(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 434 344 A2**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: **90313788.3**

(51) Int. Cl.^{5}: **G10K 9/12**

(22) Date of filing: **17.12.90**

(30) Priority: **18.12.89 US 451913**

(43) Date of publication of application: **26.06.91 Bulletin 91/26**

(84) Designated Contracting States: **FR GB**

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(54) **Edge driven flexural transducer.**

(57) An electro-acoustic transducer utilizing a plurality of flexural bars or staves to form an interface member between the electrorestrictive driver element and the water transmission medium. The staves are fastened to end plates to form a concave barrel-shaped structure that results in substantial mechanical amplification. The driver element consists of a stack of electrorestrictive elements with the stack's axis essentially coincident with the transducer's longitudinal axis. A tension member, threaded at both ends, passes through holes in the end plates and through an axial hole in the stack. Nuts at each end of the tension member are tightened to provide the required compressional "bias" to the stack. The transducer offers the advantages of lower cost of fabrication, increased amplification of the flexural driver interface elements and improved capability to withstand hydrostatic pressures.

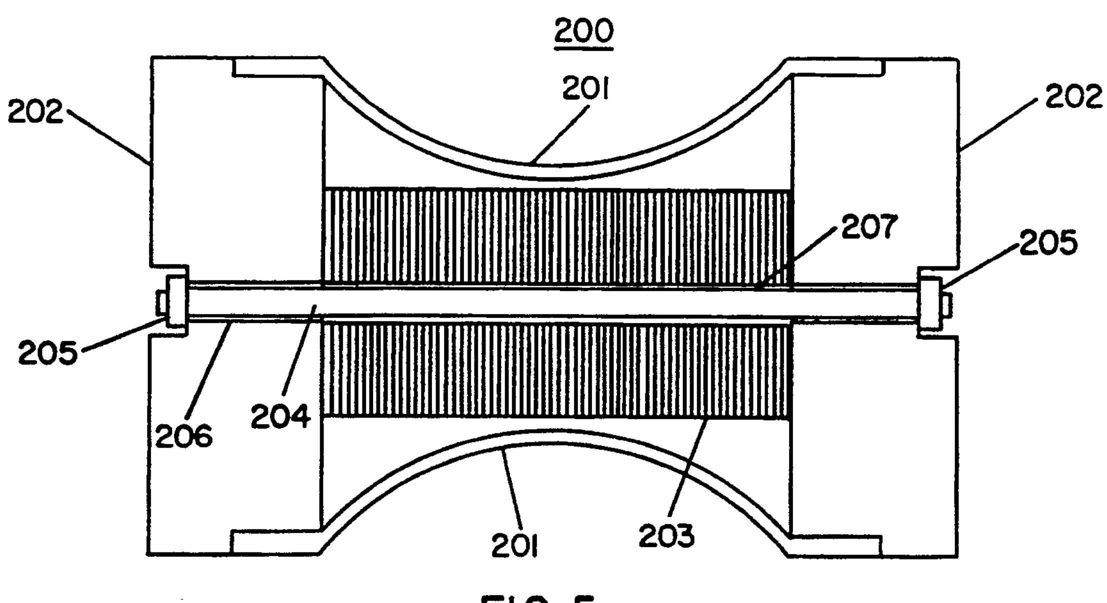

FIG. 5

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EDGE DRIVEN FLEXURAL TRANSDUCER

FIELD OF THE INVENTION

This invention relates to a transducer apparatus which serve as sources, and detectors, of acoustic waves, wherein electrical (or magnetic) signals produce corresponding acoustic waves in a fluid medium, normally sea water.

