United States Patent [19]

Blanchard

[11] **3,745,384**

[45] **July 10, 1973**

[54] **RESONANT PRESSURE SENSOR**

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[52] **U.S. Cl.** .... **310/8.2,** 73/386, 73/398 R, 310/8.1, 310/8.5, 331/65

[51] **Int. Cl.** **H04r 17/00**

[58] **Field of Search** .....310/8.1–8.3, 8.5, 8.7; 340/8, 10, 15.5, 17; 331/65, 154; 73/67, 67.2, 386, 398 R, 71.5 U; 332/30

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Assistant Examiner—Mark O. Budd
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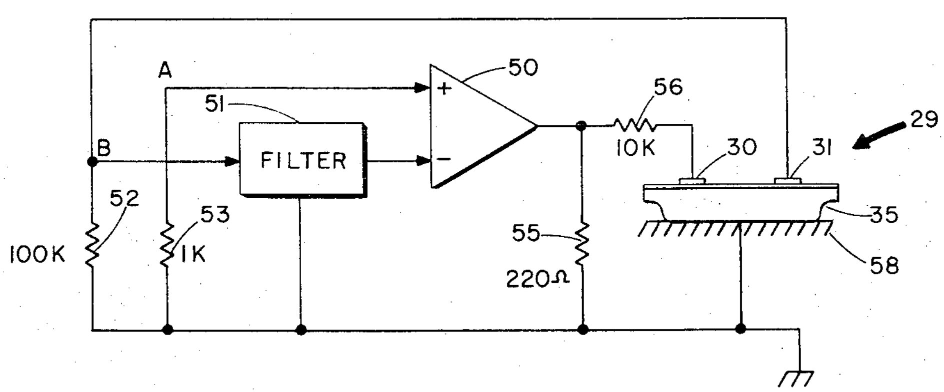
[57] **ABSTRACT**

A pressure responsive diaphragm or capsule having a variable self-resonant frequency characteristic is excited to vibrate in a mode other than the fundamental or f_{01} mode, that is, vibration occurs in a mode wherein at least first and second portions of the diaphragm are simultaneously moving 180° out of phase with respect to one another. This is accomplished by suitably coupling first and second electromechanical transducers to the first and second diaphragm portions respectively. A feedback amplifier whose output frequency is determined by the frequency at which the first transducer is vibrating is connected to drive the second transducer.

9 Claims, 12 Drawing Figures



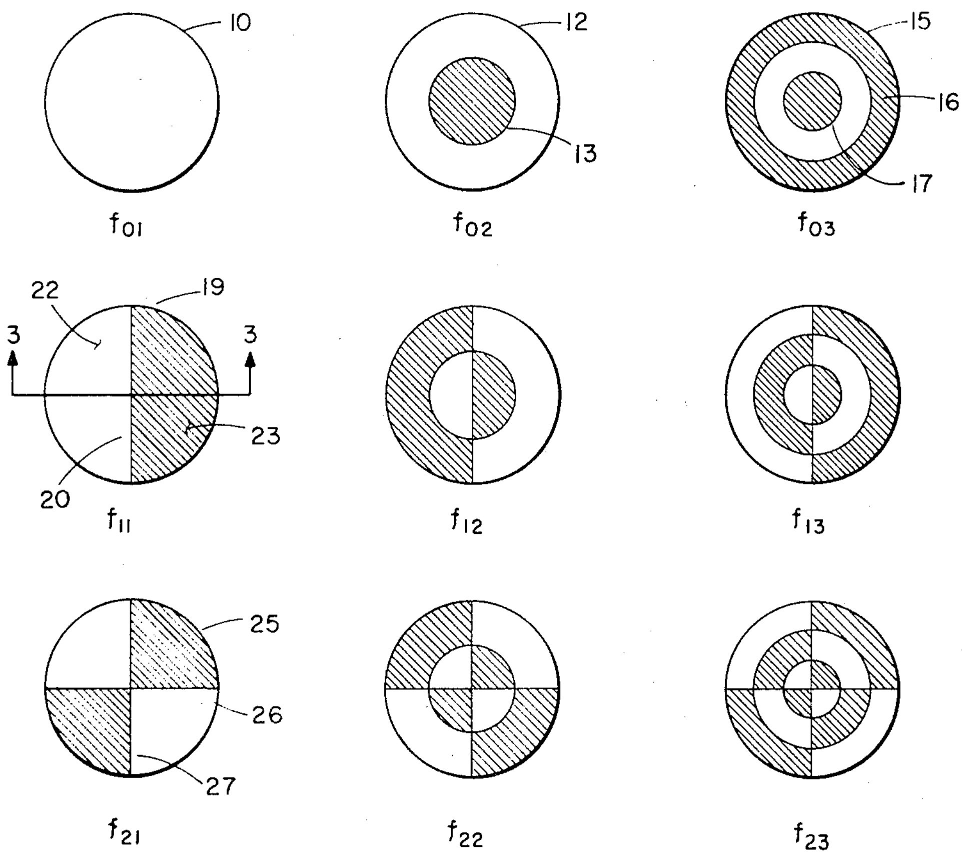


FIG. 1

	PLATE	MEMBRANE
f_{02}	3.91 X f_{01}	2.30 X f_{01}
f_{03}	8.75	3.60
f_{11}	2.09	1.59
f_{12}	5.98	2.92
f_{13}	11.9	4.22
f_{21}	3.43	2.14
f_{22}	8.74	3.50
f_{31}	4.95	2.65

