March 29, 1960 L. W. CAMP ET AL 2,930,913

TRANSDUCERS FOR GENERATING VIBRATIONS IN LIQUIDS

Filed Oct. 2, 1957 2 Sheets-Sheet 1

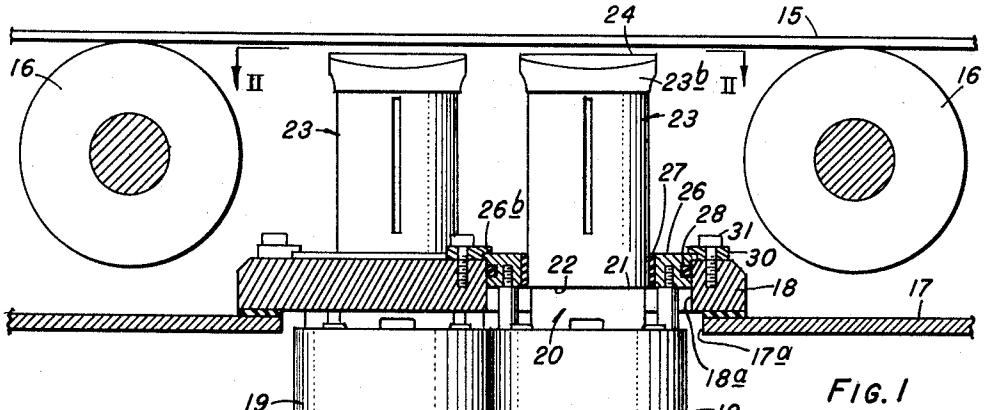
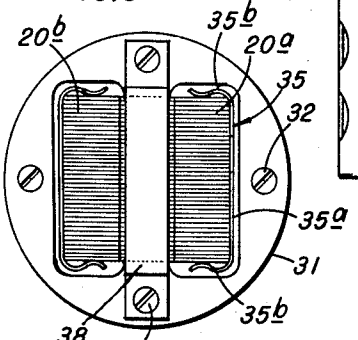