BACKGROUND OF THE INVENTION

In general, transducers (for underwater applications) which employ continuous wave or modulated-wave input signals utilize piezoelectric, electrostrictive, or magnetostrictive energy-conversion materials. Electrostrictive materials are available in a wide variety of shapes, including rectangular plates and annular discs which may be stacked to provide the amplitude and power of mechanical motion required by the transduction mechanism. In transducers, certain mechanical dimensional charges produced in the electrostrictive element (or stack of elements), as a result of application of an input signal, are coupled to a driver element which interfaces with the water transmission medium. In some applications the mechanical coupling arrangement is such that the maximum amplitude of motion in the driver element essentially equals the amplitude of the driving motion of the electrostrictive member. However, in other types of transducers it is advantageous to apply the electrostrictive driving motion to flexural interface member(s) in a manner which results in increased amplitude of movement of the interface member(s). This amplification may be accomplished, for example, through the use of mechanical leverage, and/or the use of mechanical resonance in the flexural driver-interface element.

The use of mechanical amplification is particularly advantageous in transducers designed for low-frequency applications. The term "low-frequency" used herein generally applies to the region below approximately 1 khz. However, the features of this invention are not limited to that range. In the low-frequency region, significant transducer power output and driver motion are normally required. These requirements are best met through the use of large volumes of the electrostrictive energy-converting material, relatively large area of the flexural driver interface elements, and through the further use of transduction mechanisms which provide mechanical movement of the driver-interface elements which is amplified with respect to the mechanical movement of the electrostrictive energy-conversion element.

The ceramic-crystal type electrostrictive materials normally used in transducers have relatively low tensile strength, and, unless precautionary measures are taken, are subject to fracturing when strong electrical signals are applied. However, their compressive strengths are much greater. Therefore, in transducer applications, the stacks of crystals normally are subjected to a compressive "bias" to more nearly center the internal stress variations (produced by the electrical input signal) between the limits of the tensile and compressive strength of the crystal(s).

To better understand the advantages of the present invention a brief review of some prior art embodiments is in order.

Fig. 1 shows a cross-section view of a prior art transducer which was claimed to essentially eliminate the undesired effect of the water pressure changes. This figure is taken from Figure 2 in United States Patent No. 3,258,738, "Underwater Transducer Apparatus", which was issued June 28, 1966. The present Fig. 1 has been somewhat simplified by omission of some detail not germane to the principles to be described here.

The embodiment shown is effective in providing efficiency which is improved over the earlier prior-art transducers employing elliptical tubes.

Figs. 2 and 3 are pictorial and cross-sectional views, respectively, of a prior-art cylindrical transducer employing the principles of the embodiment shown in Fig. 1. Figs. 2 and 3 correspond (in somewhat simplified form) to the Figs. 5 and 6 in the aforereferenced United States Patent No. 3,258,738.

While effective in principle, the embodiment of Figs. 1, 2 and 3 have disadvantages, as follows :

a. Flexible cylinder surface member 85 requires somewhat costly fabrication methods.

b. Assembly of all internal parts and connections including assembly to top and bottom plates 81 and 82 cannot be completed outside cylindrical member 85 and boot 88. The bonding of one insulated end of driver member 90 to either top or bottom plate 81 or 82 must be completed with the rest of the internal assembly within cylinder member 85 and boot 88.

c. Boot 88, because of the hydrostatic pressure on exposed areas in slots 87, is subject to tearing away from the inner surface of tabular member 85.

It is an object of the present invention to provide a transducer utilizing a design in which parts are more easily and less expensively fabricated, and in which manufacturing assembly is simplified.

It is a further object to utilize flexural driver interface elements which provide amplification of mechanical motion of the driver element, and, if desired, resonance at some predetermined frequency.

It is still another object of the invention to provide improved capability to withstand hydrostatic pressures.

A further object is to provide a transducer capable of effective low-frequency applications.

SUMMARY OF THE INVENTION

According to the invention, an electro-acoustic transducer uses a first means for producing an acoustic signal in response to a stimulus. The first means comprises a plurality of staves with predetermined shapes, arranged generally parallel and forming an enclosure. A second means is provided to produce the stimulus and is coupled to the first means

BRIEF DESCRIPTION OF THE DRAWINGS

An embodiment of the present invention will now be described by way of example, with reference to the accompanying drawings, in which :

Fig. 1 is a cross-section view of a prior-art transducer employing a compliant tube in which the sides parallel to the cross-sectional major axis are concave.

