UNDERWATER TRANSDUCER APPARATUS

Filed Nov. 20, 1963 2 Sheets-Sheet 1

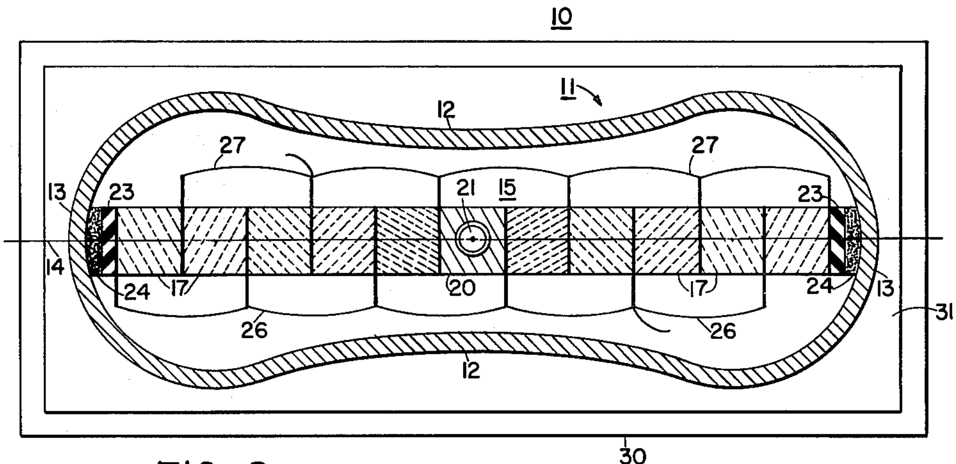

FIG. 2

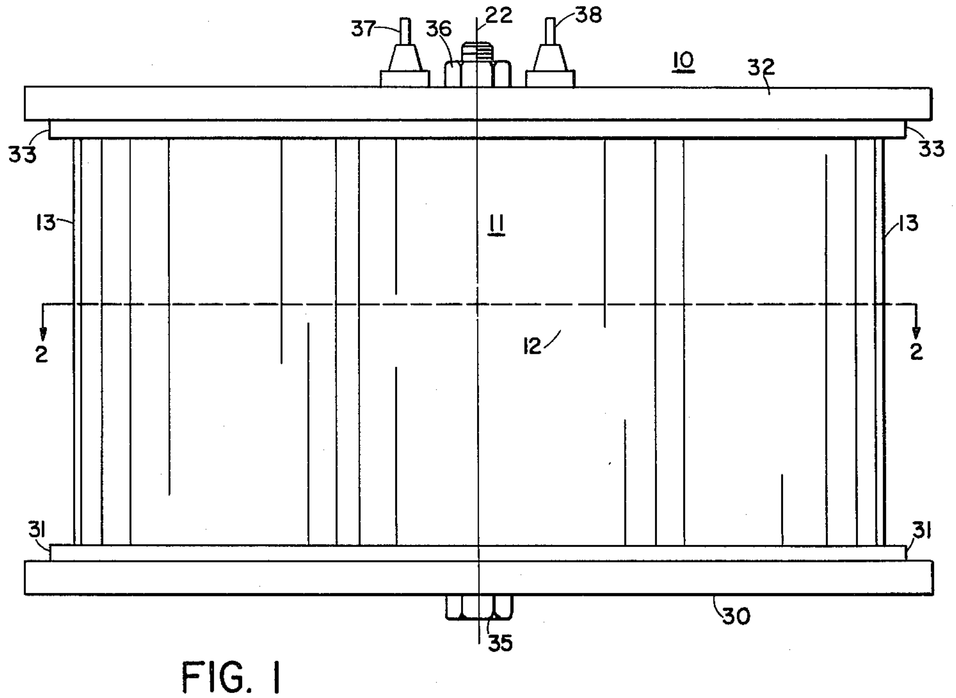

FIG. 1

INVENTOR.
HOWARD C. MERCHANT

BY Roger W. Jensen
ATTORNEY

June 28, 1966 H. C. MERCHANT 3,258,738

UNDERWATER TRANSDUCER APPARATUS

Filed Nov. 20, 1963 2 Sheets-Sheet 2

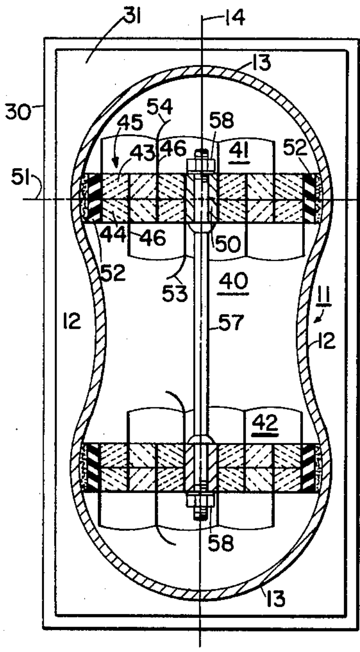

FIG. 3

