Nov. 21, 1967 F. MASSA 3,354,426

PRESSURE GRADIENT HYDROPHONE

Filed Jan. 28, 1966

FIG.1

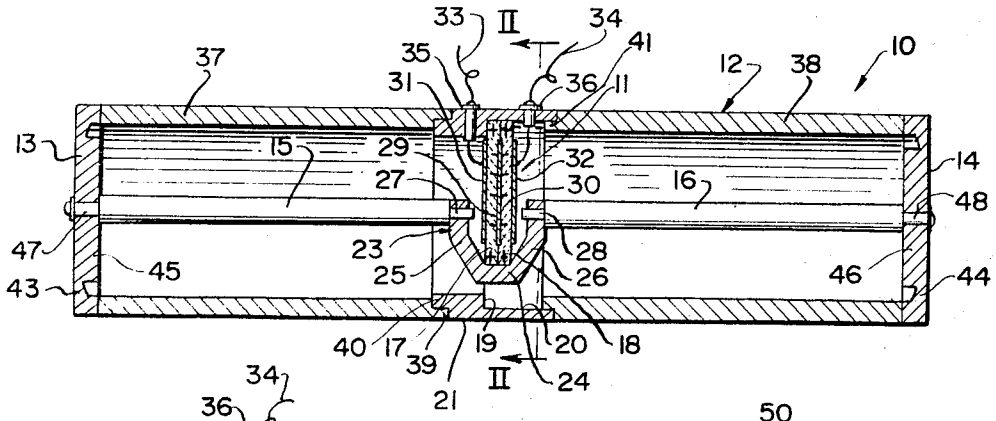


FIG.2

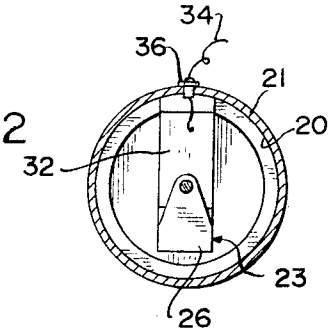


FIG.3

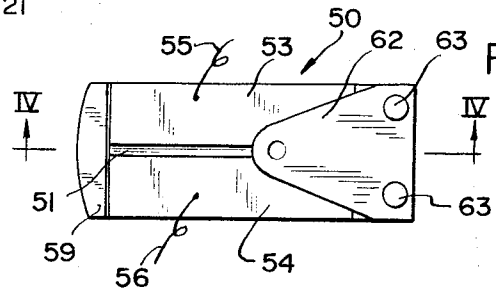


FIG.4

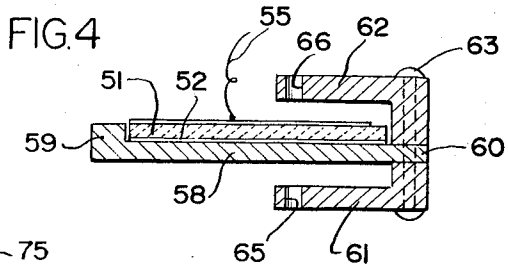
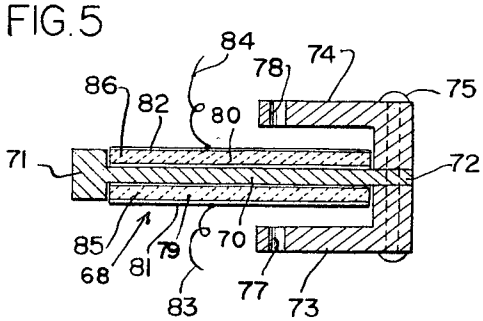


FIG.5



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PRESSURE GRADIENT HYDROPHONE

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11 Claims. (Cl. 340—10)

This invention is a continuation-in-part of my copending application Serial No. 481,809, filed August 23, 1965, which discloses a pressure gradient hydrophone that will operate satisfactorily throughout the lower portion of the audible frequency region. The novel design of that application also provides for an equalization of the hydrostatic pressure before the pressure is transferred to the active transducer element so that the hydrophone is capable of operation when it is immersed in deep water.

This invention relates to pressure gradient transducers and more particularly to pressure gradient transducers usable as hydrophones to be positioned underwater at relatively great depths. The transducers of this invention are relatively simple in construction and operation, are readily and inexpensively manufacturable while being rugged and reliable in operation, with excellent response characteristics and sensitivity, particularly at extremely low frequencies.

The present invention achieves the same objects as set forth in the aforesaid copending application and has in addition the further object of providing increased sensitivity at extremely low frequencies.