Fig. 2 is a pictorial view of a prior-art cylindrical transducer.

Fig. 3 is a section view of the prior-art transducer shown in Fig. 2

Fig. 4 is an isometric drawing (partially sectional) of a transducer in accordance with the present invention.

Fig. 5 is a section side view of an improved transducer in accordance with the present invention.

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

Fig. 7 shows two views of one of the 12 staves which make up the sides of the transducer shown in Fig. 5.

DETAILED DESCRIPTION OF THE INVENTION

One embodiment of the present invention is illustrated by the isometric, partially cross-sectional drawing in Fig. 4.

For purposes of explaining the operation and features of this invention, the use of electrostrictive material, a commonly used energy-conversion material, will be assumed. However, for persons skilled in the art it will be apparent that the principles of operation and features of the invention are equally applicable if other types of energy-conversion material are used.

Transducer 100 utilizes six flexural bars 101 fastened to two end plates 102 (the one at the distant end of the drawing not being visible). The flexural bars are shaped as shown in Fig. 7 (to be described later) to form, in the assembled transducer 100, an outer surface which is concave with respect to the transducer's longitudinal axis. Flexural bars 101 normally are fastened to end plates 102 by means of screws, not shown. A stack of electrostrictive elements 103 (shown diagrammatically) is assembled within transducer 100 with its axis essentially coincident with the transducer's longitudinal axis. A tension member 104, threaded at both ends, passes through holes in end plates 102 and through an axial hole through stack 103.

The tension member can be a rod, or bar with any shape, provided it meets the requirements detailed in the description below.

Two nuts 105, one at each end of rod 104, are tightened against the outer surfaces of end plates 102 to provide the required compressional "bias" to stack 103. It should be noted that hydrostatic pressure is in a direction to also produce compression on the stack and may be used to supplement the compression provided by nuts 105 on rod 104 to provide the desired total compression. It is well known by persons skilled in the art that insulation may be required between the ends of crystal stack 103 and end plates 102, and that bonding of the stack assembly to the end plates may be required. Therefore, these details are not shown. Further, since methods of making electrical connections to the stack are also known to those skilled in the art, these details are not shown either. Boot material (such as rubber) is bonded to the outer surfaces of bars 101, at least to cover the outer region where the longitudinal edges of each bar meet the edges of adjoining bars. This detail is not shown, but it is noted here that hydrostatic pressure reinforces the bonding, whereas in the prior art cylindrical transducer of Figs. 2 and 3 the hydrostatic pressure may tend to tear the boot away from the inner cylindrical surface.

In the embodiment of Fig. 4, when the electrical input signal causes stack 103 to expand in the direction along transducer 100's longitudinal axis, end plates 102 are caused to move outward in the direction of arrows 106. This outward movement of end plates 102 also causes the concave surfaces of flexural bars 101 to move outward in the direction of arrows 107. Thus, the resultant positive pressure changes in the fluid medium at the outer surfaces of end plates 102 and flexural bars 101 are reinforcing. Conversely, when the electrical input signal causes stack 103 to contract, both the outer surfaces of end plates 102 and flexural bars 101 move inward, in the direction opposite to that indicated by arrows 106 and 107, respectively, thereby producing reinforcing negative pressure changes in the fluid medium.

A preferred embodiment of the invention is shown in cross-section in Fig. 5, and in the cut-away end view in Fig. 6, where the upper end plate is not shown.

The operation of this embodiment is essentially the same as described for the Fig. 4 embodiment. However, this preferred embodiment employs a greater number of flexural bars, twelve instead of six, and a large volume of electrostrictive, magnetostrictive, or other rare earth types of energy conversion material, to essentially fill the available space within the interior of the transducer shell. The large volume of energy conversion material and larger radiating area provide generally desired lower Q (wider bandwidth) and greater power capability.

