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(54) Title: STRAIN COMPENSATION FOR PRESSURE SENSORS

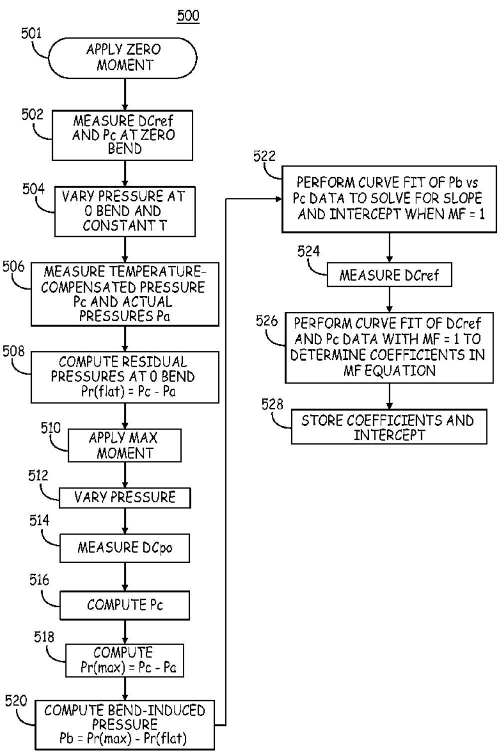

FIG. 6

(57) Abstract: A pressure sensing system provides signals representative of a magnitude of pressure at a selected site. A sensor module includes a first transducer producing a first signal having an associated first response to pressure and strain applied to the sensor module and a second transducer producing a second signal having an associated second response to pressure and strain applied to the sensor module. A calculated pressure, a bending pressure error and a bend-compensated pressure are computed in response to the first signal and the second signal.

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STRAIN COMPENSATION FOR PRESSURE SENSORS

TECHNICAL FIELD

The instant disclosure relates generally to strain compensation in physical sensors. In particular, it relates to strain compensation for pressure sensors.

BACKGROUND

Sensors of physical signals are typically sensitive to multiple physical influences. The art of sensor design is to ensure that the sensor is the most sensitive to a physical parameter of interest. The challenge is to isolate a sensing element of one physical phenomenon from confounding physical phenomena.

For example, sensors that are placed in an environment in which varying mechanical loads may be imposed on the sensor may be subject to strain-induced errors in a physical signal measurement. It is often desirable to measure or monitor pressure within a patient's body. Blood pressure, cranial pressure or other intracavitary or internal body pressures may be monitored for assessing a patient condition and may be used in managing or controlling medical treatment. A pressure sensor implanted in a patient's body will be subjected to temperature changes as well as movement and physical forces other than pressure. For example, motion due to the beating heart, respiration or body motion may cause bending or strain of a pressure sensor module. A sensor module may be at least partially isolated from other movement and forces by positioning the pressure in or on a stiff housing that does not bend under normal operating conditions.

A housing or sensor platform that is stiff enough to prevent flexure or strain due to imposed forces on the sensor, however, may be undesirable or poorly tolerated by a patient when incorporated in an implantable medical device (IMD). For example, in a transvenous lead for monitoring blood pressure, added stiffness to the lead may make lead advancement and navigation through a tortuous pathway along the patient's cardiovascular system difficult or impossible. The stiffness of a sensor housing implemented along an otherwise flexible lead body may cause undesired strain between the housing and flexible lead body when exposed to flexure and movement associated with a beating heart or other motion. A need remains, therefore, for a pressure sensor and associated method for compensating for bending error caused by strain applied to the pressure sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an illustration of an implantable medical device (IMD) 100 configured to monitor pressure in a patient's heart in accordance with at least one embodiment of the present disclosure.

FIG. 2 is a functional block diagram of a medical device system for monitoring transducer signals and providing strain compensation of the pressure signal.

FIG. 3 contains a partial exploded perspective top view of the components of a sensor module in accordance with at least one embodiment of the present disclosure.

FIG. 4 is a first order plot of bending pressure error as a function of actual applied pressure (under varying applied bending moments).

FIGs. 5A and 5B show calibration test fixture apparatus used during a calibration procedure for establishing equation coefficients for computing a bending pressure error.

FIG. 6 is a flow chart of one method for establishing equation coefficients for computing a bending pressure error.

FIG. 7 is a flow chart of a method for monitoring a pressure signal according to at least one embodiment.

FIG. 8 is a flow chart of an alternative embodiment for establishing values of pressure bending error Pb.

DETAILED DESCRIPTION

In the following description, references are made to illustrative embodiments. It is understood that other embodiments may be utilized without departing from the scope of the disclosure.

FIG. 1 is an illustration of an implantable medical device (IMD) 100 configured to monitor a patient's heart 110 in accordance with at least one embodiment of the present disclosure. In this illustration, a human heart 110 is depicted showing two possible positions of sensing leads 120, 130 that are implanted inside the heart 110. Each sensing lead 120, 130 has a distal tine assembly 140 located at the distal end of the lead. The distal tine assembly 140 is used as an anchor to implant the distal end of the lead into the heart's chamber.

The sensing leads 120, 130 also each include a sensor module 150, 160 that is located towards the distal end of the lead. Each sensor module 150, 160 includes at least two transducers and circuitry for measuring transducer signals enclosed within a sensor module housing. The sensor modules 150, 160 provide signals that are representative of the magnitude of the absolute pressure and body temperature at the site of implantation. These signals are transmitted from the sensor modules 150, 160 to the IMD 100 via electrical conductors extending through sensing leads 120, 130, which are coupled at their proximal ends to connector block 180 of IMD 100.

The leads and sensor locations shown in FIG. 1 are intended to show possible locations and configurations of a lead carrying a sensor module. For example, sensor module 150 is positioned near the right ventricular apex whereas sensor module 160 is positioned substantially in the right ventricular outflow tract. The sensor location may vary between applications. For example, a single right ventricular sensor module may be employed to monitor pressure in the right ventricle instead of the two sensors as shown here.

In other embodiments, the system may employ more or less sensing leads than as illustrated in FIG. 1. In alternative embodiments, sensing leads 120, 130 may be placed at other locations in heart 110 than those shown in FIG. 1 or other locations along the cardiovascular system, including venous or arterial locations. In addition, in some embodiments, the system may employ leads 120, 130 that contain more than one sensing module 150, 160 per lead.

In still other embodiments, sensor modules may be implemented in a leadless design in which a deployable housing including a sensor module and telemetric communication circuitry is deployed to a body location for monitoring pressure. The wireless sensor transmits signals to IMD 100 or to an external device via wireless telemetry. Examples of implantable medical device (IMD) communication systems that may be employed by the system of the present disclosure include, but are not limited to, the systems disclosed in commonly-assigned U.S. Pat. No. 7,013,178 (Reinke et al.) and U.S. Pat. No. 7,139,613 (Reinke et al.), the disclosures of which are incorporated herein by reference in relevant parts.

In the illustrative embodiment of FIG. 1, sensor modules 150, 160 are deployed for measuring a patient's blood pressure. In alternative embodiments, a pressure sensor may be deployed in other body chambers or cavities, such as along the digestive tract, within the bladder, within the thoracic or abdominal cavity, or within or along an organ such as the brain, a muscle, etc. A pressure sensor module may be deployed for measuring a fluid pressure or measuring a pressure within or between tissues, such as an intramuscular pressure.

FIG. 2 is a functional block diagram 50 of a medical device system for monitoring a pressure signal and providing strain compensation of the pressure signal. A sensor module 51, which may correspond to modules 150 or 160 in FIG. 1, is coupled to an IMD 61, in either wired or wireless communication to enable signal transmission from sensor module 51 to IMD processor and control 59.

Sensor module 51 includes a pressure transducer 52 provided for producing an electrical signal output 53 correlated to the pressure imposed on a sensor module housing (not shown in FIG. 2) containing or carrying transducer 52. Pressure transducer 52 may be embodied as any pressure-sensitive transducer, including, but not limited to, piezoelectric, capacitive, electromagnetic, piezoresistive, optical, or potentiometric transducers. The pressure transducer 52 is also subject to temperature changes and strain imposed on the housing enclosing transducers 52, 54, and 56. The pressure transducer 52 produces an electrical signal 53 that varies with pressure P, temperature T and strain or bending B applied to the sensor module housing containing transducer 52. The output signal 53 of transducer 52 used alone for deriving a pressure measurement or monitoring relative changes in pressure would result in erroneous measurements due to strain-induced changes in the output signal 53 caused by bending or strain imposed on the sensor housing.

In order to compensate for strain-induced error of the pressure transducer signal 53, a second signal transducer 54 is provided which is also sensitive to strain, temperature and pressure but not with the same dependency as pressure sensor 52. Transducer 54 produces a signal 55 correlated to strain or bending imposed on the sensor housing holding transducers 52, 54 and 55, with additional dependency on temperature and pressure changes.

A third transducer 56 is included which produces an electrical output signal 57 that is sensitive to changes in temperature and pressure (and optionally strain) but with different dependencies on these variables than the first and second transducers 52 and 54. The transducers 52, 54 and 56 may be selected and configured such that signal 53 is most highly sensitive to pressure, signal 55 is most highly sensitive to strain or bend, and signal 57 is most highly sensitive to temperature. In this way, each transducer output signal 53, 55 and 57 may vary with the three variables of pressure, temperature and bending but in an independent manner that allows the three signals to be used in solving for each of the variables independently.

