April 22, 1947. H. BENIOFF 2,419,196

ELECTROACOUSTIC TRANSDUCER

Filed May 3, 1940 6 Sheets-Sheet 1

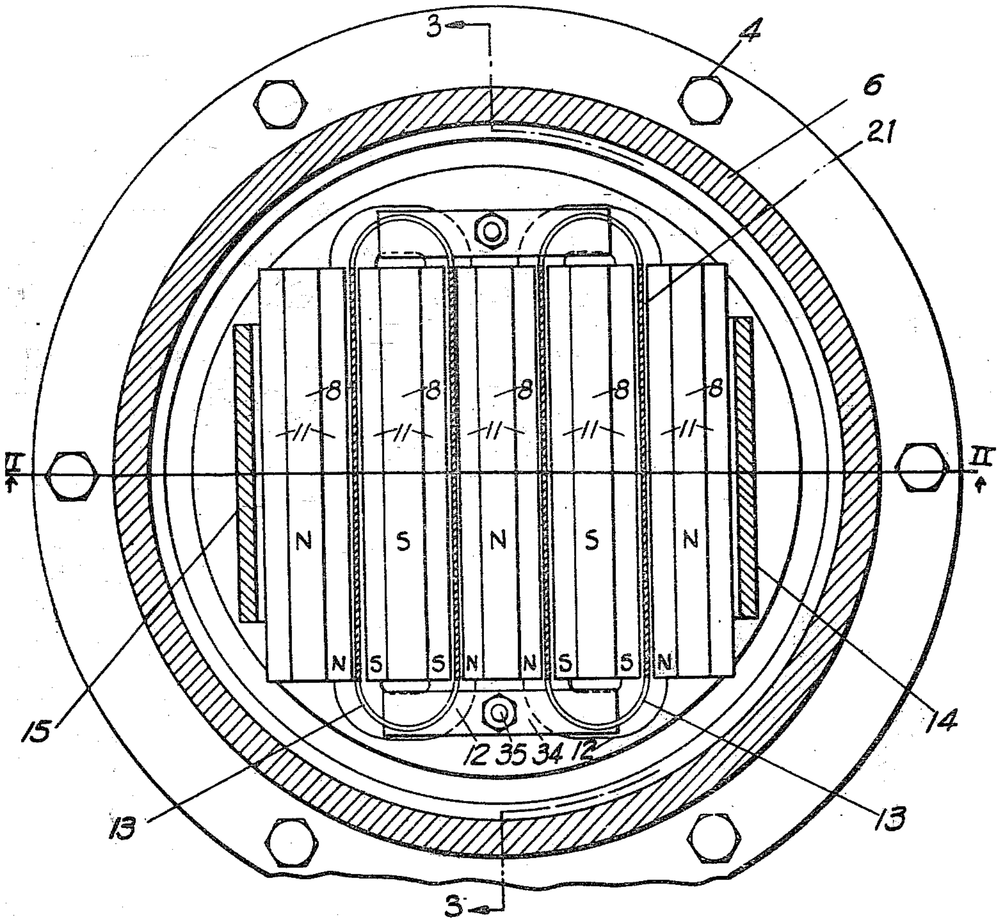

FIG. 1

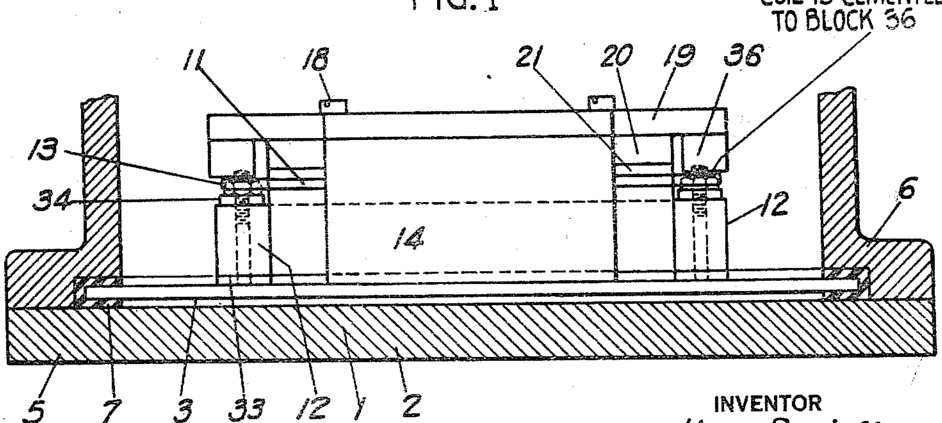

