FORM 1
REGULATION 9

613072

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952-1973

APPLICATION FOR A PATENT

AUSTRALIAN PATENT OFFICE SEC 34(4)

We SECTION 34(4)(a) DIRECTION SEE FOLIO 4
NAME DIRECTED INTERNATIONAL CONTROL AUTOMATION FINANCE S A

of ville de Luxembourg, 16 Rue des Bains, Luxembourg

hereby apply for the grant of a Patent for an invention entitled:

DUAL SIDED PRESSURE SENSOR

which is described in the accompanying complete specification. This Application is a Convention Application and is based on the Application(s) numbered: 07/133,761 for a Patent or similar protection made in U.S.A. on 16th December, 1987.

Our address for service is:

GRIFFITH HACK & CO.
71 YORK STREET
SYDNEY N.S.W. 2000
AUSTRALIA

DATED this 15th day of August, 1988.

THE BABCOCK & WILCOX COMPANY
By their Patent Attorneys

GRIFFITH HACK & CO.

3001737 15/08/88

TO: THE COMMISSIONER OF PATENTS
COMMONWEALTH OF AUSTRALIA

8148A/ls

ASSIGNEE - APPLICANT

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952

DECLARATION IN SUPPORT OF AN APPLICATION FOR A PATENT

In support of an Application made by:
THE BABCOCK & WILCOX COMPANY

for a patent for an invention entitled:
DUAL SIDED PRESSURE SENSOR

I, Robert J. Edwards

of, THE BABCOCK & WILCOX COMPANY, 1010 Common St., New Orleans, Louisiana, U.S.A.

do solemnly and sincerely declare as follows:

1. I am authorised by the above mentioned applicant for the patent to make this Declaration on its behalf.

2. The name and address of each actual inventor of the invention is as follows:

William Jay Kaigler

of 4100 Sweet Briar Drive, Apartment F103, Erwin, Pennsylvania 15642, U.S.A.

and the fact(s) upon which the applicant is entitled to make this application are as follows:

The Applicant is the assignee of the said invention from the actual inventor.

3. The basic application(s) as defined by Section 141 of the Act was (were) made as follows:

Country	U.S.A.	on	16th December, 1987
in the name(s)	WILLIAM JAY KAIGLER		

4. The basic application(s) referred to in the preceding paragraph of this Declaration was (were) the first application(s) made in a Convention country in respect of the invention the subject of this application.

Declared at New Orleans, Louisiana, U.S.A. this 1st day of September, 1988.

THE BABCOCK & WILCOX COMPANY

Signed: [signature]

Robert J. Edwards

Position: Chief Patent Counsel

GRIFFITH HACK & CO., SYDNEY, AUSTRALIA

8148A/ls

(12) PATENT ABRIDGMENT (11) Document No. AU-B-21038/88
(19) AUSTRALIAN PATENT OFFICE (10) Acceptance No. 613072

(54) Title
DUAL SIDED PRESSURE SENSOR

International Patent Classification(s)
(51)[4] G01L 013/02

(21) Application No. : 21038/88 (22) Application Date : 15.08.88

(30) Priority Data

(31) Number	(32) Date	(33) Country
133761	16.12.87	US UNITED STATES OF AMERICA

(43) Publication Date : 22.06.89

(44) Publication Date of Accepted Application : 25.07.91

(71) Applicant(s)
INTERNATIONAL CONTROL AUTOMATION FINANCE S A

(72) Inventor(s)
WILLIAM JAY KAIGLER

(74) Attorney or Agent
GRIFFITH HACK & CO., GPO Box 4164, SYDNEY NSW 2001

(56) Prior Art Documents
AU 21039/88 G01L 9/04 G01B 7/18
EP 74574

(57) Claim

1. A pressure sensor, for exposure to a pressure to be measured, comprising:

a diaphragm;

a first pair of strain gauges having a non-linear electrical response characteristic when fixed on the diaphragm; and

a second pair of strain gauges having a non-linear electrical response characteristic when fixed on the diaphragm; wherein the first pair of strain gauges are located on a first side of the diaphragm and the second pair of strain gauges are mounted on the opposite side of the diaphragm, and whereby the non-linear responses of the first and second pairs of strain gauges are of substantially equal magnitudes and cancel each other to produce a substantially linear output when the diaphragm is exposed to a pressure.

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952 Form 10

COMPLETE SPECIFICATION

FOR OFFICE USE

Short Title:

Int. Cl:

613072

Application Number:
Lodged:

Complete Specification–Lodged:
Accepted:
Lapsed:
Published:

Priority:

Related Art:

TO BE COMPLETED BY APPLICANT

Name of Applicant: INTERNATIONAL CONTROL AUTOMATION FINANCE S A
~~THE BABCOCK & WILCOX COMPANY~~

Address of Applicant: ville de Luxembourg, 16 Rue des Bains, Luxembourg
~~1010 Common Street, New Orleans, Louisanna, 70160 U.S.A.~~

Actual Inventor: William Jay Kaigler

Address for Service: GRIFFITH HACK & CO.
71 YORK STREET
SYDNEY NSW 2000
AUSTRALIA

AUSTRALIAN PATENT OFFICE sec 34(4)

Complete Specification for the invention entitled:

DUAL SIDED PRESSURE SENSOR

The following statement is a full description of this invention, including the best method of performing it known to me/us:–

8148A/ls

DUAL SIDED PRESSURE SENSOR

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates in general to pressure sensors, and, in particular, to a dual sided pressure sensor which can be used for measuring both high absolute pressures and low differential pressures.