FIG. 1

FIG. 3



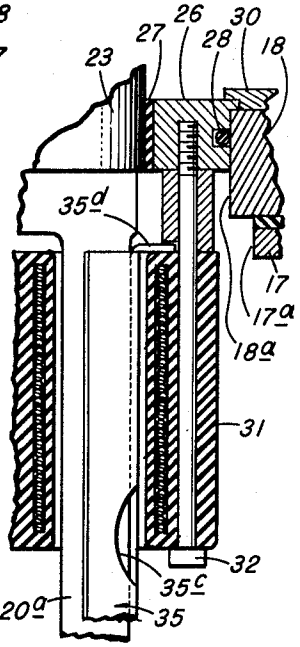


FIG. 4

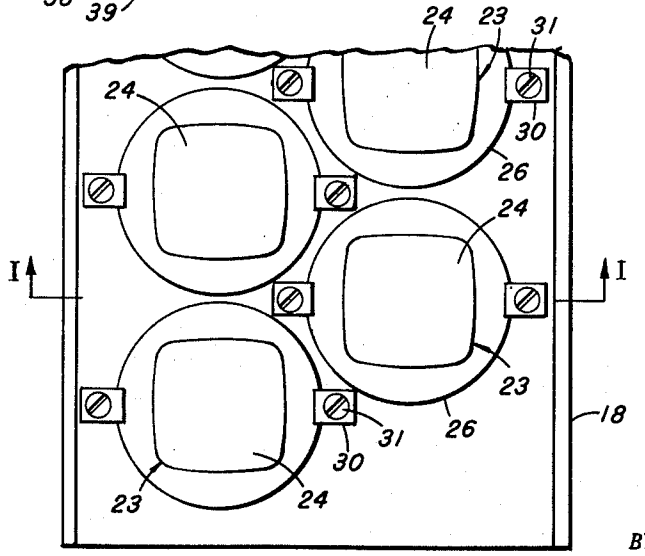


FIG. 2

INVENTORS
L. W. CAMP
J. P. O'NEILL

BY

ATTORNEY

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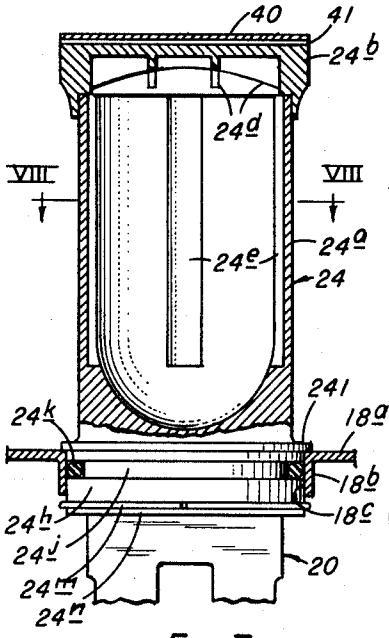


FIG. 7

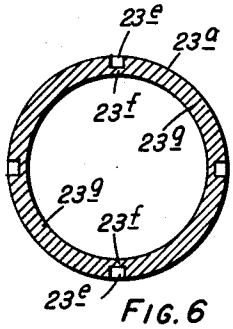


FIG. 6

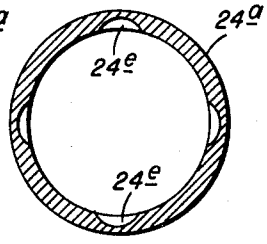


FIG. 8

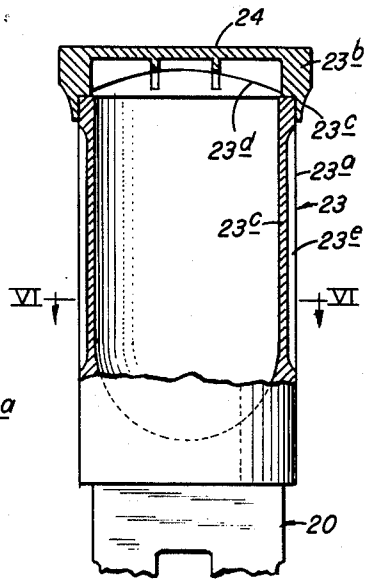


FIG. 5

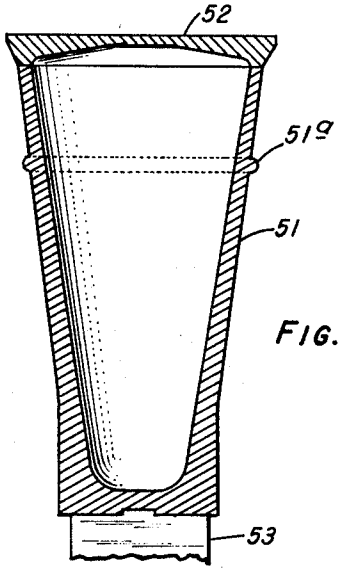


FIG. 10

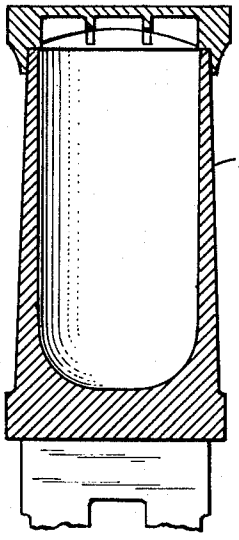


FIG. 9

INVENTORS
L. W. CAMP
J. P. O'NEILL
BY
ATTORNEY

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TRANSDUCERS FOR GENERATING VIBRATIONS IN LIQUIDS

Leon W. Camp, Santa Monica, and James P. O'Neill, Sunland, Calif., assignors to Bendix Aviation Corporation, North Hollywood, Calif., a corporation of Delaware

Application October 2, 1957, Serial No. 687,725

20 Claims. (Cl. 310—26)

This invention relates to electromechanical transducers for generating sonic waves in fluid media, the term "sonic," as here used, including waves of frequencies above audibility, as well as those within the audible range.

An object of the invention is to provide transducers of satisfactory efficiency that can be manufactured relatively cheaply.

Another object is to provide a satisfactory and inexpensive motion-translating structure for coupling the electromechanically-responsive element of a transducer to the working face thereof that is in contact with the fluid medium.

Another object is to provide simple and effective structures for supporting transducers in a wall of a tank.

Another object is to provide a simple and effective structure for preventing lateral vibration of the laminations of a magnetrostrictive transducer.