In Fig. 5, twelve staves 201 are fastened to end plates 202 which have an end-view shape corresponding to a dodecagon, a twelve-sided regular polygon. The staves are fastened to the end plates by means of screws which are not visible in Fig. 5, but for which provision is shown in Fig. 7. The electrostrictive stack, comprised of a stack of annular discs having a center hole 207, operates in the extensional mode, i.e. it expands and contracts along the longitudinal axis of the stack in response to corresponding variations in polarity of the input signal. Tension member 204, which passes through holes 206 in end plates 202 and hole 207 in stack 203, is secured in place by threaded nuts 205 at each end. The tightness of adjustment of nuts 205, in conjuction with the hydrostatic pressure of the fluid medium, provides the required compressional bias on stack 203. As explained in Fig. 4, details well known to persons skilled in the art are not shown in Fig. 5 ; these omissions are as follows :

Insulation between the ends of stack 203 and end plates 202 ;

Bonding of the ends of stack 203 (and insultors applied thereto) to end plates 202 ;

Electrical connections to stack 203 ; and

Flexible material.

As described for the embodiment shown in Fig. 4, boot or sealing material is assembled on the exterior surfaces of flexural bars 201, whereby hydrostatic pressure reinforces the bonding of the boot material to the bars

An end view of transducer 200 is shown in in Fig. 6, in which the upper end plate is not shown. The narrowing of the twelve flexural bars 201 as they curve inward to form the concave exterior surface is illustrated. These bars are fastened, as previously described, to lower end plate 202. The twelve-sided upper end plate (not shown) fits within the polygon formed by the inner faces of the upper ends of flexural bars 201. The end view of stack 203, with its center hole 207, is shown. Tension member 204 (shown in Fig. 5) passes through hole 206 in lower end plate 202.

To assist in visualization of transducer 200 shown in Figs 5 and 6, two views of one of the twelve staves are shown in Fig. 7. The outer surface of stave 301 is shown in the left view. Countersunk holes 303 (four at each end of the stave) provide for mounting the staves to the end plates of transducer 200 with flat-head screws. The heads of the screws, after assembly are flush with surfaces 304 at the ends of the staves in the side view at the right. Surface 302 in that view corresponds to the outer surface of the transducer.

Referring again to Fig. 5, when the applied signal causes the energy conversion crystal stack 203 to expand along its longitudinal axis, end plates 202 are caused to move outward, producing a positive pressure change in the fluid medium at their outer surfaces. Simultaneously, the two ends of flexural staves 201 are pulled in opposiste directions and their concave surfaces are caused to move outward, away from the longitudinal axis of tranducer 200, thereby producing a positive pressure change in the fuid medium at the outer surfaces of bars 201. Thus, the pressure changes at the end plate surfaces and flexural stave surfaces are reinforcing. Further, the amplitude of motion of end plates 202 in opposing directions parallel to the transducer longitudinal axis cause an increased amplitude of motion in the center portion of the concave surfaces of bars 201. The amplified motion of the concave surfaces of the staves coupled with the relatively large combined surface of the multiplicity of bars provides for significant power transfer to the fluid medium.

When the applied signal causes stack 203 to contract, end plates 202 are drawn inward toward each other in directions parallel to the longitudinal axis of transducer 200. The end plate motion causes the concave surfaces of flexural staves 201 to flex inward toward the transducer's longitudinal axis. Thus, reinforcing negative pressure changes occur in the fluid medium at the outer surfaces of the end plates and the flexural staves.

While two embodiments of the invention have been described, employing simulated concave cylindrical surfaces comprised of six and twelve flexural staves, respectively, the invention is not limited to those numbers of staves. Within the scope of the invention, the number of flexural staves employed, the degree of their concavity, their dimensions, and the mechanical properties of the materials of which the bars are composed may be varied to provide the desired Q, frequency range, and power capability of the transducer.

