United States Patent

Nagata et al.

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[54] **PRESSURE RESPONSIVE APPARATUS**

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[73] Assignee: **Hitachi, Ltd.,** Tokyo, Japan

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[21] Appl. No.: **888,568**

[30] **Foreign Application Priority Data**

Dec. 27, 1968 Japan 44/311

[52] **U.S. Cl.**.....**137/85**

[51] **Int. Cl.**.....**G05d 16/00,** F15b 5/00

[58] **Field of Search** 73/419; 137/82, 85; 251/57

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[57] **ABSTRACT**

A pressure responsive apparatus having a differential piston operable in response to a measuring pressure, and elements for sealing a fluid which transfers the pressure to said piston. The apparatus is designed to detect said pressure in the form of a displacement of said piston.

9 Claims, 16 Drawing Figures

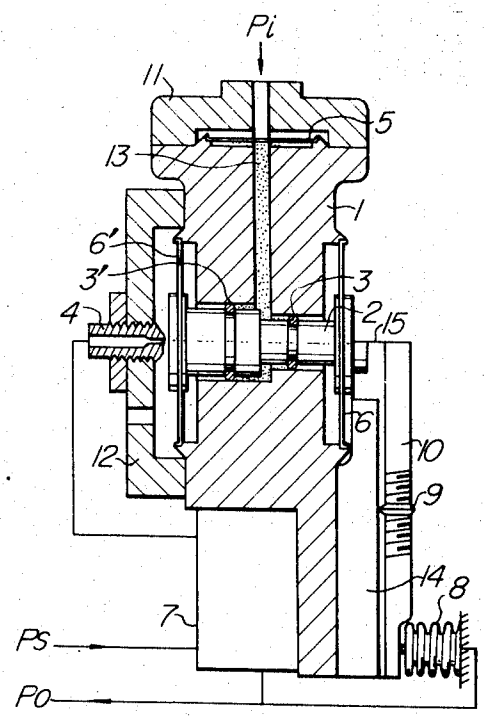


FIG. 1

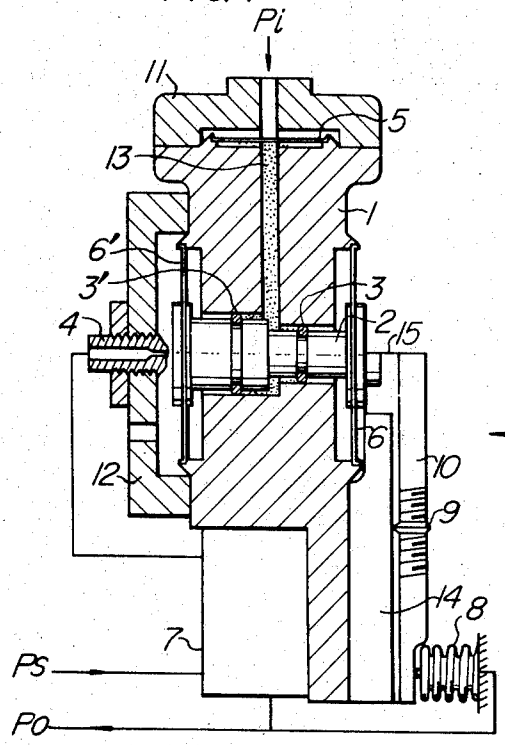


FIG. 2

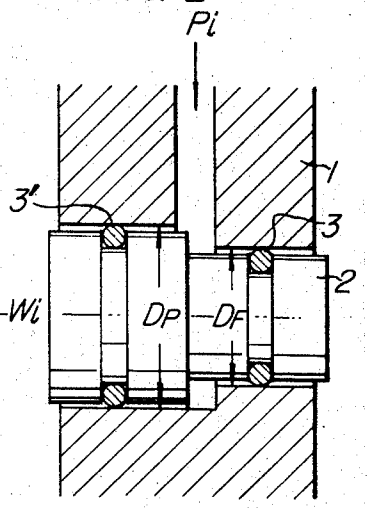


FIG. 4A

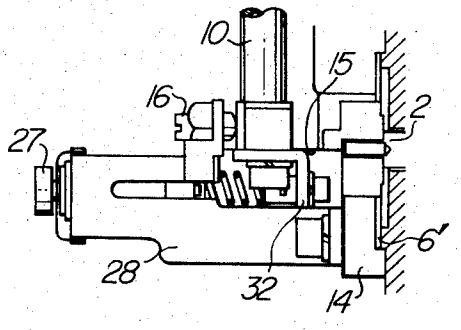
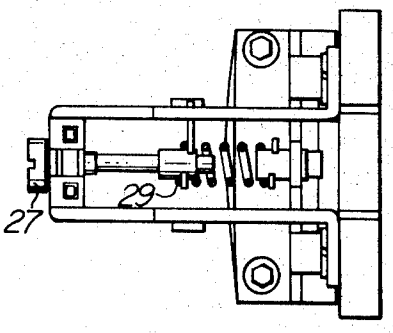