Other more specific objects and features of the invention will bceome apparent from the following description.

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. application Serial No. 556,991 of J. P. O'Neill, filed January 3, 1956, that consists of an elongated hollow body defining a closed, gas-filled cavity, which body is rigidly joined to an electromechanically-responsive element at one end, the other end constituting the working face in contact with the liquid medium. That motion transducer is highly efficient and satisfactory in performance, but is relatively expensive to construct.

The present invention resides in motion transducers having many of the desirable operating characteristics of the prior construction, but of simpler constructions that are substantially cheaper to manufacture. One embodiment of the present invention comprises a hollow cylindrical midsection interconnecting the base and head portions, with peripherally-spaced longitudinal grooves in the inner or outer surface. The midsection thereby consists of an integral hollow tubular member having a plurality of longitudinal sections of different thickness, the thinner sections being at the grooves and the thicker sections being between the grooves. The combination of thick and thin sections reduces undesired lateral vibration to a substantial degree relative to the desired longitudinal vibration. The structure is relatively cheap to make, because it can be produced by simple machining operations from a solid body, or can be fabricated from standard tubing.

Another embodiment of the invention comprises a hollow conical midsection with a peripheral rib intermediate the ends, the rib greatly reducing the magnitude of vibrations in the undesired lateral mode.

It is desirable that transducers mounted in the wall of a tank be readily replaceable, either individually or in groups. This is accomplished by a modular construction.

The foregoing, together with other lesser improvements, will become apparent from the following detailed description with reference to the drawing, in which:

Fig. 1 is an elevation view, partly in section, of an apparatus incorporating the invention for cleaning the under side of sheets moving horizontally through a tank.

Fig. 2 is a plan view taken in the plane II—II of Fig. 1.

Fig. 3 is a lower end view of one transducer element taken in the plane III—III of Fig. 1.

Fig. 4 is a detailed vertical section through one of the units of Fig. 1.

Fig. 5 is an elevational view, partly in section, of one of the motion-transforming members in Fig. 1.

Fig. 6 is a cross-section taken in the plane VI—VI of Fig. 5.

Fig. 7 shows an alternative construction to that of Fig. 5.

Fig. 8 is a cross-section taken in the plane VIII—VIII of Fig. 7.

Fig. 9 is a vertical sectional view showing another alternative construction.

Fig. 10 is a vertical sectional view showing still another alternative construction.

Referring first to Figs. 1 and 2, a sheet **15** to be cleaned is adapted to be moved through liquid in a tank while supported at a fixed level by rollers **16**. Only the bottom wall **15** of the tank is shown.

Detachably mounted over a rectangular aperture **17***a* in the bottom wall **17** is a transducer module consisting of a mounting plate **18** carrying a plurality of transducer units **19** arranged in staggered relation in two rows extending the full width of the sheet **15**, so that each portion of the latter passes over a transducer and is subjected to intense sonic waves generated in the liquid by the transducers.

Each transducer unit **19** comprises a longitudinally expansible and contractible electromechanically-responsive body **20** having a front end face **21** of substantial area joined to the rear end **22** of a motion-transforming member **23** having a front working face **24** of substantial area. For convenience, this end face **24** will hereafter be referred to as the diaphragm. The member **23** and the body **20** are joined at their faces **22** and **21**, respectively, by brazing, soldering, or in any other suitable way.

In the construction shown in Fig. 1, the assembly of the body **20** and the member **23** are supported by a mounting ring **26** having an aperture larger than the diameter of the member **23** with a rubber ring **27** filling the space therebetween and bonded to the ring **26** and the body **23**. This provides a watertight connection between the ring and the member **23**, and at the same time permits longitudinal vibration of the member **23** relative to the ring **26**. The ring **26** fits in an aperture **18***a* in the plate **18** and is sealed with respect thereto by an O-ring **28** mounted in a groove in the external surface of the ring **26**. A flange **26***b* on the upper end of the ring **26** rests on the plate **18** and supports the ring with respect to the plate. Upward movement of the ring is prevented by lugs **30** secured to the plate **18** by screws **31**, which lugs overlap the upper edge of the ring **26**.