According to an important feature of the invention, connection means are provided between diaphragm means which sealingly close opposite ends of a generally tubular housing and an end portion of transducer means movable axially within the housing with the other end of the transducer means being secured to an intermediate point in the housing. Preferably, the transducer means is in the form of a cantiliver beam. With this arrangement, a very simple construction is provided with an equalization of hydrostatic pressure such that the transducer can be immersed in deep water, and increased sensitivity is obtained particularly at extremely low frequencies.

In accordance with a specific feature of the invention, the movable end of the transducer means is positioned beyond a center line of the tubular housing and generally U-shaped yoke means are provided having a bight portion secured to the movable end of the transducer means and having a pair of leg portions extending to the center line, with a pair of means extending along the center line connecting the leg portions to the diaphragm means. Preferably, the transducer means has a length dimension which is substantially greater than the width dimension thereof. With these features, a relatively long narrow transducer means results, to further increase sensitivity at extremely low frequencies while obtaining pressure equalization.

In accordance with further features of the invention, the transducer means comprises a multilaminar plate assembly at least one element of which comprises a transducer material capable of converting oscillatory mechanical stresses to alternating electrical signals. Preferably, at least one plate of a polarized ceramic material is used.

In certain preferred embodiments of the invention, a pair of polarized plates are used having faces of one polarity in facing relation. In one of such embodiments, thin electrodes on the inward faces of the aforesaid one polarity are bonded together, while in another embodiment, a metallic plate is provided sandwiched between the transducer plates, having an inner end portion secured to an intermediate point of the housing and having an opposite end portion mechanically coupled to the diaphragm means.

In another embodiment of the invention, the transducer means comprises a single plate of piezoelectric material and a supporting plate bonded to one face of the plate of piezoelectric material.

This invention contemplates other objects, features and advantages which will become more fully apparent from the following detailed description taken in conjunction with the accompanying drawings which illustrate preferred embodiments and in which:

FIGURE 1 is a longitudinal sectional view of one preferred embodiment of a pressure gradient hydrophone constructed according to the principles of this invention;

FIGURE 2 is a sectional view taken substantially along line II—II of FIGURE 1;

FIGURE 3 is a plan view of a modified form of transducer assembly usable in place of that shown in FIGURE 1;

FIGURE 4 is a sectional view taken substantially along line VI—VI of FIGURE 3; and

FIGURE 5 is a sectional view similar to FIGURE 4, but illustrating another modified form of transducer assembly according to the invention.

Referring to FIGURE 1, reference numeral **10** generally designates a pressure gradient hydrophone constructed in accordance with the principles of this invention. The hydrophone **10** comprises transducer means **11** disposed within a generally tubular housing structure which is generally designated by reference numeral **12**, with vibratile diaphragm means **13** and **14** sealingly closing opposite ends of the tubular housing structure **12** and mechanically coupled to the transducer means **11**, by means including a pair of rods **15** and **16** extending along the central axis of the housing means **12**.

The transducer means **11** comprises two plates **17** and **18** of piezoelectric material, preferably polarized barium titanate or polarized lead zirconate titanate which are bonded together, with one end of the assembly being cemented against both an internal annular shoulder **19** and an internal generally cylindrical surface **20** of a ring **21** forming an intermediate part of the housing structure **12**.

The other end of the transducer assembly **11** is movable axially within the housing structure **12** and is mechanically coupled to the diaphragm means **13** and **14** through the rods **15** and **16**. Preferably, and in accordance with an important feature of the invention, the mechanical coupling means comprises a generally U-shaped yoke **23** having a bight portion **24** cemented to the movable end of the transducer assembly, and having leg portions **25** and **26** extending to the center line of the housing structure **12** and having openings for receiving reduced diameter pin portions **27** and **28** at the ends of the rods **15** and **16**. With this arrangement, the movable end of the transducer assembly **11** extends well beyond the center line of the housing structure **12** and, as shown in FIGURE 2, the width of the transducer assembly is less than the length thereof, these features cooperating to increase the sensitivity of the hydrophone at extremely low frequencies.

As indicated by the plus and minus signs in FIGURE 1, the inner facing surfaces of the polarized transducer plates **17** and **18** are of the same polarity (a negative polarity as indicated on the drawing), and thin electrodes **29** and **30** formed on such inner faces are bonded together. Electrodes **31** and **32** are provided on the outer faces of the transducer plates **17** and **18**, which are also of the same polarity (a positive polarity as indicated on the drawing), and such electrodes **31** and **32** are connected to wires **33** and **34** extending through insulated bushings **35** and **36** in the wall of the ring **21**.

The wires **33** and **34** form terminal means for connection of the hydrophone to a suitable amplifier. With the

described polarization of the transducer plates **17** and **18**, the combined series voltages across both plates are additive when the movable end of the transducer assembly is deflected in response to movements of the diaphragm means **13** and **14**.