Signal processor 58 receives the transducer output signals 53, 55 and 57 and computes three measurement signals S1, S2 and S3 that are provided for use by processor and control 59 for computing a calculated pressure (that is not compensated for bending-induced pressure signal changes) and a bending pressure error using at least two out of the three signals. S1, S2 and S3 are derived from the transducer signals, in any combination, to obtain a measurement signal S1 that is most sensitive to pressure (but also sensitive to temperature and bending), S2 that is most sensitive to temperature (and may be sensitive to bending and pressure), and S3 that is most sensitive to bending (and may be sensitive to temperature and pressure).

The pressure measurement calculated from S1 alone will include error due to strain or bending of the sensor module. The bending pressure error is a correction term computed using an established relationship between strain on the sensor module and a difference between actual applied pressure and the calculated pressure or the measurement signal S1. Using the third transducer signal S3, which is most sensitive to bending, to compute a pressure correction term, the signal processor 58 can compute a pressure signal corrected for the influences of both temperature and strain or bending.

Signal processor 58 thus processes the transducer output signals 53, 55 and 57 to compute three measurement signals S1, S2 and S3 from which processor and control 59 can compute a pressure measurement corrected for temperature changes and for strain-induced error, also referred to herein as a bend-compensated pressure signal.

Processor and control 59 may additionally compute a temperature signal output using at least S2. In some embodiments, temperature may be controlled such that temperature changes do not influence the pressure transducer signal 53. In that case, S3 is used to compensate S1 for pressure error due to strain. In some sensor module designs, one transducer 56 is embodied as a MEMs or other sensor incorporated on a rigid portion of the sensor module and may be isolated from pressure changes such that one output signal 57 varies substantially with temperature only and is used to provide S2.

Processor and control 59 receives S1, S2, and S3 and computes a corrected pressure measurement to control a therapy delivered by therapy delivery unit 22 and/or to generate reports, data or other information that is communicated via communication unit 24. Communication unit 24 may include a telemetry communication system, display, patient alert or other functionality for communicating information or data derived from the corrected pressure signal to the patient or a clinician.

Operations performed by signal processor 58 and processor and control 59 for computing a corrected pressure measurement may be implemented entirely in signal processor 58 within the sensor module 51, entirely within processor and control 59 within an IMD 61, which is communicatively coupled to sensor module

51 for receiving transducer output signals 53, 55 and 57, or in a distributed manner across processing components included in IMD system 50.

FIG. 3 contains a partial exploded perspective top view of the components of the sensor module 150, 160 in accordance with at least one embodiment of the present disclosure. Sensor module 150, 160 senses pressure at the site of implantation and transmits signals that are correlated to the magnitude of the absolute pressure, temperature, and externally applied static and dynamic moments at the site of implantation through a feedthrough pin 297 that is located at the proximal end 235 of the sensor module.

In this exploded view, the sensor module 150, 160 is formed with a first and second titanium cylindrical housing half member 270, 280. When the cylindrical housing half members 270, 280 are joined together, they provide an assembled titanium housing that surrounds a ceramic hybrid circuit substrate 230.

In this illustrative embodiment, sensor module 150, 160 includes a capacitive type of pressure transducer. The sensor module 150, 160 is shown to contain a first capacitive plate 210 forming an air gap pressure sensitive capacitor, also referred to herein as a “pick-off” capacitor (Cpo) and a second capacitive plate 220 forming an air gap reference capacitor (Cref). Cpo provides a signal that is sensitive to pressure, temperature, and bending of module 150, 160. The Cref plate 220 is located towards the distal end 225 of the sensor module. Cref provides a signal that is sensitive to temperature and to bending with less sensitivity to pressure than Cpo. Each capacitor plate 210, 220 is electrically coupled to a top side of substrate 230. The sensor module 150, 160 further includes three plated standoffs 240, 250, 260.

When the cylindrical housing half members 270, 280 are assembled, the capacitor plates 210, 220 are spaced from the inner surface 290 of cylindrical half housing member 270 by the height of the three standoffs 240, 250, 260. The air gap pressure sensitive capacitor Cpo varies in capacitance with the amount of pressure and moment that is imposed on the diaphragm 295 that is located on cylindrical half housing member 270. When sensor module 150, 160 is implanted in a patient’s body, the temperature inside module 150, 160 can vary with body temperature, for example during fever or exercise. Temperature induced changes in pressure inside the sensor module will affect the deflection of diaphragm 295 and will therefore also cause changes in the capacitance of Cpo 210.

A measurement of temperature may be used to compensate for temperature induced changes in pressure. This can be performed in conjunction with capacitance measurements, such as disclosed in U.S. Pat. No. 5,564,434 (Halperin, et al.), hereby incorporated herein by reference in its entirety. Alternatively, temperature changes may be separate from the capacitance measurements using any temperature measurement technique.

The Cref plate 220 is located in a peripheral region of substrate 230 relative to diaphragm 295. Deflection of diaphragm 295 in the peripheral region of Cref plate 220 is substantially less than deflection of diaphragm 295 in the region of Cpo plate 210. Capacitance Cref is relatively less sensitive to changes in pressure than the capacitance Cpo. Changes in Cpo and Cref measurements, however, may introduce measurement error as changes in bending moment applied to sensor module 150, 160 occur.

The sensor module 150, 160 includes a hybrid circuit 232 on the bottom side of substrate 230. Circuit 232 includes circuitry that provides measurement signals S1, S2 and S3 as shown in FIG. 2 for processing in an algorithm that computes a corrected pressure measurement compensated for both temperature and bending moment. In one embodiment, a measurement signal S1 is a measurement of capacitances Cpo and Cref, which may correspond to transducers 52 and 54 in FIG. 2. S1 may be expressed as a ratio of these capacitances (or measurements correlated thereto) and such a ratio is referred to herein as a duty cycle, DCpo.

S2 is provided as a measurement signal that is correlated to temperature. S3 is provided as a measurement signal that is correlated to bending moment, for example a measurement of Cref and a third capacitor Coc that is relatively insensitive to bending moment, as further described below. These capacitances Cref and Coc may correspond to the output signals 55 and 57 of transducers 54 and 56, respectfully, in FIG. 2. The measurement signal S3 may be expressed as a ratio of these capacitances or measurements correlated thereto, which is referred to herein as a duty cycle DCref.

As such, the S1 measurement signal will primarily be affected by application of external pressure to the sensor module and secondarily affected by application of temperature and bending moment. S2 will be primarily affected by changes in temperature applied to the sensor module and secondarily affected by application of pressure and bending moment. S3 will be primarily affected by bending or strain applied to the sensor module and secondarily affected by application of pressure and temperature. In order to measure pressure with a high degree of accuracy, the pressure-sensitive measurement signal S1 having the highest sensitivity to pressure but also affected by temperature and bending moment needs to be compensated for confounding changes in temperature and bending moment. This compensation can be achieved by using the additional measurement signals S2 and S3.

At body temperature of 37 degrees C and 740 mmHg barometric pressure with no bending applied to sensor module 150, 160, capacitances of the Cref and Cpo capacitors will be substantially equal and can be measured as a 50% duty cycle (calculated as the ratio of Cpo to Cpo+Cref). This duty cycle is referred to herein as DCpo because it is a ratio of a capacitance of Cpo to the sum of capacitances of Cpo and Cref.

Measurement of the capacitance ratios can be provided by charging one capacitance to a reference voltage while discharging the second capacitance to ground. Connecting the two capacitances together to share the charge between them will result in a voltage that is proportional to the ratio of C1 to C1+C2, which is defined herein as a duty cycle, DC. This voltage can then be preconditioned and digitized by a high resolution analog-to-digital converter for digital processing. Reference is made to U.S. Pat. No. 7,623,053 (Terry, et al.) and U.S. Pat. No. 7,714,757 (Denison, et al.), both of which patents are hereby incorporated herein by reference in their entirety. It is recognized that in order to obtain three measurement signals S1, S2 and S3 using three transducer signals 53, 55 and 57 (shown in FIG. 2), signals may be acquired in a time-multiplexed manner.

Measurement of capacitance by providing a voltage proportional to a capacitance ratio is one method for obtaining a signal correlated to changes in capacitance of the transducers due to dynamic physical conditions. Other methods, such as capacitance to time interval conversion and measurement of the time intervals or ratios of the time intervals may be used. Reference is made to US Pat. No. 5,535,752 (Halperin, et al.), hereby incorporated herein by reference in its entirety.

In other embodiments, a duty cycle, or more generally a ratio of signal outputs, can be determined using any time-, voltage-, or other converted measure of the transducer signals shown in FIG. 2. Use of a ratio of the transducer signals in a duty cycle for providing a pressure, temperature, or bend sensitive measurement signal S1, S2 or S3, instead of the transducer signals directly, cancels the influence of any factors that affect the individual transducer signals proportionally or in the same manner, i.e. common mode signals such as certain types of drift. Capacitance measurements and subsequently determined duty cycles of those measurements is one approach to measuring signals S1, S2, and S3, particularly when S1, S2 and S3 are obtained from capacitive transducers. It is recognized that in other embodiments, other signal measurements derived from three transducer signals as shown in FIG. 2 may be substituted in the equations described below for computing a calculated pressure and bending pressure error.

In alternative embodiments, the capacitance-based transducers of the illustrative embodiments presented herein can be substituted for by other types of transducers and measurement signal conversions for measuring the parameters of interest. As an example, strain based measurement of membrane deflection, for example using a piezoresistive film, may be substituted for the capacitive based measurement of pressure-induced membrane deflection used for determining pressure-sensitive signal S1. Similarly, strain-based measurements in a region of the sensor capsule that is substantially sensitive to bend moment, but substantially insensitive to pressure may be substituted for producing S3.