Differential pressure transducers have been built using a large variety of sensing devices. Two of today's most common are capacitive sensors and strain ~~gage~~ gauge sensors mounted on beams. Capacitive sensors include three diaphragms, 2, 4 and 6 shown in FIG. 1. Diaphragms 2 and 6 are subjected to pressures P_1 and P_2 and one diaphragm, 4 (the center one), is not. The volumes 8 and 10, between these diaphragms, is filled with dielectric fluid. As a result, two variable capacitors are formed which can be integrated with electronics to form a reliable and accurate sensor. A problem with a sensor such as this is that it is difficult to make the accuracy as good as some other approaches, and static pressure effect can be a problem (see SAMA standard PMC 31.1).

The strain ~~gage~~ gauge beam sensor shown in FIG. 2 is another commonly used technology for differential pressure sensing. This involves a beam 12 which is coupled with a pressure collecting diaphragm 14. The diaphragm transmits the force created by the pressure P_1-P_2 to the beam 12. This force is then converted to a strain which is measured by a strain ~~gage~~ gauge 16. Most commonly, this strain ~~gage~~ gauge sensor is positioned on the beam in a Wheatstone Bridge configuration in order to subject half of the Bridge to compressive strain and half to tensile strain. The common problems with this type of sensor is that it can be very difficult and costly to manufacture.

Another type of sensor which is rarely used in differential pressure applications is a flat diaphragm sensor. This sensor consists of a flat circular plate which is firmly secured around the outside diameter. The sensing device is some sort of strain sensitive element which can be bonded to the diaphragm. This type of sensor is well known and most commonly used to sense ~~gage~~ gauge or absolute pressure when high pressures (usually above 1000 pounds per square inch) are being measured (see U.S. Patents 3,341,794 to Stedman; 3,456,226 to Vick and 3,505,634 to Von Vick).

~~Gage~~ Gauge or absolute pressure sensors often measure a much higher pressure range than would a differential pressure sensor. Due to the physical characteristics of a flat diaphragm, large membrane stresses develop because the material is stretching rather than bending when pressure is applied. This causes the sensor to become more nonlinear when the displacement increases with relation to the thickness of the diaphragm. When this displacement-to-thickness ratio 'K' (referred to as the 'K' factor) approaches approximately 0.1, the sensor becomes too nonlinear for acceptable performance without linear compensation. The reason this approach is only used on high pressures is that when a lower pressure is being measured, the strains in the diaphragm must be maintained at a certain level to produce an adequate output. This can only be done by:

1. Decreasing the thickness of the diaphragm; or

2. Increasing the radius of the diaphragm.

Both will increase the 'K' factor of the diaphragm. As a result, this sensor displays high nonlinearities when used for lower pressure ranges.

The most common arrangement for a flat diaphragm sensor, as shown in FIG. 3, is to place four strain sensitive ~~gages~~ gauges 20 on one side of the diaphragm 22 to respond to compressive, radial strains on the center and tensile, tangential strains at the outer edge of the diaphragm. The strain ~~gages~~ gauges are connected in a Wheatstone Bridge configuration so that adjacent legs of the bridge sense strains of opposite sign resulting in an additive effect to the transducer output. The problem with this arrangement is that the gages placed at the outer edge are subjected to different nonlinearities than the center ~~gages~~ gauges. These nonlinearities are of opposite sign, but different magnitude with a resulting nonlinear output from the bridge dependent on the 'K' factor.

Recently, ceramic diaphragms with screen printed and fired thick film resistors have attracted interest as pressure transducers (see U.S. Patent 4,311,980 to Prudenziati). These ceramic/thick film transducers have been designed in a manner very similar to the transducers before them with the resistors arranged in a Wheatstone Bridge configuration. As with the metal or silicon diaphragms, if the sensor is being used for a lower pressure range, the 'K' factor must be increased to achieve an adequate output and will become nonlinear.

Thick film resistors change resistance as a function of the average strain over the area of the resistor. Unlike thin-film strain gages or bonded foil ~~gages~~ gauges, thick film gages are sensitive to normal strain. This is the strain produced in the 'Z' direction, normal to the surface of the diaphragm. It is this significant normal strain sensitivity which creates an additional problem for thick film sensors in a differential application. If the ~~gages~~ gauges are arranged in a similar manner to thin-film strain ~~gages~~ gauges, with two gages in the center and two ~~gages~~ gauges near the outer edge in order to produce the maximum output from the sensor, the normal strain will vary, depending upon which side of the sensor is pressurized. If the pressure range to be measured happens to be centered around zero, the resulting output will be significantly higher when the pressure is applied to the side of the sensor with the ~~gages~~ gauges bonded thereto. When the pressure crosses over to the other side of the sensor, the output will decrease and therefore become highly nonlinear (FIG. 4 shows this result in a graph).

One of the advantages of using the Wheatstone bridge circuit is that all equal effects would cancel and therefore not effect the output. However, if the normal strain sensitivity is not consistent between each gauge, then the effects would not be equal and the sensor would be bad. To control this problem, with all gauges on one side of the sensor, the manufacturer must somehow control normal sensitivity.

SUMMARY OF THE INVENTION

According to the present invention, there is provided a pressure sensor, for exposure to a pressure to be measured, comprising:

a diaphragm;

a first pair of strain gauges having a non-linear electrical response characteristic when fixed on the diaphragm; and

a second pair of strain gauges having a non-linear electrical response characteristic when fixed on the diaphragm; wherein the first pair of strain gauges are located on a first side of the diaphragm and the second pair of strain gauges are mounted on the opposite side of the diaphragm, and whereby the non-linear responses of the first and second pairs of strain gauges are of substantially equal magnitudes and cancel each other to produce a substantially linear output when the diaphragm is exposed to a pressure.

Preferably the first pair of strain gauges is located on a top surface of the diaphragm at a selected radial position near the centre of the diaphragm and the second pair of strain gauges is located on a bottom surface of the diaphragm substantially at said selected radial position.

Alternatively the first pair of strain gauges is located on a top surface of the diaphragm at a selected radial position near an outer periphery of the diaphragm and the second pair of strain gauges is located on a bottom surface of the diaphragm substantially at said selected radial position.