Advantages of the invention apparatus over prior art include :

a. The staves, of which the simulated concave cylindrical surface is comprised, are much simpler and less costly to fabricate than the prior-art solid concave cylinder.

b. Transducer assembly is simpler and less costly. All internal parts, including driving member, insulators, bonding materials, the tension member and all electrical connections can be assembled to and between both end plates prior to assembly of the staves comprising the outer shell.

c. Access to the interior parts of the transducer for service, if required, is readily accomplished by removal of one or more staves.

d. Flexible material, is applied to the exterior, rather than interior, portion of the simulated concave cylindrical surface, either in the form of a sheet of material over the entire surface, strips of material bonded to the exterior surface and covering the areas where the longitudinal edges of adjacent staves adjoin, or by a sealant 210 applied to the slight gaps between certain portions of the adjoining edges of adjacent staves. Spacing between the central portion of adjoining edges of the staves normally is only sufficient to allow for maximum required flexing of the staves in operation without interfering contact between adjacent staves. The use of boot material or sealant at the external surfaces simplifies assembly, and further, the bonding forces are reinforced by hydrostatic pressure.

e. A tension member permits adjustment of compression of the driving member crystal stack. This compression is augmented by hydrostatic pressure.

The principle of reciprocity applies in the invention apparatus, i.e., in addition to serving as sources of accoustic waves, the apparatus may also serve as detectors of acoustic waves (or hydrophones), in which acoustic waves are detected and corresponding electrical (or magnetic) signals are produced. Such transducers find wide application in Sonar systems.

Claims

1. An electro-acoustic transducer (100) characterized by :
   first means for producing acoustic signals in response to a stimulus, said first means comprising a plurality of staves (101, 201, 301), each stave having two ends, with predetermined shapes, parallel, and forming an enclosure ; and
   second means (103, 203) for producing said stimulus, coupled to said first means.

2. A tranducer according to claim 1 characterized in that said means (103, 203) for producing said stimulus comprises an assembly of : a stack (103, 203) of energy conversion elements located in said enclosure, with each element having an aperture (207) approximately centered ; end plates (102, 202) coupled near the ends of said staves ; and a member (104, 204) attached to said end plates and traversing the center of said stack of energy conversion elements for applying a compression force to said stack.

3. A transducer according to claim 2, characterized in that said staves (101, 201, 301) are concave with respect to said member (104, 204).

4. A transducer according to claim 2 or claim 3, characterized in that said stack (103, 203) comprises a series of annular energy conversion disks.

5. A transducer according to any one of claims 2 to 4 characterized in that said stack (103, 203) causes said end plates (102, 202) to move, resulting in said staves having a component of motion in a direction perpendicular to that of said end plates.

6. A transducer according to any one of claims 1 to 5 characterized by a means for sealing between said staves, wherein hydrostatic pressure on said means enhances said sealing.

7. A transducer according to claim 6 characterized in that said means for sealing comprises flexible material applied to the outside of said enclosure.

8. A transducer according to any one of claims 1 to 7 characterized in that the enclosure formed by said staves (101, 201, 301) has a cross-section that is approximately circular.

9. An underwater acoustical projector, characterized by : a spaced apart pair of polygonal shaped end plates (102, 202), a ceramic driver (103, 203) of smaller cross-sectional size than each end plate, positioned between the end plates, and a set of staves (101, 201, 301) secured from one end plate to the other, each stave being concave inwardly towards the driver and being separated from each other stave by a gap.

10. A projector according to claim 9 characterized in that each stave (101, 201, 301) is secured to the end plates (102, 202) by adhesive bonding and by a bolt screwed into each end plate.

11. A projector according to claim 9 or claim 10 characterized in that the driver (103, 203) is cylindrical and has an aperture (207) therethrough along its longitudinal axis, and including a sealer coating inside the longitudinal aperture of the driver.

12. A projector according to any one of claims 9 to 11 characterized by an end cap secured to each end plate (102, 202) to prevent the inside of the driver (103, 203) from being exposed to the outside medium, and wherein electrical wiring from the driver passes through a sealing grommet in one of the end caps.

13. A projector according to any one of claims 9 to 12 characterized in that said set of staves (101, 201,

301) is a set of separate staves secured at each end thereof to one of the end plates (102, 202), and each stave being separated from adjacent staves by a gap extending the entire length of each stave from one end plate to the other end plate.