The electromechanically-responsive body **19** is a magnetostrictive vibrator, as shown in Fig. 1, and consists of a stack of generally U-shaped laminations so that the body as a whole has two downwardly depending legs which extend through a potted coil assembly **31**, which is supported by screws **32** from the ring **26**. As best

shown in Fig. 4, the coil assembly 31 has apertures of sufficient size to permit the legs 20*a* and 20*b* of the transducer to extend therethrough without contacting the coil assembly.

It has been general practice in the construction of laminated magnetostrictive drivers of the type here disclosed to bond the laminations together with some adhesive. However, it is found that in practice when such transducers are operated under heavy duty, the forces and the heat usually separate the laminations, causing them to bow and vibrate. In accordance with the present invention, such bowing and vibrating is prevented, and the bonding made unnecessary, by placing a U-shaped spring clip 35 over each transducer leg. As best shown in Fig. 3, each clip 35 has a broad base 35*a* extending across the edge portions of all the laminations, and curved leg portions 35*b* which bear against the outer faces of the opposite laminations in the stack. Apertures 35*c* (Fig. 1) are preferably cut out of the clips to facilitate circulation of the ambient cooling fluid or cooling gas or liquid to the laminations. As best shown in Fig. 4, each clip 35 is supported in position by an integral outwardly extending lug portion 35*d* at the upper end, which engages the upper face of the potted coil assembly 31. The clip 35 vibrates with the transducer leg on which it is mounted, and normally the lug 35*d* rides slightly above the potted coil 31.

With a structure as so far described, the entire module can be removed from the tank with the plate 18, or transducers can be removed individually. Thus, any individual transducer can be removed from the inside of the tank by simply removing the screws 31 that hold it to the plate 18, and lifting the assembly consisting of the body 20, the member 23, and the ring 26 away from the plate 18. The coil 31 also is a part of the assembly and is of such size as to pass through the aperture 18*a*.

A polarizing magnet 37 is positioned between the two legs 20*a* and 20*b* of each magnetostriction element and is supported by a U-shaped clip 38 secured by bolts 39 to the potted coil.

The particular construction of the motion-transforming member 23 is shown in Figs. 5 and 6. It is solid at its base, but is hollow thereabove, having a cylindrical wall 23*a* extending through the major portion of its length. The upper end or head 23*b* is preferably formed separately and joined to the upper end of the wall 23*a* by brazing or welding. Desirably, the head 23*b*, in a brazed assembly, has a downwardly depending skirt 23*c* in which the upper end of the wall 23*a* is a tight-pressed fit. The interior of the head 23*b* desirably has crossed, downwardly-depending webs 23*d* to stiffen it, so that the outer face 24 vibrates as a solid element in a single mode.

The construction involving the cylindrical wall 23*a* is highly desirable from a manufacturing standpoint, since it can be fabricated inexpensively. However, simple hollow cylindrical structures have a tendency to vibrate undesirably in lateral modes, and because of this undesirable characteristic much more complicated structures have been resorted to in the past. In accordance with the present invention, it has been found that by forming longitudinal grooves 23*e* in the thin cylindrical wall 23*a*, so that the latter consists of a plurality of longitudinal sections integral with each other and each of uniform thickness longitudinally, but one set of alternate sections being of greater thickness than the intervening section, the fundamental resonant frequency of lateral vibration is reduced to a sufficient extent to make the device practicable. The grooves 23*e* provide thin longitudinal sections 23*f* joining the thicker sections 23*g*.

Fig. 7 shows a slight modification of the structure of Fig. 5 in that the grooves 24*e* are formed in the inner surface of the cylindrical wall 24*a*, instead of in the outer surface. Both constructions are equally efficient, and the choice depends on which is easier to manufacture. In each case, the resultant thin sections joining thicker sections serve to suppress the lateral vibrations.

The head 24*b* in Fig. 7 is identical with that in Fig. 5, except that an outer hard corrosion-resistant wear plate 40 is attached to the outer end of the head and constitutes the working face 24 of Figs. 1 and 5. This wear plate 40 may be of some hard corrosion-resistant material, such as stainless steel, and can be joined to the head 24*b* by an epoxy cement indicated at 41. It is found that such cement satisfactorily resists the vibration forces involved, and yet permits removal of the wear plate 40 and substitution of a new one.