An alternative temperature measurement may be generated by comparison of two circuit parameters that have substantially different temperature responses.

For example two circuit reference voltages having two different temperature coefficients may be used to generate a temperature signal S2. It is recognized that numerous sensor module configurations may be conceived for providing transducer signals each having differing sensitivities to pressure, temperature and bending moment and from these transducer signals generating measurement signals S1, S2, and S3, having respective primary sensitivities to pressure, temperature and bending.

Referring again to FIG.3, hybrid circuit 232 includes an “on-chip” capacitor (Coc) 234 shown schematically in FIG. 3. The on-chip capacitor is insensitive to pressure and bend because it is incorporated in the integrated circuit 232. Coc will be sensitive to temperature-induced changes in charge current. By providing the two air-gap capacitors, Cpo and Cref, an absolute pressure measurement, Pc, can be calculated that is compensated for temperature changes. By adding the third, on-chip capacitor Coc, a pressure bending error, Pb, can be computed. Pb is correlated to pressure changes caused by bending of the sensor module 150, 160. By providing a third capacitor Coc, capacitance measurements, Cpo, Cref and Coc, are available. By acquiring three signals that vary with three unknown influences (i.e. actual pressure changes in the patient’s body, temperature-induced pressure changes, and bending-induced pressure changes) a temperature-compensated and bend-compensated pressure signal can be computed.

In the embodiment shown, the combination of Cref and Coc can be considered to be a transducer from which a signal S3 that is sensitive to strain can be determined and can be used in combination with S1 for determining a bending pressure error as will be further described below. In alternative embodiments, another strain-sensitive element could be substituted for determining a signal S3 sensitive to strain in place of the combination of Cref and Coc. For example, a microelectromechanical system (MEMS) device that is configured as a strain sensor may be included in sensor module 150, 160. A MEMS device may be positioned along the sensor housing 270, 280, off of a neutral axis of the sensor housing 270, 280, such that it is subjected to bending moments applied to sensor module 150, 160 and produces a signal that is correlated to the applied bending moment. In other embodiments, other types of strain sensors may be used to provide the signal S3 having a primary sensitivity to strain.

FIG. 4 is a first order plot 300 of pressure bending error Pb 304 as a function of actual applied pressure (Pa) 302 under varying applied bending moments, Ma1, Ma2 and Ma3. As applied pressure increases, the influence of bending on the pressure sensor causes an increase in the measured pressure. This bending-induced pressure increase, Pb 304, increases in a substantially linear manner with increasing applied pressure over expected operation conditions as shown by plotted lines 306, 308 and 310. The slope of this linear relationship, however, changes with different applied bending moments, Ma1, Ma2, and Ma3 as shown by lines 306, 308, and 310 having distinct slopes m1, m2, and m3, respectfully. A second order influence of Pa on Pb is included in the following equations, but not represented in FIG. 4 for the sake of simplicity of the illustration.

In order to determine an exact value for Pb, both the actual bending moment, Ma, applied to the sensor and the actual applied pressure, Pa, would need to be known. Since the actual bending moment and actual applied pressure are unknown under implant conditions, estimates correlated to Ma and Pa are used along with calibration constants to compute an estimate of Pb.

In one embodiment, a general equation for pressure bending error Pb is given by:

[1] $Pb = f(DCpo, ADCtemp) \times mf$

wherein $f(DCpo, ADCtemp)$ is a function of DCpo (representing S1 described above) and ADCtemp (representing S2). ADCtemp is a digitally-converted independent measurement of temperature that is based on comparison of two circuit parameters having different temperature responses. The term mf represents a moment fraction, which will be described in further detail below.

DCpo is defined above as the duty cycle of the air-gap, pressure-sensitive capacitor Cpo and the air-gap capacitance Cref and is given by a ratio of the capacitances Cpo to Cpo +Cref. DCpo will be highly sensitive to changes in applied pressure and thus a function of DCpo can be used to account for the influence of applied pressure Pa on Pb, as shown by the relationship plotted in FIG. 4. A calculated pressure Pc, which is compensated for temperature but not bending, is a function of DCpo. Accordingly, the term *f*(DCpo, ADCtemp) could be replaced by a function of the calculated, temperature-compensated pressure Pc, *f*(Pc), in some embodiments.

The moment fraction term mf in Equation 1 is a fractional measure of the bending applied to the pressure sensor. The mf is the ratio of actual bending applied to the sensor and the maximum bending expected under operating conditions. The mf can vary between 0 (no bending applied) and 1 (applied bending equals maximum bending expected under operating conditions). Since an actual applied moment Ma is not measured by the pressure sensor, a relative change in bending moment determined as a fraction of the maximum bending can be used to estimate the effect of applied bending on the slope of the Pb vs. Pa relationship. The moment fraction is computed using capacitance measurements obtained from the three sensor capacitors, Cpo, Cref, and Coc, as will be further described below.

In Equation 1, the *f*(DCpo, ADCtemp) may be expressed as a linear function. For example, when determined as a function of Pc:

[2] $f(\text{DCpo}, \text{ADCtemp}) = F \times (Pc - G)$

wherein G is the intercept 322 shown in FIG. 4 and F is the slope of Pa vs. Pb under a constant bending moment. When Equation 2 is substituted into Equation 1, Pb becomes:

[3] $Pb = F \times (Pc - G) \times mf$

In a first order estimation, the term mf can be thought of as a “slope adjustment” term because the term mf x F defines the first order slope of the Pb vs. Pa relationship, which is mf dependent. During a calibration procedure, the pressure bending error Pb of a calculated temperature-compensated pressure measurement Pc can be measured relative to an actual applied pressure. The slope F and intercept G can then be determined during a calibration procedure when a known moment fraction is applied and at least two different actual pressures are applied. A calibration procedure for determining F and G in Equation 3 will be further described below.

In one embodiment, moment fraction, mf, is computed by:

[4] $mf = H(DCref - DCref^0) + K(Pc - Pc^0) + L(ADCtemp - ADCtemp^0)$

wherein H, K and L are constants. Equation 4 could be considered generally as mf = H*(S3-c3) + K(S1-c1) + L*(S2-c2) where H, K and L are calibration coefficients and c1, c2 and c3 correspond to constants determined as the measurement signals S1, S2, and S3 measured at zero bending moment and at a controlled pressure and temperature.

In Equation 4, S3 is represented as DCref, the ratio of the capacitances Cref to Cref + Coc. $DCref^0$ is DCref measured at zero bending moment for a controlled temperature and applied pressure. S1 is represented as the calculated, temperature-compensated pressure Pc, and Pc^0 is Pc measured at zero bending moment for a controlled temperature and applied pressure. S2 is represented as ADCtemp, a digitally-converted temperature measurement, and $ADCtemp^0$ is the temperature measurement at a controlled temperature and pressure when zero bending moment is applied.

Cref and Coc capacitance measurements will be affected substantially equally by measurement circuit changes. Coc will not be sensitive to bending because it is integrated in the hybrid circuit board. DCref will therefore be influenced by bending as Cref changes due to bending but is normalized by changes in measurement circuit variation (and therefore is largely insensitive to temperature change). The relative difference between DCref and $DCref^0$ when pressure and temperature are held constant but bending moment changes from zero to some unknown amount of bending will therefore be correlated to the relative change in bending moment. This relative change can be used in estimating a moment fraction mf.

In alternative embodiments, another electrical signal correlated to a relative change in bending moment may be substituted for the $(DCref - DCref^0)$ term in Equation 4. For example, if a strain sensor embodied as a MEMS device is incorporated in the sensor module housing as described in conjunction with FIG.

3, the MEMS device signal may be used to determine a relative change in bending moment that is substituted for DCref – $DCref^0$.

In addition to bending induced changes of Cref, DCref will be affected by pressure changes that may alter Cref. The relative change between DCref and $DCref^0$ will therefore depend on both bending moment and pressure changes. A second term, ($Pc - Pc^0$), is therefore included in the mf Equation 4 to account for the effect of pressure-related influences on Cref and DCref. Pc and Pc^0 are pressure measurements that have been compensated for temperature changes. The relative change in Pc from Pc^0 at a fixed temperature and applied pressure will be related to changes in the applied bending moment and are thus also included in the mf Equation 4.

A third term, "L(ADCtemp – $ADCtemp^0$)" is included in Equation 4 to account for higher order influences of temperature on DCref and Pc. In some embodiments, the constant L may be assumed equal to 0, eliminating the third term from Equation 4. If temperature sensitivity of Pb is found to exist for a specific sensor module design, the constants L and $ADCtemp^0$ can be determined using the calibration procedure described below, repeated for at least two temperatures.

The terms DCref – $DCref^0$ and Pc – $Pcref^0$, multiplied by respective coefficients H and K included in Equation 4, provide a measure related to the changes in the capacitor measurements of Cpo and Cref, provided as duty cycles, due to relative changes in bending moment. The constants $DCref^0$, Pc^0, H and K (and optionally L) in Equation 4 are determined in a calibration procedure as further described below. This relative change in bending moment is computed as a moment fraction, i.e. a relative change of duty cycles measured during an applied bend from duty cycles measured at a zero bending moment. The moment fraction is used in Equation 3 to reflect the influence of bending moment on the slope of the Pb vs. Pa relationship.