Advantageously the first and second pairs of strain gauges are substantially aligned with each other and of equal areas, the first pair of strain gauges being located on a top surface of the diaphragm and the second pair of strain gauges being located on a bottom surface of the diaphragm.

The strain gauges may be of any known type, for example, thin film strain gauges, bonded foil strain gauses, semiconductive gauges and thick film gauges. An appropriate circuitry, such as a Wheatstone Bridge arrangement, is connected to the strain gauges. The strain gauges on the top and bottom surfaces are positioned at substantially the same radial position, whether near the center of the disk or near the outer periphery of the disk. In this way, the two sets of gauges are subjected to non-linear conditions which are of opposite sign, but virtually equal magnitude. The non-linearities thus cancel each other in the bridge.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings, forming a part of this specification, and in which reference numerals shown in the drawings designate like or corresponding parts throughout the same:

Figure 1 is a schematic representation of a capacitive sensor of the prior art, including three diaphragms;

Figure 2 is a schematic view of a strain gauge beam sensor of the prior art;

Figure 3 is a top plan view of a flat diaphragm sensor of the prior art, having strain gauges connected in a bridge and applied to one surface of the diaphragm;

Figure 4 is a graph plotting input against output for a thick film strain gauge applied to a diaphragm, illustrating the non-linear response of such a strain gauge;

Figure 5 is a graph plotting percent radius against deviations in percent of span for a flat diaphragm, showing the non-linear characteristic, both for tangential and for radial strain;

FIG. 6 is a graph plotting percent radius against micro-strain for a flat ~~diagram~~ diaphragm to show the strain distribution, both for radial and tangential strain and both the top and the bottom surfaces of the diaphragm;

FIG. 7 is a graph plotting percent span against deviations for a single sided gage to illustrate the nonlinearity of a flat diaphragm sensor, whether the ~~gages~~ gauges are placed centrally or near the outer periphery of the sensor;

FIG. 8a is a side elevational view of a pressure sensor in accordance with the present invention, having ~~gages~~ gauges near the central area of a diaphragm, both on the top and the bottom surfaces of the diaphragm;

FIG. 8b is a top plan view of the diaphragm of FIG. 8a;

FIG. 8c is a bottom plan view of the diaphragm of FIG. 8a;

FIG. 9 is a graph plotting percent span against deviations for the pressure sensor of FIGS. 8a to 8c;

FIG. 10a is a side elevational view of a pressure sensor in accordance with the present invention, having a diaphragm with strain ~~gages~~ gauges on the top and bottom surface thereof, near outer peripheral areas of the top and bottom surfaces;

FIG. 10b is a top plan view of the pressure sensor of FIG. 10a;

FIG. 10c is a bottom plan view of the sensor of FIG. 10a; and

FIG. 11 is a graph plotting percent span against deviations for the embodiment for FIGS. 10a to 10c.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIGS. 8a to 8c and 10a to 10c, the invention embodied therein comprises a pressure sensor having a diaphragm with top and bottom surfaces. Pairs of strain gauges ~~gages~~ are provided, both on the top and the bottom surfaces at substantially the same radial position on the diaphragm. By connecting the two pairs of diaphragms to a bridge, an accurate pressure measurement can be taken since the nonlinear responses of the ~~gages~~ gauges are equal in magnitude and opposite in sign between the top and the bottom surface of the diaphragm.

The first problem which must be solved if a flat diaphragm sensor is to be a realistic solution for medium or low range differential pressures, is the physical characteristic of high nonlinearity which occurs when the 'K' factor is too high. Since a predetermined output must be achieved and the mechanical dimensions of the sensor can only be changed within certain limits, depending upon linearity and output requirements, another solution was needed which was independent of mechanical dimensions.

To find a solution to this problem, the first step was to determine exactly why a flat diaphragm sensor with a Wheatstone Bridge circuit placed on one side, displays nonlinearities.

It was discovered that the radial and tangential nonlinearities are related to the strain at any given point. As a result, the graph produced is very similar to the strain distribution graph for the diaphragm (see figs. 5 and 6). In FIG. 5, note that the extreme radial nonlinearities from 50% to 70% radius are a result of calculation errors caused by very small strains in that area. Because of this characteristic, the radial gauges ~~gages~~ experience different nonlinearities than do the tangential gauges ~~gages~~. When these gauges ~~gages~~ are arranged in a Wheatstone bridge configuration, these values are added together. Since the gauges ~~gages~~ are seeing different values of nonlinearity, they combine into some total value which can become significant, depending upon the 'K' factor (see FIG. 7).

The objective of this invention is to provide a sensor which is largely independent of the 'K' factor. To achieve this goal, the nonlinearities that each gauge ~~gage~~ is subjected to must be of opposite sign, but virtually equal magnitude. Through further nonlinear analysis, it was observed that the strains display a very similar magnitude from top to bottom, with opposite signs. This is exactly the situation which meets both criteria stated above.

This lends to a new arrangement for the strain gauges ~~gages~~ on a flat diaphragm sensor. If one half of the Wheatstone bridge was placed in the center of the diaphragm and the other half at the same radial location, on the reverse side, two of the gauges ~~gages~~ would be subjected to compressive strains and two to tensile strains. The two most advantageous locations for these gauges ~~gages~~ would be close to the center or the outer edge of the diaphragm. Because the average strain would be greater in the center, the output of the sensor would be greater. If the ~~gages~~ gauges were near the outside diameter, the ~~gages~~ gauges could be made more resistive to noise. This design of a flat diaphragm Wheatstone Bridge sensor can be done with a variety of different strain sensitive elements, i.e., thin film strain ~~gages~~ gauges, bonded foil strain ~~gages~~ gauges, semiconductive ~~gages~~ gauges and thick film ~~gages~~ gauges.