14. A projector according to any one of claims 9 to 13 characterized in that the driver (103, 203) is cylindrical, has an aperture (207) therethrough along its longitudinal axis, and comprises a set of annular rings, each ring being plated on its flat surfaces with conductive electrodes, axially poled to render it piezoelectrically active and bonded to the next ring, the driver (103, 203) being bonded between the end plates (102, 202) ; and wherein electrical connectors are secured to each ring and electrical wiring from each connector is potted along the length of the driver within the longitudinal aperture (207).

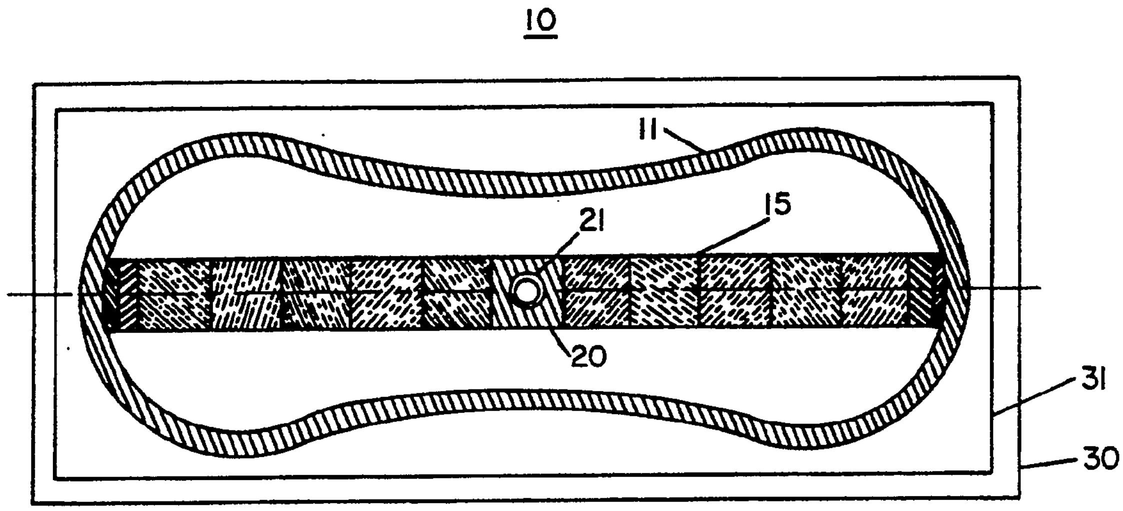


FIG. 1 (PRIOR ART)

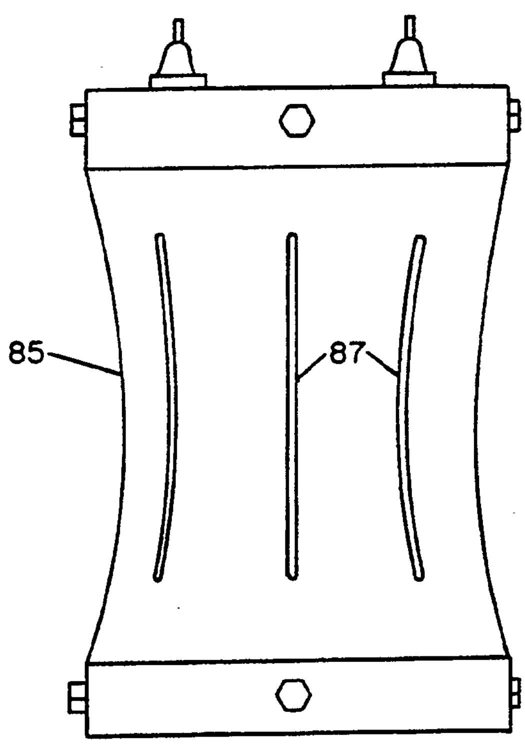


FIG. 2
(PRIOR ART)