FIG. 4B



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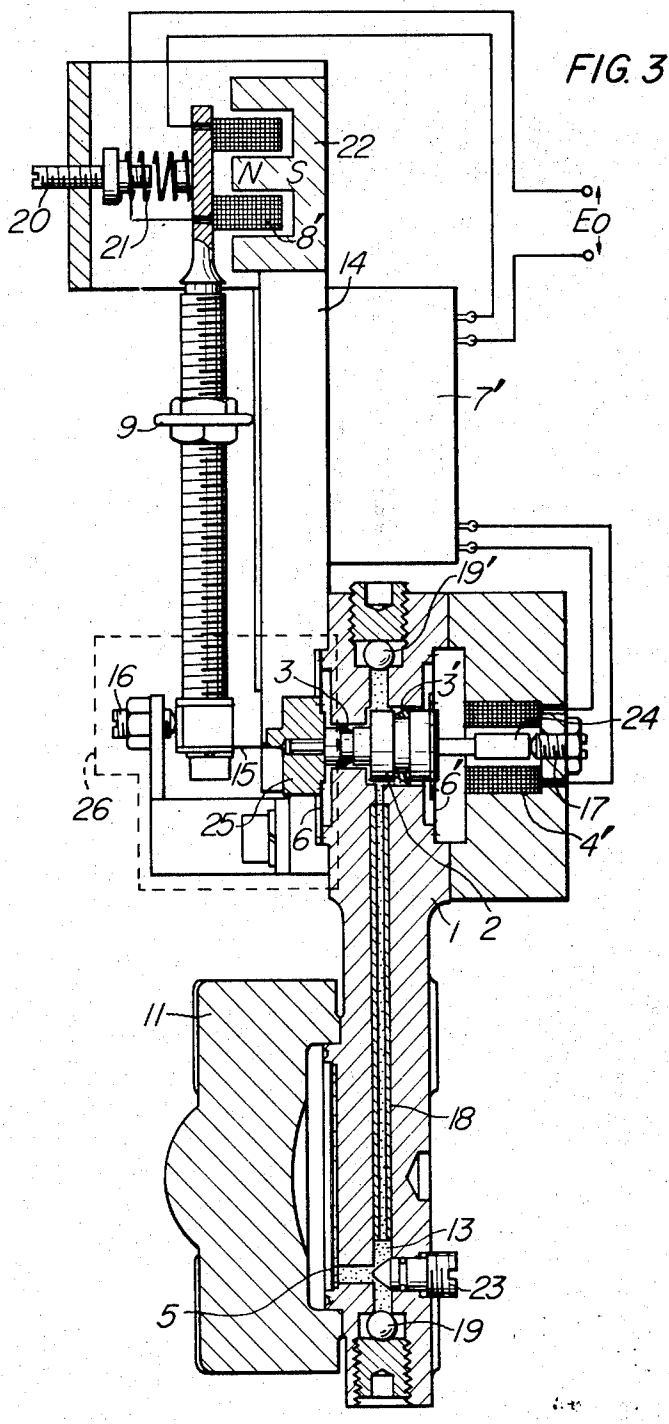
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FIG. 3



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FIG. 5B

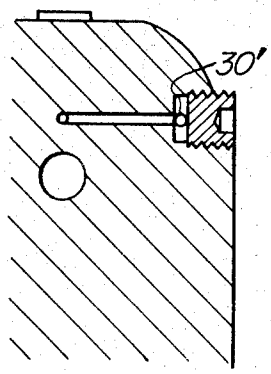


FIG. 5A

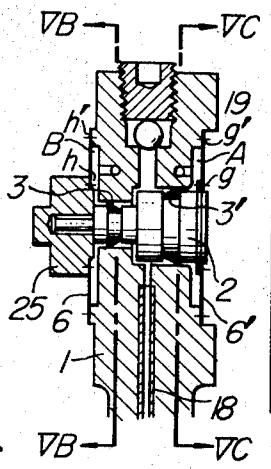


FIG. 5C

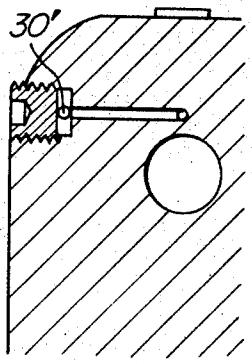


FIG. 6

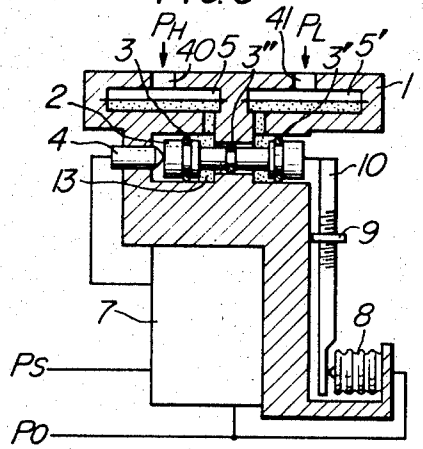
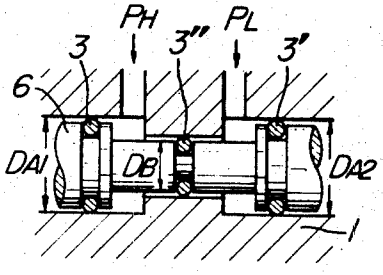