Fig. 7 also shows an alternative mounting of the transducer in the plate 18*a*, which corresponds to the plate 18 of Fig. 1, but is of sheet metal construction having drawn apertures therein which provide integral cylindrical extensions, or flanges, 18*b*. Each drawn flange 18*b* provides an inner cylindrical face in which a cylindrical piston face 24*h* on the lower end of the member 24 is slidably fitted. The face 24*h* has a groove 24*j* containing an O-ring 24*k* which effects a fluid seal between the piston surface 24*h* and the cylinder surface 18*c*. A flange 24*l* is provided at the upper end of the piston surface 24*h* to limit downward movement of the transducer with respect to the plate 18*a*, and a snap ring 24*m* mounted in a groove 24*n* in the piston face 24*h* limits upward movement of the transducer with respect to the plate 18*a*. The distance between the lower edge of the flange 24*l* and the upper edge of the snap ring 24*m* is slightly greater than the length of the cylindrical section 18*c*, so that when the transducer is vibrating, it assumes a position in which the flange 24*l* is slightly above the plate 18*a*, and the ring 24*m* is slightly below the lower end of the flange 18*b*. The mounting structure described with reference to Fig. 7 is substantially simpler than that disclosed in Fig. 1, and is generally satisfactory in service.

Fig. 9 discloses an alternative construction of motion-transforming member in which the thickness of the peripheral wall 50 is slightly tapered in thickness longitudinally, so that it is thinner at its upper end than at its lower end. It is found that this construction tends to reduce the magnitude of the undesired lateral vibrations and may be employed in place of the grooved construction shown in Figs. 5 and 7. However, it is somewhat more expensive to manufacture.

Still another alternative construction is disclosed in Fig. 10, in which the wall 51 is not only tapered as to thickness, but as to diameter, expanding from a small diameter at the lower end to a greater diameter at the upper end. This construction has the desirable characteristics of providing a larger head 52 relative to the size of the electromechanically-responsive body 53 that drives it. Such conical structures have been tried before, but have been found to be very critical as to their dimensions in order to prevent excessive lateral vibration. It has been found in accordance with the present invention that these vibrations can be greatly reduced by providing an integral peripheral rib 51*a* on the wall 51. This stiffening rib is located at the longitudinal point where the greatest lateral vibrations would occur if it were not present. In effect, it constitutes a thickening of the wall and may be placed either on the outside, as shown, or on the inside. It is usually easier in manufacture to produce it on the outside.

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

We claim:

1. A transducer for high-frequency compressional waves in fluids comprising: a longitudinally expansible

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 at least as large as said end face; a hollow motion-transforming member interposed between and interconnecting said body and daiphragm and comprising a solid base joined to said front face and a continuous peripheral wall joined to and extending between the peripheral portion of said solid base and the peripheral portion of said diaphragm and defining a closed cavity containing a gas of small acoustic impedance relative to that of a liquid contacting said working face of the diaphragm, said continuous peripheral wall being curved in peripheral direction and straight in longitudinal direction and being of uniform thickness in one of said directions and varying in thickness in the other of said directions; said motion-transforming member constituting the sole support for said diaphragm and the diaphragm being substantially rigid whereby it vibrates in a single mode with the adjacent end of said member, and the cross-sectional area of said cavity being large relative to that of the said peripheral wall whereby the major area of the diaphragm is juxtaposed to said cavity.

2. Apparatus according to claim 1 in which said peripheral wall varies abruptly in thickness in the other of said directions.

3. A transducer for high-frequency compressional waves in fluids comprising: a longitudinally expansible 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 hollow motion-transforming member interposed between and interconnecting said body and diaphragm and comprising a solid base joined to said front face and a continuous peripheral wall joined to and extending between said solid base and said diaphragm and defining a closed cavity containing a gas of small acoustic impedance relative to that of a liquid contacting said working face of the diaphragm; said continuous peripheral wall being curved in peripheral direction and straight in longitudinal direction and comprising a plurality of longitudinal sections integral with each other, each section being of uniform thickness longitudinally, but one set of alternate sections being of greater thickness than the intervening sections, whereby the fundamental resonant frequency of lateral vibration of said wall is modified relative to the fundamental resonant frequency of longitudinal vibration of said transducer.