As shown in FIGS. 8a to 8c, a diaphragm 10 has an upper surface 12, which carries a first pair of strain ~~gages~~ gauges 14. A bottom surface 16 of the disk 10 carries a second pair of strain ~~gages~~ gauges 18. Strain ~~gages~~ gauges 14 and 18 can be connected in a Wheatstone bridge to form a differential pressure measuring transducer. FIG. 9 shows how the nonlinear responses for the upper and lower ~~gages~~ gauges cancel each other to produce a substantially linear output value. The pressure ~~gages~~ gauges 14 and 18 are positioned near the central area of the top and bottom surfaces for disk 10 at substantially the same radial position on the disk.

FIGS. 10a to 10c show a further embodiment of the invention, where disk 20 is provided with a top surface 22, carrying a first pair of strain ~~gages~~ gauges 24, positioned near the outer periphery of the disk. In likewise fashion, a second pair of strain ~~gages~~ gauges 28 are provided on the bottom surface 26 of disk 20 and at the same radial position as the upper gages 24. FIG. 11 shows the cancellation of nonlinear characteristics for the upper and lower strain ~~gages~~ gauges.

The total resistance change for a thick film resistor forming the strain ~~gages~~ gauges can be found from:

$$dR/R = CxEx + CyEy + CzEz + Ex - Ey - Ez$$

where Cx, Cy and Cz are resistivity co-efficients for strains in the longitudinal, transverse and normal directions to the resistor and Ex, Ey and Ez are strains in the longitudinal, transverse and normal direction to the resistor. Since the resistivity co-efficient for normal strain 'Cz' is significant, a flat diaphragm sensor with all ~~gages~~ gauges placed on one side would give a different output, depending upon which side of the diaphragm the pressure is applied to, unless the normal strain sensitivity was controlled.

The second problem mentioned in the prior art section was the normal strain sensitivity of thick film ~~gages~~ gauges. This characteristic makes using thick film/ceramic diaphragm sensors difficult in differential applications. The dual sided Wheatstone Bridge approach, however, minimizes this problem because of its symmetry. When the measured pressure range is centered around zero, the normal strain sensitivity is not a problem because half of the Bridge is always subjected to the direct pressure. Therefore, tight control of the normal sensitivity is no longer necessary.

The most important advantage to this invention is that now with the inventive arrangement, the linearity of the flat diaphragm sensor is independent of the displacement-to-thickness ratio (the 'K' factor). What this means to the differential pressure designer is that now one can raise the strains to the appropriate level needed for a proper output by altering the physical dimensions of the flat diaphragm without affecting the linearity of the sensor. A direct result of this is that the flat diaphragm sensor, which is less expensive and simpler to manufacture, can be used for all the pressure ranges from draft range to midrange to high range.

Another advantage of this approach is that the thick film resistor's high sensitivity to normal strain will not create a linearity problem when the measured pressure range crosses zero. This allows one to use ceramic/thick film sensors in differential applications where they will prove to be much less expensive than other approaches and more reliable.

While a specific embodiment of the invention has been shown ~~showed~~ and described in detail to illustrate the application of the principles of the invention, it will be understood that the invention may be embodied otherwise without departing from such principles.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A pressure sensor, for exposure to a pressure to be measured, comprising:

a diaphragm;

a first pair of strain gauges having a non-linear electrical response characteristic when fixed on the diaphragm; and

a second pair of strain gauges having a non-linear electrical response characteristic when fixed on the diaphragm; wherein the first pair of strain gauges are located on a first side of the diaphragm and the second pair of strain gauges are mounted on the opposite side of the diaphragm, and whereby the non-linear responses of the first and second pairs of strain gauges are of substantially equal magnitudes and cancel each other to produce a substantially linear output when the diaphragm is exposed to a pressure.

2. A pressure sensor according to claim 1, wherein the first pair of strain gauges is located on a top surface of the diaphragm at a selected radial position near the centre of the diaphragm and the second pair of strain gauges is located on a bottom surface of the diaphragm substantially at said selected radial position.

3. A pressure sensor according to claim 1, wherein the first pair of strain gauges is located on a top surface of the diaphragm at a selected radial position near an outer periphery of the diaphragm and the second pair of strain gauges is located on a bottom surface of the diaphragm substantially at said selected radial position.

4. A pressure sensor according to claim 1, wherein the first and second pairs of strain gauges are substantially aligned with each other and of equal areas, the first pair of strain gauges being located on a top surface of the diaphragm and the second pair of strain gauges being located on a bottom surface of the diaphragm.

5. A pressure sensor according to claim 1, wherein said strain gauges are strain sensitive elements selected from the group consisting of thin film strain gauges, bonded foil strain gauges, semiconductive gauges and thick film gauges.

6. A pressure sensor, substantially as hereinbefore described with reference to Figures 4 to 11 of the accompanying drawings.

DATED this 30th day of April 1991

INTERNATIONAL CONTROL AUTOMATION FINANCE S.A.

By their Patent Attorneys

GRIFFITH HACK & CO.