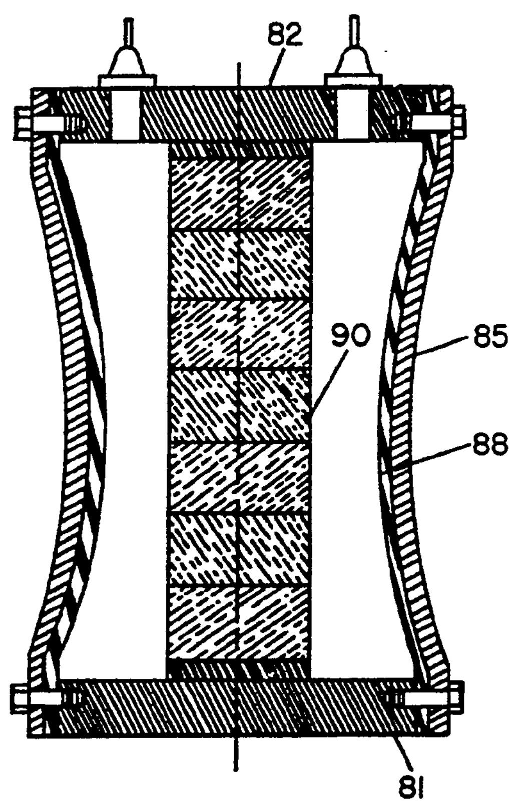
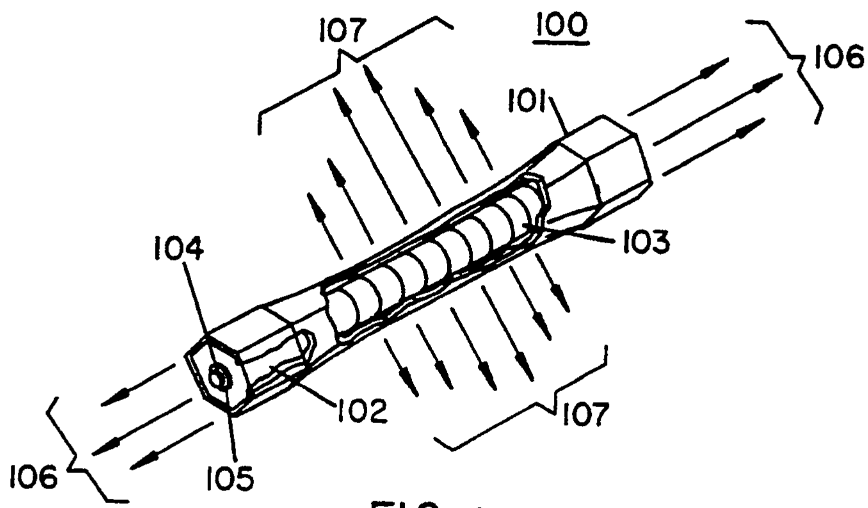


FIG. 3
(PRIOR ART)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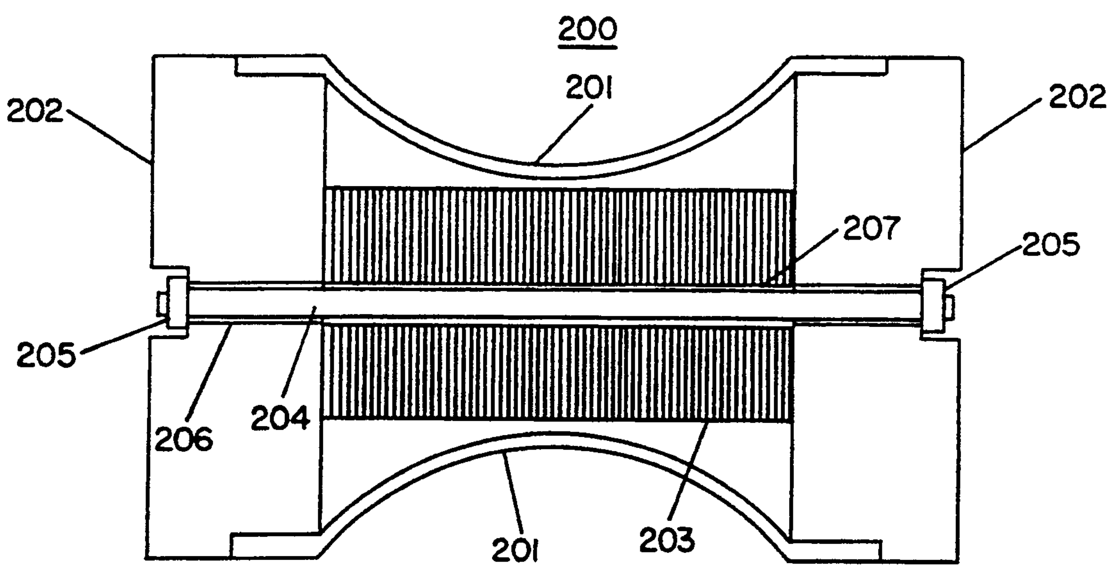
100
106
101
103
104
102
107
106
105

