

XR 3,187,579

June 8, 1965

R. J. FERRAN ETAL

3,187,579

PRESSURE-TO-FREQUENCY TRANSDUCER

Filed June 14, 1962

2 Sheets-Sheet 1

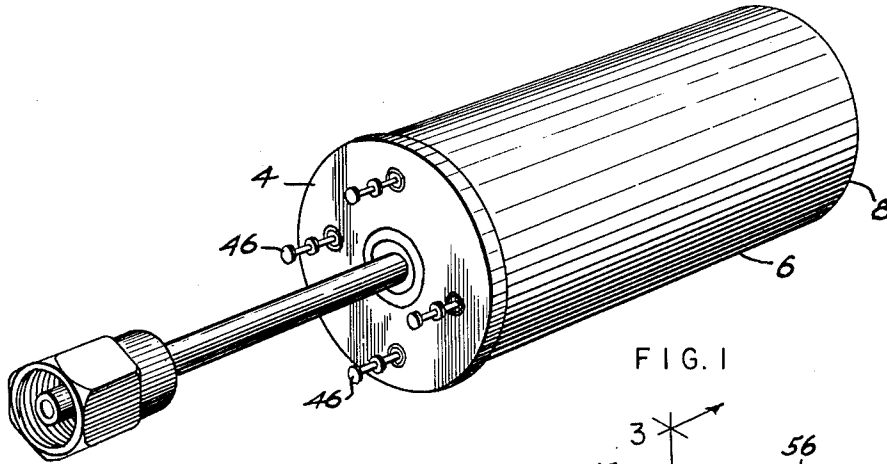


FIG. 1

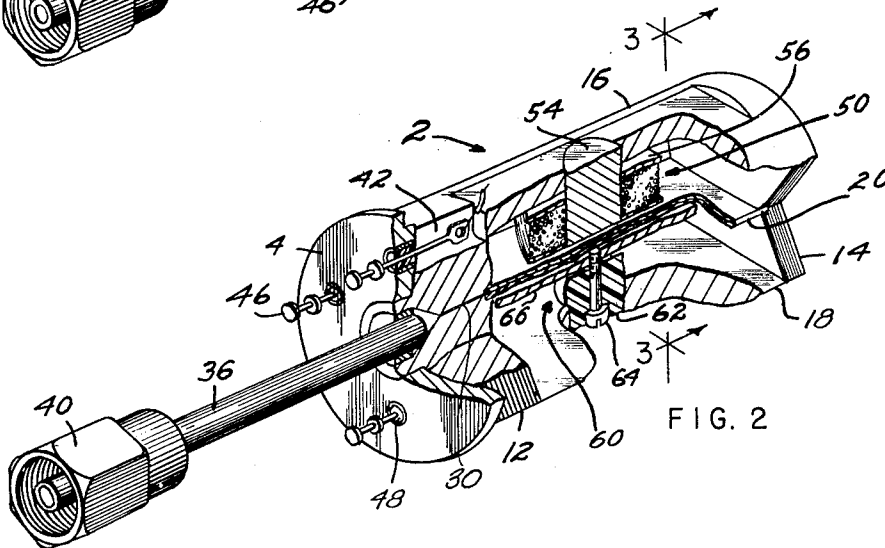


FIG. 2

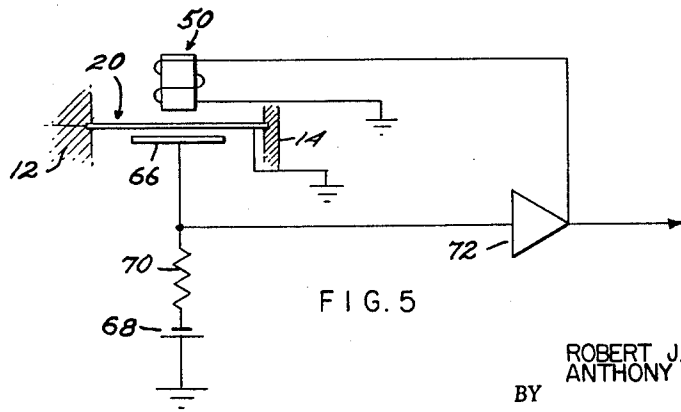


FIG. 5

INVENTORS.
ROBERT J. FERRAN
ANTHONY J. TESSICINI

BY

Wainwright, Ombach & Pardisew
ATTORNEYS

3187579
OR IN 73/398R

June 8, 1965

R. J. FERRAN ET AL

3,187,579

PRESSURE-TO-FREQUENCY TRANSDUCER

Filed June 14, 1962

2 Sheets-Sheet 2

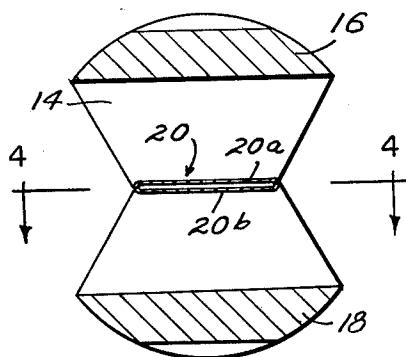


FIG. 3

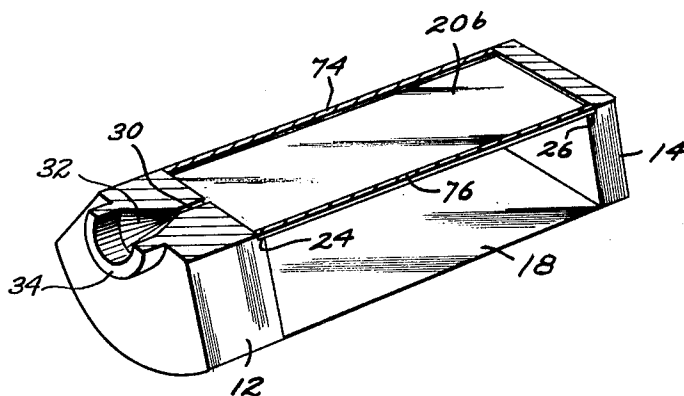


FIG. 4

INVENTORS
ROBERT J. FERRAN
ANTHONY J. TESSINI

BY

Wengert, Ambush & Pandisic
ATTORNEYS

1

2

3,187,579

PRESSURE-TO-FREQUENCY TRANSDUCER
Robert J. Ferran, Framingham, and Anthony J. Tessicini,
Wilmington, Mass., assignors to Acton Laboratories, Inc.,
Acton, Mass., a corporation of Massachusetts
Filed June 14, 1962, Ser. No. 202,602
25 Claims. (Cl. 73—398)

This invention relates to devices for translating changes in pressures to electrical signals and more particularly to a transducer adapted to provide an output signal whose frequency varies as a function of applied fluid pressure.

The primary object of the present invention is to provide a pressure transducer which is capable of producing an output signal whose frequency is modulated as a function of changes in applied fluid pressure and which, at the same time, is compact, reliable, accurate, and has good response. Such a device is especially advantageous in telemetry systems designed to handle data in the form of frequency modulated signals.