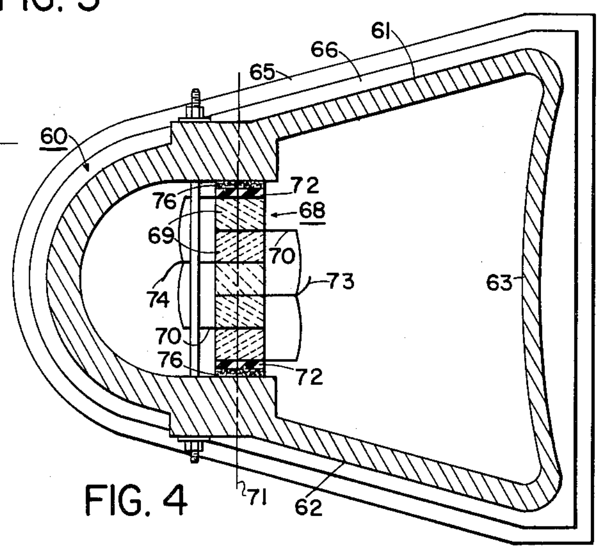

FIG. 4

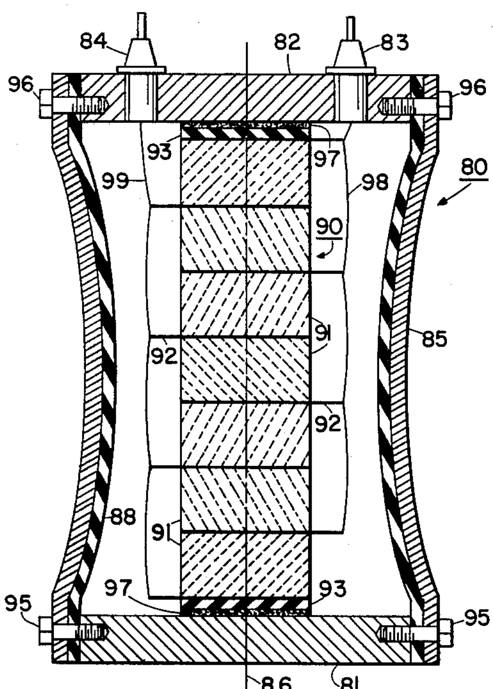

FIG. 6

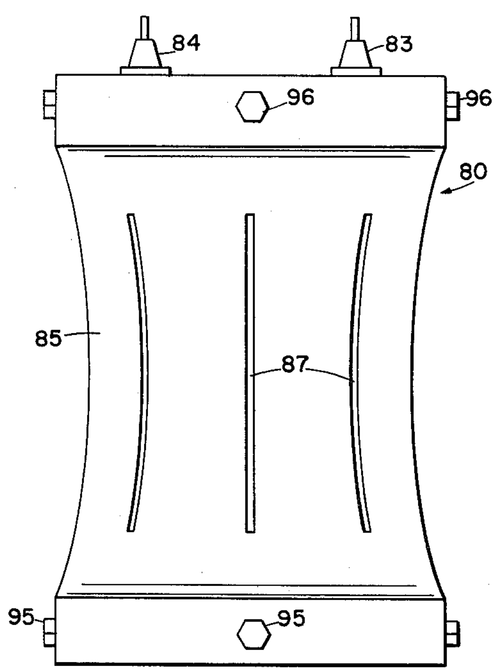

FIG. 5

INVENTOR.
HOWARD C. MERCHANT

BY Roger W. Jensen
ATTORNEY

United States Patent Office 3,258,738
Patented June 28, 1966

3,258,738

UNDERWATER TRANSDUCER APPARATUS

Howard C. Merchant, Dublin, Calif., assignor to Honeywell Inc., a corporation of Delaware