FIG. 7



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FIG. 8

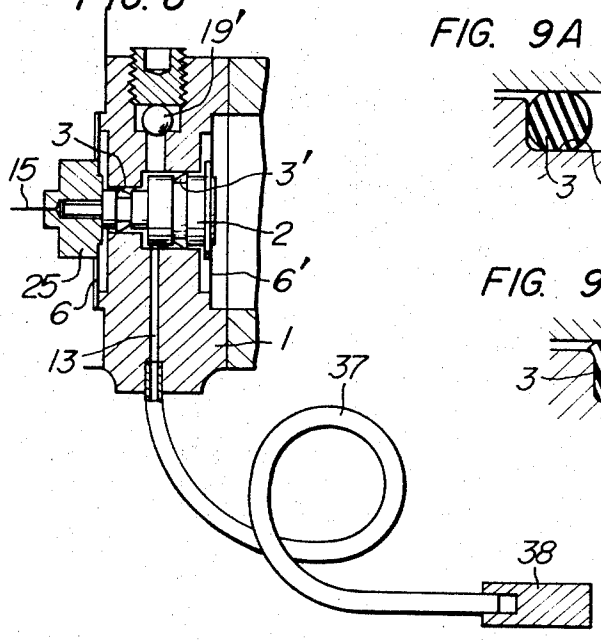


FIG. 9A PRIOR ART

FIG. 9B PRIOR ART

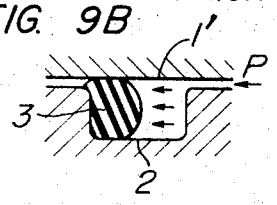


FIG. 10A

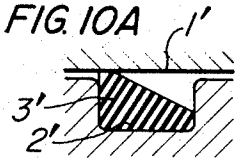


FIG. 10B

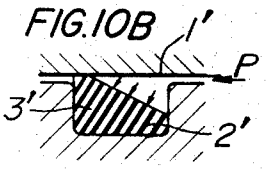
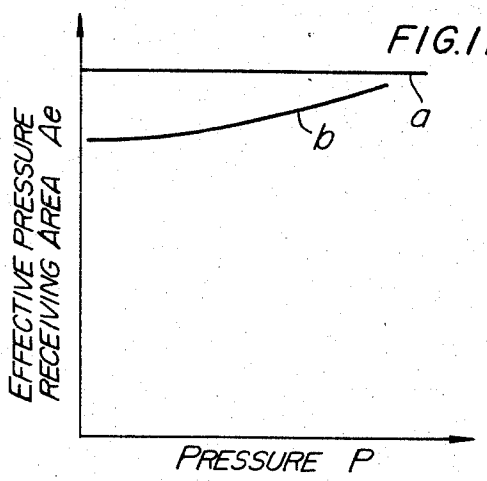


FIG. 11



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PRESSURE RESPONSIVE APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a force-balance type pressure responsive apparatus which is capable of transmitting, in the form of pneumatic or electrical signal, input variables which can be transduced into a corresponding pressure or electrical valve. The input may be any of what can be detected in the form of a magnitude related to pressure, such as, for example, positive pressure, negative pressure, differential pressure, amount of flow, temperature, etc.

2. Description of the Prior Art

A single kind of pressure receiving elements such as diaphragm, bellows, Bourdon's tube or the like cannot be applied to the measurement of a wider range of pressure. Namely, diaphragm is applicable only to the measurement of relatively lower pressure up to about 100 kg/cm². Higher pressure must be measured by means of bellows and still higher pressure should be dealt with by means of Bourdon's tube.

Moreover, prior art force-balance type pneumatic differential pressure responsive apparatus also employs diaphragms or bellows in the pressure receiving section thereof as is in the case of a pneumatic force-balance type pressure responsive apparatus. The prior art differential pressure responsive apparatus needs a pair of high and low pressure side diaphragms or bellows of exactly the same effective pressure receiving area.

All kinds of pressure responsive apparatuses are under great influence of such pressure receiving elements. Thus, the pressure receiving elements are required to represent linear characteristic over a substantially widened range of displacement, have smaller hysteresis and produce an output having its zero point which is not varied with the temperature variation and the static pressure.

Therefore, the manufacture of such pressure receiving elements needs highly skilled technique and prolonged experience.

With the arrangement of the prior art apparatus of this kind, furthermore, an output must be taken out of the apparatus in the form of a magnitude of displacement caused by the force transduced from a pressure in such a manner that the displacement is not under the influence of static pressure, temperature, friction, etc. This requirement essentially complicates the construction of the apparatus.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a force-balance type pressure responsive apparatus which may provide a greater measuring accuracy, a widened measuring range even by use of a single kind of pressure receiving elements and a pressure resistant capability as great as about 1,000 kg/cm².

Another object of the present invention is to provide an apparatus of this kind which can be utilized in the form of either a pneumatic force-balance type pressure responsive apparatus of an electronic force-balance type pressure responsive apparatus.

A further object of the present invention is to provide a force-balance type pressure responsive apparatus which can be used for a plurality of purposes such as measurements of positive pressure, negative pressure, differential pressure, flow of fluid, temperature, etc.