A more specific object of the present invention is to make a pressure-to-frequency transducer which embodies a hollow vibratory member whose natural frequency of vibration is caused to change as a function of applied fluid pressure. The hollow vibratory member is so constructed that its cross-sectional configuration will change according to changes in the difference between its interior and exterior pressures. The change in cross-sectional configuration alters its inertia characteristics so that it will have a different natural frequency.

Still a more specific object of the present invention is to provide a pressure-to-frequency transducer having a vibratory member which is elastically distorted by changes in differential pressure and, when distorted, will exhibit a different resonant frequency, plus means for causing said member to vibrate at its natural frequency, and means for developing an output signal having a frequency which is a function of the frequency of vibration of said member.

Other objects and many of the attendant advantages of the present invention will become more readily apparent when reference is had to the following detailed specification which is to be considered together with the accompanying drawings wherein:

FIG. 1 is a perspective view of a transducer embodying the present invention;

FIG. 2 is a perspective view similar to FIG. 1 but with certain portions removed and/or broken away so as to show further details of the invention;

FIG. 3 is a cross-sectional view taken along line 3—3 of FIG. 2;

FIG. 4 is a perspective view of a longitudinal half section taken along line 4—4 of FIG. 3; and

FIG. 5 is a schematic diagram of a circuit which indicates how the transducer device is used to generate an output signal indicative of changes in applied pressure.

