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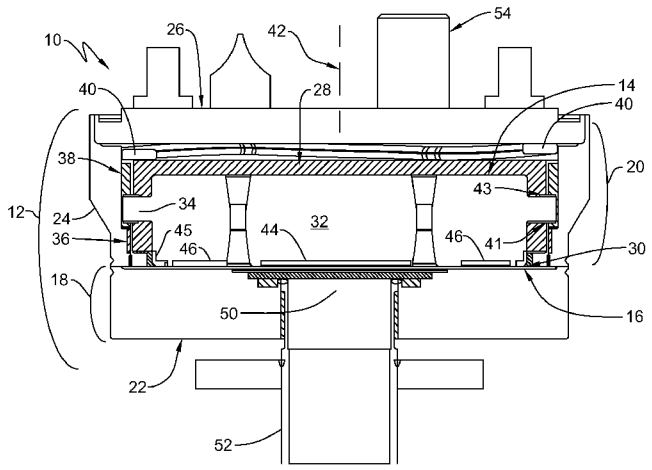


FIG. 1

(57) **Abstract**: An improved capacitive manometer, the manometer comprises: a diaphragm including (a) a common electrode and (b) an electrode structure including a center electrode and ring electrode, wherein the diaphragm is movable between (i) a zero position when the pressure on each side of the diaphragm is the same and (ii) a maximum differential position when the maximum measurable differential pressure is applied to the diaphragm, and a support structure arranged so as to support the diaphragm so that the diaphragm is constrained relative to the electrode structure, and the common electrode is spaced from and axially aligned with the center and ring electrodes relative to an alignment axis of the manometer; wherein the electrode structure is secured relative to the diaphragm at least three clamping locations angularly spaced around the alignment axis; and wherein the angle defined within each right plane containing a point of constraint of the diaphragm and the point of each clamping location relative to the plane of the diaphragm in the zero position is between 60° and 90° so as to reduce changes in electrode disk support height, enable smaller gaps and improved stability between the diaphragm and electrode structure. An additional improvement is provided by including a spacer ring including a plurality of tabs; and a clamp arranged to clamp the electrode structure to the spacer ring at the location of each of the tabs so as to define a plurality of equiangularly spaced, clamped locations around the alignment axis, so as to eliminate the possibility of an occasional spacer induced radial shear force and subsequent potential stick slip condition that could impact repeatability and stability.

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CAPACITIVE PRESSURE SENSOR

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is based upon and claims priority to U.S. provisional patent application 61/300,620, entitled "Capacitive Pressure Sensor," filed on February 2, 2010 in the name of Steven D. Blankenship, and assigned to the present assignee (Attorney docket number 056231-0984 (MKS-217PR)), which application is incorporated by reference in its entirety.

BACKGROUND

[0002] This disclosure relates generally to a capacitive pressure sensor, and more particularly to an improved sensor providing very precise and accurate measurements of pressure, particularly at very low (vacuum) pressures.

[0003] Pressure transducers have been employed in a myriad of applications. One such transducer is the capacitive manometer which provides very precise and accurate measurements of pressure of a gas, vapor or other fluid. Applications include precision control of vacuum based processes and semiconductor process control. Examples include semiconductor etch process and physical vapor deposition.

[0004] Capacitive manometers typically use (a) a flexible diaphragm forming or including an electrode structure and (b) a fixed electrode structure spaced from the diaphragm so as to establish capacitance there between. Variations in pressure on one side of the diaphragm relative to the pressure on the opposite side of the diaphragm causes the diaphragm to flex so that the capacitance between the electrode structure of the diaphragm and the fixed electrode structure varies as a function of this differential pressure. Usually, the gas or vapor on one side of the diaphragm is at the pressure being measured (Px), while the gas or vapor on the opposite side of the diaphragm is at a known reference pressure (Pr), the latter being at atmosphere or some fixed high or low (vacuum) pressure, so that the pressure on the measuring side of the diaphragm can be determined as a function of the capacitance measurement.

[0005] Many applications requiring extremely low pressures (high vacuum) have been and continue to be developed resulting in the need for capacitive manometers capable of

measuring such low pressures. However, increasing the sensitivity of capacitive manometers to provide very precise and accurate pressure measurements at low pressures poses several design challenges. In order to measure extremely low pressures (high vacuum), capacitive manometers require very narrow gaps between the flexible diaphragm and the fixed electrode structure so that they can detect small changes in pressure.

[0006] A drawback to using very narrow gaps is that smaller changes in the shape of the electrode gap unrelated to the measurement of differential pressure across the diaphragm are also detected. One of these detrimental changes to the electrode gap shape is a change in the electrode gap spacing. Although it is common practice in the industry to reduce the effect of change in the electrode gap spacing by using the dual electrode design approach, good control over the electrode gap spacing provides further enhanced stability of the sensor output. This is especially important when one measures extremely low pressures (extremely small diaphragm deflections) enabled by the use of narrow electrode gaps.

[0007] Capacitance measurements are based on the well known equation for parallel plate capacitance C:

$$C= e_r e_o A/s,$$

where C is the capacitance between two parallel plates,
e_o is the permittivity of free space,
e_r is the relative permittivity of the material between the plates (for vacuum, $e_r = 1$),
A is the common area between the plates, and
s is the spacing between the plates.

[0008] Based on this equation, one can derive the relationship that the fractional change in capacitance is equal to the negative of the fractional change in electrode gap spacing for each measuring electrode ($\Delta C/C = - \Delta S/S$).

[0009] It can then be readily seen that it is critical to maintain good control over the electrode gap spacing in order to provide stable control over the capacitance of each measuring electrode. In a simple dual electrode design, these effects are balanced to a first order at zero differential pressure for a flat diaphragm and electrode structure (each having different real values of flatness and inclination deviation from true plane) for a given

electrical measurement technique such as with any number of commonly used bridge designs and other electrical measuring methods. Since, the sensor is configured to measure extremely low pressures (extremely small diaphragm deflections), just balancing the electrodes without making a stable electrode gap is not enough to reduce the uncertainty of the pressure measurement to adequately low levels in order to accomplish stable detection of the smallest pressures.

[00010] There is a need for a capacitive pressure manometer capable of improved electrode gap stability control at low pressure measurements so as to improve the measurement capabilities of the manometer at lower pressures.

[00011] Reference is made to U.S. Patent Nos.7757563; 7706995; 7624643; 7451654; 7389697; 7316163; 7284439; 7201057; 7155803; 7137301; 7000479; 6993973; 6909975; 6735845; 6672171; 6568274; 6105436; 6029525; 5965821; 5942692; 5932332; 5911162; 5808206; 5625152; 4785669 and 4,499,773; and U.S. Patent Published Application Nos. 20090255342; 20070023140; 20060070447; 20060000289; 20050262946; 20040211262; 20040099061; all assigned to the present assignee.