FIG. 3

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ELECTROACOUSTIC TRANSDUCER

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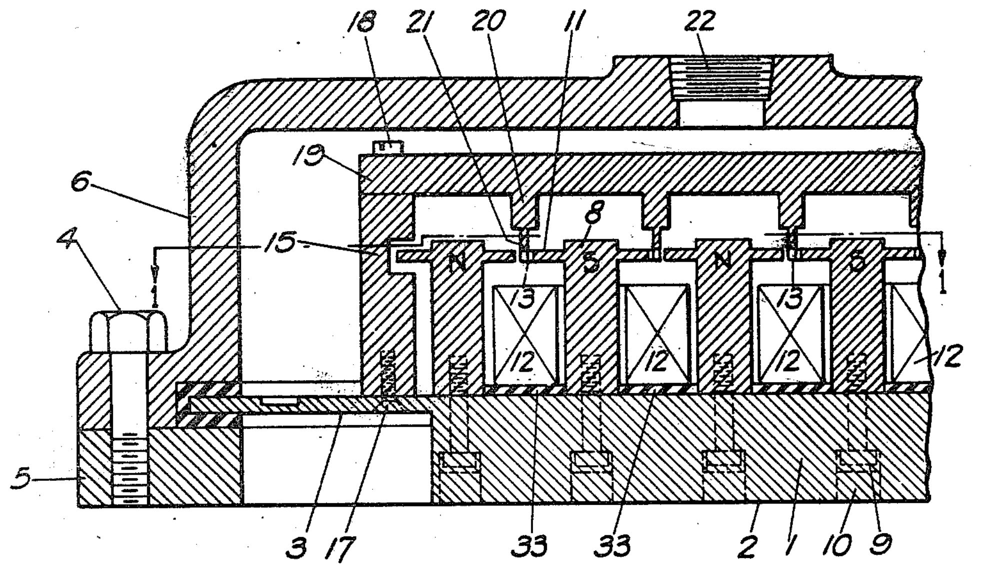

