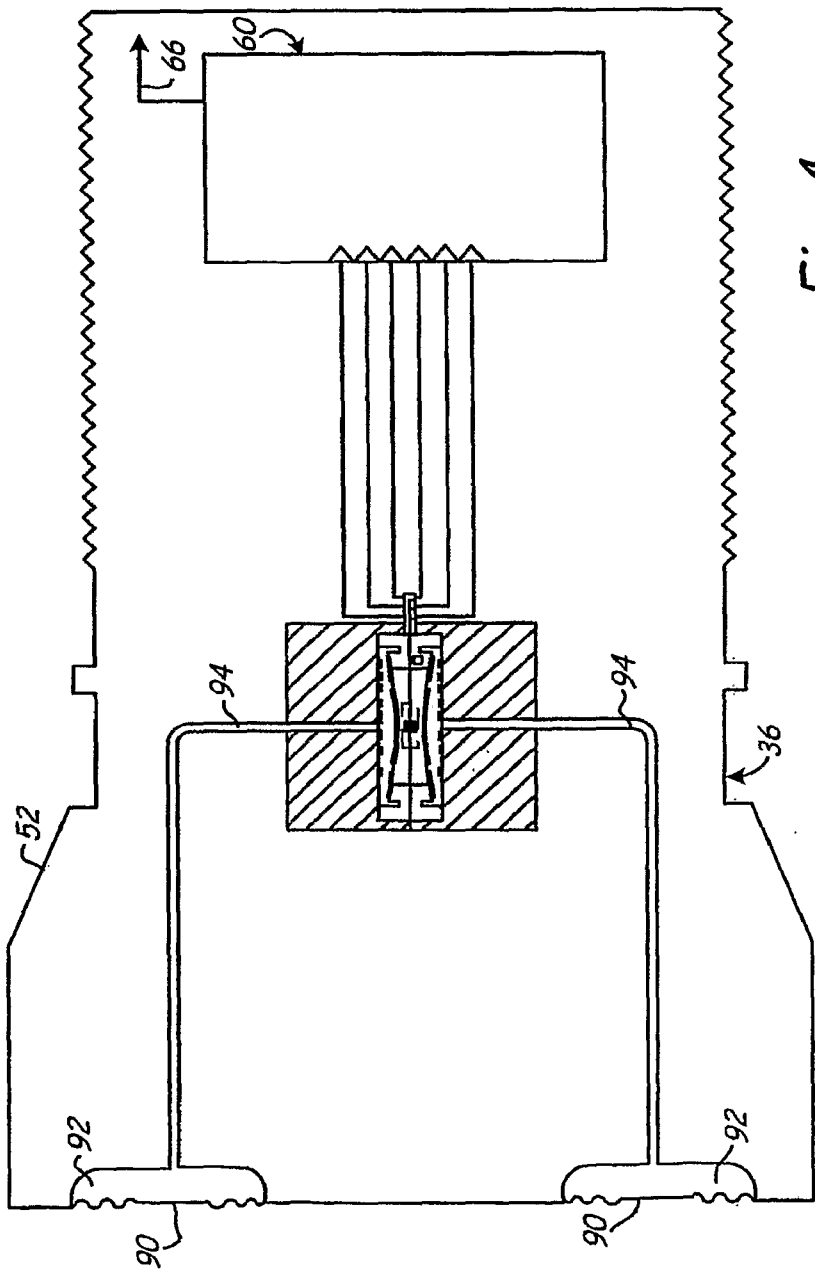

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/046742

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01L9/12 G01L13/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	US 5 969 258 A1 (GERST PETER [DE] ET AL) 19 October 1999 (1999-10-19) abstract	1,12,13, 17,25,26
Y	US 4 578 735 A1 (KNECHT THOMAS A [US] ET AL) 25 March 1986 (1986-03-25) column 10, line 44 - line 64; figure 7	12,13, 25,26
X	US 4 670 733 A1 (BELL ROBERT L [US]) 2 June 1987 (1987-06-02) abstract; figure 4	1,11,17, 24

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 March 2007	02/04/2007

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/046742

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Form PCT/ISA/210 (continuation of second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2006/046742

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US 4578735	A1		NONE		
US 4670733	A1		NONE		
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