SUMMARY

[00012] In accordance with one aspect of the improved capacitive manometer, the manometer comprises:

a diaphragm including (a) a common electrode and (b) an electrode structure including a center electrode and ring electrode, wherein the diaphragm is movable between (i) a zero position when the pressure on each side of the diaphragm is the same and (ii) a maximum differential position when the maximum measurable differential pressure is applied to the diaphragm, and

a support structure arranged so as to support the diaphragm so that the diaphragm is constrained relative to the electrode structure, and the common electrode is spaced from and axially aligned with the center and ring electrodes relative to an alignment axis of the manometer;

wherein the electrode structure is secured relative to the diaphragm at at least three clamping locations angularly spaced around the alignment axis; and wherein the angle defined within each right plane containing a point of constraint of the diaphragm and the

point of each clamping location relative to the plane of the diaphragm in the zero position is between 60° and 90° so as to reduce changes in electrode disk support height, enable smaller gaps and improved stability between the diaphragm and electrode structure.

[00013] In accordance with another aspect of the improved manometer, the manometer comprises:

a diaphragm including (a) a common electrode and (b) an electrode structure including a center electrode and ring electrode, wherein the diaphragm is movable between (i) a zero position when the pressure on each side of the diaphragm is the same and (ii) a maximum differential position when the maximum measurable differential pressure is applied to the diaphragm;

a support structure arranged so as to support the diaphragm so that the common electrode is spaced from and axially aligned with the center and ring electrodes relative to an alignment axis of the manometer;

a spacer ring including a plurality of tabs; and

a clamp arranged to clamp the electrode structure to the spacer ring at the location of each of the tabs so as to define a plurality of equiangularly spaced, clamped locations around the alignment axis.

[00014] These, as well as other components, steps, features, objects, benefits, and advantages, will now become clear from a review of the following detailed description of illustrative embodiments, the accompanying drawings, and the claims.

BRIEF DESCRIPTION OF DRAWINGS

[00015] In the drawings:

[00016] Fig. 1 is a cross sectional view of one embodiment of a sensor, along the axis of a sensor, incorporating the improvements described herein;

[00017] Fig. 2 is a more detailed, cross sectional view of a portion of the embodiment of Fig. 1, showing geometric details of improvement;

[00018] Fig. 3 is a geometric diagram for illustrating some of the geometric features of the Fig. 1 embodiment;

[00019] Fig. 4 is a top view of a spacer used in the sensor;

[00020] Fig. 5 is a more detailed, axial cross sectional view through a portion of the sensor;

[00021] Fig. 6 is a top view of the spacer used in the improvement detailed in Fig. 7; and

[00022] Fig. 7 is a more detailed, cross sectional view of a portion of the embodiment of Fig. 1, showing details of an additional improvement.

[00023] The drawings disclose illustrative embodiments. They do not set forth all embodiments. Other embodiments may be used in addition or instead. Details which may be apparent or unnecessary may be omitted to save space or for more effective illustration. Conversely, some embodiments may be practiced without all of the details which are disclosed. When the same numeral appears in different drawings, it refers to the same or like components or steps.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[00024] Illustrative embodiments are now discussed. Other embodiments may be used in addition or instead. Details which may be apparent or unnecessary may be omitted to save space or for a more effective presentation. Conversely, some embodiments may be practiced without all of the details which are disclosed.

[00025] Capacitance manometer 10 shown in Fig. 1 includes a housing 12 for supporting fixed electrode structure 14 and flexible diaphragm 16. The housing 12 can include process housing section 18 and reference housing section 20, the two housing sections being divided by the flexible diaphragm 16. The process housing section 18 includes Px cover 22. The reference housing section 20 includes a ring 24 and Pr cover 26. In the illustrated embodiment, the ring 24 of the reference housing section 20 includes a hollow cavity 28 for receiving and supporting the fixed electrode structure 14 and flexible diaphragm 16 in a predetermined relationship so that they are maintained in a stable, spaced relationship separated by a predetermined sized gap 30. As shown, the fixed electrode structure 14 includes a substrate 32 made from an electrically insulative material, such as a ceramic material, and formed into a rigid, non-flexible structure. A lip 34 can be provided at the periphery of the substrate 32 for engaging a shoulder of a spacer ring 36 provided in the housing 12, and secured in place with locking ring 38 and a wave spring 40. One or more

thin spacers 41 may be used to conveniently set the electrode gap spacing to a predetermined value. In addition, one or more thin spacers 43 may be used to conveniently set the wavespring cavity height to a predetermined value in order to set the clamping force to a predetermined value consistent with the design objectives of overpressure capability and the frictional binding forces necessary to clamp the electrode disk structure in a stable geometric relationship with the common electrode diaphragm 16, housing ring 24 and radially compliant spacer ring 36. In one embodiment the size and shape of the substrate 32 can be such that when positioned between the spacer ring 36 and the locking ring 38, the substrate will be precisely positioned within the housing 12 so that the center of the fixed electrode structure 14 is centered on central axis 42, with adequate radial spacing between the substrate 32 and housing ring 24 and spacer ring 36. This effectively reduces the stray capacitance between the electrodes and the metal housing 24 as well as the change in stray capacitance for a small change in radial position of the electrode disk. The wave spring 40 is designed to contact and exert an axial force on the lip 34 of the fixed electrode structure 14 through the radially flexible, locking ring 38 and thin spacer 43 at at least three places, equiangularly spaced in 120° around the axis 42. Similarly, the wave spring 40 is designed to contact and exert a counter force on the Pr cover 26 at at least three locations displaced 120° around the axis 42, and 60° from the locations of contact with the lip 34 of the fixed electrode structure 14 when the manometer 10 is completely assembled. The fixed electrode structure 14 also includes a center electrode 44 concentrically positioned relative to the center axis 42, and an outer electrode 46 preferably in the form of a ring concentric with the center electrode 44 and the center axis 42.