A still further object of the present invention is to provide an improved force-balance type pressure responsive apparatus which does not have any objectionable drawback when in use.

According to the present invention, there is provided a pressure responsive apparatus comprising a differential piston member having a portion of a first diameter and another portion of a second diameter larger than said first diameter, a cylinder member receiving said piston member for axial movement, sealing members in pressure-tight sealing engagement with said first and second diameter portions of said piston member, respectively, and in pressure-tight sealing and slidable contact with the inner wall of said cylinder member, said cylinder member and said sealing member cooperating together to define an annular space, said cylinder member having formed therein a passage for introducing an input pressure to said annular space whereby said piston member is caused to displace with respect to said cylinder member, and means for detecting the displacement of said piston member.

The present invention also provides a transmitter comprising, in combination, a pressure responsive apparatus of the feature set forth in the preceding paragraph, means for transducing the displacement of said piston into a corresponding pressure of electrical value and means for feeding back said pressure or electrical value to the differential piston of said pressure responsive apparatus.

The above and other objects, features and advantages of the present invention will be made more apparent by the following description made with reference to the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates in partial vertical section the arrangement of a pneumatic force-balance type pressure responsive apparatus according to an embodiment of the present invention;

FIG. 2 is a fragmentary partial sectional view of the pressure-displacement converting means of the apparatus shown in FIG. 1;

FIG. 3 is a vertical sectional side view illustrating the arrangement of an electronic force-balance type pressure responsive apparatus according to another embodiment of the present invention;

FIG. 4A is a side view of a zero point elevation or suppression device which has been designed for use, for example, in measurement of negative pressure;

FIG. 4B is a bottom view of the device shown in FIG. 4A;

FIG. 5A is a vertical sectional view of an apparatus according to a further embodiment of the present invention which has been designed for use in measurement of absolute pressure;

FIGS. 5B and 5C are vertical sectional side views of the apparatus in FIG. 5A taken substantially along lines VB—5B and VC — VC in FIG. 5A, respectively;

FIG. 6 is a schematic vertical sectional view illustrating the arrangement of a pneumatic force-balance type differential pressure responsive apparatus according to a further embodiment of the present invention;

FIG. 7 is a fragmentary sectional view of the pressure-displacement converting means of the apparatus shown in FIG. 6;

FIG. 8 is a vertical sectional side view of a pressure type temperature responsive apparatus according to a still further embodiment of the present invention;

FIGS. 9A and 9B diagrammatically illustrate in section a conventional O-ring in installed and operative positions, respectively;

FIGS. 10A and 10B diagrammatically illustrate in section the sealing ring of the present invention when it is in installed position and in operative position, respectively; and

FIG. 11 is a graphical comparative illustration of the relationships between the pressures and the effective pressure receiving areas obtainable from the sealing rings of the present invention and of the prior art when they are employed in the pressure responsive apparatus of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 illustrates the arrangement of the force-balance type pneumatic pressure transmission apparatus according to an embodiment of the present application. Numeral 1 indicates a main body of the apparatus. Pressure Pi is received by a liquid-contacting diaphragm 5 which in turn will transmit the pressure through a filling liquid 13 to a differential piston 2, said diaphragm being effective to prevent O-rings 3, 3' from being damaged by corrosive fluid and the like and to absorb variation in the input pressure. Thus, it is not always necessary to employ the liquid-contacting diaphragm in a case where the apparatus is not used to measure the pressure of such corrosive fluid.

The differential piston is reduced as illustrated and, therefore, receives a force Wi which is in proportion to the difference between the sectional areas of the small and large diameter portions of the cylinder bore. The force Wi produced by the input pressure Pi is represented by an equation;

$$Wi = Pi \times (\pi/4)\,(D_P^2 - D_F^2)$$

wherein D_P and D_F are the larger and smaller inner diameters of the cylinder bore. Thus, the piston is displaced leftwards as viewed in FIG. 1. Appropriate dimensions may be chosen for the cylinder bore diameters D_P and D_F. The displacement of the piston is directly detected by a nozzle 4 in such a manner that the clearance between the piston and the nozzle is decreased. This decrease results in increase of the back pressure of the nozzle which backpressure in turn is amplified by a pneumatic pressure amplifier 7 to thereby produce an increased output pressure Po.

The output pressure Po is introduced into a restoring bellows 8 which produces a restoring force which is transmitted through an assembly of range nut 9 and a range rod 10 to the piston. The restoring force is a negative feed back which is equalized with the force Wi produced by the input pressure.

The displacement of the differential piston 2, which acts as a flapper of a flapper mechanism for the nozzle, is detected directly by the nozzle 4 which is fixed to a supporting plate 12. The O-rings 3 and 3' seal the liquid under the input pressure so that the piston 2 having thereon these O-rings 3 and 3' will be given displacement and force in exact proportion to the input pressure. Sheets 6 and 6' fixed to the body 1 and supporting the piston 2 have minute displacements in the directions in which the differential piston 2 is movable so that the reaction forces of the diaphragms will be of a small magnitude while the sheets serve to stabilize the piston against the displacement and shock in the transverse directions or radial directions of the piston. In addition, if vacuum is applied to the spaces defined by the supporting sheets 6 and 6' and the O-rings 3 and 3', respectively, then it is easily possible to measure absolute pressure. The apparatus has a flange 11 which is detachably mounted thereon for making it possible to advantageously carry out drainage. Mark Ps represents the magnitude of the pressure fed to the pilot value 7. Numeral 14 indicates a range plate and 15 represents a connecting spring.