In addition to the intermediate ring **21**, the housing structure **12** comprises a pair of tubular members **37** and **38** with an inner end portion **39** of member **37** being tightly fitted on a reduced diameter portion **40** at one end of the ring **21** and with a reduced diameter portion **41** at the inner end of member **38** being fitted within the other end of the ring **21**.

The diaphragm means **13** and **14** are in the form of circular end plates or caps disposed tightly against the end of the tubular members **37** and **38** and having annular grooves on the inside surfaces thereof to define relatively thin webs **43** and **44** which provide a flexural suspension for central piston portions **45** and **46** connected to the ends of the rods **15** and **16**, the rods **15** and **16** preferably having reduced diameter end portions **47** and **48** extending into openings in the center of the piston portions **45** and **46**.

An epoxy cement is preferably employed at each joint where the mechanical parts are attached together, to make a permanent, rigid, waterproof bond.

Referring to FIGURES 3 and 4, reference numeral **50** generally designates a modified transducer and yoke assembly which may be substituted for the transducer means **11** and the yoke **23** of the hydrophone of FIGURE 1. In the assembly **50**, a piezoelectric plate **51** is provided, which may preferably be polarized barium titanate or polarized lead zirconate titanate, for example. The plate **51** has an electrode **52** on one face thereof and a pair of separate electrodes **53** and **54** on the other face thereof, a longitudinally extending relatively narrow gap being provided between the electrodes **53** and **54** to which leads **55** and **56** are secured. The plate **51** is bonded to a plate **58** which may be of aluminum or some other suitable material, preferably by means of a rigid cement such as epoxy which preferably also serves to insulate the electrode **52** from the surface of the plate **58**. The plate **58** has an end portion adapted to be cemented or otherwise secured to the shoulder **19** and surface **20** of the ring **21** and an opposite movable end portion **60** which is disposed between legs of a pair of L-shaped members **61** and **62** to form a yoke, with a rivet **63** extending through the legs of the members **61** and **62** and the portion **60**. The other legs of the L-shaped members **61** and **62** have openings **65** and **66** for receiving the reduced diameter portions **27** and **28** of the rods **15** and **16**.

The plate **51** may be polarized by applying a positive voltage on electrode **53** and a negative voltage on electrode **54** with a center tap from the polarizing voltage being connected to the electrode **52** on the opposite side of the plate **51**, the plate **51** being cemented on the plate **58** after polarization. When the assembly **50** is then installed in place of the transducer means **11** and yoke **23** in the arrangement of FIGURE **1**, an alternating force acting on the diaphragms **13** and **14** will set up a vibration of the end **60** of the plate **58** and alternating additive voltages will be generated across the sections to which electrodes **53** and **54** are attached, to develop an AC signal between the conductors **55** and **56**.

Referring now to FIGURE 5, reference numeral **68** generally designates another form of transducer and yoke assembly which may be substituted for the transducer means **11** and yoke **23** of the arrangement of FIGURE 1. In the assembly **68**, a plate **70** of aluminum or some other suitable material is provided, similar to the plate **58** of the assembly **50** of FIGURES 3 and 4, and having an end **71** adapted to be cemented or otherwise secured to the shoulder **19** and internal surface **20** of the ring **21** and having an opposite movable end **72** disposed between the legs of two L-shaped members **73** and **74** with a rivet **75** extending through legs of the members **73** and **74** and the end portion **72** of the plate **70**, and with openings **77** and **78** in the other legs of the members **73** and **74** for receiving the reduced diameter portions **27** and **28** of the the rods **15** and **16**. In this arrangement, an intermediate portion of the plate **70** is sandwiched between two transducer plates **79** and **80** having polarizations similar to the polarizations indicated in FIGURE 1. Electrodes **81** and **82** on the outer surfaces of the plates **79** and **80** are connected to conductors **83** and **84**, while electrodes **85** and **86** on the inside surfaces of the plates **79** and **80** are cemented to the plate **70**, preferably by means of an epoxy cement, and preferably with the cement serving to electrically insulate the electrodes **85** and **86** from the opposite surfaces of the plate **70**.

The illustrated ararngements operate in a manner similar to those disclosed in my copending application Serial No. 481,809, filed August 23, 1965. The basic difference in result is that the arrangements of this application are particularly adapted for increased sensitivity at extremely low frequencies. When operation of the pressure gradient hydrophone is desired at the lowest portion of the audible frequency range and where high frequency operation is not essential, the increased sensitivity can be obtained with the arrangements disclosed in this application. The hydrophone will have maximum sensitivity for sound arriving along an axis parallel to the normal axis of the cylindrical structure. For any sound arriving along the path which at right angles to the axis of the hydrophone, the instantaneous sound pressure will be of the same magnitude and phase on the surface of each diaphragm, and, therefore, 0 voltage will be generated by the hydrophone. For sound arriving at angles between 0° and 90°, the sensitivity will be proportional to the cosine of the angle which the axis of the sound source makes with the axis of the hydrophone.