4. Apparatus according to claim 3 in which said intervening sections are substantially narrower than said one set of sections.

5. A transducer for high-frequency compressional waves in fluids comprising: a longitudinally expansible 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 hollow motion-transforming member interposed between and interconnecting said body and diaphragm and comprising a solid base joined to said front face and a continuous peripheral wall joined to and extending between said solid base and said diaphragm and defining a closed cavity containing a gas of small acoustic impedance relative to that of a liquid contacting said working face of the diaphragm; said continuous peripheral wall being substantially cylindrical in shape and of uniform thickness in one of said directions and varying thickness in the other of said directions.

6. Apparatus according to claim 3 in which the faces of all said sections are flush with each other in one surface of said peripheral wall, and the opposite faces of said intervening sections are depressed below the opposite faces of said one set of sections.

7. Apparatus according to claim 1 in which said peripheral wall is of uniform thickness in said peripheral direction and tapers in said longitudinal direction from a maximum thickness adjacent said body to a minimum thickness adjacent said diaphragm.

8. Apparatus according to claim 7 in which one surface of said peripheral wall is substantially cylindrical and the other is frustoconical.

9. A transducer for high-frequency compressional waves in fluids comprising: a longitudinally expansible 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 hollow motion-transforming member interposed between and interconnecting said body and diaphragm and comprising a solid base joined to said front face and a continuous peripheral wall joined to and extending between said solid base and said diaphragm and defining a closed cavity containing a gas of small acoustic impedance relative to that of the liquid contacting said working face of the diaphragm; said continuous peripheral wall being of uniform thickness in said peripheral direction and tapering in longitudinal direction from a maximum thickness adjacent said body to a minimum thickness adjacent said diaphragm and having a peripheral rib intermediate its ends.

10. Apparatus according to claim 9 in which said peripheral wall expands from a minimum diameter adjacent said body to a maximum diameter adjacent said diaphragm.

11. Apparatus of the type described comprising: a wall constituting a liquid barrier and having an orifice portion defining a cylindrical passage extending therethrough; an integral vibrator comprising a vibration-translating member extending through said passage with a front end beyond the liquid side of said wall, and a rear electromechanical driver positioned beyond the other side of said wall; said vibration-translating member including a portion fitting pistonwise in fluid-sealing relation in said cylindrical passage and means for limiting axial movement in each direction of said portion of said member in said passage.

12. Apparatus according to claim 11 in which said last-mentioned means comprises a shoulder on said member at the liquid end of said passage and a detachable stop element on said member at the other end of said passage.

13. Apparatus according to claim 12 in which said stop element is a snap ring in a groove in said member.

14. Apparatus according to claim 11 in which said portion of said translating member comprises a mounting ring having an outer peripheral surface in said fluid-sealing relation with said cylindrical passage and an inner peripheral surface juxtaposed to said translating member, and a rubber ring interposed between and bonded to said juxtaposed surfaces of said translating member and mounting ring for yieldably supporting said translating member for longitudinal vibration with respect to said mounting ring.

15. Apparatus according to claim 14 in which said driver comprises a magnetostriction element; a winding assembly surrounding said magnetostriction element out of contact therewith; and means detachably supporting said winding assembly from said mounting ring; whereby said vibrator mounting ring and winding assembly are removable as a unit from said wall.

16. Apparatus according to claim 11 in which said wall is of sheet metal having an aperture therein and said orifice portion consists of an annular sheet metal ring surrounding said aperture and integral with said wall and extending from said other side of said wall.

17. A transducer having a laminated magnetostrictive core and spring clamping means pressing said laminations together to prevent relative lateral motion therebetween.

18. Apparatus according to claim 17 in which said spring clamping means comprises a U-shaped clip having a base portion adapted to extend across the edge portions of said laminations and leg portions bearing against the outer faces of the outermost laminations.

19. Apparatus according to claim 18 including an energizing coil structure surrounding said laminations and said spring clamp, means for supporting said coil structure independently of said magnetostriction element, and a lug extending from one end of said clip into engagement with a portion of said coil structure for supporting said clip against longitudinal displacement.

20. Apparatus according to claim 18 in which said U-shaped clip elements have perforations therein permitting circulation of cooling fluid to said laminations.

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