Filed Nov. 20, 1963, Ser. No. 324,934
4 Claims. (Cl. 340—9)

This invention pertains to improvements in underwater sound transducers, and more particularly to improvements in transducers of the extensional flexural type. Prior art extensional-flexural type transducers generally comprise a compliant tube having an elliptical crosssection. A suitable driving member is mounted within the compliant tube so that the plane of the driving member is coplaner with the plane of the major axis of the elliptical compliant tube, the ends of the driving member being attached to the inner walls of the elliptical compliant tube in a suitable manner. The driving member operates in an extensional mode, that is, it expands and contracts along the major axis of the ellipse, thereby applying forces to the surfaces of the compliant tube generally perpendicular to the plane of the driving member. When the driving member expands, the major axis of the elliptical tube is increased, while the minor axis is decreased, while when the driving member contracts, the major axis decreases while the minor axis increases. In other words, the expansion and contraction of the driving member causes a flexing of the surfaces of the compliant tube generally parallel with the plane of the driving member.

Since, when the driving member expands, the minor axis of the cross-section of the elliptical compliant tube decreases, or in other words, the surfaces of the compliant tube generally parallel to the driving member move toward each other, a negative pressure, negative with respect to the static equilibrium pressure, occurs in the water adjacent these surfaces. At the same time, expansion of the driving member increases the major axis of the cross-section of the elliptical compliant tube and the surfaces of the compliant tube generally perpendicular to the driving member move away from each other thereby creating a pressure in the water adjacent these surfaces. The pressure being positive with respect to the static equilibrium pressure. The negative pressure created in the water adjacent the surfaces parallel to the driving member is partially cancelled by the positive pressure created in the water adjacent the surfaces perpendicular to the driving member. This pressure cancellation decreases the efficiency of the transducer.

The present invention, on the other hand, pertains to an extensional-flexural type transducer wherein this pressure cancellation, or out of phase operation of adjacent transducer surfaces, is eliminated.

In a broad sense, the invention comprises a compliant tube having two opposing major surfaces and two opposing minor surfaces. A driving member, having opposing end members operable to expand and contract along an axis, is mounted in the compliant tube with the end members of the driving member rigidly attached to the inner faces of the opposing minor surfaces. The major surfaces of the compliant tube are concave with respect to the axis of the driving member.

The driving member operates in an extenisonal mode, that is, it expands and contracts along its axis thereby applying forces to the minor surfaces of the compliant tube. When the driving member expands, the distance between the minor surfaces is increased, while when the driving member contracts, the distance between the minor surfaces decreases.

Since the major surfaces are concave with respect to the axis of the driving member, the expansion of the driving

member causes the distance between the major surfaces to increase, while the contraction of the driving member causes the distance between the minor surfaces to decrease. In other words, the distance between the minor surfaces and the distance between the major surfaces both increase when the driving member expands, and both decrease when the driving member contracts. The expansion and contraction of the driving member causes a positive pressure to occur in the water adjacent to the minor surfaces, and at the same time, causes a positive pressure to occur in the water adjacent to the major surfaces. Therefore, the pressure cancellation caused by the out of phase operation of the major and minor surfaces, as described in conjunction with the prior art device, is minimized.

It is one object of this invention, therefore, to provide an improved extensional-flexural transducer.

Another object of this invention is to provide an extensional-flexural transducer which has increased efficiency.

A further object of this invention is to provide an extensional-flexural transducer which has opposing major surfaces concave with respect to the extensional axis of a driving member.

These and other objects of this invention will become apparent to those skilled in the art upon consideration of the accompanying specification, claims, and drawings of which:

FIGURE 1 shows a pictorial view of the transducer of the present invention;

FIGURE 2 is a section view of the transducer of FIGURE 1;

FIGURE 3 is a section view of an embodiment of this invention using a bender type driving elements;

FIGURE 4 is a section view of an embodiment of this invention having a single radiating surface;

FIGURE 5 is a pictorial view of a cylindrical embodiment of the present inveniton; and

FIGURE 6 is a section view of the transducer shown in FIGURE 5.

Referring to FIGURES 1 and 2, there is shown a transducer **10** having a tubular member **11**. Tubular body member **11** has opposing major surfaces **12** and opposing minor surfaces **13**. A cross-sectional axis **14**, of tubular body member **11** intersects opposing minor surfaces **13** and is equidistant from opposing major surfaces **12**. Opposing surfaces **12**, of body member **11**, are concave with respect to axis **14**.