Turning now to FIGS. 1 and 2, there is shown a transducer comprising a body identified generally at 2 having an annular metal header 4 attached at one end. The body is normally enclosed in a metal casing 6 which is in the shape of a cylinder closed at one end 8. The cylinder fits over the body 2 with its open end engaging the header 4. The cylinder is welded in place to make a hermetic seal with the header.

The present invention makes use of the fact that the frequency of vibration of a beam which is suspended at its ends is determined by several factors, among which are its composition, its length, and its cross-sectional shape. Thus, if the cross-sectional shape of a beam is

disturbed, its natural frequency of vibration will be affected. We have conceived that a unique pressure transducer can be made using a hollow beam which is suspended at its ends and which is adapted to be subjected to a varying pressure on its interior while the pressure on its exterior is maintained substantially constant. Its natural frequency of vibration will undergo a change with the direction and degree of change being a function of the change in its interior pressure. This unique transducer involves a driver device for causing the beam to vibrate and a pickup device for monitoring the vibrations of the beam and producing in response thereto an electrical signal indicative of any change in the frequency of vibration of the beam. The electrical signal is fed back to the driver to maintain the beam in motion at its natural frequency.

The transducer body 2 comprises an open rectangular frame formed by two parallel, spaced end wall members 12 and 14 and two parallel, spaced, longitudinal wall members 16 and 18. The longitudinal wall members are integral with the end wall members.

Suspended between the end walls 12 and 14 is a vibratory metal member 20 made of a selected material which may be attracted by a magnetic field. The latter is a hollow beam having a cross-sectional configuration generally conforming to a flattened oval or ellipse (FIG. 3). Its width is made substantially less than the inside diameter of casing 6 so as to avoid any interference by the casing. The opposite ends of the beam are disposed in grooves 24 and 26 formed on the inside faces of end walls 12 and 14, respectively. The ends of the beam are welded or brazed in place in grooves 24 and 26 so as to seal off the interior of the beam. However, it is to be noted that a small axial bore 30 is provided in end wall 12. Bore 30 intersects groove 24 and thereby communicates with the interior of the beam. The other end of bore 30 communicates with a tapered counterbore 32 drilled in the outside face of end wall 12. The front face of end wall 12 also has a projecting annular neck 34 concentric with counter bore 32. Secured in place within neck 34 by brazing is an elongate, axially disposed tube 36 which is provided at its free end with a coupling 40 whereby it may be connected to a system having a varying fluid pressure output. Changes in the latter cause deformation of the beam, and this deformation is translated into an analog electrical signal by the transducer. Neck 34 also serves to center the header 4 which is brazed or welded to the neck and preferably also to end wall 12. The latter has axially extending slots 42 to accommodate the rear ends of a plurality of terminals 46 carried by and forming part of the header. These terminals are used to couple various element (hereinafter described) of the transducer to external circuitry. Accordingly, they are secured in place by glass seals 48 which electrically insulate them from the header and also prevent moisture or gases from passing into the transducer. The top wall member 16 supports a magnetic driver identified generally at 50. The driver comprises a permanent magnet core 54 secured in a suitable opening formed in the top wall member 16 at a point in line with the center of beam 20. The magnetic core 54 supports a coil form 56 having a coil of very fine wire wound around the core. The coil form and the end face of the core 54 are proximate to but spaced from the hollow beam 20.

The bottom wall member 18 supports a capacitive pickup device identified generally at 60. The pickup device includes a plug 62 of insulating material secured in a hole formed at the center of wall member 18 and a

metal screw 64 which projects up through the plug and has on its projecting end a rectangular metal electrode plate 66. The latter is proximate to but spaced from the adjacent side of the hollow beam 20.

The ends of the coil of driver 50, the screw 64, and the body 2 are connected to appropriate ones of the terminals 46 by insulated wire leads (not shown).