FIG. 2

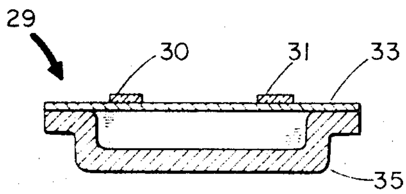


FIG. 3

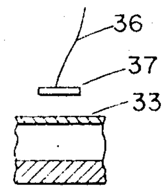


FIG. 4

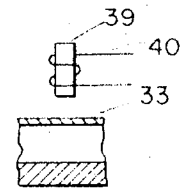


FIG. 5

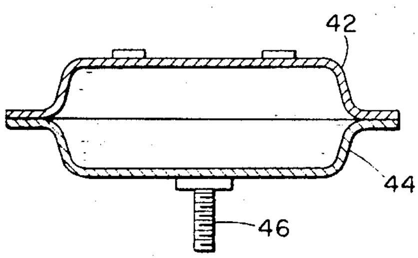


FIG. 6

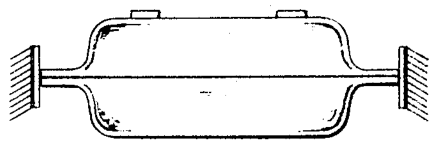


FIG. 7

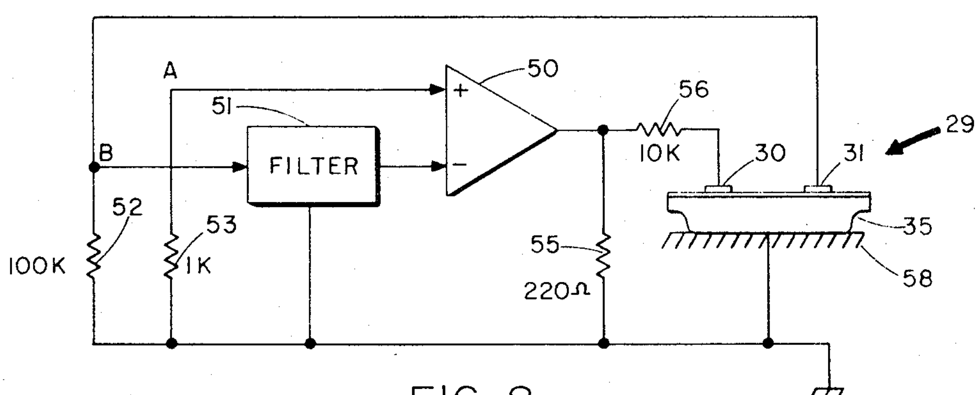


FIG. 8

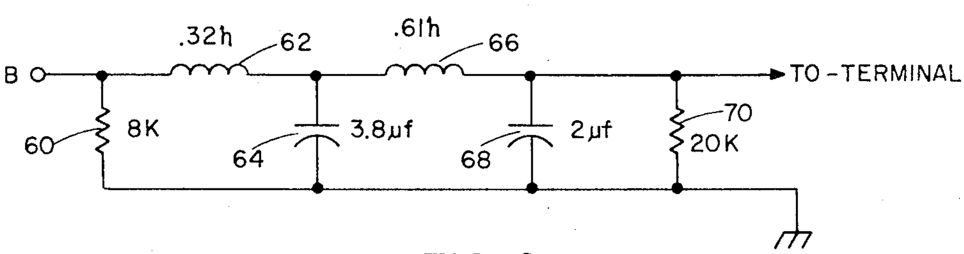


FIG. 9

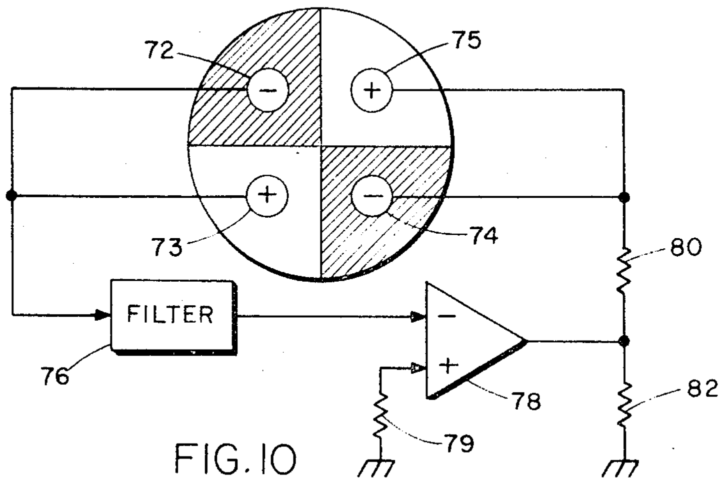


FIG. 10

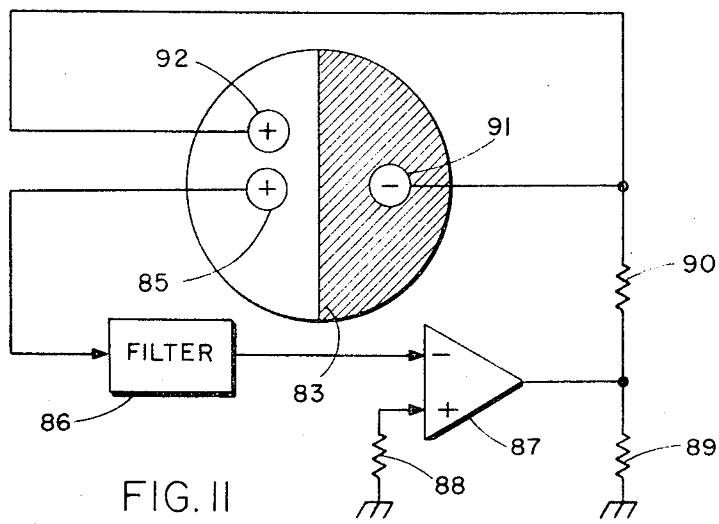


FIG. 11

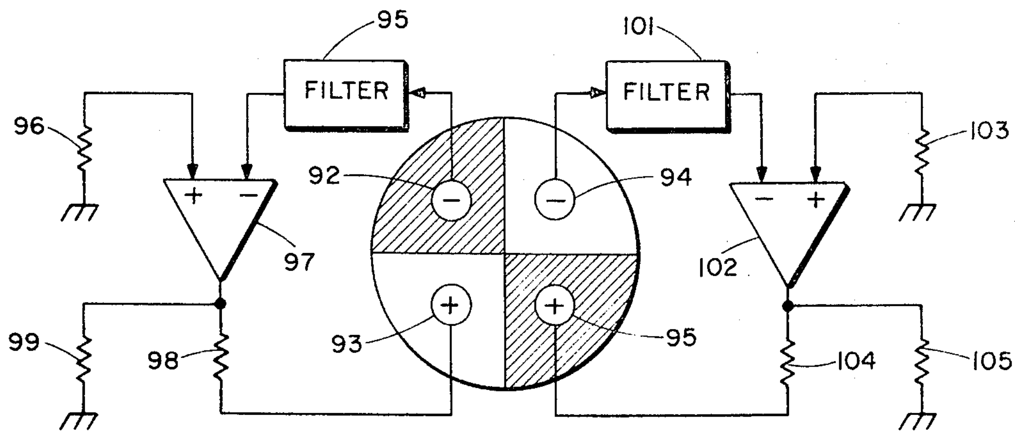


FIG. 12

RESONANT PRESSURE SENSOR

BACKGROUND OF THE INVENTION

This invention relates to fluid pressure sensors and more particularly to self-resonant vibrating pressure sensors generally comprised of a diaphragm or capsule having a variable self-resonant frequency characteristic and which thus has a generally unique self-resonant frequency for each pressure sensed.

The use of a diaphragm or a causule having a generally unique self-resonant frequency for each pressure as a self-resonant pressure sensor was first suggested by J. R. Cosby in his U. S. Pat. No. 3,019,397. This pressure sensor consists of the aforementioned capsule, electromechanical transducers for sensing the vibrating frequency of the capsule and for driving the capsule, and a positive feedback oscillator or amplifier whose output frequency is determined by the sensed frequency, which output frequency is used to drive the capsule. The oscillator in essence thus drives the capsule at its self-resonant frequency, which is a measure of the sensed pressure differential across the diaphragm. This novel use of a pressure capsule permits analog pressure to be directly converted to frequency at the sensing element. The various mechanical linkages associated with a pressure capsule when used to sense pressure by static deflection of the capsule as well as the characteristic hysteresis of the capsule are essentially eliminated by this device.

In this prior art device the drive transducer was effective for driving the capsule generally centrally of the diaphragm while the pickup transducer sensed the same portion of the diaphragm. This placement of transducers indicates that the diaphragm was excited in the f_{01} vibrational mode and generally limits the diaphragm vibration modes to those modes having no nodal diameter.

The present sensor is similar to the Cosby sensor. That is, the sensor consists of a mechanically unloaded anerode capsule and associated electronics. The capsule is suitably evacuated but may optionally be filled with a standard fluid at a standardized pressure, or may be immersed in a standardized environment and the interior of the capsule communicated with the pressurized fluid to be sensed. In most usages the fluid to be sensed will be atmospheric air. At least one side of the anerode capsule is a thin diaphragm which flexes as the pressure loading is varied. This flexing causes the tension stresses in the diaphragm to vary. The self-resonant frequency of the diaphragm is a function of the tension and therefore changes as the pressure changes. Generally, the capsule is designed so that flexing does not exceed the elastic limit of the diaphragm material and therefore the flexing is repeatable.