A driving member **15** comprises a first and second crystal stack, each containing a plurality of polarized crystals **17**, such as polarized barium titanate crystals. The crystal stacks are formed by bonding adjacent crystals to opposite sides of a beryllium copper insert by means of a conducting adhesive. Each crystal stack has an axis running in a direction such that the axis intersects each of the crystals of the first and second crystal stacks. The crystals of each crystal stack are polarized in a direction parallel to the axis of the crystal stack, however, adjacent crystals of each crystal stack are polarized in opposite directions. The crystal stacks are bonded to opposite sides of a rectangular cross-section center post **20**. Center post **20** has a circular aperture **21** therethrough, the axis of aperture **21** being coaxial with a longitudinal axis **22** of body member **12**. Longitudinal axis **22** is the axis of symmetry of body member **12** and is equidistant from the opposing surfaces **12** and the opposing surface **13**.

An insulating member **23** is bonded to the free ends of each of the crystal stacks. The driving member **15** is mounted inside tubular body member **11**, and positioned so that the axis of the crystal stacks are coaxial with axis **14**. The free ends of insulating members **23** are bonded to the inner faces of opposing surfaces **13** by a suitable bonding material 24. Alternate beryllium copper inserts between adjacent crystals of each of the crystal stacks are connected to electrical conductors 26 and 27, respectively. A bottom plate 30 and a rubber gasket, or other suitable sealing material 31, are mounted at the bottom of transducer 10, contiguous with one edge of tubular body member 11.

A top plate 32 and a rubber gasket 33 are mounted at the top of transducer 10, contiguous with the other edge of tubular body member 12. Bottom plate 30 and top plate 32 each have an aperture therethrough, the axis of the apertures being coaxial with the longitudinal axis 22 of body member 11. A mounting bolt 35 passes through the aperture in bottom plate 30, through aperture 21 in center post 20, and through the aperture in top plate 32, and is threadably engaged with a nut 36. The mounting bolt 35 and nut 36 secure the top plate 32 and the bottom plate 30 to transducer 10, and also cause the plates to compress the rubber gaskets 33 and 31, respectively, thereby forming a water tight seal for the interior of tubular body member 11.

Electrical conductor 27 is connected to an electrical connector 37, which is mounted to top plate 32, while electrical conductor 26 is connected to an electrical connector 38, which is also mounted to top plate 32.

Operation

In normal operation, electrical connectors 37 and 38 are connected to an alternating source of energizing potential. When the energizing source is of a polarity such that electrical conductor 37 is positive with respect to electrical conductor 38, an electric field is applied across each of the crystals 17 of driving member 15. The electric field applied across the crystals 17 is in the same direction as the polarization of each of the crystals. Therefore, the crystals expand in their direction of polarization. When the crystals expand, forces are applied to the inner faces of opposing surfaces 13, tending to push surfaces 13 further away from each other. As opposing surfaces 13 move away from each other, forces are applied to opposing surfaces 12, causing these members to move away from each other. Similarly, when the energizing potential source is of a polarity such that electrical conductor 38 is positive with respect to electrical conductor 37, an electric field will be applied to each of the crystals 17 in a direction opposite to the direction of polarization of the crystals. When an electric field is applied to the crystals 17 in a direction opposite to their direction of polarization, the crystals contract, and opposing surfaces 13 are moved closer together. When the distance between opposing surfaces 13 decreases, a force is applied to opposing surfaces 12, causing the distance between these surfaces to decrease also.

As can be seen from the description, since opposing surfaces 12 are concave with respect to axis 14, the movement of opposing surfaces 12 and opposing surfaces 13, due to the expansion and contraction of driving member 15, are in phase and hence the pressure conditions set up in the water surrounding transducer 10 are the same adjacent to the surfaces 12 as they are adjacent to the surfaces 13. Therefore, the pressure cancellation is minimized and the transducer efficiency increases.

Structure of FIGURE 3

Referring to FIGURE 3, there is shown a cross-sectional view of another embodiment of the present invention. The structure of FIGURE 3 is generally the same as that shown in FIGURES 1 and 2, the difference being in the type of driving member utilized. The structure of FIGURE 3 which is similar to that shown in FIGURES 1 and 2 is given the same numerical designation.

