July 19, 1966 L. W. CAMP 3,262,094

DISCONTINUOUS HOLLOW CYLINDRICAL TRANSDUCER

Filed June 28, 1962

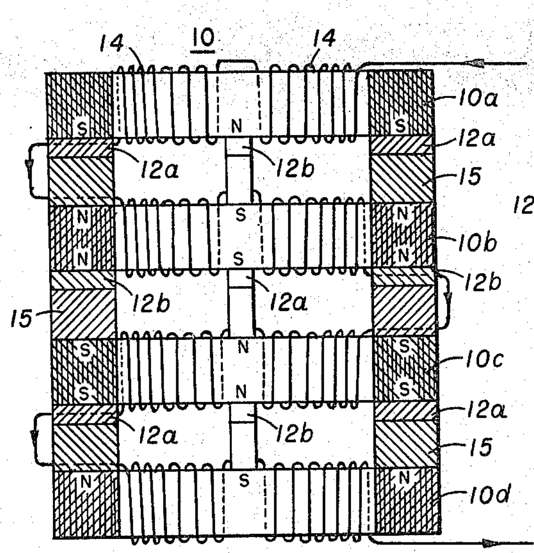


FIG. 1

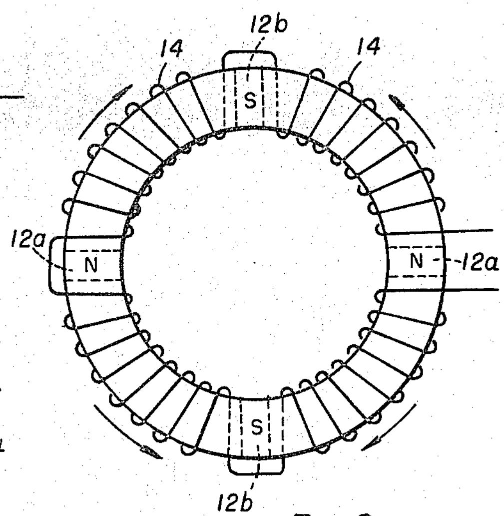
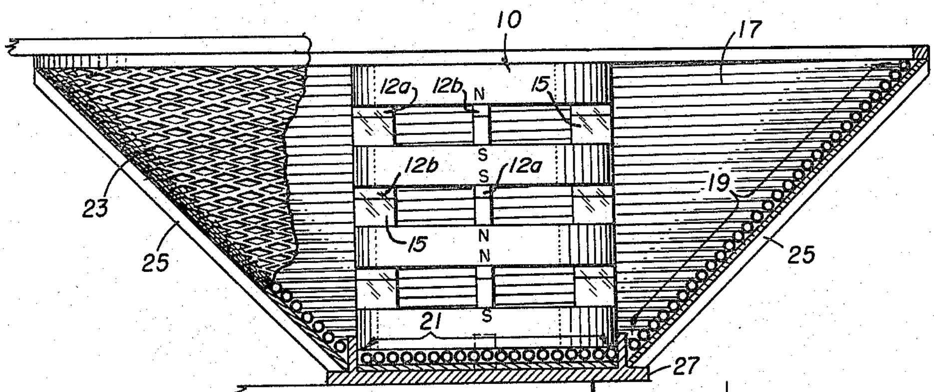


FIG. 2

FIG. 3



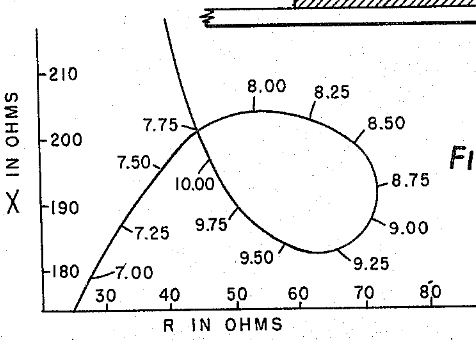


FIG. 4

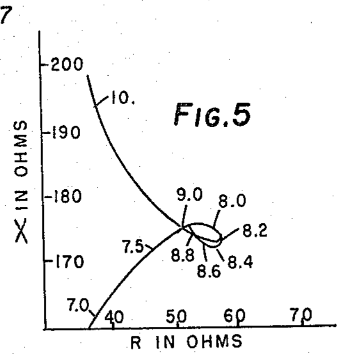


FIG. 5

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DISCONTINUOUS HOLLOW CYLINDRICAL TRANSDUCER

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4 Claims. (Cl. 340—11)

This invention relates to underwater transducers of the hollow cylindrical type vibrating in the radial mode.

An object of the invention is to improve the performance of transducers of this type as to band width and the ratio of the band width to the amount of active material.