In this new pressure sensor two or more electromechanical transducers are coupled to the surface of the diaphragm at diverse points. These transducers are suitably any of the type which will attract or repel the diaphragm in response to an electrical signal of a first or second characteristic respectively. In addition, the transducers must be capable of detecting movement of the diaphragm and converting this movement to an electrical signal. For example, the transducers might be of the electromagnetic type, wherein the coupling between the transducer proper and the diaphragm is through magnetic forces. Another type of transducer is the piezoelectric type which is physically bonded to the

surface of the diaphragm. This type of transducer physically expands or contracts when a positive or negative electrical potential is applied across the transducer. Since the transducer is mechanically connected to the surface of the diaphragm, the motion of the transducer is transferred to the diaphragm. Conversely, the pickup transducer in response to the flexing of the diaphragm generates an electrical output indicative of the frequency of diaphragm vibration. Other types of transducers are also known, such as capacitive transducers, which are suitable for use with the invention. Regardless of the type of transducer used, one transducer physically excites the diaphragm by causing it to move forward or back when a positive or negative electrical potential is applied thereacross. The motion of the diaphragm is sensed by the other transducer and converted into an electrical signal. The output of a wide bandwidth electronic amplifier is used to drive the first mentioned transducer. Initially, random excitation of the capsule or a noise pulse from the amplifier to the transducer causes the diaphragm to be plucked. The diaphragm then starts to vibrate at its resonant frequency. The second transducer picks up the mechanical motion of the diaphragm and translates that motion to an oscillating electrical voltage. This voltage is fed to the input of the amplifier. The electrical voltage signal is then amplified and fed back to the drive transducer. The vibration of the diaphragm is thus sustained.

As aforementioned, the transducers are coupled to diverse points on the diaphragm. It is thus now relatively simple and desirable to excite the capsule at a resonant frequency other than the f_{01} mode. For example, by coupling the transducers to properly located points on the diaphragm, as will be described, equally spaced from a diaphragm center line and by additionally providing a proper phase shift from one transducer to the other, it is possible to excite the capsule to vibrate in an f_{11} mode. Other modes of vibration are also possible following the teachings of this invention.

The preferred mode of vibration of the diaphragm is the f_{11} mode. This mode is identified by one nodal circle, at the rim of the diaphragm, and one nodal diameter. This vibrational mode has the following desirable characteristics:

1. Higher mechanical Q than the fundamental or f_{01} mode; hence, permitting the diaphragm to assume its resonant frequency with greater ease despite the perturbations introduced by the transducers and the means by which the capsu'e is mounted in its environment.
2. The f_{11} mode allows for symmetrical placement on a circular diaphragm of both a driver and a pickup transducer. This technique completely eliminates the frequency response of the diaphragm from being dependent upon the response of the driving electronic circuitry.
3. The range of frequency variation for a given pressure variation is greatest because both the f_{01} and the f_{21} modes can be discriminated against.

This ease of discrimination arises from the fact that there is a 180° phase reversal of the signal at the output transducer for these latter modes when referenced to the desired f_{11} mode output.

It is thus an object of this invention to provide a vibrating diaphragm pressure sensor which operates in a mode other than the f_{01} mode.

It is a further object of this invention to provide a vibrating diaphragm pressure sensor which has a greater range of frequency variations versus pressure than earlier known similar devices.

It is a still further object of this invention to provide a pressure sensor of the type described whose pressure response is relatively predictable.

It is still a further object of this invention to provide a vibrating diaphragm pressure sensor using an aneroid cell wherein mechanical problems normally associated with an aneroid cell such as mechanical linkages, hysteresis and undesirable resonances are eliminated, and wherein further mechanical problems associated with an aneroid cell when used as a vibrating pressure sensor, such as structural resonances around and attached to the vibrating sensor, are also eliminated.

These and other objects of the invention will be made obvious as this description proceeds.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates certain of the modes of vibration of a clamped circular plate or a stretched circular membrane.

FIG. **2** is a table showing the relationship of the various resonant frequencies of the plates and membranes of FIG. **1**.

FIG. **3** shows a preferred embodiment of the invention using piezoelectric transducers.

FIG. **4** shows a capacitive type of transducer.

FIG. **5** shows an electromagnetic type of transducer.

FIG. **6** shows another form of the invention.

FIG. **7** shows another form of the invention wherein the capsule is mounted at its circumference.

FIG. **8** shows an electronic feedback circuit suitable for use in the invention.

FIG. **9** shows a bandpass filter suitable for use in the invention.