More specifically, the moment fraction computed using capacitances Cpo, Cref, and Coc is used to "correct" the slope of the equation F(Pc – G) defining the relationship of Pb and Pa because the first order slope of this relationship is dependent on applied moment as shown in FIG. 4. Note that when Equation 4 is substituted into Equation 3, the expanded form includes a second order term (Pc^2) that is not represented in the illustrative plots shown in FIG. 4. The second order term Pc^2 will cause the plots shown in FIG. 4 to be non-linear, for example a parabolic function of Pa instead of the linear dependence of Pb on Pa as shown.

FIGs. 5A and 5B show calibration test fixture apparatus 400 and 420 used during a calibration procedure for determining values needed for computing Pb. In FIG. 5A, test fixture apparatus 400 includes a test fixture 402 to completely enclose sensor module 150, 160 and to hold module 150, 160 in a zero bending moment position. A temperature control and measurement module 404 applies a controlled temperature inside test fixture 402 and measures the actual applied temperature. A pressure control and measurement module 406 applies a controlled amount of pressure inside fixture 402 and measures the actual applied pressure.

A signal recovery box 410 receives signals from sensor module 150, 160 during a calibration procedure. Capacitances, capacitor charge time intervals, duty cycles, converted analog voltage signals, and/or digitally converted signals needed to compute Pc and determine Pb are recorded.

In FIG. 5B, test fixture apparatus 420 includes a test fixture 422 to completely enclose sensor module 150, 160. Test fixture 422 is designed to hold sensor module 150, 160 in a maximum bending moment configuration corresponding to a maximum strain expected during sensor operating conditions. This maximum moment position may be based on *in vivo* images of a sensor module deployed to a selected site for monitoring pressure. By holding the sensor module 150, 160 in a zero bending moment position (in fixture 402) and a maximum bending moment position (in fixture 422) calibration constants needed for computing Pb can be determined without actually measuring bending moment. This test fixture apparatus thereby eliminates the need to apply and measure controlled amounts of bending moment.

A temperature control and measurement module 424 applies a controlled temperature inside test fixture 422 and measures the actual applied temperature.

A pressure control and measurement module 426 applies a controlled amount of pressure inside 422 and measures the actual applied pressure.

A signal recovery box 430 receives signals from sensor module 150, 160 during a calibration procedure. Capacitances, capacitor charge time intervals, duty cycles, converted analog voltage signals, and/or digitally converted signals needed to compute Pc and Pb can be recorded or transferred to a microprocessor for processing and determination of calibration constants.

While test fixture apparatus 400 and 420 are shown as separate systems in FIGs. 4A and 4B, it is recognized that the test apparatus may be a single system configurable with two different test fixtures 402 and 422. Alternatively a single test fixture 402, 422 may be provided that allows the bending moment applied to the sensor module 150, 160 to be adjusted between at least a zero bend position and a maximum bending position with intermediate bending positions optional.

FIG. 6 is a flow chart 500 of one method for establishing equation coefficients for computing a pressure bending error for use in correcting a calculated pressure measurement during pressure monitoring. Flow chart 500 and other flow charts presented herein are intended to illustrate the functional operation of a medical device system, and should not be construed as reflective of a specific form of software or hardware necessary to practice the methods described. It is believed that the particular form of software will be determined primarily by the particular system architecture employed in the device for signal sensing and monitoring. Providing software to accomplish the described functionality in the context of any modern IMD system, given the disclosure herein, is within the abilities of one of skill in the art.

Methods described in conjunction with flow charts presented herein may be implemented in a computer-readable medium that includes instructions for causing a programmable processor to carry out the methods described. A “computer-readable medium” includes but is not limited to any volatile or non-volatile media, such as a RAM, ROM, CD-ROM, NVRAM, EEPROM, flash memory, and the like. The instructions may be implemented as one or more software modules, which may be executed by themselves or in combination with other software. A computer-readable medium may further include non-volatile media such as flash memory or EEPROM that is contained within the sensor module that can be accessed by a communications method, such as that represented in the above-incorporated '178 patent (Reinke, et al).

The process shown by flow chart 500 is typically performed prior to implantation or deployment of the sensor. For example, the process is performed using the test apparatus shown in FIGs. 4A and 4B which allow controlled temperature, controlled pressure and controlled bend to be applied. Controlled bend is achieved by holding the sensor in a neutral position (zero bend) and by imposing a shape on the sensor using a specialized fixture in test apparatus 420. The imposed shape corresponds to a maximum bending moment expected to occur during operating conditions.

At block 501, zero bending moment is applied to the sensor module, and Pc^0 and $DCref^0$ are measured at block 502. These zero-bending reference measurements are stored as constants and used for computing the moment fraction as given by Equation 4. Pc^0 and $DCref^0$ are recorded at a single controlled value of pressure and temperature. For example, Pc^0 and $DCref^0$ may be recorded at zero bending moment, 37 degrees C, and 740 mmHg.

At block 504, the pressure is varied between controlled settings. Zero bending moment and a constant temperature, e.g. 37 degrees C, are applied. The actual applied pressure is recorded and the temperature-compensated pressure Pc is calculated for a selected number of applied pressures at block 506. The actual applied pressure may be varied over a range of expected operating pressures. For example the pressure may be varied between approximately 450 mmHg and 900 mmHg.

At block 508, the error of Pc relative to the actual applied pressure Pa is determined as the difference between the two. The error can be referred to as the residual pressure at 0 bending (Pr_{flat}). This difference between an actual pressure and computed pressure at zero bending can be considered an offset. Knowing Pr_{flat} over a range of actual applied pressures, Pa, and calculated pressures Pc, allows calibration coefficients to be solved for in the moment fraction equation as further described below.

At block 510, a maximum moment is imposed on the sensor module. The actual bending moment or strain applied is not necessarily measured in a quantitative value. Rather, a shape is imposed on the sensor module that corresponds to a maximum strain or bending of the module expected during sensor operation after deployment. In this position, the sensor module is considered to have a moment fraction of 1. As such the moment fraction term in Equation 3 can be set equal to one when solving for coefficient F and intercept G. Similarly, moment fraction on the left side of Equation 4 can be set equal when solving for coefficients H and K.

In order to solve for the coefficient F and intercept G in Equation 3, measurements of Pb and and Pc are needed at two or more applied pressures when mf is 1. At block 514, DCpo (or an analog or digital converted measure thereof) is measured for at least two different applied pressures. For example, pressure may be varied in equal steps over a range of approximately 450 mmHg to approximately 900 mmHg.

Using DCpo, or an analog voltage or digitized signal correlated thereto, Pc is computed at block 516 for each applied pressure. A residual pressure error at the maximum bending moment (Pr_{max}) is computed as the difference between Pc and the actual applied pressure Pa at block 518.

Error caused by bending, Pb, in the calculated pressure Pc, is the difference between the residual pressure measured at maximum moment Pr_{max} and the residual pressure or offset measured at zero bending (Pr_{flat}) for a given applied pressure. This bending-induced pressure change Pb is computed at block 520 for each applied pressure.

In Equation 3, moment fraction is set to 1 (maximum moment fraction) leaving Pb = F(Pc – G). Having computed the values of Pb over a range of pressures and knowing the corresponding calculated Pc at the same applied pressure allows a curve of Pb vs. Pc to be generated. A curve fitting method is applied to the Pb and Pc data to solve or the slope F and intercept G of Equation

3 at block 522. In an alternative embodiment, Equation 3 may be written as Pb = F(DCpo – G) and a curve of Pb and DCpo data is generated and F and G are solved for.

In order to solve for the coefficient H and K in Equation 5, DCref and Pc data are needed over a range of applied pressures, which could be as few as two applied pressures. When moment fraction is set equal to 1 (maximum bending), and $DCref^0$ and Pc^0 are known values previously measured at block 502, H and K are two unknowns that can be solved for using DCref and Pc measurements at varying applied pressure.

Accordingly, DCref is measured at block 524 at maximum bending moment for at least two of the same actual pressures applied when Pc was computed at block 516. It is recognized that DCref may be measured at the same time Pc was computed at block 516. It is further noted that the order of the blocks shown in flow charts presented herein may be changed and in some cases some steps may be omitted or other steps may be added and the final result of obtaining an equation to establish Pb using capacitance measurements for correcting a calculated pressure measurement can still be achieved successfully.

At block 526, the coefficients H and K are solved for by applying curve-fitting techniques to the DCref vs. Pc data when mf is set equal to 1. At block 528, $DCref^0$, Pc^0, coefficients F, H and K and the intercept G are stored as constants in memory of an IMD (or other processing device) for use in calculating a bending-induced pressure Pb during sensor operation (or later offline) using Equations 3 and 4.

FIG. 7 is a flow chart 600 of a method for monitoring a pressure signal according to one embodiment. At block 601, pressure monitoring is initiated according to a programmed monitoring protocol. In various embodiments, pressure monitoring may be performed continuously, at programmed intervals, or on a triggered basis in response to detecting an event using another physiological signal or initiating, stopping, or adjusting a delivered therapy.

At block 602, capacitances of Cref, Cpo, and Coc are measured to compute duty cycles DCref and DCpo. As described previously, DCref is a ratio of of the air gap reference capacitor Cref and the sum of Cref and Coc. DCpo is a ratio of Cpo and the sum of Cpo and Cref. As will be described further below, a third duty cycle may be computed using a ratio Cpo and the Coc to use in place of DCpo in Equation 1 above.

At block 604, Pc is calculated using DCpo, which may be first converted to a digital signal with a gain and offset applied. Pc may be determined as generally described in the above-incorporated Halperin '752 patent. In general, Pc represents a pressure measurement which is compensated for temperature changes but is not corrected for error due to bending of the sensor module. In other embodiments, Pc may be a calculated pressure measurement that does not include temperature compensation. Pc may be computed according to any implemented method for measuring pressure using a pressure sensor module.