A driving element 40 of the transducer configuration of FIGURE 3 includes a first bender element 41, and a substantially identical bender element 42. Bender element 41 comprises a first polarized crystal 43 and a second polarized crystal 44. Crystals 43 and 44 are bonded back-to-back to form a crystal module 45. A plurality of crystal modules, similar to crystal module 45, are connected to form a first crystal stack by bonding each crystal module, by means of a conductive adhesive, to a beryllium copper insert 46 between each module. A second crystal stack is constructed in substantially the same manner as the first crystal stack. The first and second crystal stacks are bonded to opposite sides of a rectangular cross-section center post 50, the crystal stacks being aligned along an axis 51. Center post 50 has a circular aperture therethrough, the axis of the aperture being actually aligned with axis 14.

An insulating member 52 is bonded to the free ends of each of the crystal stacks.

Crystals 43 and 44, of crystal module 45, are both polarized in a direction parallel to axis 51, however, crystal 43 is polarized in a direction opposite to crystal 44. In a similar manner, the crystals in each crystal module are oppositely polarized. In addition, the crystals of each crystal module are polarized in a direction opposite to the adjacent crystal in adjacent crystal modules. Alternate beryllium copper inserts 46, between adjacent crystal modules, are connected to electrical conductors 53 and 54, respectively. Bender element 42, as explained previously, is constructed in a maner substantially identical to bender element 41.

Bender elements 41 and 42 are mounted inside tubular member 11, the axis 51 of bender elements 41 and 42 being perpendicular to axis 14. Insulating end members 52, at each end of bender element 41, are bonded to the inner face at one end of opposing major surfaces 12 by means of a suitable adhesive material, while insulating end members 52 at each end of bender element 42, are bonded to the inner face at the other end of opposing major surfaces 12.

A rigid connecting member 57 passes through the apertures of center posts 50 of each bender elements 41 and 42, and is attached to each of the bender elements by a suitable means, in this case being threadably engaged with nuts 58. Rigid member 57 holds the center posts of bender elements 41 and 42 a fixed distance apart.

In operation, an alternating electric signal is applied to the conductors 53 and 54, and this electric signal applies an elecric field across each of the crystals of the bender elements. Assume that the electric signal applied from conductors 53 and 54 to beryllium copper inserts 46 is such that the electric field applied to crystal 43, of crystal module 45, is in the direction of polarization of crystal 43, while the electric signal applied to crystal 44 is in a direction opposite the direction of polarization. In this case, crystal 43 will expand while crystal 44 will contract. Each of the crystals in adjacent crystal modules in the same row as crystal 43, is polarized such that when the instantaneous field applied to crystal 43 is of a direction such that crystal 43 tends to expand, then all of the crystals in this row tend to expand, while the crystals in the same row as crystal 44 tend to contract when crystal 44 contracts. Since all of the crystals in the crystal row 43 tend to expand, while all of the crystals in the crystal row 44 tend to contract, it can be seen that the bender element 41 will bend or flex. In a similar manner, an alternating electric signal applied to bender element 42 causes this bender element to bend or flex. Since the center posts of bender elements 41 and 42 are held a fixed distance apart, by means of rigid member 57, the ends of bender elements 41 and 42 will flex relative to their center posts 50.

The alternating electric signals applied to bender elements 41 and 42 are such that the flexing of bender element 41 is out of phase with the flexing of bender element 42. In other words, the ends of bender elements 41 and 42 move away from each other, or toward each other depending upon the polarity of the alternating energizing signals. Since the ends of bender elements 41 and 42 are rigidly attached to the inside face of major surface members 12, of tubular member 11, the flexing of the bender elements applies forces to the major surface elements 12, and causes these surface member to flex.

As explained previously, since major surface elements 12 are concave, relative to axis 14, the pressures created in the water surrounding major surfaces 12 will be in phase with the pressures created in the water surrounding minor surfaces 13, and hence, pressure cancellation is minimized and the transducer efficiency is increased.

Structure of FIGURE 4

FIGURE 4 shows another embodiment of the present invention. The transducer of FIGURE 4 comprises a housing member 60 having a generally bell shaped crosssection, housing member 60 having a first divergent side 61 and a second divergent side 62. The divergent end of housing 60 is closed by means of a flexible surface member 63, member 63 being concave with respect to the interior of housing 60.

A bottom plate 65 and a suitable sealing material such as a rubber gasket, 66, are connected to the bottom of housing 60, and form a water tight seal. Similarly, a top plate and rubber gasket (not shown) are connected to the top of housing 60 to form a water tight seal.

