

July 26, 1960

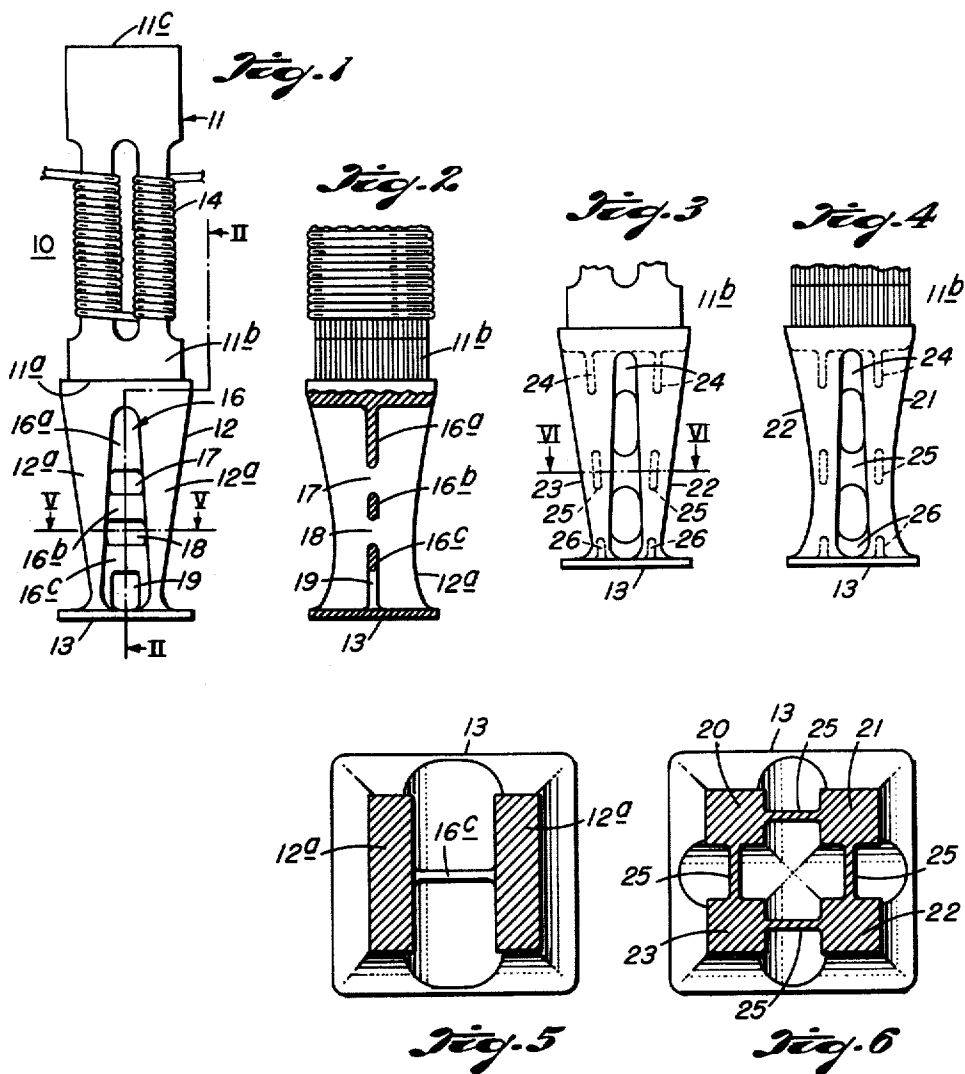
J. P. O'NEILL

2,946,981

SONIC TRANSDUCERS FOR FLUID MEDIUMS

Filed Jan. 3, 1956

2 Sheets-Sheet 1



INVENTOR.