At block 605, the moment fraction, mf, is computed using Equation 4 and the stored constants, $DCref^0$, Pc^0, coefficients H and K determined in the method shown in FIG. 6 (and optionally L and $ADCtemp^0$). The measured signals DCref and Pc obtained at blocks 602 and 604 are provided as input for computing mf.

At block 606, bending pressure error Pb is computed. Pb is computed using Equation 3 above, the calculated mf, stored coefficient F and intercept G determined during the process shown in FIG. 6, and the measured DCpo or Pc provided as input.

In some embodiments *f*(DCpo, ADCtemp) as shown in Equation 1, may use an alternative duty cycle that is measured using capacitance measured from the on chip reference capacitor Coc. For example, a duty cycle DCpo used in Equation 1 in the term *f*(DCpo, ADCtemp) may be a ratio of Cpo and the sum of capacitances Cpo and Coc instead of Cref. Similar to Cref, Coc will vary with influences of temperature on charging current. Coc will be insensitive to pressure and bending changes and can therefore be used as a reference signal for normalizing Cpo to correct for temperature-induced changes in charging current (but will not correct for temperature-induced changes in capacitance due to changes in pressure inside the sensor module).

At block 608, a corrected pressure measurement P is computed, which is corrected or compensated for bending-induced changes in Cpo and Cref. The bend-compensated pressure P is the difference between Pc and Pb. This corrected pressure measurement may then be used for monitoring a patient condition, detecting a physiological condition, monitoring the effectiveness of a therapy or the need to adjust a therapy, or the like. Any medical pressure monitoring application may implement the bend compensation apparatus methods described herein to correct pressure measurements for the effects of strain on the pressure sensor module when the module is subjected to bending forces. Furthermore, any pressure monitoring application may utilize the apparatus and methods described for correcting a pressure measurement for bending-induced changes in a measured pressure signal that are based on capacitive changes of a capacitor.

FIG. 8 is a flow chart 700 of an alternative embodiment for establishing values of bending pressure error Pb. Instead of generating and storing constants used in an equation for computing Pb using measured values of DCref and Pc, a look-up table of Pb values can be generated prior to deploying the sensor module. The look-up table of Pb values is then stored in an IMD (or in association with an external processor receiving data from the IMD) and used for correcting a calculated pressure measurement for bending error.

At block 701, zero bending is applied to the sensor module using test apparatus 400. The applied pressure is varied at block 702 over a range of expected operating pressures. The temperature is controlled at a constant value, for example, 37 degrees C.

At block 704, DCpo is measured and the calculated pressure Pc is computed using DCpo at block 706. At block 708, the residual pressure Pr(flat) is computed as the difference between the calculated pressure Pc and the actual applied pressure Pa.

After obtaining Pr(flat) for a range of applied pressures at zero bending moment, a non-zero bending moment is applied to the sensor module at block 710. Bending moment may be varied over a range of bending moments by applying varying degrees of bending to the sensor module using test fixture 402, 422. Alternatively, a maximum bending moment may be applied. Pb is measured over a range of actual pressures at the maximum bending moment. Pb values between the applied zero bending and maximum bending for the range of applied pressures may then be interpolated. The resolution of Pb values will depend on the number of bending moments and pressures applied. A minimum of two pressures, for example a minimum and maximum expected operating pressure, and two bending moments, for example zero and maximum bending, are applied to obtain Pb values. Additional Pb values may then be interpolated or extrapolated from the measured Pb values.

At block 712, DCpo and DCref are measured. Pc is computed using the DCpo measurement at block 714. The residual pressure at the applied bending moment, Pr(moment), is computed as the difference between the calculated pressure Pc and the applied pressure Pa at block 716. The bending pressure error Pb is computed as the difference between Pr(flat) and Pr(moment) for a given applied pressure Pa.

Pb is stored in a look-up table of values for an array of measured DCref and calculated pressure Pc values at block 720. During sensor operation, the measured DCref and calculated Pc are used to look-up a value of Pb from the look-up table. Pb can then be subtracted from Pc to compute a corrected pressure measurement P. In an alternative embodiment, a look up table of values of Pb may be generated for an array of DCref and DCpo values.

Thus, apparatus and an associated method for providing bend compensated pressure measurements have been presented in the foregoing description with reference to specific embodiments. It is appreciated that various modifications to the referenced embodiments may be made without departing from the scope of the disclosure as set forth in the following claims.

CLAIMS:

1. A pressure sensing system for providing signals representative of a magnitude of pressure at a selected site, comprising:

a sensor module comprising

a first transducer producing a first signal having an associated first response to pressure and bending applied to the sensor module, and

a second transducer producing a second signal having an associated second response to pressure and bending applied to the sensor module, the second response different than the first response; and

a processor configured to determine a calculated pressure, a bending pressure error and a bend-compensated pressure in response to the first signal and the second signal.

2. The system of claim 1 wherein the first transducer is a capacitive transducer.

3. The system of claim 1 wherein the second transducer comprises a microelectromechanical system (MEMS) device.

4. The system of claim 1 wherein the processor is configured to determine the calculated pressure using the first signal, the calculated pressure comprising an error due to bending of the sensor module, and to determine the bending pressure error using the first signal and the second signal.

5. The system of claim 1 wherein the second transducer comprises:

a first component and a second component, the first component producing a first output having a first response to bending and temperature applied to the module and the second component producing a second output having a second response to bending and temperature applied to the module, the second component output response being different than the first component output response;

the processor configured to determine the second signal using the first output and the second output, and determine the bending pressure error using the first signal and the second signal.

6. The system of claim 1 wherein determining the bending pressure error comprises determining a moment fraction using the first signal and the second signal, the moment fraction being an estimate of a relative change in bending moment applied to the sensor module.

7. The system of claim 5 wherein the processor is configured to determine the calculated pressure from the first signal and one of the first component output signal and the second component output signal, and determine the bending pressure error using the calculated pressure and the second signal.

8. The system of claim 7 wherein determining the calculated pressure comprises determining a ratio using the first signal and one of the first component output signal and the second component output signal, and determining the second signal comprises determining a ratio using the first component output signal and the second component output signal.

9. The system of claim 5 wherein the sensor module further comprises a substrate and a hybrid circuit mounted on the substrate, wherein the first transducer comprises a first air gap capacitor, the first component comprises a second air gap capacitor, and the second component a capacitor incorporated in the hybrid circuit.

10. The system of claim 1 wherein the sensor module further comprises a substrate and a hybrid circuit mounted on the substrate, the hybrid circuit comprising a first component having a first output associated with a first

temperature response and a second component having a second output associated with a second temperature response different than the first temperature response;

the processor further configured to determine a temperature signal using the first output and the second output and determine the bending pressure error using the temperature signal.

11. The system of claim 10, further comprising a memory associated with the processor, the memory storing a measurement of the temperature signal determined at zero bending of the sensor module,

the processor further configured to determine the bending pressure error using a difference between the stored temperature signal measurement and a temperature signal measurement at an unknown bending moment of the sensor module.

12. The system of claim 1, further comprising:

a memory associated with the processor, the memory storing a calculated pressure determined at a zero bending moment of the sensor module and a coefficient determined during a calibration procedure when a bending moment corresponding to a known moment fraction is applied to the sensor module,

the processor configured to determine the bending pressure error using a difference between a calculated pressure determined at an unknown bending moment of the sensor module and the stored calculated pressure determined at the zero bending moment and the coefficient applied to the difference.

13. The system of claim 5, further comprising a memory associated with the processor, the memory storing a reference measurement determined using the second signal measured at a zero bending moment of the sensor module and a coefficient determined during a calibration procedure when a bending moment corresponding to a known moment fraction is applied to the sensor module,

the processor configured to determine the bending pressure error using a difference between the stored reference measurement and a measurement of the second signal at an unknown bending moment applied to the sensor module and the coefficient applied to the difference.

14. The system of claim 1 wherein the bend compensated pressure is determined as a difference between the calculated pressure and the bending pressure error.

15. The system of claim 1 further comprising a memory associated with the processor, the memory storing a look-up table of bending pressure error values for a range of the calculated pressure and a range of reference measurements stored for a range of known bending moments applied to the sensor module, the processor configured to determine a reference measurement from the second signal when an unknown bending moment is applied to the sensor module and determine the bending pressure error from the look-up table using the calculated pressure and a reference measurement.