FIGS. **10, 11** and **12** illustrate further embodiments of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the figures wherein like numbers refer to like elements and referring first to FIG. **1**, there is shown represented the various modes of vibration of a clamped circular plate or alternatively of a stretched circular diaphragm. In this figure, the shaded segments are displaced in opposite phase to the unshaded segments. For example, when a clamped circular plate or stretched circular diaphragm is vibrated in its resonant frequency in the f_{01} mode the entire surface of the structure moves alternately towards the observer and then away from the observer at the resonant frequency. This mode is characterized by the single nodal circle **10** illustrated. When excited at the f_{02} resonant frequency the diaphragm will vibrate in the f_{02} mode characterized by concentric nodal circles **12** and **13**. In this case, a portion of the device enclosed by nodal circle **13** will be moving in a first direction while simultaneously the portion of the device between nodal circles **12** and **13** will be moving in the opposite direction. Similarly, when vibrated in the f_{03} mode three nodal circles **15, 16** and **17** are present. When vibrated in the f_{11} mode the device exhibits a characteristic nodal circle **19**, at the rim and one nodal diameter **20**, thus separating the device into two halves **22** and **23** which move in opposite phase to one another. The device when vibrated in the f_{21} mode exhibits the single nodal circle **25** and two nodal diameters **26** and **27**, thus dividing the device into four segments. The other vibrational modes may be derived from those already described, for example, when vibrated in the f_{12} mode the device exhibits a single nodal diameter and two nodal circles, when vibrated in the f_{13} mode a single nodal diameter is noticed and three nodal circles. In the f_{22} mode, two nodal diameters and two nodal circles are present while in the f_{23} mode, three nodal circles and two nodal diameters are present.

The diaphragm of the pressure sensor appears as a clamped edge uniformly loaded diaphragm. The loading of the diaphragm is the pressure differential created by the evacuation of the aneroid cell. The diaphragm acts over the transition range where its resonance frequency performance can be simplified from that of a clamped plate to that of a stretched membrane as the resonant frequency increases in response to pressure increase. The theoretical analysis and general equations in a differential form can be found in "Theory of Plates and Shell" by Timoshenko and will not be further discussed here.

The simplified relations of a plate and membrane are described in "Acoustical Engineering" by Olson and relates the appropriate configuration to the fundamental frequency, f_{01}. The modes of vibration are defined and the frequency of vibration for each calculation is referenced to the fundamental mode vibrational frequency. In brief, the fundamental frequency f_{01} of a clamped unloaded plate is given by:

$$f_{01} = (0.467t/R^2)\ (Q/\rho(1-\sigma 2))^{1/2}$$

where

t = thickness of plate in cm

R = radius of plate in cm

ρ = density of plate in gm/cm^3

σ = Poissons ratio

Q = Young's Modulus in dym/cm^2

The modes are identified by the resonant frequency subscripts f_{xy} where x identifies the number of nodal diameters and y identifies the number of nodal circles in the vibrational patterns. These are the modes shown in FIG. **1** and already described.

The fundamental frequency of a stretched membrane is given by:

$$f_{01} = (0.382/R)\ (T/M)^{1/2}$$

T = tension in dym/cm^2

M = mass in gm/cm^2

R = radius of membrane in cm

For a uniformly pressure-loaded circular membrane the radial stress is not uniform but varies from:

$\delta_1\ (EP^2R^2/t^2)^{1/3}$ at the center to:

$\delta_2\ (EP^2R^2/t^2)^{1/3}$ at the edge, where:

$\delta_1 \approx 0.423$

$\delta_2 \approx 0.0328$

P = pressure across the membrane and

E = modulus of elasticity.

For modes with diagonal nodal lines (for example the f_{11} mode) there is, in addition to radial stress, a tangential component of stress which is generally small in comparison to the radial component of stress. If the tangential component of stress is neglected and T is taken as uniform and as the average of these two radial component values of the stresses, the equation above becomes:

$$f_{01} = AP^{1/3}$$

where A is a constant.

In the intermediate pressure range, the restoring forces in a sensor diaphragm are expected to include both (a) the diaphragm rigidity effects and (b) the stresses caused by stretching the diaphragm as a result of pressure loading. Since the square of the resonant frequency is proportional to the restoring forces and these forces are additive, a simplified relationship is:

$$f_{01}^2 = f_0^2 + f^2 (p)$$

where:

f_0^2 is the f_{01} contribution due to the unloaded sensor and f^2 (p) is the contribution due to pressure loading.

The frequency of oscillation expressed in terms of the modes for both the plate and membrane case are given in FIG. 2.

Before referring to that figure it should first be mentioned that generally a diaphragm of the type used in the preferred embodiment of the invention acts as a plate when relatively less stressed corresponding to the sensing of low pressure differential, and acts as a membrane when relatively highly stressed, corresponding to the sensing of high pressure differential.