[00026] Flexible diaphragm 16 is either made of or is provided with a layer or coating of suitable conductive material so as to form a common electrode. Diaphragm 16 is secured to the housing so as create process pressure (Px) chamber 50 on one side of the diaphragm and reference pressure (Pr) chamber which includes gap 30 on the other side of the diaphragm. It should be noted that paths can be provided between the flexible diaphragm and the reference housing section 20 (through, for example, reduced thickness parts of etched spacers) that allow pressure to be equalized between the gap 30 and the rest of the Pr portion of the housing. The diaphragm is secured to the housing so as to seal the process pressure chamber 50 from the gap 30 of the reference pressure chamber so that the two chambers can be maintained at different pressures. The gas or vapor to be measured can be introduced into

process chamber 50 through a gas inlet 52, defined in part of the Px cover 22. Under normal operation, capacitance manometer 10, functions as an absolute pressure sensor and the reference cavity 28 (and electrode gap 30) are sealed off under vacuum; and in one embodiment the reference housing section 20 is provided with a non-evaporable getter vacuum pump 54 in order to provide a very low pressure (well below the minimum resolution of the instrument) in the reference cavity 28 and electrode gap 30. This is the absolute vacuum reference against which the process pressure is compared. In this mode the differential pressure across the diaphragm is an absolute pressure measurement. Another possible construction method is to use a second gas inlet in place of getter assembly 54 in reference housing section 20 for introducing a gas at a reference pressure into the reference chamber from a source, or at ambient pressure from the surrounding atmosphere. Thus, reference chamber including gap 30 contains a gas or vapor at a predefined reference pressure. It should be noted that the two chambers can be reversed so the reference pressure chamber functions as the process pressure chamber, and the process pressure chamber functions as the reference pressure chamber, where for example that process gas is inert with respect to the electrode and other materials provided in the chamber including the gap 30.

[00027] Center and outer electrodes 44 and 46 are preferably flat electrodes disposed on the surface of the substrate 32 so that the electrodes preferably are of uniform thickness and all lie in the same plane. Suitable electrical leads (not shown) are respectively provided for the center and ring electrodes 44 and 46. In one embodiment the common electrode diaphragm 16 is formed integrally with housing section 20 which is the electrical connection. Another possible construction could be with an electrical lead (not shown) provided for the common electrode of diaphragm 16. In the preferred embodiment, electrical guarding 45 on the substrate 32 is provided for the measuring electrodes in order to control electrode fringe capacitance, minimize stray capacitance to the housing 20 and condition the dual electrode capacitance balance at zero differential pressure. The leads are suitably connected to a capacitance measurement device (not shown).

[00028] Diaphragm 16 is preferably secured within the housing so that the plane defined by the common electrode is substantially parallel to the plane of the center and outer electrodes 44 and 46 and electrical guard 45 when the pressure is the same on both sides of the diaphragm, i.e., there is zero differential pressure. When a gas or vapor introduced through

inlet 52 into the process pressure chamber 50 is at a different pressure from the reference pressure in reference chamber, the diaphragm will flex and the capacitance between the common electrode of the diaphragm 16 and the center electrode 44 will define one capacitance different from the capacitance between the common electrode of the diaphragm 16 and the outer electrode 46. Electrical guard 45 reduces the parasitic stray capacitance between the electrodes and metal housing by blocking the path for the strays in this region. It should be appreciated that by utilizing a large, uniform gap between the major diameter of the substrate 32 and housing ring 24 as shown in Fig. 1; and by placing an electrical guard 45 at the periphery of the electrode disk as shown in Fig. 1, that any changes in these strays due to potential slight lateral displacements of the electrode disk are a much smaller fraction of the sensor capacitance stroke and thus allow for much more precise measurements of differential pressure without introducing changes in the sensor output that are unrelated to the pressure measurement. The pressure in the process pressure chamber 50 is thus a function of the measured capacitance between the common electrode of the diaphragm 16 and the center electrode 44 and the measured capacitance between the common electrode of the diaphragm 16 and the outer electrode 46.

[00029] As such, predefined capacitances are established between the common electrode structure of the diaphragm and each of the center and outer electrodes 44 and 46, such that when the differential pressure on the diaphragm is zero, the structure defines a measurable "base" capacitance. In practice, the base capacitance is the sum of the active capacitance at the electrode gap and the stray capacitance to the housing. In addition, when the diaphragm is exposed to the maximum measurable differential pressure the common electrode structure of the diaphragm will be deflected relative to the electrodes 44 and 46 so as to define the "stroke" of the sensor. One measure of the stroke of the sensor is the "capacitance" stroke which is equal to the difference between the center electrode 44 capacitance to the common electrode of the diaphragm 16 minus the outer electrode 46 capacitance to the common electrode of the diaphragm 16 between the zero differential pressure and full scale differential pressure. The maximum change in the diaphragm deflection from zero differential pressure to the full scale value is the span of the diaphragm.

[00030] One of the key parameters that define the range of the sensor is the electrode gap spacing which is equal to the distance between the plane of the common electrode structure

of the diaphragm 16 (when in the relaxed zero position) and the plane of center and outer electrodes 44 and 46, indicated at gap 30, with very low pressure (vacuum reference pressure) in the reference chamber of the housing portion 20 (which includes the gap 30), at pressures below the resolution of the instrument in the process chamber 50. For a given sensor construction, the "base" capacitance is established by the electrode gap spacing. Capacitance manometers designed for measuring very low pressures (high vacuum) must be very sensitive to and be capable of measuring very small changes in pressure. As a result the spacing between the plane of the common electrode of the diaphragm 16 and the plane of the center and outer electrodes 44 and 46 must be very small so that small changes in the diaphragm deflection can be detected in response to small changes in the differential pressure.

[00031] Making the gap 30 smaller to make the manometer 10 more sensitive for measuring smaller differential pressures increases the sensitivity to changes in the shape of the electrode gap which are unrelated to the measurement of differential pressure across the diaphragm. One of these detrimental changes to the electrode gap shape is a change in the electrode gap spacing. Although it is common practice in the industry to reduce the effect of change in the electrode gap spacing by using the dual electrode design approach, good control over the electrode gap spacing provides further enhanced stability of the sensor output. This is especially important when one measures extremely low pressures enabled by the use of narrow electrode gaps.

[00032] With the current need to measure smaller and smaller pressures, current capacitive pressure sensors do not possess the inherent electrode gap stability required for stable measurement of extremely low pressures.

[00033] The present disclosure describes a capacitive manometer in which the structure of the device provides greater stability between the diaphragm and electrodes allowing for even smaller gaps and measurements of lower differential pressures. In providing such a structure the dimensional stability of the sensor electrode gap is improved, especially the electrode disk registration with respect to the diaphragm under normal operating conditions and especially against external influences such as temperature, barometric pressure, overpressure, mechanical shock and vibration. Key sensor parameters that are addressed with the new structure include electrode gap spacing, electrode tilt and electrode distortion. The improvements provide enhanced capabilities allowing for the transducer (i.e., the sensor and

the signal conditioning electronics capable of providing a high level dc output - not shown) to require less electrical gain and exhibit less electrical noise (as a result of less electrical gain) and have better zero stability performance when compared to prior art sensors for measuring comparable full scale pressure ranges. And as mentioned, the sensor is capable of providing lower pressure range instruments with less electrical noise and better overall zero stability performance, including but not limited to reduced barometric pressure sensitivity (at zero and at pressure), reduced temperature coefficients and reduced zero drift.