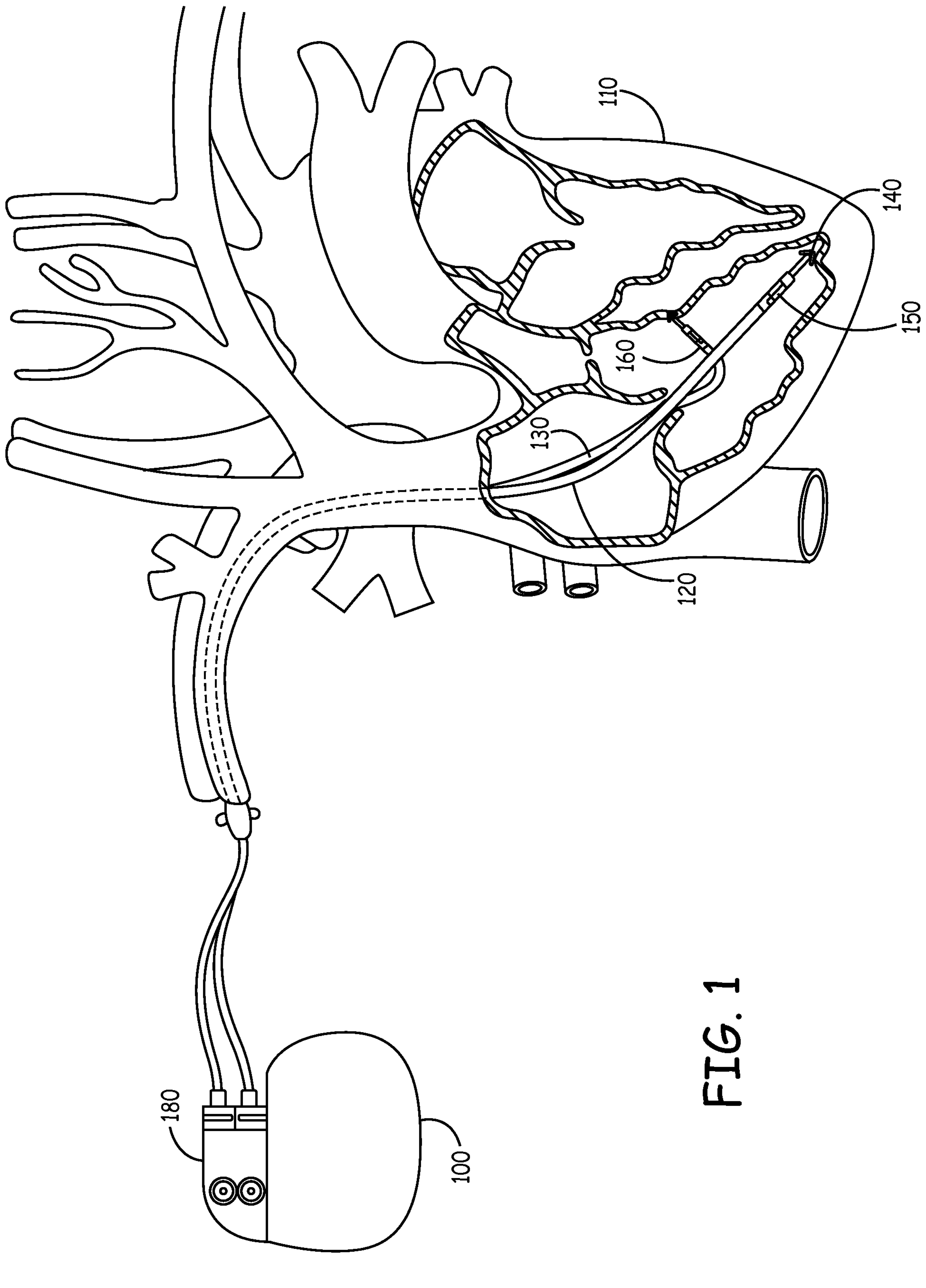

FIG. 1

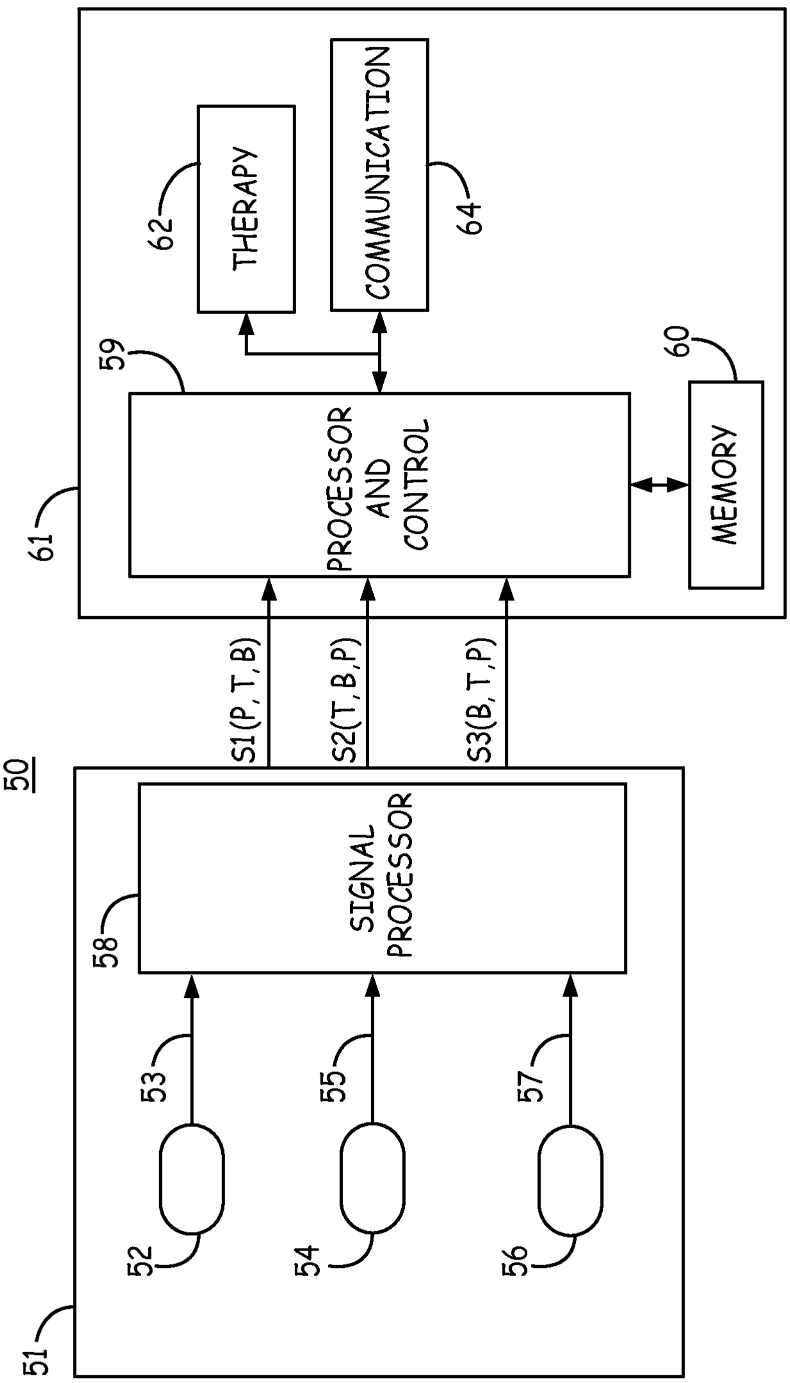
50
51
52
53
54
55
56
57
58
SIGNAL PROCESSOR
S1(P, T, B)
S2(T, B, P)
S3(B, T, P)
61
59
PROCESSOR AND CONTROL
60
MEMORY
62
THERAPY
COMMUNICATION
64

FIG. 2

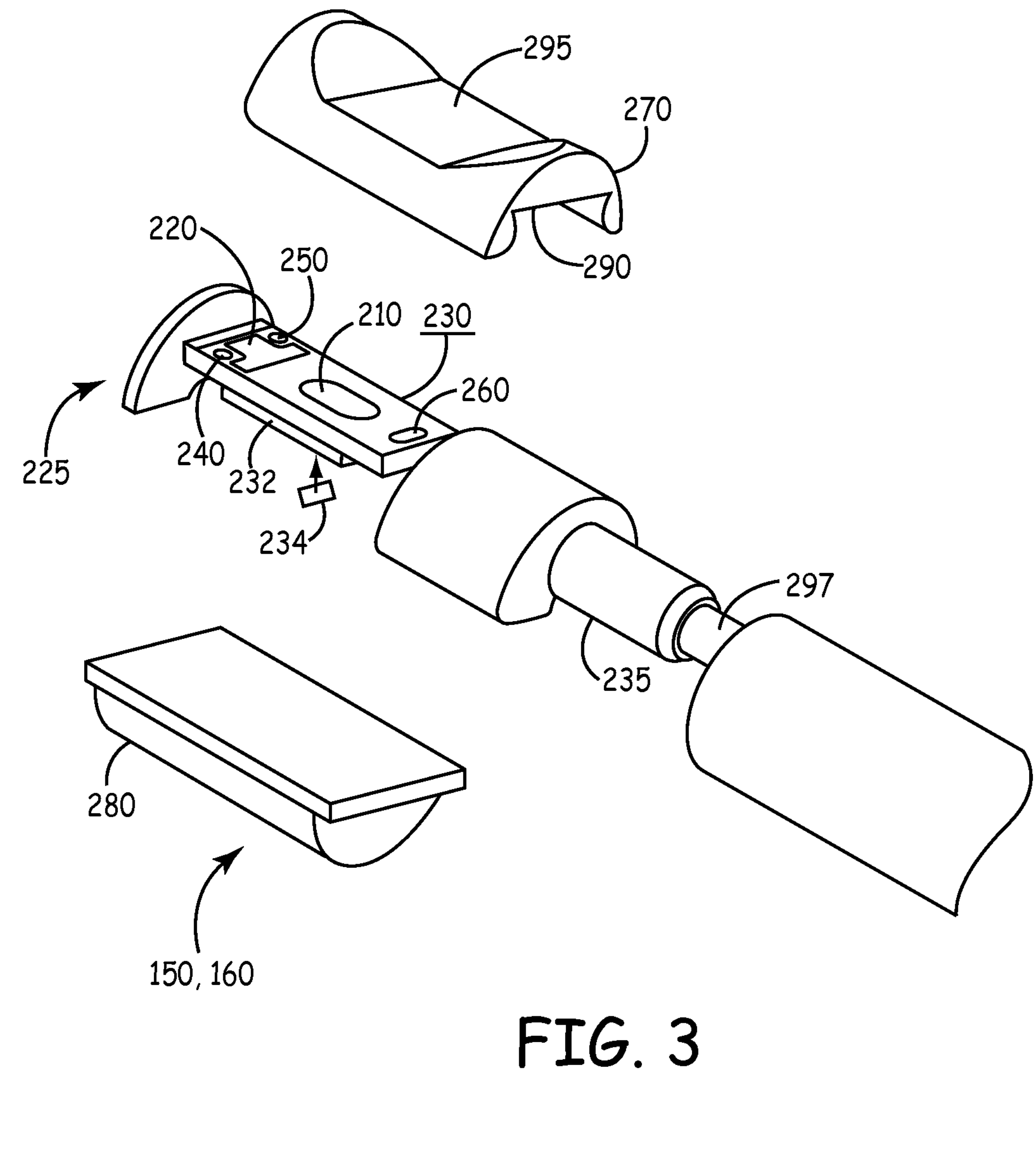
295
270
290
220
250
210
230
260
225
240
232
234
297
235
280
150, 160