FIG. 2

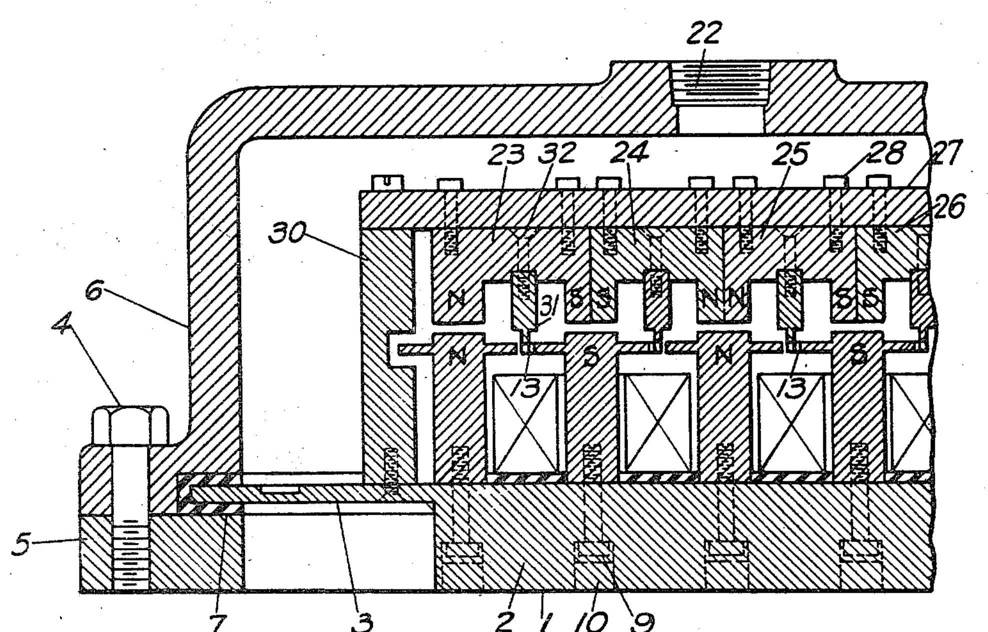

FIG. 4

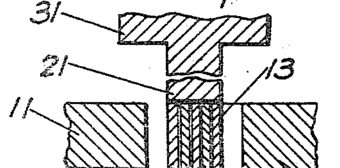

FIG. 2a

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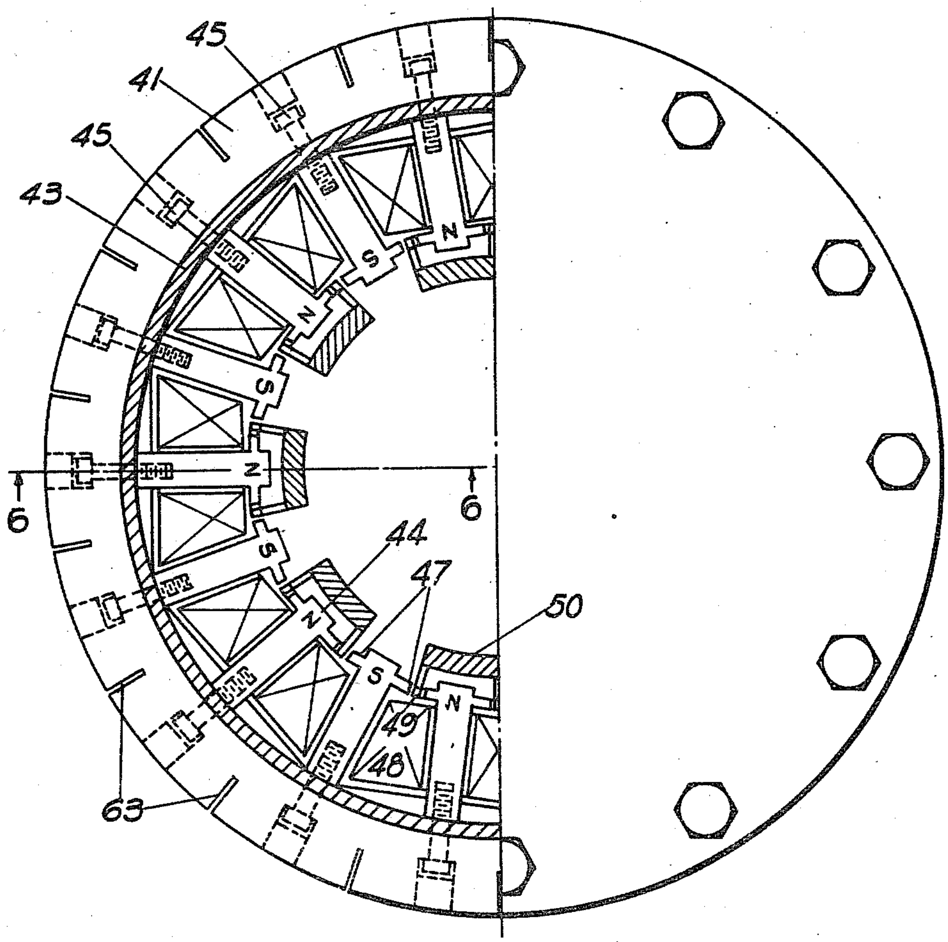