In any event, FIGS. 1 and 2 clearly illustrate the desirability of exciting the device in the f_{11} mode whether the environment in which the device is operating causes it to act as a circular plate or a membrane. Refer to these two figures now and particularly to the portion of FIG. 1 that illustrates the f_{11} vibrational mode. It has previously been mentioned that this is the optimum mode for exciting the vibrating diaphragm of the pressure sensor. It will be noted that this mode allows for symmetrical placement of the transducers. That is, the transducers may be placed respectively in portions 22 and 23 on either side of the nodal diameter 20. In this description the word located is used in the sense of coupled to. The transducers are optimally located at the center of the maximum motion perpendicular to the plane of the diaphragm. For a membrane this occurs when J_1 (X) is a maximum where J_1 is the Bessel function of the first kind and of the first order. The argument of X is 1.8, and 0.58 is the value of the function. The location of the maximum motion is therefore $0.58r$ from the center of the diaphragm where r is the effective radius of the membrane. The actual configuration of the pressure sensor to be described does not allow the diaphragm to act as a membrane over the entire pressure range. This is because the diaphragm has thickness and is welded to a backup cup to form a sensor cell. The rim or periphery of of the diaphragm therefore remains rigid or clamped and not simply supported. The value of r is thus also a function of the pressure loading. The physical size of the transducers, however, is large compared to the variation of the effective radius of the diaphragm and therefore the variation in r is ignored.

With the transducers located at diverse portions of the diaphragm the feedback circuit must be correctly phased in order to apply positive feedback from one transducer to the other transducer. Since for the f_{11} mode the motion of the transducers is oppositely phased one to the other the feedback circuit must take account of this phasing to produce the positive feedback, as will be fully described below.

FIG. 2 shows the resonant frequency of the diaphragm when vibrated in the various vibrational modes with respect to the resonant frequency of the f_{01} mode. For example, if the device is acting as a plate in the f_{02} mode its resonant frequency will be 3.91 times the resonant frequency of the device in the f_{01} mode. In the same manner if the device is acting as a membrane its resonant frequency in the f_{02} mode will be 2.3 times the resonant frequency when in the f_{01} mode. Three vibrational modes are of particular interest at this time, the f_{11}, the f_{12} and the f_{13} modes. It can be seen that the resonant frequency of the device in the f_{12} mode when acting as a membrane is almost twice the resonant frequency of the device in the f_{11} mode when acting as a membrane. The resonant frequency of the f_{13} mode as well as the device when acting as a plate is even further removed from the resonant frequency of the device in the f_{11} mode. A filter is provided in series with the feedback oscillator to prevent feedback of the higher resonant frequencies associated with the f_{12} and f_{13} modes as well as the other listed modes to thus ensure that the device is vibrated only at the f_{11} mode. The characteristics of the feedback oscillator will be disclosed below.

FIG. 3 shows a cross-section of a capsule 29 taken along line 3—3 of FIG. 1. Reference should now be made to this figure. Transducers of the type which are bonded to the diaphragm, such as piezoelectric transducers 30 and 31 are shown coupled to the diaphragm 33. In a device actually built the sensor diaphragm was constructed of Ni Span-C alloy. The diaphragm was 0.004 inch thick and had an effective diameter of 1¼ inches. A backup cavity 35 was constructed of the same material but was 0.016 inch thick in a cup shape as shown. The two members were welded together at the disk circumference. The welding operation was performed in an evacuated chamber so that the gas pressure inside the capsule was at a very low predetermined pressure. Of course, a pump-out tube may be provided in backup cavity 35 for evacuating the capsule after welding.

The transducers of the constructed model consist of two lead zirconate titanate piezoelectric ceramic devices. The electrodes on the polarized ceramic disks are made of silver fused to the faces of the ceramic. The ceramic disks used are 0.25 inch in diameter by 0.010 inch thick. Soft copper wire (not shown) is soldered to the top of the transducers for electrical connection therewith in the sensor of FIG. 3.

Other forms of transducers can be used as previously discussed. For example, in FIG. 4 there is shown the capacitor type of transducer wherein plate 37, together with diaphragm 33, form a capacitor which receives an electrical signal on electrical lead 36. FIG. 5 shows an electromagnetic type of transducer wherein winding 40 cooperates with armature 39 and diaphragm 33.

A further form of the invention is shown in FIG. 6 wherein the vibrating diaphragm 42 has a generally hat-shaped form and the backup cavity 44 has a similar form. In this embodiment a stud 46 supports the backup cavity and provides means for mounting the capsule. A further means of mounting a capsule such as that shown in FIG. 6 is shown in FIG. 7 where the capsule is mounted about its circumference.

During the manufacture of the Ni Span-C alloy from which the diaphragm is fabricated the material undergoes a work hardening due to the rolling operation. This causes an additional stiffness on the rolling axis. It is desirable that a nodal diameter coincide with this rolling axis. For example, when the diaphragm is excited to resonate in the f_{11} mode the nodal diameter is optimally parallel with the roll marks on the diaphragm. Thus, the proper location for the transducers to excite and sustain the f_{11} mode should be on a diameter line perpendicular to the roll marks.

In order to ensure a continuous pressure-frequency transfer function for the sensor all undesirable resonant structures in the desired sensor frequency range should be removed. If this is not done, the vibrating diaphragm will impart energy to the undesired resonating structure. As this occurs, the frequency of vibration of the sensor will be altered. This change of sensor frequency is a function of the Q of the diaphragm and of the undesired resonating structure, of the coupling coefficient between the structures and of the separation of the center frequencies of the resonating structure. These undesired resonances might be introduced by the transducer leads, the sensor backup cavity, mounting structure and adjacent structures. The undesired resonance frequency of the backup cavity **35** of the device of FIG. **3** is far removed from the resonant frequency of the sensor and is thus less objectionable than the undesired resonances introduced by the backup cavities of the devices of FIG. **6** or FIG. **7** where the resonant frequency of the backup cavity is closer to the resonant frequency of the sensor due to similar configuration of the backup cavity with the diaphragm. For this reason, the device of FIG. **3** is preferred. Of course, radiators of energy with a spectral content near the desired frequency of the sensor should also be avoided since in this case the sensor will absorb energy from the radiator with resultant frequency shift.