FIG. 3

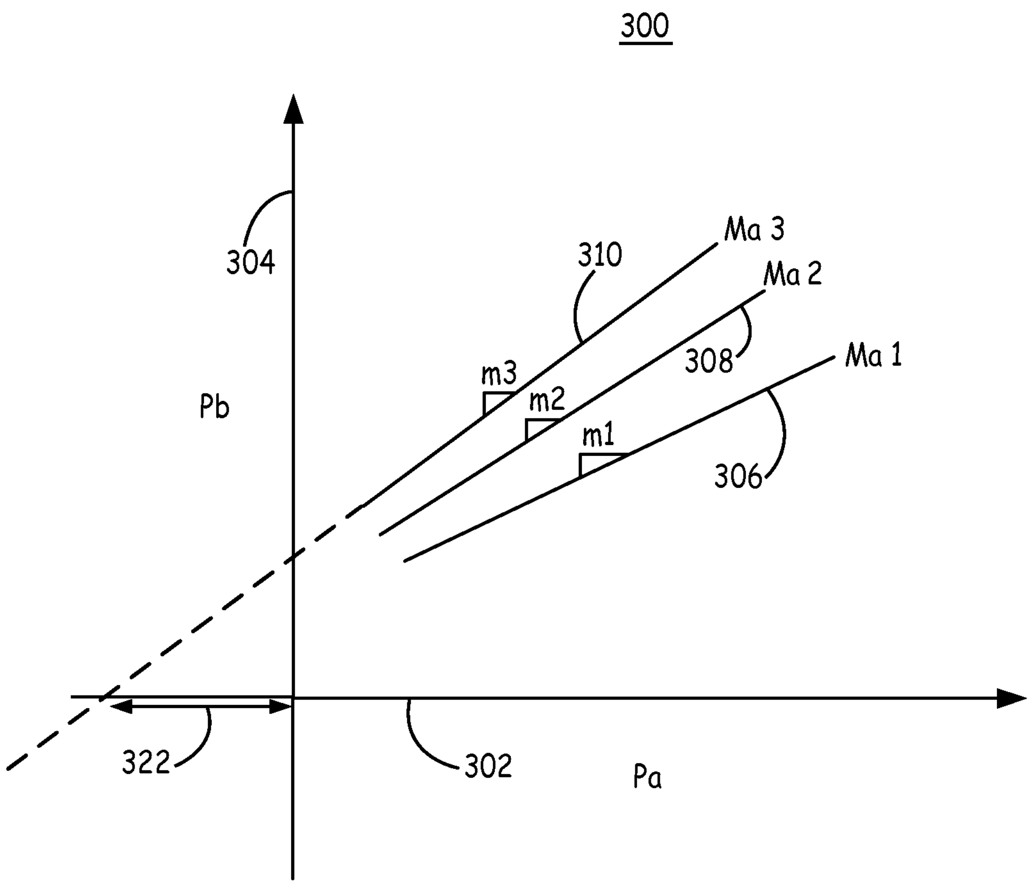

FIG. 4

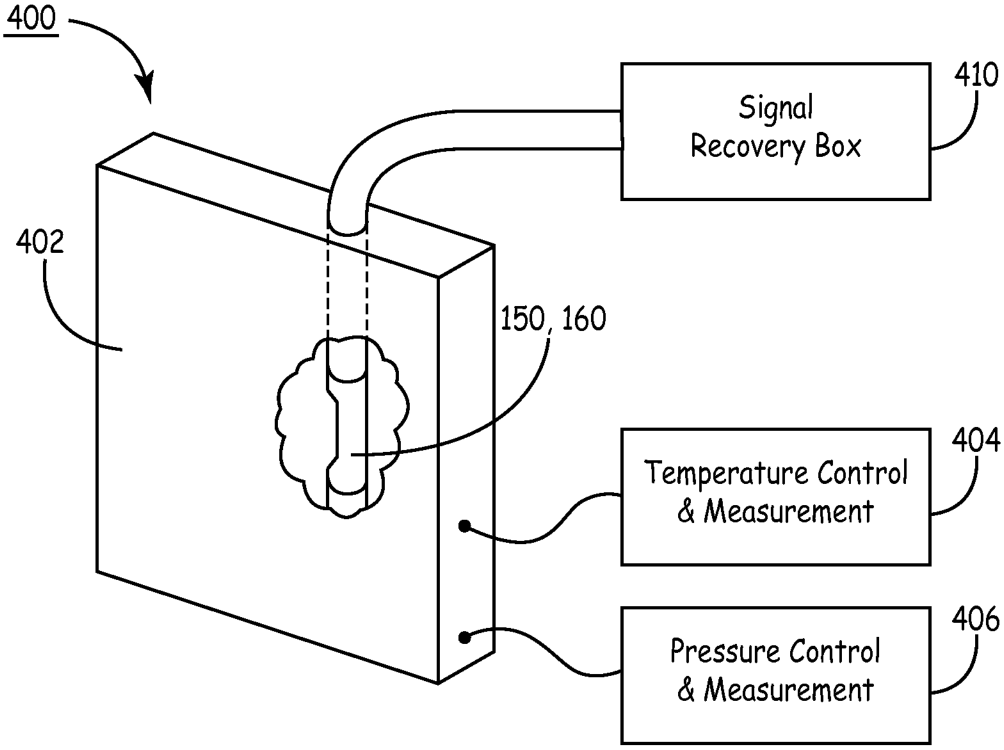
400
Signal Recovery Box
410
402
150, 160
Temperature Control & Measurement
404
Pressure Control & Measurement
406

FIG. 5A

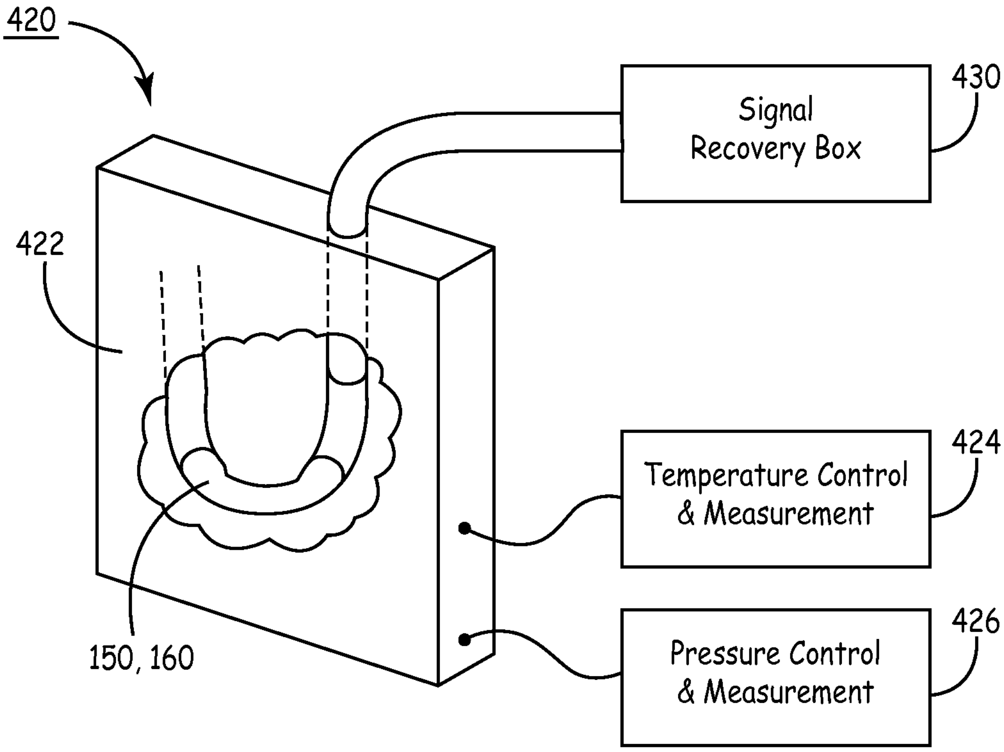
420
Signal Recovery Box
430
422
Temperature Control & Measurement
424
Pressure Control & Measurement
426
150, 160