Although I have chosen only a few examples to illustrate the basic principles of my invention, it will be obvious to those skilled in the art that numerous departures may be made from the details shown, and I, therefore, desire that my invention shall not be limited except insofar as is made necessary by the prior art and by the spirit of the appended claims.

I claim as my invention:

1. In combination in a pressure gradient transducer, generally tubular housing means, end plates on opposite ends of said housing means having annular grooves therein defining relatively thin webs for flexural suspension of central piston portions thereof, transducer means comprising a multilaminar plate assembly with at least one element of said plate assembly comprising a transducer material capable of converting oscillatory mechanical bending stresses to alternating electrical signals, means for rigidly supporting one end of said multilaminar plate assembly at a point within said housing means intermediate said end plates to position the opposite end of said assembly beyond a center line of said tubular housing means, U-shaped yoke means having a bight portion secured to said opposite end of said assembly and having a pair of leg portions extending to said center line, a pair of rigid rods extending along said center line and rigidly connected to said central piston portions of said end plates and to said leg portions of said yoke means, and electrical terminal means for connecting said transducer material to an external circuit.

2. In combination in a pressure gradient transducer, generally tubular housing means, vibratile diaphragm means sealingly closing opposite ends of said housing means, a somewhat elongated transducer means having two end portions, said transducer being sealed within said housing means, one of said end portions being secured to a point in said housing means intermediae said opposite ends, the opposite end portion being free to move axially in said elongated dimension within said housing means, and connection means extending through said housing and rigidly attached between the diaphragm means for

mechanically coupling said opposite end portion to said diaphragm means.

3. In a pressure gradient transducer as defined in claim 2, said transducer means being in the form of a cantilever beam.

4. In a pressure gradient transducer as defined in claim 2, said transducer means comprising a multilaminar plate assembly with at least one element of said plate assembly comprising a transducer material capable of converting oscillatory mechanical stresses to alternating electrical signals, and electrical terminal means connected to said transducer material.

5. In a pressure gradient transducer as defined in claim 2, said transducer means having a length dimension as measured in a direction between said one end and said opposite end which is many times greater than a width dimension as measured in a direction transverse to said length direction.

6. In a pressure gradient transducer as defined in claim 2, said transducer means comprising a plate of a polarized ceramic material.

7. In a pressure gradient transducer as defined in claim 2, said transducer means comprising a pair of plates of polarized ceramic material having faces of one polarity in facing relation, electrode means on said faces of said one polarity, electrodes on the opposite faces of said plates, and electrical terminal means connected to said electrodes on said opposite faces of said plates.

8. In a pressure gradient transducer as defined in claim 7, said electrodes on said faces of said one polarity being directly bonded together.

9. In a pressure gradient transducer as defined in claim 7, a supporting plate sandwiched between said faces of said plates of said one polarity and having one end portion secured to said intermediate point in said housing means and an opposite end portion defining said opposite end portion which is mechanically coupled to said diaphragm means.

10. In combination in a pressure gradient transducer, generally tubular housing means, vibratile diaphragm means sealingly closing opposite ends of said housing means, transducer means within said housing means having one end portion secured to a point in said housing means intermediate said opposite ends and having an opposite end portion movable axially within said housing means, said transducer means comprising a multilaminar plate assembly with at least one element of said plate assembly comprising a transducer material capable of converting oscillatory mechanical stresses to alternating electrical signals, electrical terminal means connected to said transducer material, connection means mechanically coupling said opposite end portion to said diaphragm means, said opposite end portion of said transducer means being positioned beyond a center line of said tubular housing means, and said connection means comprising generally U-shaped yoke means having a bight portion secured to said opposite end of said transducer means and having a pair of leg portions extending to said center line and a pair of means extending along said center line connecting said leg portions to said diaphragm means.

11. In combination in a pressure gradient transducer, generally tubular housing means, vibratile diaphragm means sealingly closing opposite ends of said housing means, transducer means within said housing means having one end portion secured to a point in said housing means intermediate said opposite ends and having an opposite end portion movable axially within said housing means, connection means mechanically coupling said opposite end portion to said diaphragm means, said transducer means defining a plate of piezoelectric material and a supporting plate bonded to one face of said plate of piezoelectric material and having one end portion secured to said intermediate point in said housing means and an opposite end portion defining said opposite end portion which is mechanically coupled to said diaphragm means, a pair of electrodes on separate portions of the opposite face of said plate of piezoelectric material, said piezoelectric material being a polarized ceramic material with the portions on which said pair of electrodes are attached being oppositely polarized, and terminal means connected to said pair of electrodes.

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