J. P. O'Neill

BY

Ellenbury

ATTORNEY

July 26, 1960

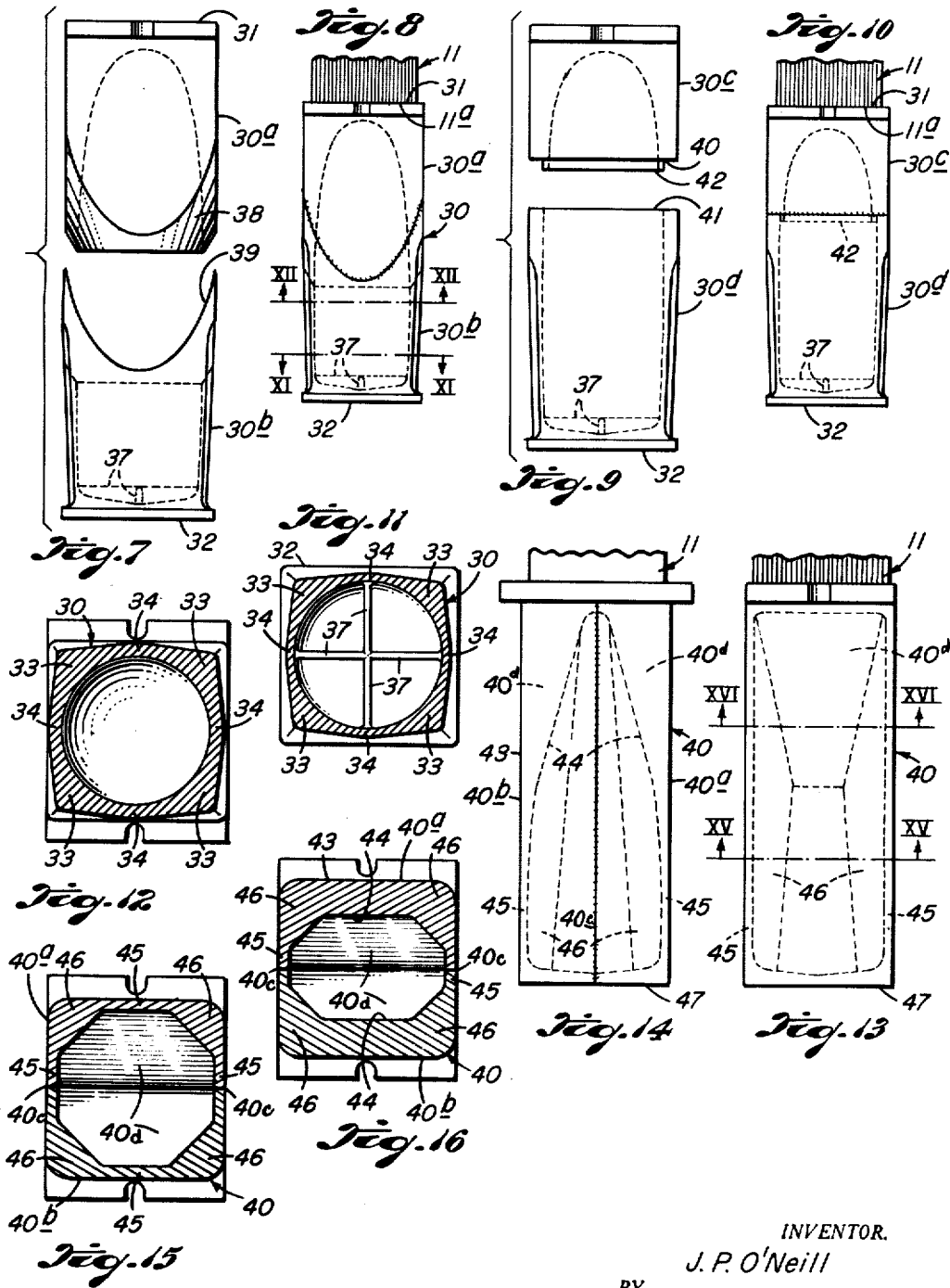
J. P. O'NEILL

2,946,981

SONIC TRANSDUCERS FOR FLUID MEDIUMS

Filed Jan. 3, 1956

2 Sheets-Sheet 2



INVENTOR.
J. P. O'Neill
BY
Elwoodbury
ATTORNEY

1

2,946,981

SONIC TRANSDUCERS FOR FLUID MEDIUMS

James P. O'Neill, Sunland, Calif., assignor to Bendix Aviation Corporation, North Hollywood, Calif., a corporation of Delaware

Filed Jan. 3, 1956, Ser. No. 556,991

15 Claims. (Cl. 340—8)

This invention relates to electromechanical transducers for generating or detecting sonic waves in fluid mediums. In this connection, the term "sonic" is intended to include waves of frequencies above the audible range, as well as those within it.

A general object of the invention is to improve the over-all efficiency of electromechanical sonic transducers.

Another object is to provide an electromechanical transducer of the mechanically resonant type having a good impedance match with the fluid medium with which it works.

Another object is to improve the performance of transducers having a vibrator and a motion-translating structure for coupling the vibrator to a fluid medium.

Another object is to reduce cavitation corrosion in underwater transducers.