A driving member 68 comprises a crystal stack containing a plurality of polarized crystals, such as polarized barium titanate crystals, 69. The crystal stack is formed by bonding adjacent crystals to opposite sides of beryllium copper inserts 70, by means of a conducting adhesive. The crystal stack has an axis 71 intersecting each of the polarized crystals 70. Each crystal 70 of driving member 68 is polarized in a direction parallel to axis 71, however, adjacent crystals of the crystal stack are polarized in opposite directions.

End members 72 are bonded to opposite ends of the crystal stack. Alternate beryllium copper inserts 70 between adjacent crystals are connected to electrical conductors 73 and 74, respectively.

Driving member 68 is mounted inside housing member 60, the axis 71 of driving member 68 being generally parallel to flexible surface member 63. The end members 72 of driving member 68 are attached to the inner faces of divergent side surfaces 61 and 62, respectively, by means of a suitable bonding material 76.

In operation eelctrical conductors 73 and 74 are connected to an alternating source of energizing potential. When the energizing force is of a polarity such that the electric field applied to polarized crystal 69, on the same direction as the polarization of each of the crystals, the crystals expand and a force is applied to the divergent side members 61 and 62 tending to force these side members further apart. The movement of side members 61 and 62 applies forces to the ends of surface member 63, causing member 63 to move in an outward direction. When the polarity of the alternating energizing signal applied to conductors 73 and 74 is such that the electric fields applied to crystals 69 are in a direction opposite to the direction of polarization of the crystals, the crystals contract and forces are applied to the divergent side members 61 and 62, tending to move these side members closer together. As side members 61 and 62 move closer together, forces are applied to the flexible surface member 63, causing this member to move inward. Thus, it can be seen that the operation of the driving member 68 in expanding and contracting, causes a flexing of the surface member 63. As flexing member 63 vibrates, or flexes, acoustic energy is transmitted through the surrounding acoustic medium.

Structure of FIGURES 5 and 6

FIGURES 5 and 6 show a cylindrical transducer utilizing the principle of the present invention. Referring to FIGURES 5 and 6, a transducer 80 comprises a circular bottom plate 81 and a circular top plate 82, the diameters of plates 81 and 82 being substantially the same. Top plate 82 has a first electrical connector 83 and a second electrical connector 84 mounted thereon. A flexible cylindrical surface member 85 has a diameter substantially the same as the diameter of top and bottom plates 82 and 81, the sides of cylindrical member 85 being concave, with respect to the cylindrical axis 86.

Cylindrical member 85 has a plurality of slots or grooves 87 in the surface thereof, the slots being generally parallel to the axis 86, and spaced around the periphery of member 85.

A cylindrical sleeve or boot 88, having substantially the same diameter as cylindrical member 85, is inserted inside of member 85 and is coaxial therewith.

A driving member 90 comprises a plurality of polarized crystals, for example, polarized barium titanate or lead zirconate crystals, 91. The crystals 90 are assembled to form a crystal stack by bonding adjacent crystals to oposite sides of beryllium copper inserts, or other suitable conducting materials, 92. Each of the crystals is polarized in a direction parallel to the axis of the crystal stack, however, adjacent crystals are polarized in opposite directions. Insulating end members 93 are bonded to opposing ends of the crystal stack by means of a suitable bonding material.

Circular bottom plate 81 is mounted in one end of the cylindrical rubber boot 88 and cylindrical surface member 85, the surface member 85 and boot 88 being attached to the periphery of circular bottom plate 81 by means of a plurality of bolts 95 passing through the cylindrical member 85 and boot 88 and threadably engaging with bottom plate 81. Similarly, circular top plate 82 is mounted in the other end of cylindrical boot 88, and cylindrical surface member 85. A plurality of bolts 96 pass through surface member 85 and boot 88, and threadably engage with the periphery of top member 82.

Driving member 90 is mounted inside cylindrical surface member 85 and the insulating end members 93, of driving member 90, are rigidly connected to the inner faces of top and bottom plates 82 and 81 by means of a suitable bonding material 97, the axis of the crystal stack being coaxial with the axis 86 of cylindrical member 85.

Alternate beryllium copper inserts 92, between adjacent crystals of driving member 90, are connected to electrical conductors 98 and 99, respectively. Electrical conductor 98 is connected to electrical conductor 83, while electrical conductor 99 is connected to electrical conductor 84.