As having been described, since the arrangement of the present invention is such that the displacement in the pressure receiving section is detected directly by a nozzle, the invention provides advantages that there will be encountered little mechanical obstruction and an improved accuracy is obtainable. In addition, since the cylinder bore inner diameters $D_{P \text{ and } DF}$ may be appropriately varied, it is possible to conduct measurement of widened range of pressures from lower one to higher one. As to the pressure-withstanding or pressure resistant capability, the input pressure received by the liquid-contacting diaphragm is transmitted therefrom to and received by the O-ring seals. Thus, the capability concerned depends on the pressure-withstanding ability of the O-rings. By appropriately determining the hardness of the O-rings and the clearance between the piston and the surrounding cylinder, it is possible to make the pressure-withstanding capability up to about 1,000 kg/cm^2.

In addition, the piston-supporting diaphragms provide an improved stability of the piston against vibration and the like so that measurement of absolute pressure can be rendered easy, as having been discussed in the above.

With the present invention, therefore, it is possible not only to completely eliminate the drawbacks accompanied by conventional force-balance type pressure transmission apparatus, but also to provide at a lowered price a pressure transmission apparatus which is of simple construction and which simplifies measurement of absolute pressure, and provides an increased accuracy, a widened range of measurement and an improved stability against vibration. Moreover, since the apparatus of the present invention utilizes pneumatic pressure, the apparatus is not always required to be arranged in horizontal position so as to be operated. Furthermore, even if a filling liquid such as silicon oil is used, the apparatus does not require a circulation passage for such liquid, which also contributes to the simplification of the arrangement of the apparatus.

Referring to FIG. 3 which illustrates an electronic force-balance type pressure responsive apparatus according to another embodiment of the present invention, the apparatus of the instant embodiment is generally composed of a differential piston and sealing materials as shown in FIG. 1. For this reason, similar reference numerals are added to similar elements, respectively. A differential piston 2 when it receives an

input pressure is displaced rightwards as viewed in FIG. 3. This piston has mounted thereon a core 24 which is movable in unison with the piston. Thus, the core is subjected to the displacement which produces a variation in the inductance of a detector coil 4' of a differential transducer. The inductance variation is transformed into a variation in current or voltage and this variation is fed into an amplifier 7' as an input thereof. The amplifier provides an amplified output which is fed back into a coil 8' which is adapted to produce a restoring force. Namely, the coil 8' cooperates with a permanent magnet 22 to produce therebetween an electromagnetic force which is imparted to a range rod 10 which is turn produces a negative feedback force equilibrated with a force Wi produced by the input pressure Pi.

The differential piston of the instant embodiment also has a minute displacement as is in the pneumatic force-balance type pressure responsive apparatus so that the seal rings 3 and 3' seal the input pressure while having a displacement in exact proportion to the input pressure because of the resilient deformation of the rings.

In the drawings, the numeral 20 indicates a zero adjusting screw, 21 represents a zero adjusting spring, 16 a stop for preventing a reversed displacement of the range rod 10, 17 indicating a stop for preventing an over-displacement, 19 and 19' indicating sealing balls utilized to seal the filling liquid, 23 indicating a throttle for adjusting the damping of pulsating input pressure and the quickness of the response of the apparatus and 18 representing a small diameter pipe which is utilized as a result of consideration that the smaller is the influence of the variation in the volume of the liquid due to temperature change to which influence the apparatus is subjected. Numeral 25 indicates a coupling of metal connecting a connecting leaf spring 15 to the cylinder. The apparatus according to the instant embodiment provides a functional advantages similar to those obtainable from the apparatus of the preceding embodiment.

FIGS. 4A and 4B illustrate in side elevation and top plan view, respectively, the apparatus of the present invention which is adapted for the measurement of negative pressure. This apparatus is adapted to be installed on the apparatus shown in FIG. 3 in substitution for the section surrounded by broken line 26. In order to carry out measurement of negative pressure, a zero elevation or suppression screw is employed to adjust zero point. The zero elevation or suppression screw 27 is adjustably mounted on a bracket 28 which is secured to a range plate 14. A compression spring 29 is in engagement with a bracket 32 which is secured to the range rod 10 of the apparatus. When the zero adjusting screw is rotated, the compression spring 29 receives a force and is displaced rightwards as viewed in these figures. The differential piston 2 reduces the clearance of the nozzle in case of pneumatic type by means of a connecting leaf spring 15 so that the zero point of the output is shifted. The device may be so adjusted that an output of a predetermined value is obtainable when the input pressure is 0 kg/cm^2 . Thus, when the device is subjected to negative pressure, the output of the apparatus will be of a reduced value than the predetermined one. The device of the instant embodiment, therefore, makes it possible to measure negative pressure.