Another object is to suppress undesirable lateral vibrations in motion-translating structures of transducers.

A feature of the invention is a motion-translating structure for coupling a vibratile element to a diaphragm, which structure isolates the rear face of the diaphragm from the fluid that contacts the front working face.

Other more specific objects and features of the invention will appear from the description to follow.

The invention has to do with that type of sonic transducer in which an electromechanically-sensitive body has its vibratile working face coupled by a mechanical motion-translating structure to a diaphragm in contact with a working liquid medium, as distinct from those in which the working face itself is in contact with the liquid. Various advantages can be obtained by the addition of a motion-translating structure and separate diaphragm, one of which is to obtain a better impedance match with the liquid. A motion-translating structure for this purpose is disclosed in U.S. Patent No. 2,723,386 and consists of two or more tapered solid horns rigidly connected to an electromechanical vibrator at one end and to a radiating face (hereinafter referred to as the diaphragm) at the other end, but not mechanically interconnected to each other intermediate their ends. Such a motion transformer has substantial utility, as pointed out in the patent, but may have the defect that the horns, in addition to vibrating in the principal desired longitudinal mode, vibrate in secondary undesired lateral modes. The vibration in the secondary modes is sometimes objectionable, because it wastes energy and alters the frequency and/or amplitude of vibration in the principal mode.

In part, the present invention resides in the addition to a multiple leg motion amplifier of lateral bracing means between the legs which suppresses the spurious lateral vibrations by reducing the freedom to vibrate in the secondary modes and/or shifting the natural fre-

2

quencies of lateral vibration further away from the desired natural frequency of longitudinal vibration.

The invention also includes a motion-translating structure in the form of a hollow or tubular wall extending between the electromechanical vibrator and the diaphragm and defining therewith a sealed space providing an air backing for the diaphragm. This structure permits immersion of the diaphragm in a liquid medium for acoustic coupling between the working face and the liquid, while isolating the rear face from the liquid. This has several advantages. One is elimination of cavitation corrosion of the rear surface of the diaphragm. Another is elimination of acoustic loading on the rear face of the diaphragm.

In addition to the foregoing advantages resulting directly from the closed tubular wall translator, efficient motion amplification can be obtained by longitudinally tapering the wall thickness. For best results, the wall thickness is also varied peripherally, the thickened portions being analogous to legs, and the intermediate thinner portions serving as lateral reinforcements between the legs.

A full understanding of the invention may be had from the following detailed description with reference to the drawing, in which:

Fig. 1 is a side elevational view of a transducer assembly including a motion-amplifying mechanical transformer in accordance with the invention.

Fig. 2 is a view taken at right angles to the view of Fig. 1, being partially in elevation and partially in section, the view being taken along the line II—II of Fig. 1.

Fig. 3 is a side elevational view of a modified form of motion-amplifying transformer having four legs.

Fig. 4 is an elevational view of the same transformer taken at right angles to the view of Fig. 3.

Fig. 5 is a cross-section taken in the plane V—V of Fig. 1.

Fig. 6 is a cross-section taken in the plane VI—VI of Fig. 3.

Fig. 7 is an exploded view showing the two parts of a motion transformer defining a closed cavity back of the diaphragm.

Fig. 8 is a side elevational view of an assembled transformer employing the parts shown in Fig. 7.

Fig. 9 is an exploded view showing the two parts of a modified construction.

Fig. 10 is a side elevational view of an assembled transformer employing the parts shown in Fig. 9.

Fig. 11 is a cross-section in the plane XI—XI of Fig. 8.

Fig. 12 is a cross-section taken in the plane XII—XII of Fig. 8.

Fig. 13 is a side elevational view of a modified form of closed cavity transformer.

Fig. 14 is a side elevational view of the same transformer taken at right angles to the view of Fig. 13.

Figs. 15 and 16 are cross-sections in the planes XV—XV and XVI—XVI, respectively, of Figs. 13 and 14.

Referring to Figs. 1 and 2, there is shown a transducer element 10 comprising an electromechanically-responsive body 11 having a front face 11a joined to the rear end of a motion-transforming member 12, the front end 13 of which constitutes a sound-absorptive or radiating diaphragm.

The body 11, as shown, is a magnetostriction vibrator consisting of laminations 11b of nickel and having a winding 14. This vibrator is of the type shown in Patent

No. 2,530,224 of L. W. Camp and, as heretofore used, would have its front face 11a directly coupled to the sound-conveying medium.