[00034] Prior efforts to achieve a stable, reduced gap between the electrodes and the diaphragm include making the Pr ring housing wall somewhat thinner to in an attempt to bring the electrode disk lip contact with the Pr ring step closer to the diaphragm support. But making the Pr housing wall thinner to bring the step closer to the diaphragm support weakens the sensor housing (Pr ring wall), allows more distortion during the manufacturing process and further weakness the Pr ring step against distortion caused by the forces induced by thermal differential expansion, and by changes in the surface loads on the sensor driven by barometric pressure and any external mechanical loading.

[00035] In Fig. 2, details of a prior art manometer compared to the new improved manometer are shown. In the prior art, diaphragm 74 is secured to ring 60 around its periphery at a loci of points, one of which is indicated at 62. In a similar manner the fixed electrode structure 64 can be held in place by a annular disk (lock disk) (not shown) applied to the peripheral edge of the electrode structure 64 and held in place by the axial force 68 provided by the wave spring (not shown in Fig. 2) at at least three points, one of which is indicated at 70. As seen, the construction defines a solid angle formed between locus point 62 where the diaphragm is attached to the ring 60 and the locus point 70 where the axial force 68 is applied to maintain the electrode structure in place. This angle is shown as 45°. The radial distance from the axis (such as axis 42 in Fig. 1) of the sensor of the loci of points where the diaphragm is attached (such as point 62) is the same, 360° around the axis.

[00036] The advantages of the present approach are achieved by constructing and securing the diaphragm and the electrode structure within the manometer so as to place the diaphragm boundary (and support) 72 more directly under the applied clamping load in order to make a more direct support as opposed to a cantilevered (indirect) support. The resulting improved geometry can also be described in more analytic terms by defining the angle α (see Figs. 2

and 3) of the line drawn from the diaphragm boundary support 72 to the intersection of the Pr housing support for the electrode disk also at the interface 70 between the Pr housing and spacer 66, relative to the plane of the diaphragm 74. The benefits of this geometry are two fold. First and most importantly when changes in barometric pressure or other externally applied loads to the surface of the Px cover occur, the cover bows under this load and the outer diameter of the cover at the diaphragm boundary dilates (increases in size) for a positive pressure against the external surface. This dilation distorts the Pr housing and essentially causes a minute rotation of the lower section of the Pr housing which may be approximated by the change in the angle α at 82 (see Fig. 2). As mentioned above, this angle in at least one prior art manometer is at about 45°. The improved manometer is designed so as to increase this angle to a value with a range of about 60° to 90°. As can be seen in Fig 3, for small angles, such as in prior art example (about 45°), for a change in this angle, there is a relatively large change ΔY_1 in the height of the support. For large angles as in one construction of one embodiment of the present design (about 75°) for the same change in the support angle there is a relatively small change ΔY_2 in the support height for the fixed electrode structure. Reducing this change in the support height of the electrode disk relative to the diaphragm translates into improved electrode gap spacing stability. Secondly, the benefits of the new geometry provide a stiffer support so that any changes in the applied axial load at the top of the electrode disk result in smaller changes in the support height and subsequently improved electrode gap stability.

[00037] Wave spring forces such as those provided by wave spring 40 (of Fig. 1) as shown at 68 in Fig. 2, may vary due to changes in temperature, changes in the wave spring mounting and seating in the sensor cavity which may be induced by mechanical shock and vibration, and also changes in the wave spring cavity height that result from deflection of the Pr cover 26 (shown in Fig. 1) due to barometric pressure changes. The improved structure disclosed herein provides improved dimensional stability and greater axial stiffness of the electrode disk support (housing ring 24 and spacer ring 36 of Fig. 1) and reduces changes in the electrode gap spacing that are due to variations in the force exerted by the wave spring 40.

[00038] In the improved sensor, the diaphragm is thus constructed and secured so as to place the diaphragm boundary (at 72 in Fig. 2) more directly under the applied clamping load (shown at 68) in order to make a more direct support as opposed to a cantilevered (indirect)

support. This has the effect of increasing the angle between the two sets of loci of points from 45° to an angle within a range of angles that significantly reduce the amount of axial movement between the diaphragm and the electrode disk support (housing ring 24 and spacer ring 36 of Fig. 1). The range of angles that provide the best result are between about 60° up to 90°. The actual choice within this range is a design compromise between maximizing the electrode gap stability versus making an easy to manufacture, high quality stretched diaphragm. One compromise is where the angle α at 82 (Figs. 2 and 3) is about 75°.

[00039] One manufacturing technique for increasing the angle is to make the ring in two parts, one (Pr ring 24) with a reduced diameter near the diaphragm and the other (spacer ring 36) as shown in Fig. 1. The two parts can be secured together by welding or other suitable means. This provides the necessary geometry for the invention and allows for easy assembly of the diaphragm 16 relative to the sensor housing (Pr ring 24 and Px cover 22).

[00040] A further improvement relates to a radially compliant spacer. Fig. 5 shows a prior art approach in which the internal sensor parts are dropped in place and the raised pads (where the clamping loads are applied) 116 are only lined up circumferentially, not radially relative to the central axis 100. A manometer could be assembled under conditions such as shown in Fig. 5, where the spacer 102 is just touching the internal wall 104 of the Pr ring 106 at the location 108, where one of the (3) clamping loads (at the raised pad) are transmitted from the wave spring (not shown). As seen the portion of the electrode structure at location 108 is spaced from the wall 104, while the electrode structure 180° opposite location 108 is touching the internal wall 104 of the Pr ring 106 at location 110.

[00041] With this misalignment in the prior art sensor, when temperature drops and the Pr ring 106 shrinks faster and further than the electrode structure 112, since the coefficient of thermal expansion of the Pr ring is greater than that of the electrode disk it induces mechanical strain in the sensor. The differential contraction creates a large, radial shear force at the location of the clamping load 107 (shown on the right side of Fig. 5), and can exceed the frictional clamping force between the electrode structure 112 and the spacer 102, causing the electrode disk to slip to a new position. Upon returning back to the previous temperature in this new assembled position the electrode disk 112 experiences a large radial force at point 107 that is in the opposite direction. This force couple distorts the sensor, including the

electrode gap and causes a change in the diaphragm tension. These changes have a detrimental effect on the accuracy of the manometer.