Similarly, if the spring 29 is caused to act as a tension spring, the zero point of the output is shifted in the opposite direction so that the apparatus may be operated as a pressure transmission apparatus which has so called elevation mechanism.

FIGS. 5A to 5C illustrate the arrangement of the transmission apparatus of the present invention which is utilized to measure absolute pressure. The body 1 of the apparatus is bored, as illustrated, to make the body serve as a cylinder. Seals are formed against the atmospheric air between the differential piston 2 and a supporting spring 6 and between the body 1 and a supporting spring 6' by conventional sealing means such as weldings. Similarly, a connecting piece 25 and the supporting leaf spring 6' and the body 1 and the supporting leaf spring 6' are sealed against the atmospheric air by means of conventional sealing means such as weldings. In this arrangement, if chambers A and B are vacuumed and maintained at 0 kg/cm^2 by absolute pressure, the differential piston 2 is always subjected to a pressure. Thus, it is possible to measure absolute pressure by means of the apparatus of the invention.

Numerals 30 and 30' represent sealing balls used when the apparatus is vacuumed.

FIG. 6 diagrammatically illustrates the principle of a force-balance type differential pressure responsive apparatus according to a further embodiment of the present invention. FIG. 7 diagrammatically illustrates the arrangement of the pressure responsive means of the apparatus shown in FIG. 6. The apparatus according to the instant embodiment generally comprises a body 1 and a differential piston 2 placed within the body 1 and sealed against outside by means of seal or O-rings 3, 3' and 3'', diaphragms 5 and 5', a filling liquid 13, a nozzle 4, a stable bellows 8, a pilot valve 7 and a range rod 10. High and low pressures P_H and P_L are introduced into high and low pressure chambers 10 and 11, respectively, to act on the diaphragms 5 and 5' which in turn respectively cause the filling liquid 13 to act as input pressures at the inlets of the cylinder in which the differential piston is received. The diaphragms 5 and 5' are adapted to prevent the seal rings from suffering from corrosion and damage. Thus, in case wherein the fluid to be measured is of a nature which does not adversely affect the characteristic of the seal rings, the diaphragms may be omitted. The displacement of the differential piston is so minute that the displacement of each of the diaphragms 5 and 5' is of small magnitude. Thus, no problem is caused by the non-linear characteristic and hysteresis of the diaphragms 5 and 5' so that these diaphragms are not required to have complicated configuration as is required by the prior art differential pressure responsive apparatus.

Now, since the bore or cylinder in the body 1 has different inner diameters as will be seen in FIG. 7, a force F will be produced by the pressures. The force F_H produced at the high pressure side will be represented by an equation:

$$F_H = P_H \times (\pi/4)(D_{A1}^2 - D_B^2) \quad (2)$$

wherein D_{A1} represents the larger diameter (at the high pressure side) of the bore in the body 1 and D_B represents a smaller diameter of the bore in the body.

The pressure F_L produced at the lower pressure side will be represented by an equation:

$$F_L = P_L \times (\pi/4)\,(D_{A2}^2 - D_B^2) \quad (3)$$

wherein D_{A2} represents the larger diameter (high pressure side) of the bore in the body. Since the differential piston **2** is of single or unitary structure, the composite force F will be represented by:

$$F = F_H - F_L = (\pi/4)\,[P_H(D_{A1}^2 - D_B^2)] - P_L(D_{A2}^2 - D_B^2) \quad (4)$$

If the piston is worked into such an arrangement that $D_{A1} = D_{A2} = D_A$, then the produced force F will be represented by:

$$F = F_H - F_L = (\pi/4)\,(D_A^2 - D_B^2)(P_H - P_L) = K\,(P_H - P_L) \quad (5)$$

wherein $K = (\pi/4)\,(D_A^2 - D_B^2)$.

Thus, it will be appreciated that the produced force F is in proportion to the differential pressure $(P_H - P_L)$. With the apparatus of the instant embodiment, the displacement of the piston **2** caused by the force F which is in proportion to the differential pressure $(P_H - P_L)$ is detected by the nozzle **4** in such a manner that the clearance between the piston and the nozzle is varied. The variation in the clearance results in the variation in the backpressure of the nozzle **4**. The variation in backpressure is then fed into a pneumatic pressure amplifier (pilot valve) **7** from which as amplified output is delivered. The output of the amplifier is taken out as an output pressure Po of the apparatus and is utilized as an feedback pressure to the restoring bellows **8** which cooperates with the range rod **10** to produce and impart to the piston **2** a negative feedback which is in equilibrium with he force F produced by a predetermined differential pressure.

In this case, the displacement of the differential piston **2** is so minute that no substantial sliding movement of the seal rings **3**, **3'** and **3''** takes place relative to the bore in the body **1**, but these rings are subjected to resilient deformation. In addition, the apparatus of the instant embodiment does not always need the diaphragms **5** and **5'** and the input pressures P_H and P_L may be directly imparted to the differential piston **2**.