Another object is to provide a highly efficient polarized magnetostriction transducer of this type in which permanent magnets supply the polarizing field.

Another object is to provide a particularly simple, practicable, and reliable reflecting structure for underwater transducers.

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

Longitudinally continuous (sometimes herein referred to as closed) radially vibratile hollow cylindrical transducers are known. It is also known that in order to perform well, such transducers must not be too short, or the inside must be acoustically shielded from the outside to reduce interaction between the out-of-phase radiations from the inside and outside surfaces, respectively.

I have discovered that although, without auxiliary shielding, a certain overall length must be maintained for good performance, the amount of electromechanically-sensitive material required can be substantially reduced by employing a plurality of short, axially-spaced cylinder elements instead of a continuous cylinder. It has been determined that the spacing between elements for optimum performance is one-half wavelength of sound in the liquid medium. With a given amount of material, a plurality of spaced cylinder elements has the following advantages over a single, or closed, cylinder:

(a) It has a greater band width.

(b) It has a greater efficiency in converting electrical power into sound, and vice versa.

(c) It enables a desired high radiation impedance with a smaller quantity of material, which with a power source of given magnitude results in a higher power intensity in the material, which is sometimes desirable. Thus, a high power level is required to efficiently drive an unpolarized magnetostriction transducer.

The following detailed description refers to the drawing, in which:

FIG. 1 is a longitudinal sectional view of a transducer incorporating the invention.

FIG. 2 is an end view of the transducer shown in FIG. 1.

FIG. 3 is a side view, partly in section, showing a reflecting structure that may be used with a transducer of the type shown in FIG. 1.

FIGS. 4 and 5 are graphs showing impedance characteristics of transducers in accordance with the prior art and the present invention, respectively.

FIG. 1 shows a transducer **10** comprising four axially-spaced annular transducer elements or rings **10***a*, **10***b*, **10***c* and **10***d*, all driven to expand and contract circumferentially with resultant radial vibration. The elements may be of any known type insofar as the acoustic advantages of axially-spaced rings are concerned. Thus they may be of the ceramic element type, as disclosed in my Patent No. 2,733,423, or of the magnetostrictive type. Magnetostrictive transducers are usually laminated, either by stacking annular laminations or winding a long strip into a tight scroll. At the moment, we are concerned

with the advantages of axially spacing radially vibratile rings or cylinders, regardless of their material.

In order to radiate sound energy into a fluid medium, a vibrating source must experience a reaction from the medium, known as radiation impedance. Absolute values of radiation impedance for short cylinders are difficult to determine, but relative values are readily obtained from impedance curves such as shown in FIGS. 4 and 5. Both curves were derived from transducers consisting of magnetostrictive rings 6″ in diameter and of rectangular cross-section, measuring .3″ radially and ½″ axially. These rings were stacked in groups of three, each group being enclosed by a winding and a Neoprene housing. Such a group would not show optimum performance as a sound source, because the out-of-phase sonic pressures developed inside and outside would largely neutralize each other in the ambient medium. However, a close assembly of four such groups defines a longer closed wall between inside and outside and becomes an efficient source. The impedance curve of such a four-group assembly having an overall length of 7″ is shown in FIG. 4.

An unexpected performance, shown by the curve of FIG. 5, is obtained from an assembly of four groups by spacing the groups apart axially one-half wavelength (3.6″ for the transducer dimensions cited) of sound in the ambient medium at the resonant frequency. FIG. 5 indicates a higher radiation impedance than FIG. 4 because the impedance varies less with change of frequency near the resonant frequency. Thus in FIG. 4, over a range of frequency of 1 kc. from 7.75 to 8.75 kc., the resistance varies from about 45 ohms to 72 ohms, or a range of 27 ohms, and the reactance varies between 204 ohms and 190 ohms, or a range of 14 ohms. In contrast, in FIG. 5 over the same 1-kc. range from 7.5 to 8.5 the resistance varies between about 45 ohms and 57 ohms, or a range of 12 ohms, and the reactance varies between about 175 ohms and 172 ohms, or a range of 3 ohms. Contrariwise, within resistance and reactance ranges of 4 ohms the open construction of FIG. 5 permits a frequency range of about 1½ kc. as against less than ¼ kc. for the closed construction.

The use of spaced rings or cylinders adds another degree of freedom in the design of a transducer. Some illustrations of the advantages are as follows:

(1) For the example shown, without changing the material used, an increase in band width for the sound source was achieved; also its output as a sound source per watt of input power was increased.

(2) One could design for the same band width, as with the closed construction, using approximately half the active material.