FIG. 1
PRIOR ART

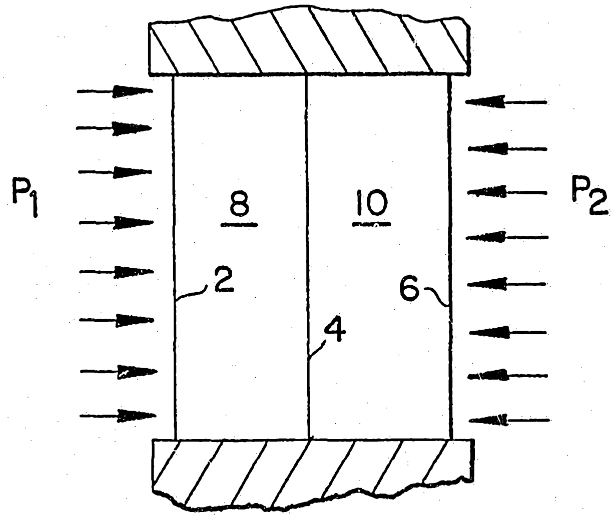


FIG. 2
PRIOR ART

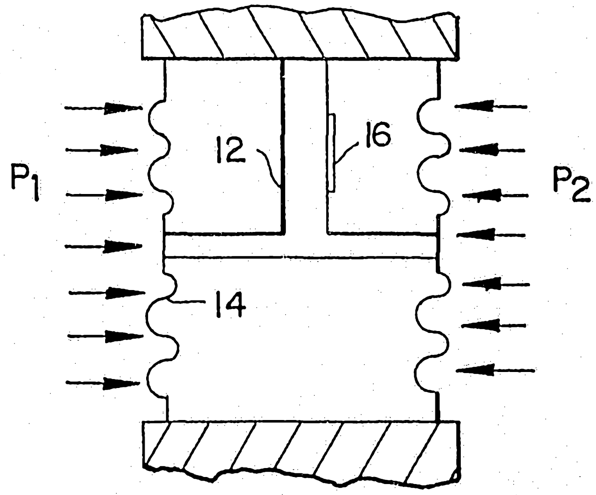


FIG. 3
PRIOR ART

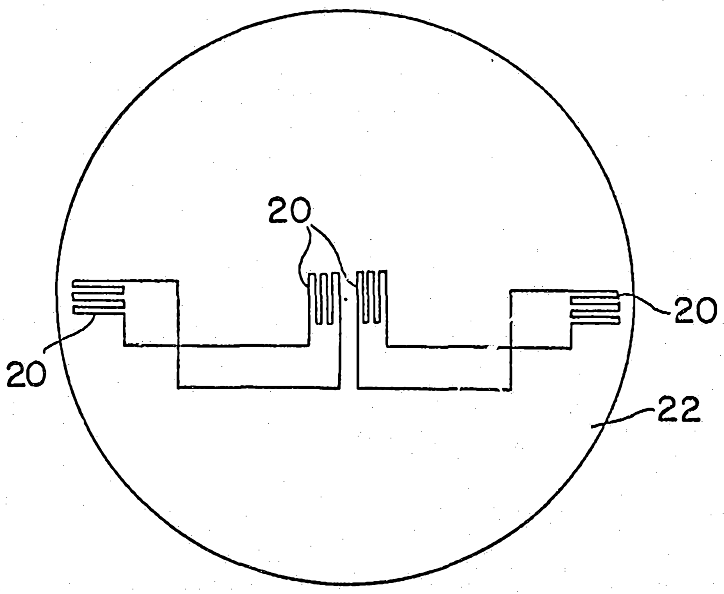