As having been described, the construction of the present invention is such that the high and low pressure receiving parts may readily be so worked as to have equalized pressure receiving areas. Thus, the influence by static pressure and temperature is almost negligible. In addition, the pressure and temperature is almost negligible. In addition, the pressure receiving parts act as movable parts whose displacements are so minute that non-linear characteristic and hysteresis do not cause any problem. Thus the characteristic in accuracy, reproducing ability etc will be improved. In addition, the apparatus of the present invention provides further advantages that the displacement of the differential piston may easily taken out without employing any sealing mechanism of complicated arrangement, that a desired magnitude of the force produced at the pressure responsive means may be obtainable by appropriately determining the inner diameters of the bore in the body, that the range of measurement is widened up to 25,000 mm H_2O, and that the capability of withstanding pressure is of a magnitude substantially equal to 1,000 kg/cm^2. It will be therefore well appreciated that the present invention provides an industrially highly improved and advantageous differential pressure responsive apparatus.

The signal transducing means and the restoring means of the pneumatic force-balance type differential pressure responsive apparatus shown in FIG. **6** may also be modified into an electronic type apparatus as the force-balance type pneumatic pressure responsive apparatus may be. In addition, the differential pressure responsive apparatus of FIG. **6** may also be utilized as a flow transmitter.

FIG. **8** illustrates a pressure type temperature transmitter or detector according to a further embodiment of the present invention. The pressure receiving means of the apparatus of this embodiment generally comprises a differential piston, a heat sensitive means **38** and a capillary tube **37** which is filled with a liquid or a gas. Specifically, the pressure type temperature transmitter detects temperature at the heat sensitive means **38** which is generally made from steel. The capillary tube **37** is connected to the heat sensitive means so that the filling fluid **13**, which may be a liquid such as mercury or alcohol or a gaseous material such as an inert gas, for example, nitrogen, is subjected to heat-expansion which will results in pressure build-up within the capillary tube **37**. The pressure build-up displaces the differential piston **2** rightwards as viewed in FIG. **8**. A force Wi is produced by the pressure as is in the preceding embodiments. In addition, the signal transducing means have an arrangement similar to those in the pneumatic and electronic force-balance pressure responsive apparatuses above described. In a modified feature of the instant embodiment, the heat sensitive means **38** contains an appropriate liquid. The variation in the vapor pressure due to the heat in the heat sensitive means is detected by the differential piston **2**.

In the case a piston is utilized as a pressure receiving element so as to transduce pressure into a force, there are two method for preventing pressure leakage between the piston and a cylinder for receiving the piston. In the former method, a minute clearance is acceptable between the diameters of the piston and the cylinder. In the latter method, sealing rings are employed to form seals between the piston and the cylinder. In the case where sealing rings are employed, conventional O-rings, when subjected to pressure, are shifted and deformed by the pressure so that the effective diameter (that is, the diameter of common surface of contact formed between each ring and a mating wall) is varied, with the result that any constant effective pressure receiving area is not obtainable. Thus, conventional O-rings are not suited for the accurate measurement and detection of a pressure.

It is, therefore, an object of the present invention to also provide sealing rings which eliminate the shortcomings in the conventional O-rings and which provide constant effective pressure receiving areas even during the application of pressure for thereby rendering the rings suitable for the accurate measurement and detection of a pressure.

Now, the reason why a constant effective pressure receiving area is not obtainable from conventional O-rings is discussed in reference to FIGS. **9A** and **9B**. FIG. **9A** diagrammatically illustrates a conventional O-ring in installed position and under no pressure, that is, pressure $P = 0$. FIG. **9B** diagrammatically illustrates the O-ring of FIG. **9A** when it is subjected to a pressure, P_1. A description will be made with respect to the installed condition of conventional rings which are represented by an O-ring in the illustration herein.

When pressure P equals 0, the O-ring **3** is in a state that it is deformed by an inner wall **1'** of the cylinder and by a bottom **2'** of a piston groove. Assuming that the pressure is caused to have a minute pressure variation ΔP and varies from the state that P equals 0 to a state that is represented by P = ΔP, since the piston is supported by the portions of the cylinder at which the cylinder contacts the O-rings and since the O-rings are considered to be flexible, the piston will receive a force represented by an equation:

$$W = \Delta P \times Ae0,$$

wherein W is the force and $Ae0$ is the effective pressure receiving area when pressure P equals 0. Then, assuming that the pressure P has been varied to P_1, the O-ring is shifted and deformed as seen in FIG. **9B** by the pressure increment. Again assume that the pressure has been increased from the value $P = P_1$ to a value $P = P_1 + \Delta P$ as is in the case of P = 0. In this case, since the resilient part extends only within the gap between the material of the piston and the inner surface of the cylinder, the resultant pressure receiving effective area is Ae1 which is of a value different from the corresponding value in the case of P = 0 and consequently the increment in the produced force is of a value which is represented by $W = \Delta P \times Ae1$. Thus, it will be appreciated that it is difficult for the conventional O-rings to seal the pressure and, at the same time, the generate a force in exact proportion to the received pressure and to transmit the generated force to the piston. Thus, the conventional O-rings are not suited for serving as pressure receiving elements for use in measurement and detection of pressure.