FIG. **8**, reference to which should now be made, shows the entire sensor including the capsule **29** connected in an electronic circuit for detecting and sustaining the resonant frequency of the sensor diaphragm. The sensor backup cavity **35** is rigidly attached (through means not shown) to a relatively massive structure **58**. The pickup transducer **31** is connected to terminal B and hence through filter **51** to the negative input port of operational amplifier **50**. In addition, terminal B is connected through resistor **52** to ground. The positive input port of the operational amplifier is connected through resistor **53** to ground. The output of the operational amplifier is grounded through resistor **55** and is additionally used to drive transducer **30** through resistor **56**. In order to ensure the proper phase shift relationship in the feedback circuit, one transducer is mounted with the positive side to the diaphragm while the other transducer is mounted with the negative side to the diaphragm. This yields a −90° phase shift through the transducers. Of course, if both transducers are mounted with the positively polarized side up or down, the voltage phase shift through the transducers would be +90°. The gain of the feedback circuit must be sufficient to overcome the transducer or mechanical losses associated with the sensor. It will also be remembered that the gain through the feedback circuit should be reduced as frequency is reduced to minimize exciting higher order modes on the diaphragm.

The gain variation versus frequency and the phase shift requirements are satisfied by using the operational amplifier beyond its cutoff frequency. Beyond the cutoff frequency the voltage gain of the amplifier is reduced by 20 DB per decade. Also beyond the cutoff frequency the phase shift through the amplifier is ±90° depending on the inversion resulting from the connections at the amplifier input. These connections should be made such that the phase shift through the operational amplifier is +90° so that the total phase shift is zero degrees resulting in positive feedback.

The resistance network comprised of resistors **55** and **56** reduce the amplified gain thus improving the feedback stability and aiding in the elimination of higher frequency oscillation.

As previously discussed the gain at higher frequencies should be low enough to prevent the diaphragm from oscillating at undesirable frequency modes. This can be accomplished by placing a filter in series with the amplifier input such as filter **51**. The requirements of this filter are rather severe. The phase error introduced by the filter over the desired frequency range causes an error which is a function of the loaded Q of the mechanical resonating sensor. The more phase error the greater the pulling and therefore the greater pressure reading error. This filter is shown as item **51** in FIG. **8** and is shown in greater detail in FIG. **9**, reference to which should now be made. The filter of FIG. **9** is a Chebishev 0.1 DB ripple, four section impedance transforming type described by Matthaei in IEEE Transactions on Microwave Theory and Techniques, Volume MTT-14, Number 8, August 1966 at Page 372. The filter is connected in FIG. **8** between terminal B and the negative input terminal of operational amplifier **50**. The filter is comprised of a resistor **60** shunted between terminal B and ground and a resistor **70** shunted across the filter output terminal and ground. A capacitor **68** shunts resistor **70**. Inductors **62** and **66** are serially connected between terminal B and the negative input terminal of the operational amplifier **50**. A further capacitor **64** is connected between the common junction of inductors **62** and **66** and ground. The circuit values illustrated provide for a reduction in feedback gain above 8 KHz.

The invention can be practiced under some circumstances by using a plurality of transducers. For example, if the f_{21} mode is to be excited, the system designer can use four transducers, one coupled to each of the quadrants illustrated in FIG. **10** for the f_{21} mode. Reference to FIG. **10** should now be made. In this figure, piezoelectric transducers **72** to **75** are seen. Transducers **72** and **74** are located on diametrically opposite quadrants as are transducers **73** and **75**. In addition, transducers **72** and **74** are coupled to the diaphragm with a common polarity, for example, with the negative side to the diaphragm while transducers **73** and **75** are coupled with an opposite polarity, for example, with the positive side to the diaphragm. The output leads from transducers **72** and **73** are connected together and through bandpass filter **76** to the negative terminal of operational amplifier **78**. Filter **76** permits those frequencies expected when the diaphragm is excited in the f_{21} mode to pass therethrough. Resistor **79** is connected between the operational amplifier positive terminal and ground. The output from the operational amplifier is supplied in common to drive transducers **74** and **75** through resistor **80**. A resistor **82** is connected between the amplifier output and ground. It will be noted that except for the multiplicity of transducers the circuit of FIG. **10** is very similar to the circuit of FIG. **8** and like principles of operation apply. In the case of the device of FIG. **10** the f_{11} mode is absolutely suppressed due to the constraint on the transducers where transducers **72** and **74** are constrained to move in one direction while transducers **73** and **75** are moving in the opposite direction.