The motion-transforming member 12 is preferably of metal and may be brazed or welded directly to the face 11a, so that it is firmly affixed thereto. The member 12 is divided longitudinally into two legs or horns 12a, 12a which are rectangular in cross-section (Fig. 5) throughout their length, but gradually taper from a maximum cross-section at their rear ends to a minimum cross-section at a neck closely adjacent the front end. In front of its neck, each leg expands smoothly but rapidly into the diaphragm 13 which as shown, is of approximately the same area as the transducer face 11a.

Because of the smooth and relatively gradual reduction in the cross-sectional area of each leg 12a up to the neck, a horn action is obtained, which results in an increase in amplitude of longitudinal particle movement at the neck substantially inversely proportional to the square root of the ratio of the area of the rear end of the leg to the area at the neck. However, because of the short distance from the necks of the horns to the diaphragm face 13 and the rapid expansion of the area between these points, the horn action (which, if present, would greatly reduce the amplitude in the face 13 as compared to the neck) is relatively slight, and the amplitude of motion of the diaphragm face is very nearly as great as that in the necks of the legs or horns.

For efficient longitudinal vibration, the vibrator or transducer 11 and the transformer structure 12 are of the same longitudinal dimensions in terms of wave length of sound in the material. Each may be one-half wave length long, so that the over-all length is one wave length, or each portion may be one-quarter wave length long so that the over-all length of the assembly is one-half wave length.

As previously indicated, the principal and desired mode of vibration of the structure described is longitudinal. However, the legs or horns 12a are also capable of vibrating in secondary lateral modes. It is found that this ability to vibrate in the lateral mode can be relatively strong with long thin horns, and it is found that the horns frequently have a natural frequency of lateral vibration that is closely adjacent the principal longitudinal mode of vibration. Such lateral vibrations may be out of phase with each other or, if in phase, of unequal magnitude, and undesirably affect the principal longitudinal mode of vibration. Such undesirable lateral vibrations are controlled in accordance with the invention by providing a strut means 16 between the two horns or legs 12a, 12a. This strut means may consist of a continuous wall or web between the legs, or, as shown in Fig. 1, it may consist of several distinct sections (in this instance, three sections, 16a, 16b and 16c, respectively).

Following is an example of the effects produced by the lateral strut means:

A first assembly like Fig. 1, but without the lateral strut structure 16, had a natural frequency in the principal longitudinal mode of 9,713 c.p.s., resonated laterally at a first partial secondary mode at a frequency of 4,722 c.p.s., and in a second partial secondary mode at a frequency of 10,804 c.p.s. The frequency of the second partial was objectionably close to the frequency of the principal longitudinal mode.

In a second assembly similar to the first except for the addition of the strut sections 16a and 16c, lateral vibration in the second partial mode was substantially eliminated, but the frequency of the lateral vibration in the first partial mode was increased to 10,879 c.p.s.

In a third assembly similar to the first but having the three-section strut 16 of Fig. 1, the frequency of the first lateral partial mode was raised to 13,194 c.p.s., and the activity was greatly reduced, thereby substantially eliminating its effect at the frequency of the principal longitudinal mode of vibration.

The strut means may be a continuous web (as by eliminating the windows 17, 18 and 19 in Figs. 1 and 2), or it may have any number of windows of varying sizes, depending upon the nature of the lateral vibration that is to be controlled. In general, an interrupted web has an advantage over a continuous web in that it does not provide paths for longitudinal vibration non-parallel to the principal longitudinal vibration paths in the legs. However, this advantage may be relatively slight in some cases and may be small compared to the advantages of using continuous webs.

Figs. 3, 4 and 6 show the application of the invention to a four-legged horn. Each of the four legs is joined to the next adjacent legs by strut sections 24, 25 and 26 corresponding to the strut sections 16a, 16b and 16c of Fig. 1.

Increasing the number of legs provides a better distribution of the driving force on the diaphragm and facilitates vibration of all portions of the diaphragm in phase. The extent to which the legs should be subdivided in any particular case depends upon the wave length or frequency employed and the area of the diaphragm. In general, the more the legs are subdivided, the thinner they become, and the more apt they are to vibrate laterally in undesired modes. Hence, the present invention is as much or more applicable to motion-transforming devices having a large number of legs than to those having a small number of legs.