FIGS. **10A** and **10B** illustrate a sealing ring according to the present invention when the ring is in installed position and in operative position. The sealing ring according to the present invention has such a cross-section in installed position that it has a pair of opposite top and bottom sides, a pair of right and left sides and an inclined side between the top and bottom sides, the right and left and bottom sides being in intimate contact with the side and bottom faces **3'**, **2'** of annular groove in the piston, the top side being in sealing contact with the inner surface **1'** of the cylinder and the inclined side being subjected to the fluid pressure within the cylinder.

Thus, even if the pressure P has become a higher pressure, the configuration of the ring according to the present invention has a minimum deformation as will be seen in FIG. **10B**. Therefore, the piston, which acts as a pressure receiving part, is subjected to a much smaller variation in pressure receiving area as compared with a piston which employed a conventional O-ring. Accordingly, the sealing rings of the configuration employed by the present invention can well act as pressure receiving elements for use in an accurate measurement of pressure.

FIG. **11** graphically illustrates the relationships between the pressures and the effective pressure receiving areas obtainable from the seal ring according to the present invention (*a*) and from the O-ring of prior art (*b*). As seen in the graphical illustration, the sealing ring of the present invention is not subjected to any change or variation in the effective pressure receiving area by the pressure. An error in a measured value is the function of the effective pressure receiving area and the latter is the function of the pressure. With the conventional O-ring, the error in the measured value is of the order up to 3.0 percent while, with the seal ring of the present invention, the error in question is of the order less than 0.5 percent at the maximum.

As having been described in the above, the present invention provides seal rings which afford substantially constant effective pressure receiving areas when installed as sealing materials for the pressure responsive member and which enable the latter to receive a force in proportion to an input pressure. Thus, the seal rings of the invention are suited for the accurate measurement and detection of pressure.

What is claimed is:

1. A pressure responsive apparatus comprising a differential piston member having a portion of a first diameter and at least one other portion of a second diameter larger than said first diameter, a cylinder member receiving said piston member for axial movement, sealing members in pressure-tight sealing engagement with said first and second diameter portions of said piston member, respectively, and in pressure-tight sealing and slidable contact with the inner wall of said cylinder member, said piston member, said cylinder member and said sealing members cooperating together to define at least one annular space, said cylinder member having formed therein at least one passage for introducing an input pressure to said at least one annular space whereby said piston member is caused to displace from its original position with respect to said cylinder member, means for detecting the displacement of said piston member, said detecting means including first means connected to one end of said piston member and movable with respect to a second means cooperating therewith for providing an output signal indicative of the displacement of the piston member, piston repositioning means responsive to said output signal for moving said piston member to its original position with respect to said cylinder member, said repositioning means including a pivotable rod member having an adjustable fulcrum and having one end connected to means responsive to said output signal for displacing the end of said rod member in accordance with said signal and having the other end of said rod member connected to the other end of said piston member for moving said piston member to its original position.

2. A pressure responsive apparatus comprising as defined in claim **1**, wherein said piston member has opposite end portions of said second diameter and an intermediate portion between said end portions of said first diameter, said sealing members being in pressure-tight sealing engagement with said end and intermediate portions of said piston member, respectively, and in pressure-tight sealing and slidable contact with the inner wall of said cylinder member, said cylinder member and said sealing members cooperating with said intermediate and opposite end portions of said piston member to define at least first and second annular spaces, said cylinder member having formed therein at least one passage for introducing input pressures into each of said first and second annular spaces whereby said piston member is caused to displace from its original position with respect to said cylinder member.

3. A pressure responsive apparatus as claimed in claim 1, further comprising thin sheets of metal for supporting said piston.

4. A pressure responsive apparatus as claimed in claim 1, further comprising at least one diaphragm defining a closed chamber which is in communication with said annular space through said passage, and fluid filling up said chamber, said passage and said annular space, said fluid serving to transmit to said piston the pressure imparted to said diaphragm.

5. A pressure responsive apparatus as defined in claim 1 in which each of said sealing members is disposed in a groove of said piston member and has in cross-section a pair of opposite sides and a bottom side which are in intimate contact with the side and bottom faces of the groove, one of said opposite sides of said cross-section being larger than the other, a top side in sealing contact with the inner surface of said cylinder and an inclined side between said top and bottom sides, said inclined side being subjected to the fluid pressure within said cylinder member.

6. A pressure responsive apparatus as claimed in claim 3, further comprising means for maintaining a vacuum within the spaces defined by said differential piston, said piston supporting metal sheets and said sealing members.

7. A pressure responsive apparatus as defined in claim 1, wherein said detecting means provides a pressure output signal indicative of the piston displacement and said means responsive to said output signal includes pressure amplifier means and a bellows connected to said one end of the pivotable rod for displacing said end in accordance with the amplified pressure signal.

8. A pressure apparatus as defined in claim 1, wherein said detecting means provides an electrical output signal indicative of the piston displacement and said means responsive to said output signal includes amplifier means and electromagnetic means connected to said one end of the pivotable rod for displacing said end in accordance with the amplified electrical signal.

9. A pressure responsive apparatus as claimed in claim 8 further comprising elevation means connected to the other end of said differential piston member.

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