Reference should now be made to FIG. **11** wherein the invention is further illustrated to produce the f_{11} mode of vibration. The device of FIG. **11** is also very similar to the device of FIG. **8** having transducers **85** and **91** located on opposite sides of the nodal diameter **83** and oppositely poled with respect to one another. Transducer **85** is connected through a suitable filter **86** for allowing f_{11} frequencies to pass therethrough to the negative terminal of operational amplifier **87**. As before, the amplifier has a resistor **88** connected between ground and the amplifier positive terminal and a resistor **89** connected between ground and the amplifier output terminal. The amplifier output is also connected through resistor **90** to not only drive transducer **91** in a direction opposite from the direction of transducer **85** motion but also to drive transducer **92**, located on the same side of nodal diameter **83** as transducer **85**, in the same direction as transducer **85**. The location and connection of transducer **92** absolutely suppresses the f_{21} mode for example.

Referring to FIG. **12** a further means of using multiple transducers is seen. Here the f_{21} mode is to be excited, however, as will become clear, other modes are not absolutely suppressed by this means and filtering alone provides the suppression of certain modes. In this figure transducers **92** and **95** are coupled to diametrically opposite quadrants of the diaphragm as are transducers **93** and **94**. In addition, transducer **92** is oppositely poled from transducer **93** while transducer **94** is oppositely poled from transducer **95**. The feedback circuit between transducers **92** and **93** is essentially identical to the feedback circuit of FIG. **8**. That is, the feedback circuit includes filter **95** between transducer **92** and one input to operation amplifier **97**, a resistor **96** connected between ground and the other input terminal, the amplifier output being connected to drive transducer **93** through resistor **98** and the amplifier output being also connected through resistor **99** to ground. In like manner, transducer **94** is connected through the feedback circuit comprised of filter **101**, operational amplifier **102** and resistors **103**, **104** and **105** to drive transducer **95**. If filters **95** and **101** are designed to pass the frequencies of the f_{21} mode, that mode will generally be excited. However, if filters **95** and **101** are designed to pass the f_{11} mode, that mode will be excited. Thus, there is a possibility that some ambiguity will exist when using the means illustrated at FIG. **12** and the constrains imposed by the filters are thus more critical.

The invention claimed is:

1. In a pressure transducer including a diaphragm having a variable self resonant frequency wherein said frequency is correlated to pressure differential across said diaphragm and wherein said frequency can occur in at least one vibrational mode, characterized in that one portion of said diaphragm moves in a first direction while a second portion of said diaphragm moves simultaneously in a second direction, means for maintaining vibration of said diaphragm in said at least one vibrational mode comprising:

converting means operatively coupled to said one portion of said diaphragm for converting mechanical oscillations into an electrical output;

drive means operatively coupled to said second portion of said diaphragm for exciting said diaphragm to vibrate in response to an electrical signal; and,

electrical means responsive to said electrical output for generating said electrical signal.

2. The pressure transducer of claim **1** wherein said electrical means comprises means for generating said electrical signal phased to drive the portion of said diaphragm coupled to said drive means in an opposite direction than the direction in which the portion of said diaphragm coupled to said converting means is simultaneously moving.

3. The pressure transducer of claim **2** wherein said electrical means includes filter means for generating said electrical signal only within a predetermined frequency band.

4. The pressure transducer of claim **2** wherein said diaphragm is a rolled metallic alloy having a rolling axis, and wherein an imaginary straight line through said converting means and said drive means is perpendicular to said axis.

5. The pressure transducer of claim **1** wherein said at least one vibrational mode is characterized by at least one nodal diameter, said one portion being to one side of said nodal diameter and said second portion being to the other side of said nodal diameter.

6. A vibrating diaphragm pressure transducer operable in the f_{11} vibrational mode having a single nodal diameter comprising:

a diaphragm having a variable self resonant frequency characteristic;

means for impressing fluid pressure differential across said diaphragm;

converting means operatively coupled to a first portion of said diaphragm to one side of said nodal diameter for converting mechanical oscillations of said diaphragm into an electrical output;

drive means operatively coupled to a second portion of said diaphragm to the other side of said nodal diameter for exciting said diaphragm to vibrate in response to an electrical signal; and,

electrical means responsive to said electrical output for generating said electrical signal phased with respect to said electrical output so that said drive means drives said second portion of said diaphragm in a direction opposite to the simultaneous direction of movement of said first portion.

7. The vibrating diaphragm pressure transducer of claim **6** wherein said diaphragm is a rolled metallic alloy having a rolling axis and wherein said nodal diameter is substantially parallel with said rolling axis.

8. The vibrating diaphragm pressure transducer of claim **6** wherein said electrical means includes a filter whereby said electrical signal is contained within a predetermined frequency band related to the f_{11} vibrational mode frequencies.

9. The vibrating diaphragm pressure transducer of claim **6** with additionally further means coupled to said first portion of said diaphragm and responsive to said electrical signal for driving said first portion in a direction opposite to the direction in which said second portion is simultaneously driven by said drive means.

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