In Figs. 1, 2, 3 and 4, the rear face of the diaphragm 13 is exposed to a liquid in which the transducer is immersed. This has the disadvantage that the rear face is exposed to the cavitation corrosion resulting from high-power oscillation in liquids. Furthermore, the rear face, if exposed to liquid, is loaded by the liquid, and power is wasted there.

The present invention also includes structures that not only provide bracing to control undesired lateral vibration, but shield the rear side of the diaphragm from the ambient liquid to eliminate cavitation corrosion and acoustic loading thereof. The latter result is accomplished as shown in Figs. 7-12 by using as the motion-transforming structure a continuous hollow member defining with the diaphragm a closed cavity containing a gas.

Referring to Fig. 8, there is shown a motion-transforming body 30 of generally tubular shape having a closed base end, the external face 31 of which is joined to the working face 11a of the electromechanically-responsive body 11, as by brazing or welding. The other end of body 30 is joined to, as by forming it integrally with, a diaphragm 32, the outer face of which is contacted by the working liquid.

As shown in Figs. 8, 11 and 12, the major portion of the body 30 consists of a circumferentially closed hollow wall tapering longitudinally from a maximum thickness adjacent the base end 31 to a minimum thickness adjacent the diaphragm 32 and rapidly expanding into the diaphragm. This provides motion amplification.

The body 30 is also preferably tapered circumferentially, as shown in Figs. 11 and 12, to define thick sections 33 corresponding to the discrete legs of the four-legged motion transformer shown in Fig. 6, and connecting thin sections 34 corresponding to the discrete lateral stiffening webs of Fig. 6. When the diaphragm 32 is rectangular, as shown, the thickened portions 33 are four in number and are conveniently formed by making the inner surface of the body 30 round in cross-section and the outer surface approximately square in cross-section.

In order to reduce exposure of the rear face of the diaphragm 32 to ambient liquid, it is desirable to have the entire outer surface of the body 30 longitudinally straight and flush with the edge of the diaphragm. On the other hand, the diaphragm should vibrate as a rigid piston, but have as little mass as possible. Piston action with minimum mass is most easily obtained by making the outside lateral dimensions of the body 30 less than

5

the lateral dimensions of the diaphragm, and fairing the outer surface of the body rapidly out to the edge of the diaphragm. The best design may, in some instances, be a compromise, as shown in Figs. 8, 11 and 12, in which the neck portion (thinnest portion) of the body 30 is of slightly smaller external lateral dimensions than the diaphragm.

The diaphragm may be stiffened, as by radial ribs 37 on its inner surface.

It will be observed from Fig. 11 that the major portion of the rear face of the diaphragm overlies the cavity within the body 30 and is exposed to gas having low acoustic impedance relative to liquid, which is highly desirable. This advantage results solely from the closed cavity construction and may be obtained without longitudinally tapering the thickness of the body 30, the latter providing the additional advantage of motion amplification.

In manufacture, it is most practicable to form the body 30 of two sections joined together. The body of Fig. 8 is formed in two sections 30a and 30b (Fig. 7) having conical mating surfaces 38 and 39, respectively, of relatively large area which are rigidly joined together, as by cementing or brazing.

In the alternative construction shown in Figs. 9 and 10, the body 30 is formed in two sections 30c and 30d which have flat mating surfaces 40 and 41, respectively, which are rigidly joined together by cementing or brazing. To facilitate maintenance of the sections 30c and 30d in alignment while they are being joined together, the cavity in the member 30d may be made slightly larger than that in the section 30c, and the latter may be provided with a flange 42 projecting beyond the surface 40 and dimensioned to fit snugly in the cavity in the section 30d.

The structure shown in Fig. 9 has the advantage that the parts are easily held in alignment during a brazing operation or the like. It has the disadvantage that since the surfaces of joinder 40 and 41 are normal to the direction of vibration, the joint must be relatively strong. The structure of Fig. 7 has the advantage that the surfaces of joinder are of larger area and are not normal to the direction of vibration. It is possible with the structure of Fig. 7 to join the parts by suitable cements where the use of cements would be impracticable with the structure of Fig. 9.

Referring to Figs. 13, 14, 15 and 16, there is shown a closed cavity motion-transforming body 40 formed of two lateral sections 40a and 40b joined along a longitudinal section by a welded or brazed seam 40c. The longitudinal seam has the advantage over the transducer seams of Figs. 8 and 10 that it does not have to resist the tensile stresses resulting from longitudinal vibration.