[00042] The improved sensor described above utilizes a radially compliant spacer ring (118 as shown in Figs. 6 and 7) which is designed so that only the radial locating tabs 120 may touch the Pr ring bore, and the raised pads (where the clamping loads are applied) 122 always have a radial gap to the Pr ring bore. So, when temperature drops, if a radial locating tab 120 is touching the wall of the Pr ring, then the Pr ring drives the locating tab of the spacer radially inward at a location that is 60° removed from the raised pads which support the electrode disk as shown in the right hand side of the sectional view in Fig. 7. The 60° segments of the thin compliant spacer are flexible and deform relatively easily so that only small lateral forces may be applied to the clamped joint (indicated at 140 at the right side of Fig. 6). This eliminates any possibility of the occasional force couple distortion of the sensor and subsequent changes in the accuracy of the manometer.

[00043] As shown in Fig. 6 the radially compliant spacer 118 includes radial tabs 120 located so that it centers the spacer when disposed in the manometer. Three tabs are shown, angularly spaced 120° apart. The tabs 120 are displaced in between (in the example given, 60°) the locations 122 (three in the example) where the clamping load is applied to the electrode structure.

[00044] As shown in Fig. 7, the radially compliant spacer 118 is installed in the Pr ring 130 so that there is always a space between the wall 132 of the Pr ring 130, and pads where the clamping force is applied. The spacer may still occasionally touch the Pr ring wall at the radial locating tabs (60° removed from the sectional view shown in Fig. 7). However, since there is a flexible 60° segment on either side of the locating tab made of thin spacer material that is not clamped and free to move, the shear force applied to the electrode disk at the mounting pad is greatly reduced.

[00045] It should be evident that various changes can be made to the embodiments described without departing from the scope of the claims. For example, while the embodiment described utilizes a dual electrode with a guard, other electrode configurations are possible, including a single electrode structure, and a multiple electrode structure with more than two electrodes. The embodiment shown is illustrative and any number of

conductors and conductor patterns may be on the electrode disk. Further the electrical guard and extra conductors can be maintained at signal ground, or at some other fixed potential. Further the guard can be actively driven. If actively driven, it is preferable that the guard voltage and phase match the instantaneous voltage and phase of the physically adjacent electrode.

[00046] The components, steps, features, objects, benefits and advantages which have been discussed are merely illustrative. None of them, nor the discussions relating to them, are intended to limit the scope of protection in any way. Numerous other embodiments are also contemplated. These include embodiments which have fewer, additional, and/or different components, steps, features, objects, benefits and advantages. These also include embodiments in which the components and/or steps are arranged and/or ordered differently.

[00047] Unless otherwise stated, all measurements, values, ratings, positions, magnitudes, sizes, and other specifications which are set forth in this specification, including in the claims which follow, are approximate, not exact. They are intended to have a reasonable range which is consistent with the functions to which they relate and with what is customary in the art to which they pertain.

[00048] All articles, patents, patent applications, and other publications which have been cited in this disclosure are hereby incorporated herein by reference.

[00049] The phrase "means for" when used in a claim is intended to and should be interpreted to embrace the corresponding structures and materials which have been described and their equivalents. Similarly, the phrase "step for" when used in a claim is intended to and should be interpreted to embrace the corresponding acts which have been described and their equivalents. The absence of these phrases in a claim mean that the claim is not intended to and should not be interpreted to be limited to any of the corresponding structures, materials, or acts or to their equivalents.

[00050] Nothing which has been stated or illustrated is intended or should be interpreted to cause a dedication of any component, step, feature, object, benefit, advantage, or equivalent to the public, regardless of whether it is recited in the claims.

[00051] The scope of protection is limited solely by the claims which now follow. That scope is intended and should be interpreted to be as broad as is consistent with the ordinary

meaning of the language which is used in the claims when interpreted in light of this specification and the prosecution history which follows and to encompass all structural and functional equivalents.

What is claimed is:

1. A capacitive manometer comprising:

a diaphragm including (a) a common electrode and (b) an electrode structure including a center electrode and ring electrode, wherein the diaphragm is movable between (i) a zero position when the pressure on each side of the diaphragm is the same and (ii) a maximum differential position when the maximum measurable differential pressure is applied to the diaphragm, and

a support structure arranged so as to support the diaphragm so that the diaphragm is constrained relative to the electrode structure, and the common electrode is spaced from and axially aligned with the center and ring electrodes relative to an alignment axis of the manometer;

wherein the electrode structure is secured relative to the diaphragm at at least three clamping locations angularly spaced around the alignment axis; and wherein the angle defined within each right plane containing a point of constraint of the diaphragm and the point of each clamping location relative to the plane of the diaphragm in the zero position is between 60° and 90° so as to reduce changes in electrode disk support height, enable smaller gaps and improved stability between the diaphragm and electrode structure.

2. A capacitive manometer according to claim 1,wherein the support structure includes a substrate configured to support the electrode structure.

3. A capacitive manometer according to claim 2, wherein the support structure includes a spring configured to secure the substrate relative to the diaphragm at the at least three locations.

4. A capacitive manometer according to claim 3, wherein the spring is a wave spring configured so as to apply force on the substrate at a right angle to the plane of the diaphragm in the zero position.

5. A capacitive manometer comprising:

a diaphragm including (a) a common electrode and (b) an electrode structure including a center electrode and ring electrode, wherein the diaphragm is movable between (i) a zero position when the pressure on each side of the diaphragm is the same and (ii) a

maximum differential position when the maximum measurable differential pressure is applied to the diaphragm;

a support structure arranged so as to support the diaphragm so that the common electrode is spaced from and axially aligned with the center and ring electrodes relative to an alignment axis of the manometer;

a spacer ring including a plurality of tabs; and

a clamp arranged to clamp the electrode structure to the spacer ring at the location of each of the tabs so as to define a plurality of equiangularly spaced, clamped locations around the alignment axis.

6. A capacitive manometer according to claim 5, wherein the electrode structure is clamped to the spacer ring at three locations spaced apart 120° from one another, and the spacer ring includes three tabs equiangularly spaced 120° from one another, and positioned 60° from the adjacent clamped locations.