The driving member 90, of transducer 80, operates in a manner similar to the driving members previously described; that is, when an alternating electric signal is applied to electrical connectors 83 and 84, the driving member 90 will expand and contract along axis 86. The expansion of driving member 90 along axis 86 will cause the top plate 82 and the bottom plate 81 to move further apart, while the contraction of driving member 90, along axis 86, will cause top plate 82 and bottom plate 81 to move closer together. The movement of top and bottom plates 82 and 81 respectively, will cause the flexible cylindrical member 85 to flex or vibrate, thereby generating an acoustic wave in the surrounding acoustic medium. The slots 87, in the face of cylindrical member 85, allow radial motion of member 85 without buckling of the entire tube.

It is to be understood that while I have shown specific embodiments of my invention, that this is for the purpose of illustration only, and that my invention is to be limited solely by the scope of the appended claims.

I claim as my invention:

1. A transducer comprising:

a hollow resilient housing having an axis, said housing having a chamber therein and having a front surface concave with respect to said axis and a back surface concave with respect to said axis;

a first flexing driving member connected between said concave front surface and said concave back surface;

a second flexing driving member connected between said concave front surface and said concave back surface, said second driving member being spaced apart from said first driving member;

a rigid member connected between said first driving member and said second driving member;

first energizing means connected to said first driving member to cause said first driving member to flex in the direction of said axis; and

second energizing means connected to said second driving member to cause said second driving member to flex in the direction of said axis, the flexing of said second driving member being 180° out of phase with the flexing of said first driving member.

2. A transducer comprising:

a resilient concave cylindrical housing having a chamber therein, said cylindrical housing having a plurality of longitudinal slits spaced around the circumference thereof;

a first end plate mounted in said cylinder to close one end thereof;

a second end plate mounted in said cylinder to close the other end thereof;

a signal driving member mounted in said chamber and abutting said first end plate and said second end plate; and

signal supplying means for supplying a signal to said driving member, the driving member operating in response thereto to apply forces to said first end plate and said second end plate thereby causing said concave cylindrical housing to flex.

3. Extensional-flexural transducer means comprising, in combination;

a hollow compliant tube having two opposing convex relatively inflexible minor surfaces and two opposing concave flexible major surfaces;

a first driving member energizable by an alternating signal to operate in a flexural mode with respect to an axis defined by a line running from one end to the other end of said first driving member;

means mounting said first driving member in said hollow compliant tube at one end thereof, said driving member abutting said hollow compliant tube at the approximate junctions between said two opposing concave major surfaces and one of said two opposing convex minor surfaces;

a second driving member energizable by an alternating signal to operate in a flexural mode with respect to an axis denfied by a line running from one end to the other end of said second driving member;

means mounting said second driving member in said hollow compliant tube at the other end thereof opposite said first member, said second driving member abutting said hollow complaint tube at the approximate junctions between said two opposing concave major surfaces and the other one of said two opposing convex minor surfaces;

a rigid member connected between said first and second driving members; and

means for supplying energizing signals to said first and second driving member to flex said driving members in opposing directions simultaneously to provide flexural-extensional vibrations in said compliant tube.

4. Extensional-flexural transducer means comprising, in combination:

a hollow compliant tube having two opposing convex relatively inflexible minor surfaces and two opposing concave flexible major surfaces;

driving member means energizable by an alternating signal to operate in an extensional mode with respect to an axis defined by a line running from one end to the other end of said driving member;

means mounting said driving member in said hollow complaint tube at the ends thereof said member abutting to said two opposing convex minor surfaces; and

means for supplying energizing signals to said driving member means to extend said driving member means thereby extending said two convex surfaces in an outward direction and simultaneously flexing two opposing concave major surfaces in an outward direction.

References Cited by the Examiner

UNITED STATES PATENTS

2,064,911	12/1936	Hayes	340—9
2,452,068	10/1948	Peterson.	
2,870,521	1/1959	Rudnick.	
2,930,912	3/1960	Miller.	
3,021,504	2/1962	Toulis	340—8
3,025,359	3/1962	Schilling et al.	
3,054,084	9/1962	Parssinen et al.	340—10

LEWIS H. MYERS, *Primary Examiner.*

CHESTER L. JUSTUS, *Examiner.*

J. P. MORRIS, *Assistant Examiner.*