Aside from the use of the longitudinal seam, the transformer of Figs 13-16 differs from that of Figs. 8 and 9 in that externally its faces are flat and define a rectangular parallelepiped. Each section 40a and 40b has a generally wedge-shaped portion 40d extending from the transducer 11 and lying between an outer, lateral face 43 and an inner flat face 44. Except at the two wedge portions 40d, the four lateral walls are relatively thin along their longitudinal median portion 45, but thick at the corner portions 46, the latter tapering to a lesser thickness toward the diaphragm 47.

Although for the purpose of explaining the invention certain particular embodiments thereof have been disclosed, obvious modifications will occur to a person skilled in the art, and I do not desire to be limited to the exact details shown and described.

I claim:

1. A transducer for high-frequency compressional waves in fluids comprising: a longitudinally expandible and contractible electromechanically-responsive body having a front end face of substantial area; a diaphragm longitudinally spaced from said end face and having a

6

front working face of substantial area; an integral motion-transforming means interposed between and interconnecting said body and diaphragm and comprising a base portion approximately coextensive with and attached to said face of said body for longitudinal vibration therewith, a pair of adjacent leg portions generally parallel to each other, and a lateral strut portion extending between said leg portions and joined thereto for modifying the natural vibration periods of said leg portions in lateral modes, said strut portion being substantially thinner than the leg portions.

2. Apparatus according to claim 1 in which said strut portion comprises a web extending laterally between said leg portions in a longitudinal plane.

3. Apparatus according to claim 2 in which said web comprises a plurality of longitudinally separated sections lying in a common plane and each section extending laterally between and joined to said leg portions.

4. Apparatus according to claim 1 including additional leg portions similar to said mentioned leg portions, all said leg portions being disposed about the central longitudinal axis in a polygonal pattern; and additional strut portions extending between each additional leg portion and the leg portions next adjacent thereto.

5. Apparatus according to claim 4 in which each said strut portion is a continuous wall extending from end to end of said leg portions and defining with said base portion, leg portions, and diaphragm a closed cavity.

6. Apparatus according to claim 5 in which said leg portions and strut portions fair gradually into each other circumferentially.

7. Apparatus according to claim 5 in which the outer surfaces of said leg portions and strut portions are approximately straight longitudinally.

8. A transducer for high-frequency compressional waves in fluids comprising: a longitudinally expandible and contractible electromechanically-responsive body having a front end face of substantial area; a diaphragm longitudinally spaced from said end face and having a front working face of substantial area; a motion-transforming member interposed between and interconnecting said body and diaphragm and comprising a continuous peripheral wall joined to and extending between said front face and said diaphragm and defining a closed cavity back of said diaphragm, said cavity containing a gas of small acoustic impedance relative to that of a liquid contacting said working face of the diaphragm.

9. Apparatus according to claim 8 in which said peripheral wall tapers in thickness from a maximum cross-section at each end to a neck of minimum cross-section at an intermediate point located substantially closer to the diaphragm end than to said one end.

10. Apparatus according to claim 8 in which said diaphragm is polygonal in shape and said continuous peripheral wall is of the same corresponding polygonal shape externally, and is continuously curved circumferentially internally.

11. Apparatus according to claim 8 in which said motion-transforming member is formed in two separate longitudinal sections having juxtaposed conical mating surfaces joined together.

12. Apparatus according to claim 8 in which said peripheral wall varies in thickness peripherally.

13. Apparatus according to claim 8 in which said diaphragm is polygonal in shape having discrete corners, and said peripheral wall is of the same general polygonal shape externally having discrete corners and being substantially thicker at said corners than intermediate said corners.

14. Apparatus according to claim 8 in which said diaphragm is polygonal in shape and said peripheral wall is of the same corresponding polygonal shape externally as said diaphragm defining a plurality of outer faces and corners at the intersections of the faces, and internally the said wall is generally polygonal in shape having twice

as many inner faces as outer faces, one set of alternate inner faces being respectively juxtaposed to the outer faces, and the other alternate set of inner faces being juxtaposed to the said corners of the exterior.

15. Apparatus according to claim 8 in which said motion-transforming member is formed in two separate lateral sections having juxtaposed longitudinal edge surfaces joined together.

References Cited in the file of this patent

UNITED STATES PATENTS

2,044,807 Noyes ----- June 23, 1936

2,415,407
2,723,386

Benioff ----- Feb. 11, 1947
Camp ----- Nov. 8, 1955

OTHER REFERENCES

5 Hueter-Bolt, "Sonics," pp. 276-277, published 1955,
John Wiley & Son.