At this point, it is to be emphasized that the end wall members 12 and 14 and the longitudinal wall members 16 and 18 are made of metal and are sufficiently permeable to form part of the magnetic circuit for the magnetic field of the magnet core 54 and the magnetic field generated by the coil when it is energized. The magnetic circuit for both fields comprises the beam 20, the end wall members 12 and 14, the upper wall member 16, and the core 54.

The magnet core functions to subject the beam 20 to a magnetic biasing force which causes it to bow out toward the core by a predetermined amount symmetrically about its center and to stay bowed at that predetermined amount in the absence of any other force. Despite the loading effect of the field of core 54, the beam will vibrate at its natural frequency if subjected to a sharp force, as, for example, by energizing the coil with a pulse. If the magnetic field produced by the pulse has the same polarity as the field of the permanent magnet, the beam will be drawn nearer to the magnetic driver. As the pulse decays, the beam will tend to return to its normal biased position, but instead, will overtravel and then vibrate at its natural frequency. If the field generated by the pulse has a polarity opposite to that of the field of the permanent magnet, the influence of the latter will be reduced and the beam will tend to return to its original unbowed state. As the pulse decays, the beam will tend to return to its normal biased position, but instead, will overshoot and vibrate at its natural frequency. In either case, the beam will not resonate continuously; instead, its vibrations will decay in amplitude and disappear. However, it is recognized that if the driver is energized again with another pulse in phase with the vibrations, it will reinforce them and delay their decay. Accordingly, if an alternating current having the same frequency and phase as the vibrations of the beam 20 is applied to the magnetic driver, the latter will function to keep the beam vibrating continuously. However, since the natural frequency of vibration of the beam may change due to a change or deformation in its cross-sectional shape, it is imperative that the frequency of the alternating current change correspondingly. Otherwise it will not be in phase and, therefore, will act to dampen rather than sustain the vibrations of beam 20. In this case, the frequency of the current applied to the coil is determined by the capacitive pickup which monitors the vibrations of the beam. In this connection, it is to be appreciated that when the beam vibrates, the capacitance between the beam and the electrode plate will vary according to the instantaneous spacing between the two plates. The result is that if the capacitor comprising the beam and the plate 66 are connected in a circuit providing bias to the capacitor, the instantaneous voltage across the capacitor will vary at the same frequency as the beam vibrates, becoming larger as the beam moves away and smaller as the beam moves toward plate 66. This A.C. voltage can be used to operate the magnetic driver to keep the beam in motion.

FIG. 5 shows how this is accomplished. A D.C. voltage from a battery 68 is applied across the parallel plates 20 and 66 through a large bias resistor 70. The junction of electrode plate 66 and resistor 70 is connected to the input side of an amplifier 72. The output side of the latter is coupled back to the coil of magnetic driver 50. With this arrangement, vibration of beam 20 will cause an A.C. voltage to be developed at plate 66 and resistance 50. This voltage is amplified by amplifier 72 and fed back to the magnetic driver in phase to bolster the vibra-

tions of beam 20. The output of the amplifier is also fed to external circuitry (not shown) adapted to perform one or more functions such as measuring and indicating the frequency or change in frequency of the output.

From the foregoing, it is believed to be apparent that with the apparatus herein described and illustrated it is possible to produce an alternating current signal whose frequency is modulated as a function of change in fluid pressure.

Since the invention is based upon the premise that a change in pressure applied to a hollow beam will cause it to change dimensionally in cross-section and that this dimensional change will be reflected in a new natural frequency of vibration, the normal cross-sectional configuration is quite important. The object is to have a configuration which exhibits relatively large changes in natural frequency for relatively small changes in applied pressure. Although a variety of cross-sectional shapes may be employed, the most satisfactory configuration is the one shown in the drawings, i.e., a flat oval. As used herein, the term "flat oval" means a configuration having a relatively small height versus a relatively large width. Generally flat, rectangular and elliptical shapes are to be considered as falling within the term "flat oval." This preferred shape is highly satisfactory since an increase in interior pressure will have a substantial distorting effect on the top and bottom walls of the beam since they are akin to metal diaphragms but will have little effect on the side walls thereof since they are of little area and mass. A circular cross-section provides a much less satisfactory response because of its symmetry.