FIG. 5B

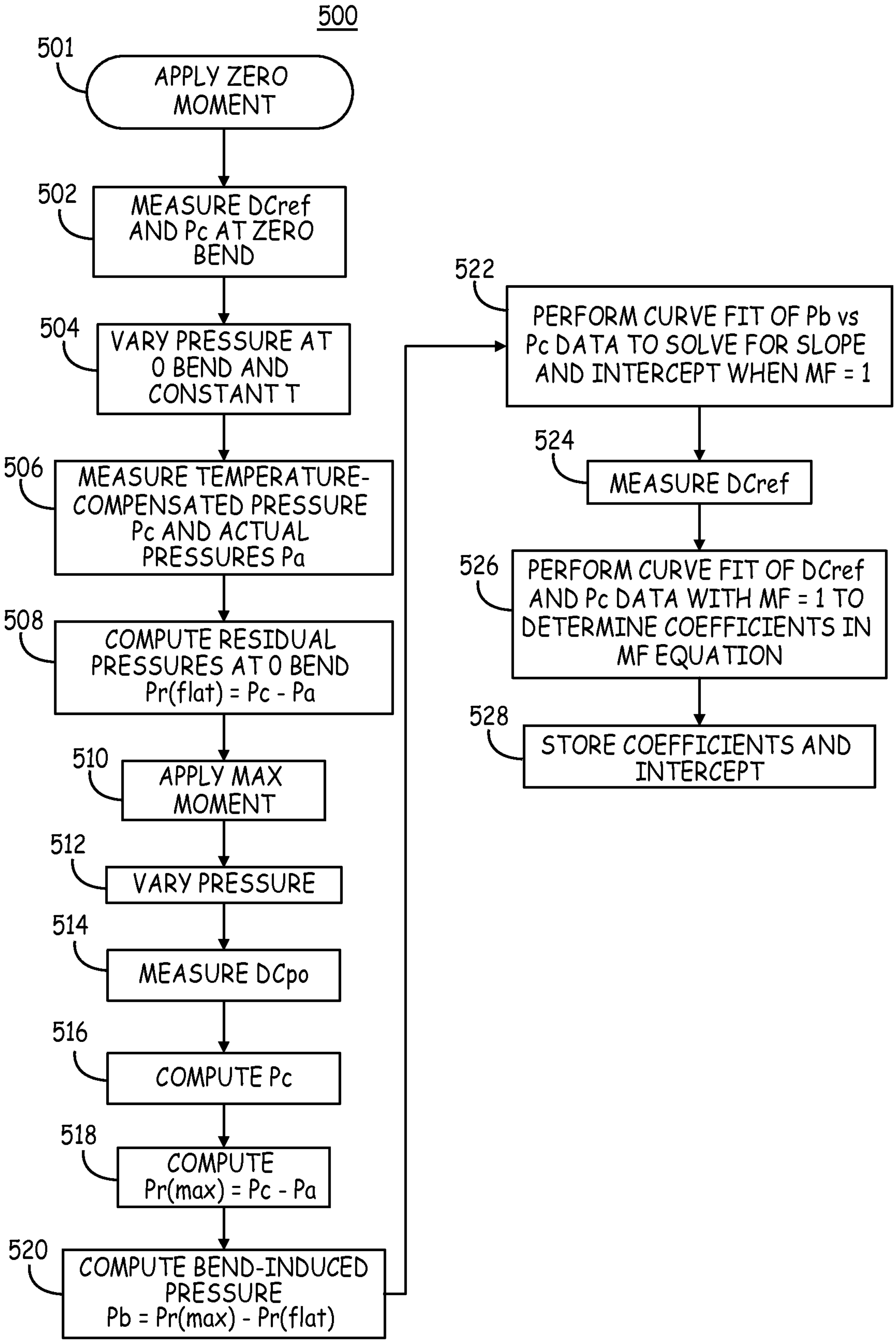
500
501
APPLY ZERO MOMENT
502
MEASURE DCref AND Pc AT ZERO BEND
504
VARY PRESSURE AT 0 BEND AND CONSTANT T
506
MEASURE TEMPERATURE-COMPENSATED PRESSURE Pc AND ACTUAL PRESSURES Pa
508
COMPUTE RESIDUAL PRESSURES AT 0 BEND Pr(flat) = Pc - Pa
510
APPLY MAX MOMENT
512
VARY PRESSURE
514
MEASURE DCpo
516
COMPUTE Pc
518
COMPUTE Pr(max) = Pc - Pa
520
COMPUTE BEND-INDUCED PRESSURE Pb = Pr(max) - Pr(flat)
522
PERFORM CURVE FIT OF Pb vs Pc DATA TO SOLVE FOR SLOPE AND INTERCEPT WHEN MF = 1
524
MEASURE DCref
526
PERFORM CURVE FIT OF DCref AND Pc DATA WITH MF = 1 TO DETERMINE COEFFICIENTS IN MF EQUATION
528
STORE COEFFICIENTS AND INTERCEPT

FIG. 6

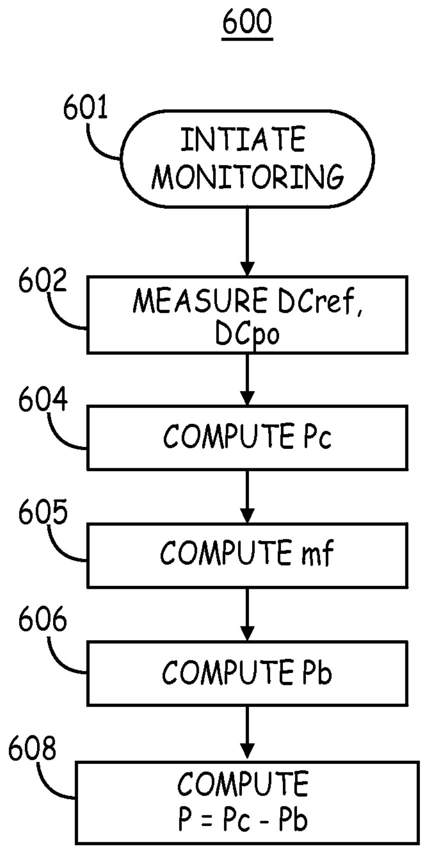
600
601
INTIATE
MONITORING
602
MEASURE DCref,
DCpo
604
COMPUTE Pc
605
COMPUTE mf
606
COMPUTE Pb
608
COMPUTE
P = Pc - Pb

FIG. 7

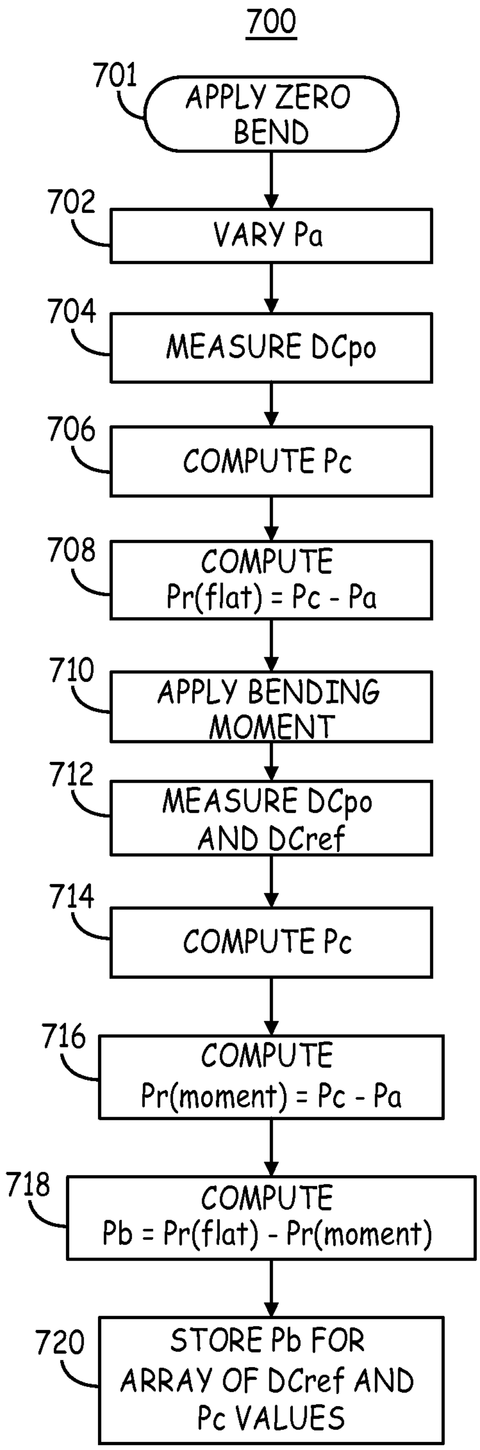
700
701
APPLY ZERO BEND
702
VARY Pa
704
MEASURE DCpo
706
COMPUTE Pc
708
COMPUTE Pr(flat) = Pc - Pa
710
APPLY BENDING MOMENT
712
MEASURE DCpo AND DCref
714
COMPUTE Pc
716
COMPUTE Pr(moment) = Pc - Pa
718
COMPUTE Pb = Pr(flat) - Pr(moment)
720
STORE Pb FOR ARRAY OF DCref AND Pc VALUES

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/030293

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01L1/14 G01L19/00
ADD.

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 practicable, 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.
A	US 2002/056324 A1 (PENZAR ZLATKO [DE] ET AL) 16 May 2002 (2002-05-16) abstract figures 1-4 paragraph [0004] - paragraph [0047] claims 1-11 -----	1-15
A	US 2009/167327 A1 (HARISH DIVYASIMHA [US]) 2 July 2009 (2009-07-02) the whole document -----	1-15

☐ Further documents are listed in the continuation of Box C.

☒ 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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 June 2012	05/07/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Daman, Marcel

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2012/030293

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2002056324 A1	16-05-2002	EP 1189048 A2	20-03-2002
		KR 20020022620 A	27-03-2002
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US 2009167327 A1	02-07-2009	NONE	