(3) One can control the radiation impedance by spacing while selecting the appropriate quantity of active material to make possible the solution of a problem in driving unpolarized magnetostrictive cylinders. For this condition, the active material may be efficiently driven only at a high power level. Therefore the power-handling capability of the active material must be matched to the electric power available.

Where spaced magnetrostrictive rings are usable, as in the present invention, a highly desirable polarizing structure utilizing permanent magnets becomes possible. This structure, as shown in FIG. 1, comprises a set of uniformly circumferentially spaced permanent magnets **12***a* and **12***b* between each adjacent pair of rings **10***a* and **10***b*, **10***b* and **10***c*, **10***c* and **10***d*, respectively. Each set of magnets includes equal numbers of magnets **12***a* and **12***b*, respectively, alternately spaced. The only difference between magnets **12***a* and **12***b* is that they are oppositely poled. In FIG. 1 all magnets **12***a* have their south poles uppermost, and all magnets **12***b* have their north poles uppermost. This produces a circumferential flux in each quadrant of each ring, the direction of which flux is opposite to that in adjacent rings. Thus the relative directions of the fluxes in different quadrants of the top ring in FIG. 1 are shown by the arrows in FIG. 2. In corresponding quadrants of each pair of adjacent rings, the directions of the fluxes are opposite. Because of this reversal of the direction of the polarizing flux from quadrant to quadrant, the direction of the windings **14** on each ring must also reverse from quadrant to quadrant, as shown in FIGS. 1 and 2, in order for the effects of the current in different quadrants to be in additive instead of subtractive relation to each other.

FIG. 1 shows a body **15** inserted in series with each magnet **12***a* or **12***b*. These bodies are of high permeability material to keep the reluctance of the magnetic circuits low. In some instances the bodies **15** may be eliminated, and the permanent magnets **12** dimensioned to fill the gaps between adjacent rings **10**. However, many otherwise desirable permanent magnet materials have a very low permeability, and it is desirable to keep the permanent magnets as short as possible and fill the gap with a highly permeable material, such as powdered or laminated soft iron or one of the many alloys having even higher permeability.

It is sometimes desirable to increase the directivity of an underwater transducer by a suitable sound reflector. Such a reflector must have radically different sound-transmission characteristics from the ambient liquid in order to reflect. It may be massive and relatively immovable, or of the pressure-relief type such as a gas. For this purpose it is old to employ free gas and also old to employ gas entrapped in a yieldable solid material such as sponge rubber.

I have found that a novel and efficient sound-reflecting wall can be formed from gas-filled tubing of rubber or the like. Such a structure is shown in FIG. 3 in combination with a transducer of the type shown in FIG. 1. In FIG. 3 the reflector is formed of contiguous coils of gas-filled rubber tubing **17** and comprises a frustoconical portion **19** surrounding the transducer for upwardly reflecting sound emanating radially from the exterior surface of the transducer, and a flat portion **21** closing the small end of the frustoconical portion and the lower end of the transducer and functioning to upwardly reflect the sound emanating from the interior surface of the transducer. The gas in the tubing **17** is pressurized sufficiently to prevent its collapse at the operating depth.

The tubing **17** may be supported in various ways. A practical way is to glue or cement it to a semirigid wall **23** which, as shown, is formed of expanded metal which in turn is welded or otherwise attached to a spider frame consisting of rods **25** emanating from a central face **27**.

Although for the purpose of explaining the invention a particular embodiment thereof has been shown and described, 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 immersion in a liquid medium for translating sound waves in said medium into electrical waves in an electric circuit, and vice versa, comprising:

a plurality of axially aligned, spaced-apart, electromechanically responsive, radially vibratile rings and means electrically coupling said rings to said circuit for vibration in phase with each other, said rings being of magnetostrictive material;

polarizing means for producing a polarizing flux in said rings comprising an even number of circumferentially spaced connecting elements extending longitudinally between each pair of adjacent rings;

each element comprising a permanent magnet, and next adjacent elements being oppositely poled with respect to each other;

a set of windings individual to each ring, the respective windings on each ring being circumferentially located between said connecting elements whereby each winding is associated with a ring section in which the polarizing flux is of a single polarity;

and means connecting all of said windings in said circuit in such polarity that the flux generated by every winding in the ring section it encompasses has the same polarity relative to the polarizing flux in that section.

2. Apparatus according to claim **1** in which each of said connecting elements comprises, in addition to said permanent magnet, a ferromagnetic body of high permeability in series therewith;

said permanent magnet and ferromagnetic body having substantially the same lateral dimensions and being aligned with each other.

3. Apparatus according to claim **2** in which said rings, magnet, and ferromagnetic body have the same radial dimensions and are aligned.

4. Apparatus according to claim **2** in which the longitudinal thickness of said ferromagnetic body exceeds that of said permanent magnet.

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