In practice, it is preferred that the size of the chamber within the beam be very small. By way of example but not of limitation, the height of an oval chamber may be in the order of .004 inch, and its width may be in the order of 0.5 inch. Changing the width of the beam changes the range of pressures to which it will respond. Changing the wall thickness of the beam also affects the useful pressure range. It is preferred also that the wall thickness be .010 inch. As is to be expected, changing the length, i.e., span, of the beam changes its natural frequency of vibration.

Also of primary importance is the composition of the beam. It is essential that the beam be made of a material having a modulus of elasticity which is substantially constant. Actually, all materials depart from ideal elastic behavior in one way or another, primarily drift, hysteresis, and change of modulus with temperature. However, there exists a number of materials known in the art as "constant modulus alloys" which have been formulated to have almost ideal elastic behavior. These alloys are sold under a variety of trade names, including Ni-Span-C, Elinvar, Durinval, Nivarox, and Iso-elastic. These materials exhibit unusually low drift and hysteresis, as well as temperature coefficients of modulus which are zero or are made to have a desired positive or negative value near to zero. Accordingly, as used herein, the terms "substantially constant modulus of elasticity" and "constant modulus alloys" shall be construed to mean materials which closely approach ideal elastic behavior, having substantially no or very low drift or hysteresis and a temperature coefficient of modulus which is zero or has a positive or negative value very near zero.

Using a constant modulus alloy is essential. Otherwise the distortion of the beam in response to changes in pressure applied via the tube 36 will not vary according to a determinable function and the output of the transducer will be useless. A constant modulus of elasticity, on the other hand, causes the beam 20 to distort according to a recognizable or determinable function of the applied pressure, thereby providing an electrical output which can be used to provide a measure of the changes in applied pressure.

In practice, it is preferred that the beam be made of

Ni-Span-C. The nominal analysis of Ni-Span-C is as follows:

Elements:	Nominal composition, percent
Nickel -----	42.2
Chromium -----	5.3
Titanium -----	2.5
Chromium and titanium -----	7.6
Carbon -----	.03
Manganese -----	.4
Silicon -----	.4
Aluminum -----	.4
Sulphur -----max--	.04
Phosphorous -----max--	.04
Iron -----	Balance

This material is magnetic and is preferred since its thermoelastic coefficient is not determined solely by its chemical composition but can be modified by heat treatment. Hence, its thermoelastic coefficient can be controlled from one lot to another despite minor differences in melting and alloying conditions. What is even more important is that its modulus is constant from -50° F. to $+150^{\circ}$ F. Moreover, although its modulus begins to change above 150° F., it does so to a lesser degree than other related alloys.

Although the frame which supports the beam may be made of a different material, it is preferred that it be made of the same material as the beam. There are various reasons for this, the chief one being that it provides equal coefficients of expansion which help assure that no strain will be induced due to changes in operating temperatures. The construction of the frame also may be varied. Thus, for example, it could be made in two pieces with each piece comprising half of each of the end walls 12 and 14 and one of the walls 16 and 18. The two pieces would be joined together by welding or brazing with the ends of the beam captivated in the same manner as shown in the drawings.

Although the beam may be made in several ways, it is preferred to make it from two thin plates 20a and 20b which have their confronting surfaces milled away so as to leave narrow ribs 74 and 76 (FIG. 4) along their longitudinal edges. The two plates are welded together along their edges, producing a cross-section as shown in FIG. 3. It is to be understood that the plates need not be flat but could be curved in cross-section, whereby the chamber formed therebetween would vary in height with the greatest height at the center. Of course, the wall thickness would be uniform in each case, with the widths of the ribs 74 and 76 the same as the wall thickness of the beam.

It is to be appreciated that the pressure on the outside of beam 20 could be a vacuum, in which case, the pressure in the tube 36 must be viewed as absolute. On the other hand, the exterior pressure could be atmospheric, in which case, the interior pressure would be gauge. It is also possible for the exterior pressure to vary, as, for example, a control pressure related to but varying at a different rate than a signal pressure applied to tube 36. In each case, the resulting distortion is due to a change in pressure differential.