FIG. 4

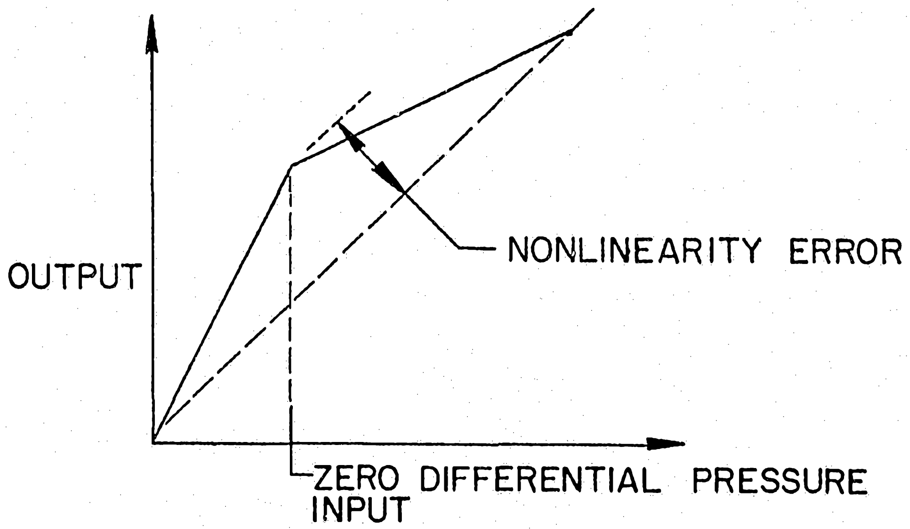


FIG. 5

FLAT DIAPHRAGM LINEARITY
RADIAL POINT VALUES

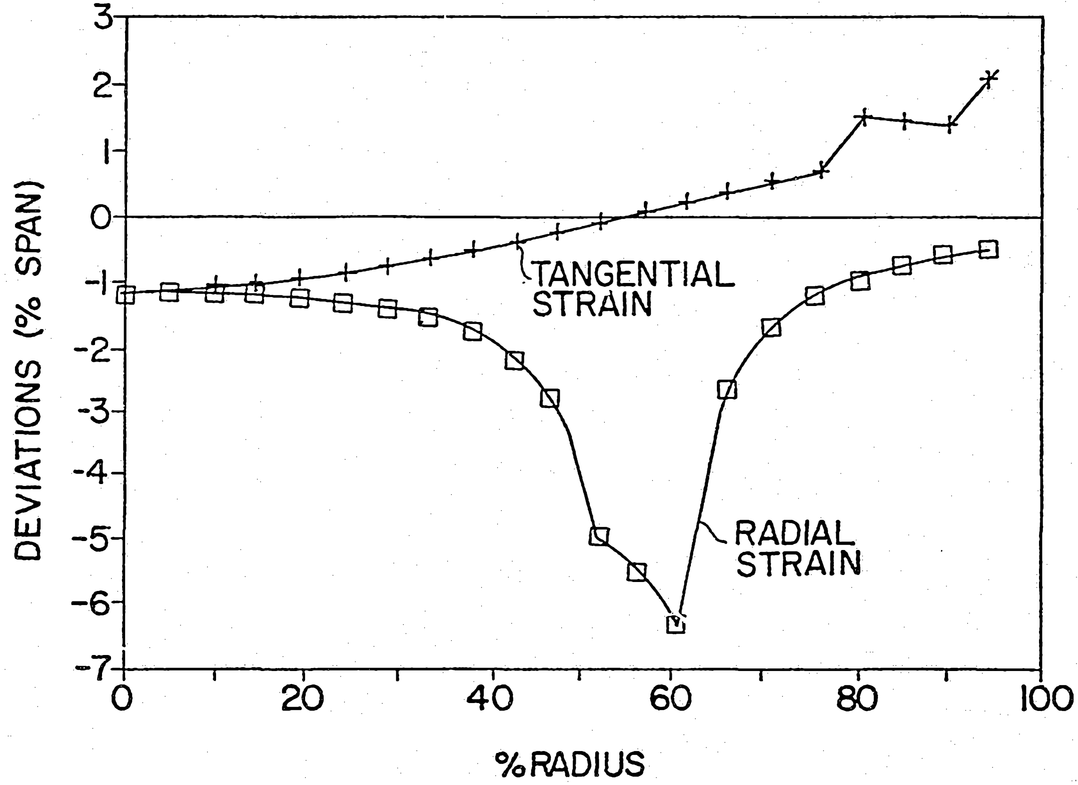
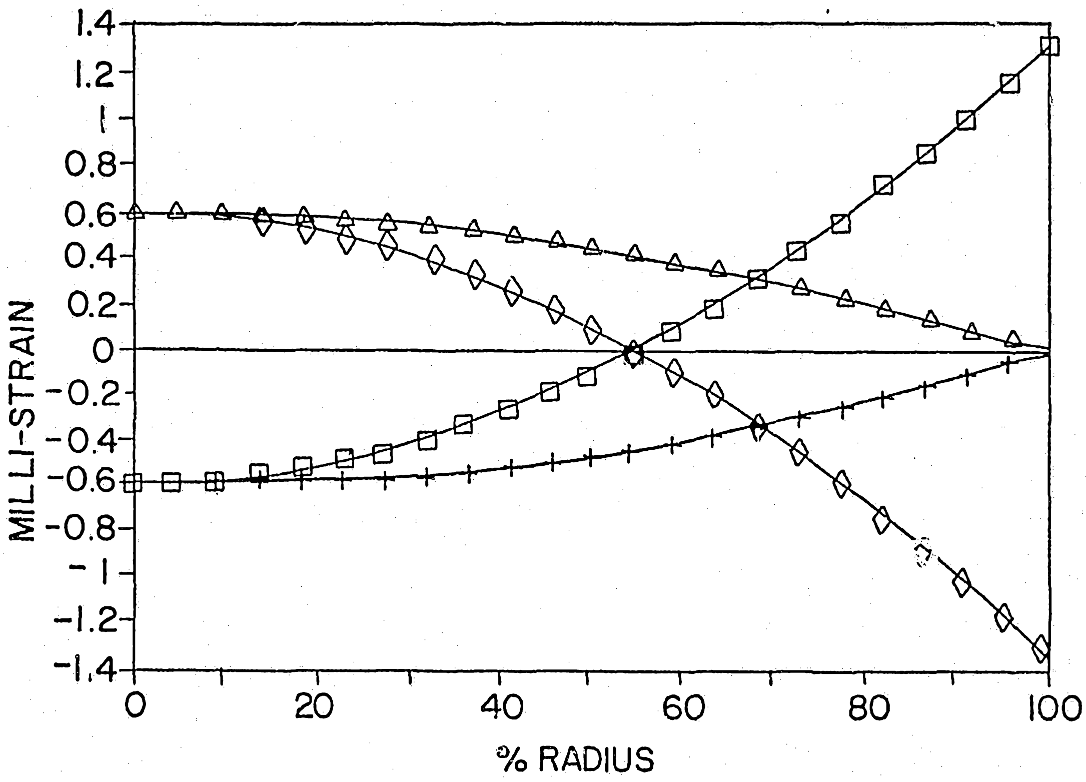