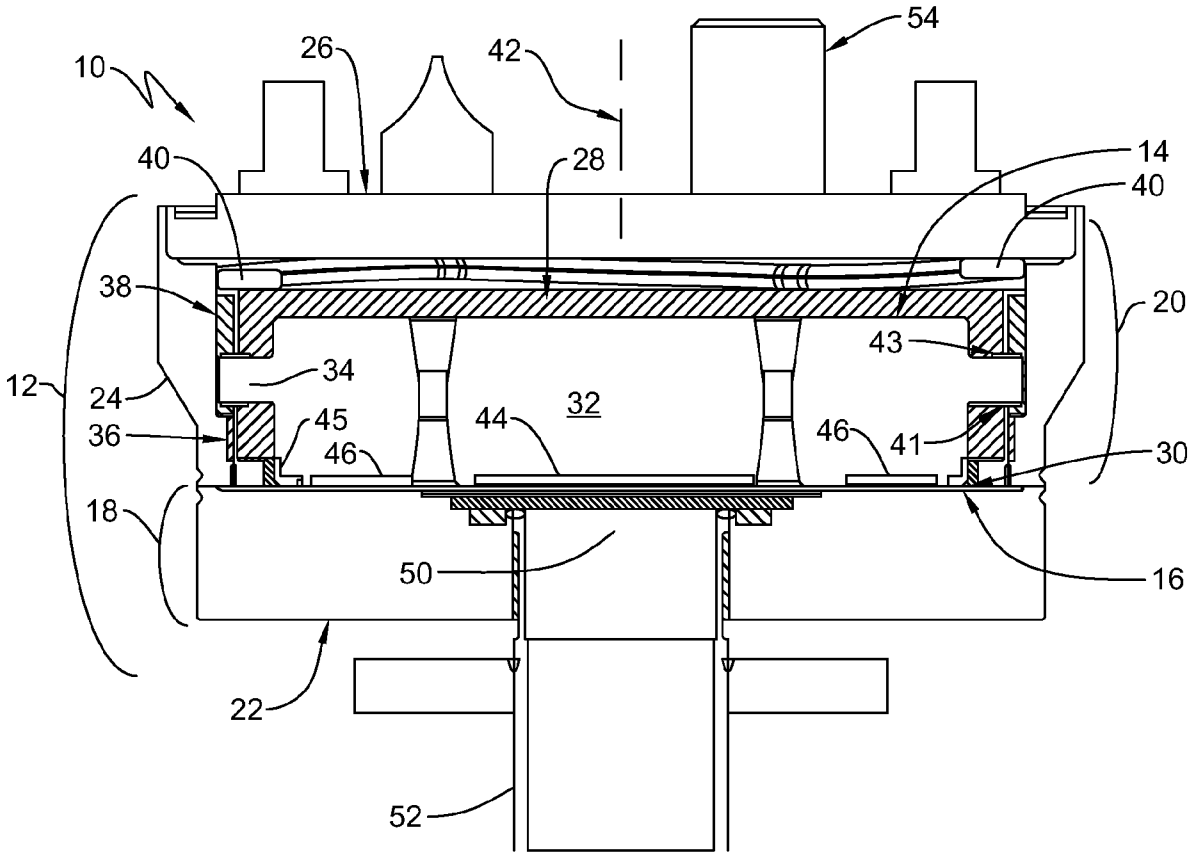

10
26
42
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FIG. 1

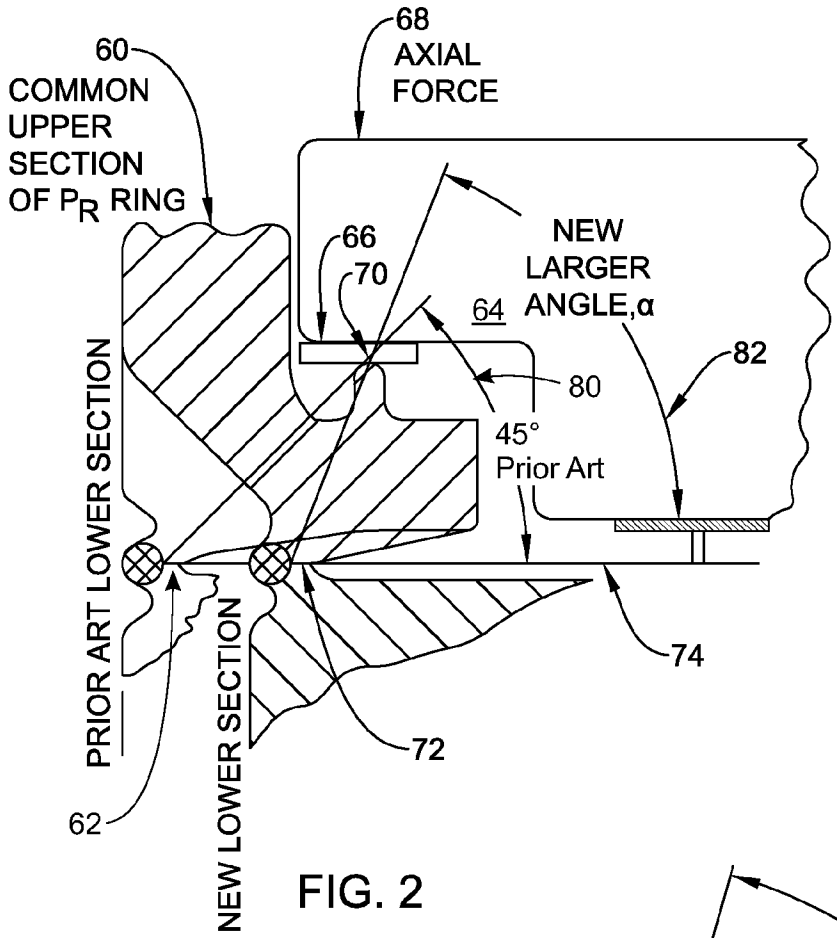

60
COMMON
UPPER
SECTION
OF P_R RING
68
AXIAL
FORCE
66
70
64
NEW
LARGER
ANGLE,α
82
80
45°
Prior Art
PRIOR ART LOWER SECTION
NEW LOWER SECTION
74
72
62