Although a magnetic driver and capacitive pickup are preferred, it is to be understood that other choices may be made. Thus, for example, the pickup may be magnetic in nature. It is also appreciated that the core 54 need not be a permanent magnet, in which case, a continuous biasing current may be applied to the magnetic driver. Another variation using a core which is not a permanent magnet is to pass the signal from amplifier 72 through a half wave rectifier before being applied to the magnetic driver.

The present invention has many advantages. It is compact, rugged, and has a relatively long life. It is usable over a relatively wide temperature range and can be made to accommodate different ranges of pressures.

Thus, for example, it has been possible to fabricate models responsive to pressure fluctuations in the range of 0-10 p.s.i. and in the range of 0-300 p.s.i. Since its output is based on frequency rather than amplitude changes, it may be transmitted over long lines without distortion and lends itself readily to counting. A further advantage is that it is completely insensitive to external vibration up to just below the base frequency of the beam. The base frequency is the natural frequency of vibration when the interior pressure has an absolute value of zero. In a typical case, the base frequency is 2500 cycles/sec. and the natural frequency at full-scale pressure 3000 cycles/sec. Hence, it is insensitive to low frequency mechanical vibration, as, for example, 60-cycle motor hum.

Obviously, many modifications and variations of the present invention are possible in the light of the foregoing teachings. It is to be understood, therefore, that the invention is not limited in its application to the details of construction and arrangement of parts specifically described or illustrated, and that within the scope of the appended claims, it may be practiced otherwise than as specifically described or illustrated.

We claim:

1. A pressure responsive transducer comprising an hermetically sealed hollow beam supported at both ends, said beam adapted to vibrate at a resonant frequency dependent upon the cross-section thereof, means for introducing fluid under pressure to the interior of said beam whereby to distort the cross-section of said beam and change its resonant frequency as a function of the magnitude of said pressure, means for deriving an electrical signal having a frequency which is a function of the instantaneous resonant frequency of said beam, means for amplifying said signal, and means responsive to said amplified signal for causing vibration of said beam at its resonant frequency.

2. A transducer as defined by claim 1 wherein said beam is made of a constant modulus alloy.

3. A pressure-to-frequency transducer comprising an elongated hermetically sealed hollow mechanical element supported at its opposite ends and having a resonant frequency which is a function of its cross-sectional configuration, said hollow element adapted to alter its cross-sectional configuration as a function of changes in fluid pressure, means for applying fluid pressure to the interior of said hollow element whereby to distort its cross-sectional configuration and thereby change its resonant frequency, means for deriving an electrical signal having a frequency varying with the resonant frequency of said hollow element, and means responsive to said electrical signal for causing said hollow element to vibrate at its resonant frequency.

4. A pressure-to-frequency transducer as defined by claim 3 wherein said means for deriving an electrical signal is disposed outside of said hollow element.

5. A pressure-to-frequency transducer as defined by claim 3 wherein said last-mentioned means is disposed outside of said hollow element.

6. A pressure-to-frequency transducer as defined by claim 3 wherein said hollow element is made of a material having a substantially constant modulus of elasticity.

7. A pressure-to-frequency transducer as defined by claim 3 wherein said means for deriving an electrical signal comprises an electrostatic pickup device.

8. A pressure-to-frequency transducer as defined by claim 3 wherein said means for causing said hollow element to vibrate is an electromagnetic device.

9. A pressure-to-frequency transducer as defined by claim 3 wherein said hollow element has a flat oval cross-section.

10. A pressure-to-frequency transducer as defined by claim 3 wherein said hollow element is formed from two separate plates welded together along their edges.