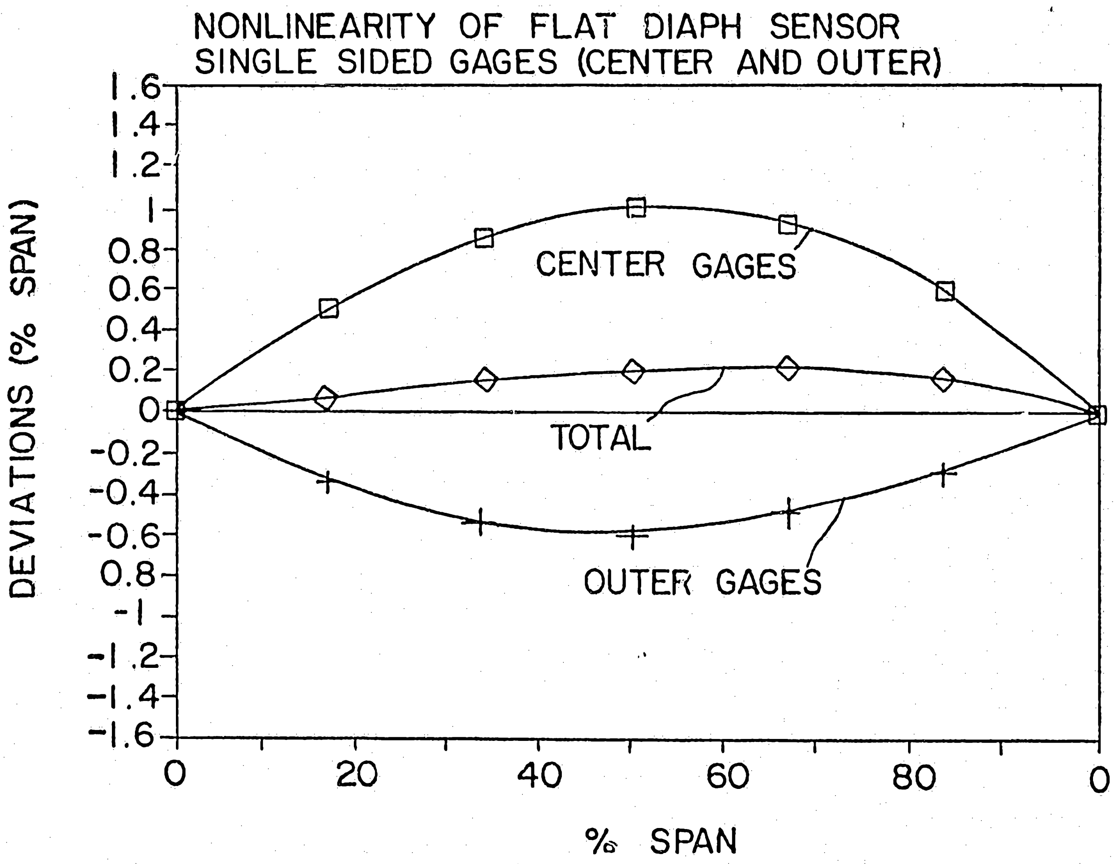
FIG. 6

FLAT DIAPHRAGM STRAIN DIST.



LEGEND: □ TOP SIDE RADIAL STRAIN
+ TOP SIDE TANGENTIAL STRAIN
◊ BOTTOM SIDE RADIAL STRAIN
△ BOTTOM SIDE TANGENTIAL STRAIN

FIG. 7


NONLINEARITY OF FLAT DIAPH SENSOR
SINGLE SIDED GAGES (CENTER AND OUTER)
DEVIATIONS (% SPAN)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0.8
-1
-1.2
-1.4
-1.6
CENTER GAGES
TOTAL
OUTER GAGES
0
20
40
60
80
0
% SPAN

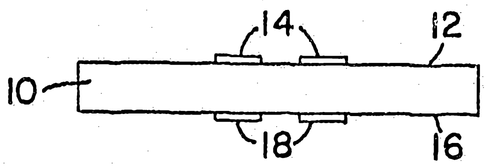


FIG. 8a

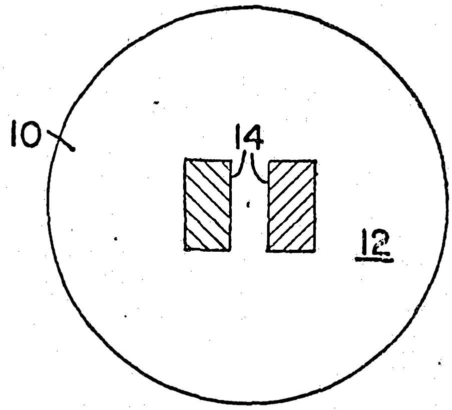


FIG. 8b

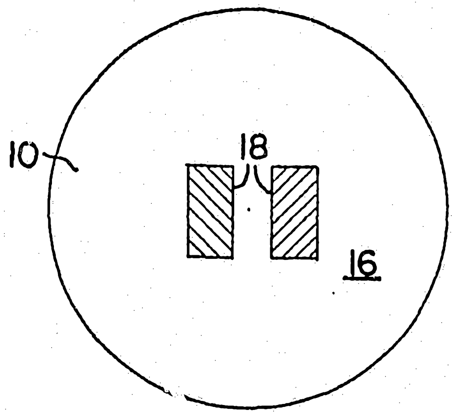
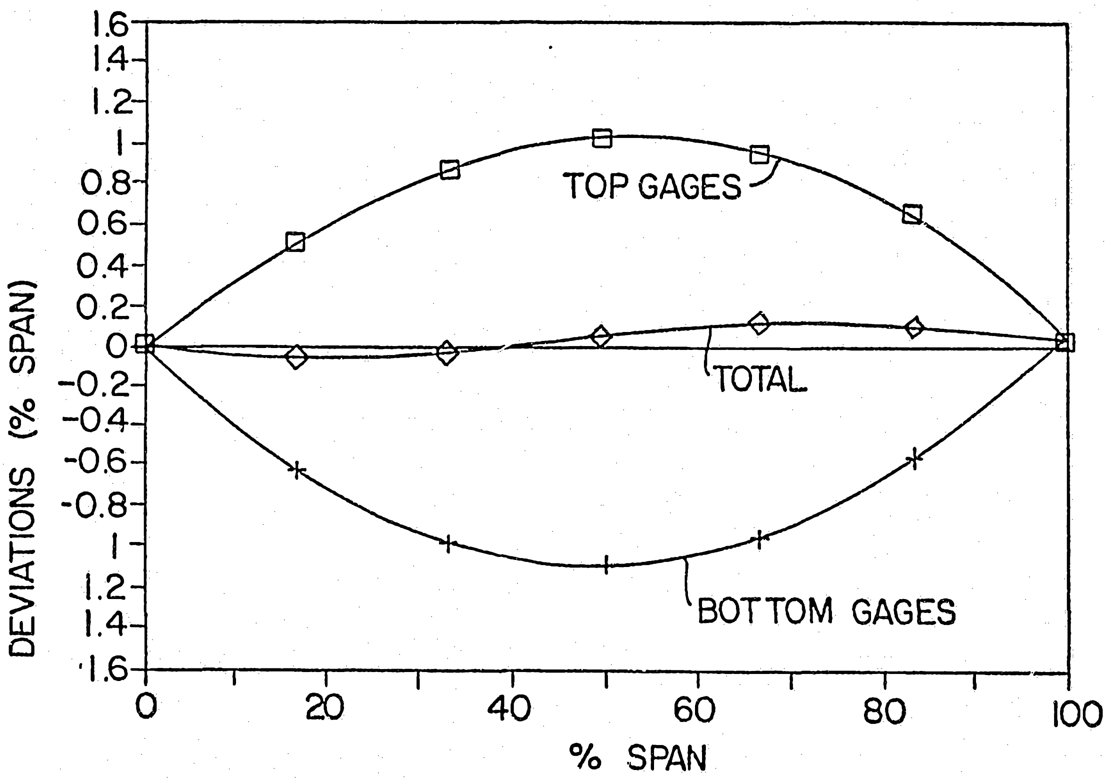