FIG. 2

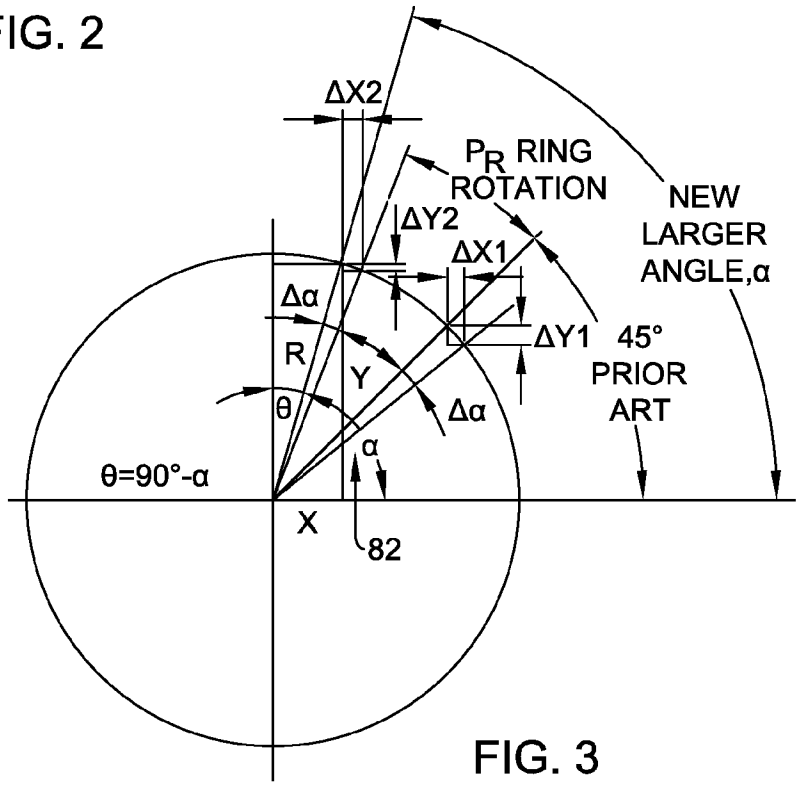

ΔX2
P_R RING
ROTATION
NEW
LARGER
ANGLE,α
ΔY2
ΔX1
Δα
ΔY1
45°
PRIOR
ART
R
Y
θ
Δα
α
θ=90°-α
X
82

FIG. 3

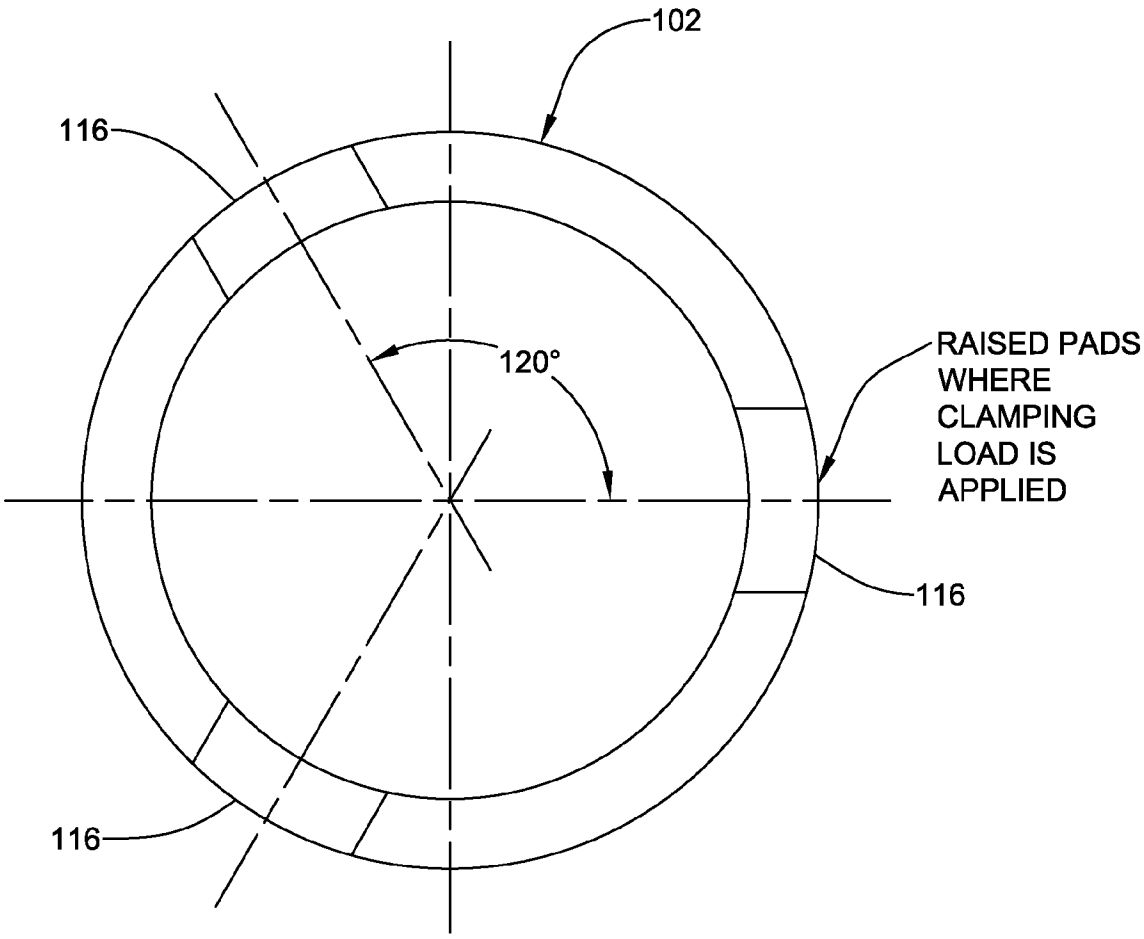

102
116
120°
RAISED PADS WHERE CLAMPING LOAD IS APPLIED
116
116

FIG. 4

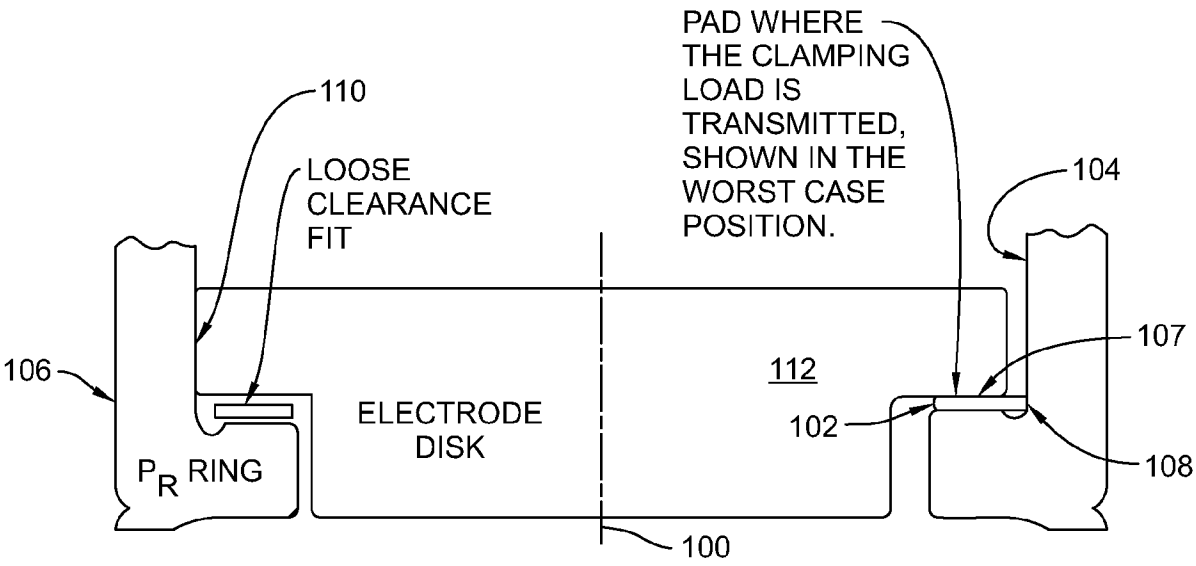

PAD WHERE THE CLAMPING LOAD IS TRANSMITTED, SHOWN IN THE WORST CASE POSITION.
110
LOOSE CLEARANCE FIT
104
107
106
112
ELECTRODE DISK
102
108
P_R RING
100

FIG. 5

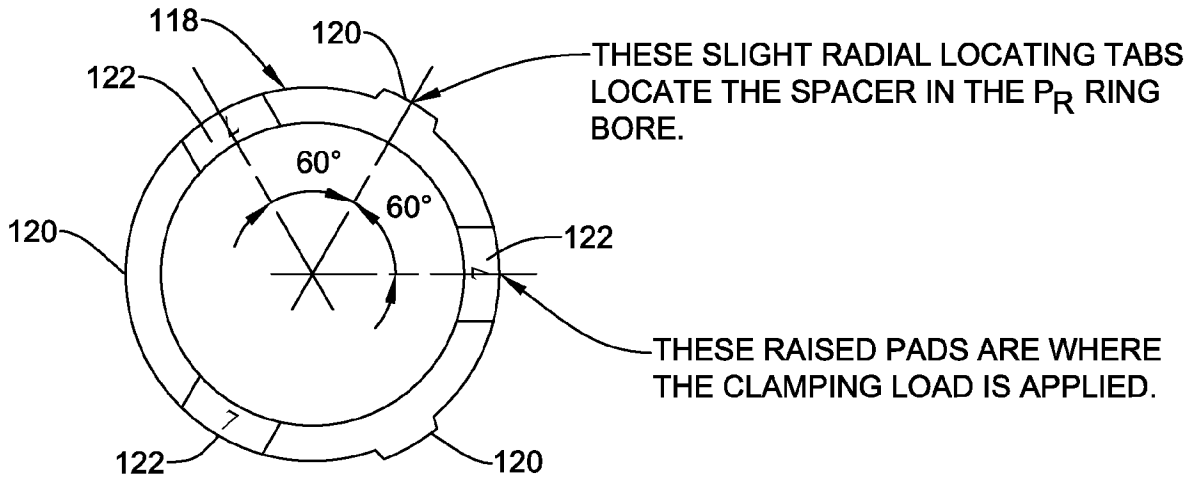

118
120
122
THESE SLIGHT RADIAL LOCATING TABS LOCATE THE SPACER IN THE P_R RING BORE.
60°
60°
120
122
THESE RAISED PADS ARE WHERE THE CLAMPING LOAD IS APPLIED.
122
120

FIG. 6

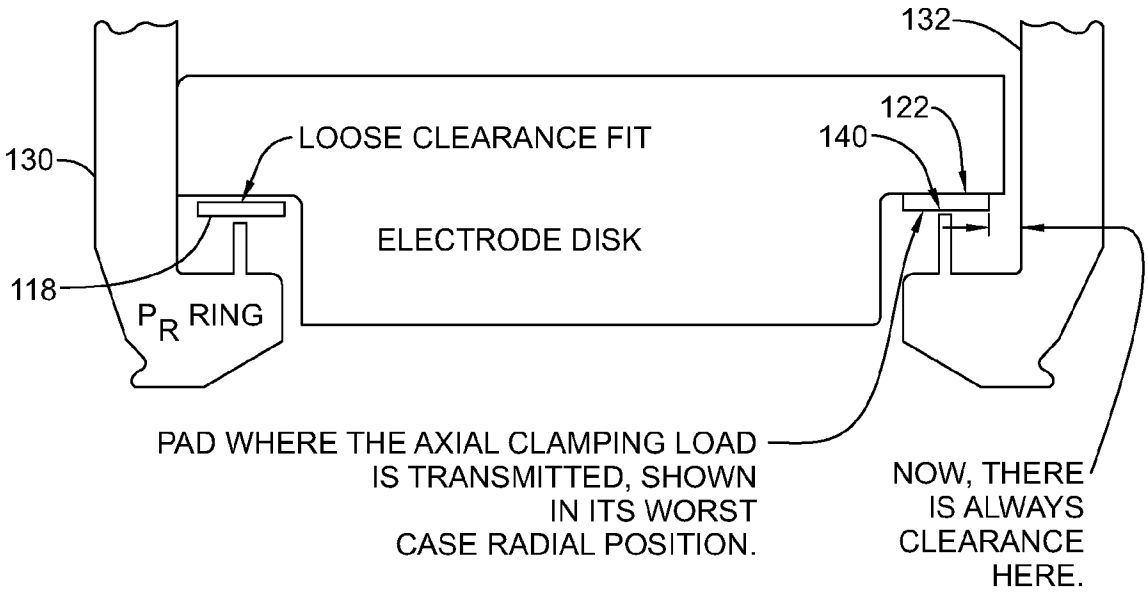

132
122
LOOSE CLEARANCE FIT
140
130
ELECTRODE DISK
118
P_R RING
PAD WHERE THE AXIAL CLAMPING LOAD IS TRANSMITTED, SHOWN IN ITS WORST CASE RADIAL POSITION.
NOW, THERE IS ALWAYS CLEARANCE HERE.

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2011/023384

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01L9/00
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 practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 105 436 A (LISCHER D JEFFREY [US] ET AL) 22 August 2000 (2000-08-22) figure 5a	1-6

☐ 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 document 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
15 April 2011	27/04/2011

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

International application No
PCT/US2011/023384

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6105436 A	22-08-2000	DE 60006126 D1	27-11-2003
		DE 60006126 T2	22-07-2004
		EP 1200810 A1	02-05-2002
		JP 2003505688 T	12-02-2003
		WO 0107883 A1	01-02-2001