FIG. 4


200
201
202
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207
205
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206
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201
203

FIG. 5

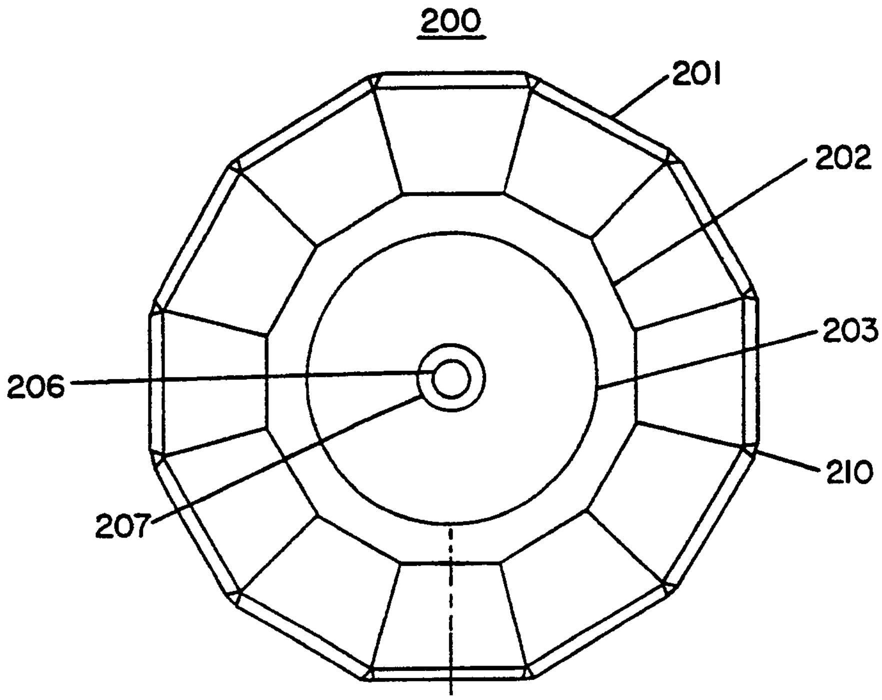

FIG. 6

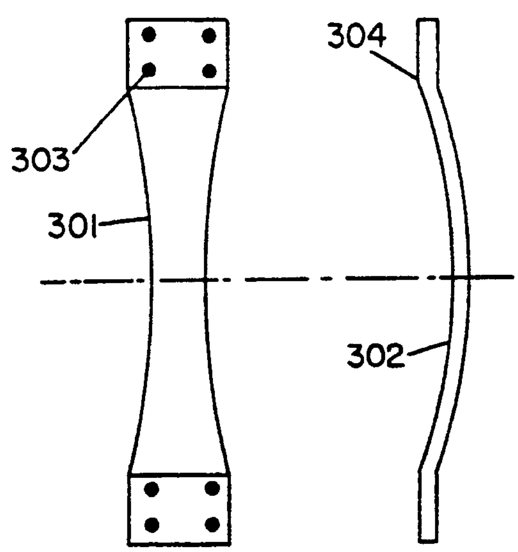

FIG. 7