FIG. 8c

FIG. 9

NONLINEARITY OF FLAT DIAPH SENSOR
DUAL SIDED CENTER GAGES



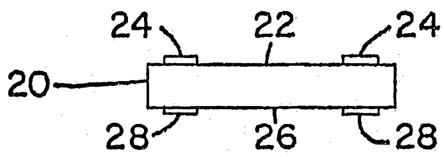


FIG. 10a

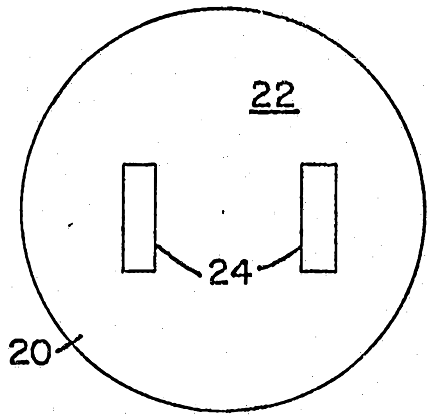


FIG. 10b

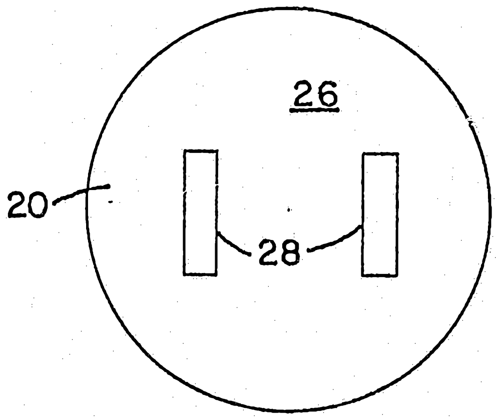
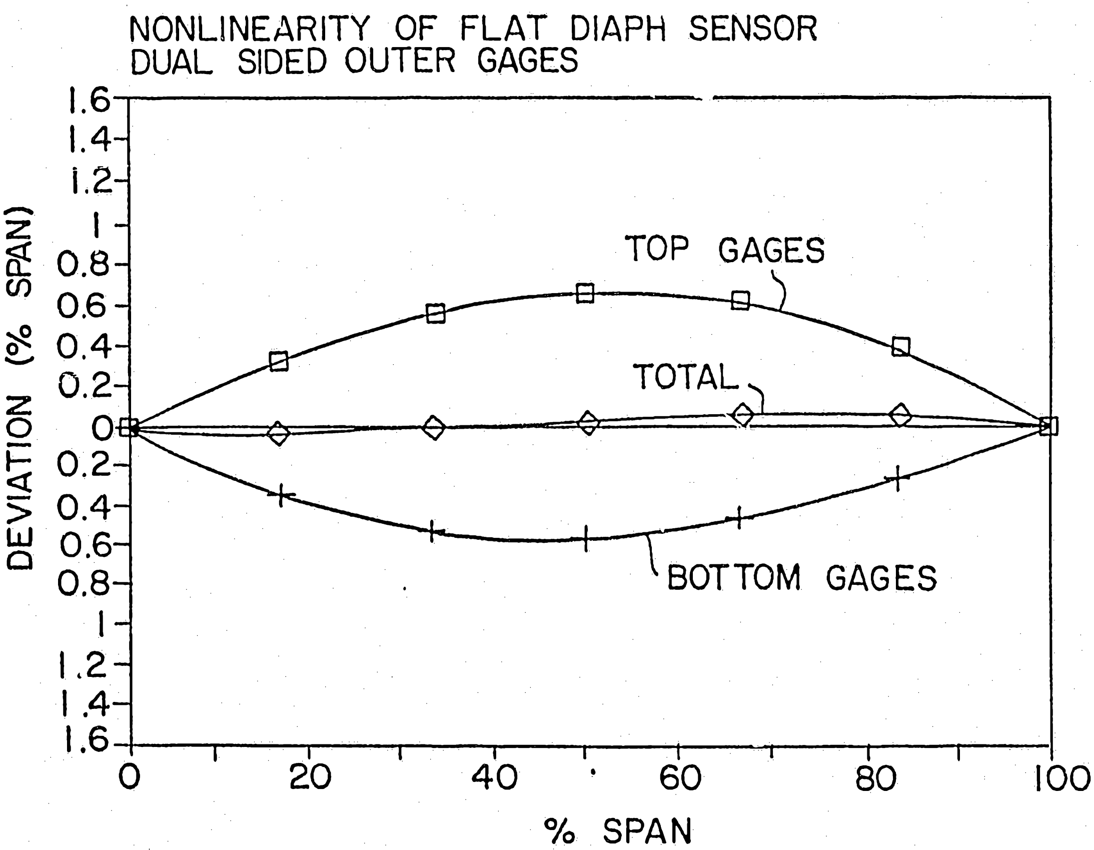


FIG. 10c

FIG. 11


NONLINEARITY OF FLAT DIAPH SENSOR
DUAL SIDED OUTER GAGES
DEVIATION (% SPAN)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
TOP GAGES
TOTAL
BOTTOM GAGES
0
20
40
60
80
100
% SPAN