11. A pressure-to-frequency transducer comprising a frame having first and second end parts held in fixed

spaced relation to each other by third and fourth spaced longitudinally extending parts, an elongate vibratory member supported at its ends by said first and second parts, said vibratory member having an internal chamber open at one end, said first part having a port communicating with said open end whereby a fluid pressure may be admitted to said chamber, said vibratory member having a construction which permits its cross-sectional configuration to change as a function of the pressure within said chamber, the natural frequency of vibration of said vibratory member being a function of its cross-sectional configuration, first means supported by said third part for causing said member to vibrate at its natural frequency, and second means supported by said fourth part for producing an electrical signal indicative of the instantaneous natural frequency of said member.

12. A pressure-to-frequency transducer as defined by claim 11 further including means for rendering said first means responsive to said second means.

13. A pressure-to-frequency transducer as defined by claim 11 wherein one of said first and second means is an electromagnetic device.

14. A pressure-to-frequency transducer as defined by claim 11 wherein one of said first and second means is an electrostatic device.

15. A pressure-to-frequency transducer as defined by claim 11 wherein said first, second, third, and fourth parts are made of the same material.

16. A pressure-to-frequency transducer as defined by claim 11 wherein said vibratory member is formed of two parts welded together along confronting marginal portions thereof.

17. A pressure-to-frequency transducer as defined by claim 11 wherein said vibratory member has a generally flat oval cross-section.

18. A pressure-to-frequency transducer as defined by claim 11 wherein said vibratory member has a substantially uniform wall thickness.

19. A pressure-to-frequency transducer as defined by claim 11 wherein said vibratory member is constructed of a material having a substantially constant modulus of elasticity.

20. A pressure responsive transducer comprising an hermetically sealed hollow mechanical element supported at two spaced apart points and having a resonant frequency which is a function of its cross-sectional configuration, said hollow element adapted to alter its cross-sectional configuration in response to changes in fluid pressure applied thereto, means for applying fluid pressure to said hollow element, first means located outside of said hollow element for causing said hollow element to vibrate at its resonant frequency, and second means located outside of said hollow element for deriving an electrical output having a frequency which is a function of the instantaneous resonant frequency of said hollow element.

21. A pressure responsive transducer as defined by

claim 20 wherein said first means operates in response to the electrical output derived by said second means.

22. A pressure responsive transducer comprising an hermetically sealed hollow mechanical element of flat oval cross-section supported at two spaced apart points and having a resonant frequency which is a function of its cross-sectional configuration, said hollow element adapted to alter its cross-sectional configuration in response to changes in fluid pressure applied thereto, means for applying fluid pressure to said hollow element, first means located outside of said hollow element for causing said hollow element to vibrate at its resonant frequency, and second means located outside of said hollow element for deriving an electrical output having a frequency which is a function of the instantaneous resonant frequency of said hollow element.

23. A pressure responsive transducer comprising an hermetically sealed hollow mechanical element made of a material having a substantially constant modulus of elasticity, said hollow element supported at two spaced apart points and having a resonant frequency which is a function of its cross-sectional configuration, said hollow element adapted to alter its cross-sectional configuration in response to changes in fluid pressure applied thereto, means for applying fluid pressure to said hollow element, first means located outside of said hollow element for causing said hollow element to vibrate at its resonant frequency, and second means located outside of said hollow element for deriving an electrical output having a frequency which is a function of the instantaneous resonant frequency of said hollow element.

24. A pressure transducer comprising a frame, an elongate vibrating member supported at its ends by said frame, said vibrating member having an internal chamber open at one end, means supported by said frame for coupling said chamber to a source of fluid pressure, said vibrating member having a construction which permits its cross-sectional configuration to change as a function of the pressure applied to said chamber, the natural frequency of vibration of said vibratory member being a function of its cross-sectional configuration, first means supported by said frame for causing said vibratory member to vibrate at its natural frequency, and second means supported by said frame for producing an electrical signal indicative of the instantaneous frequency of vibration of said vibratory member.

25. A pressure transducer as defined by claim 24 wherein said vibratory member has a non-circular cross-section.

References Cited by the Examiner

UNITED STATES PATENTS

2,800,796	7/57	Westcott et al.	73—398
2,912,861	11/59	Coyne et al.	73—398 X
3,021,711	2/62	Arvidson	73—398

RICHARD C. QUEISSER, *Primary Examiner*.

DAVID SCHONBERG, *Examiner*.