FIG. 5

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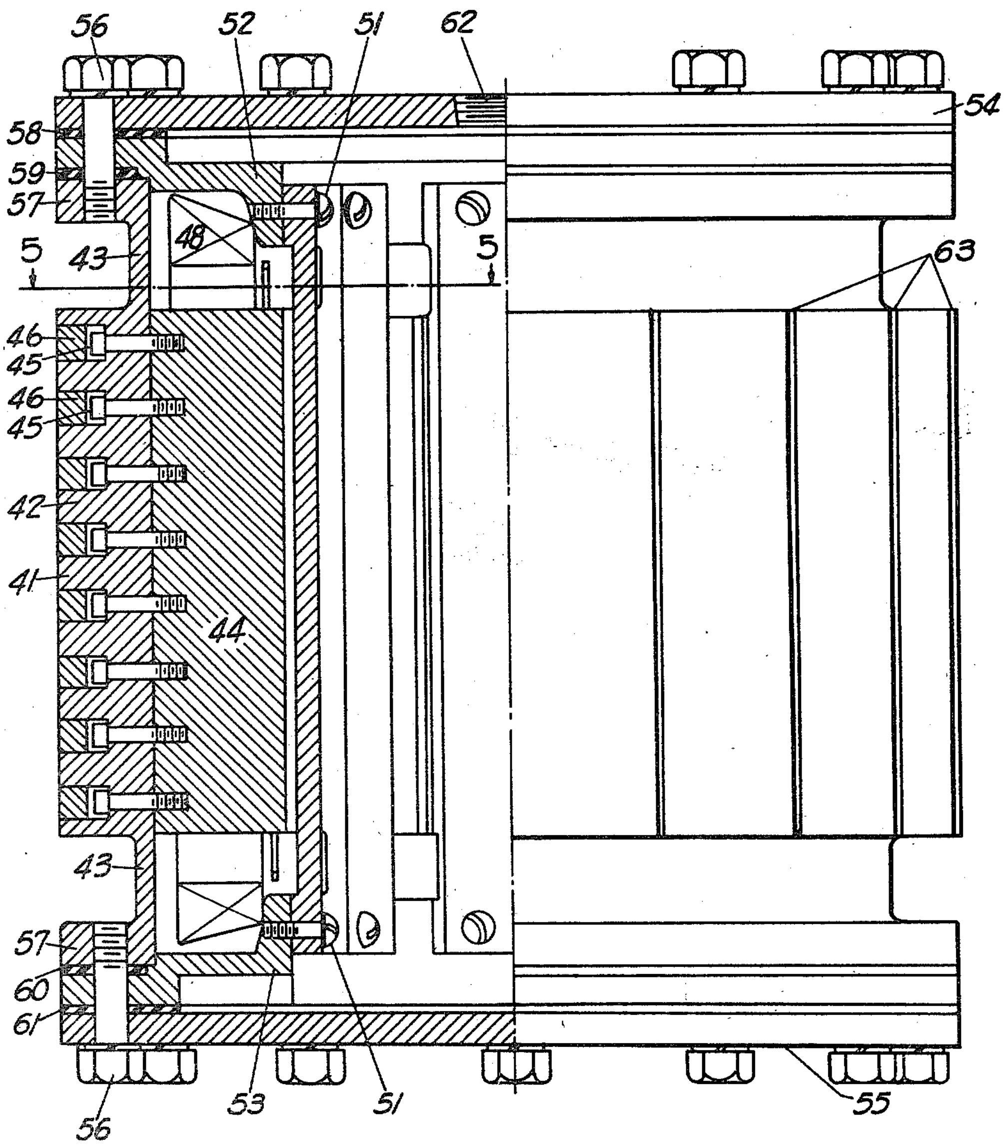

FIG. 6

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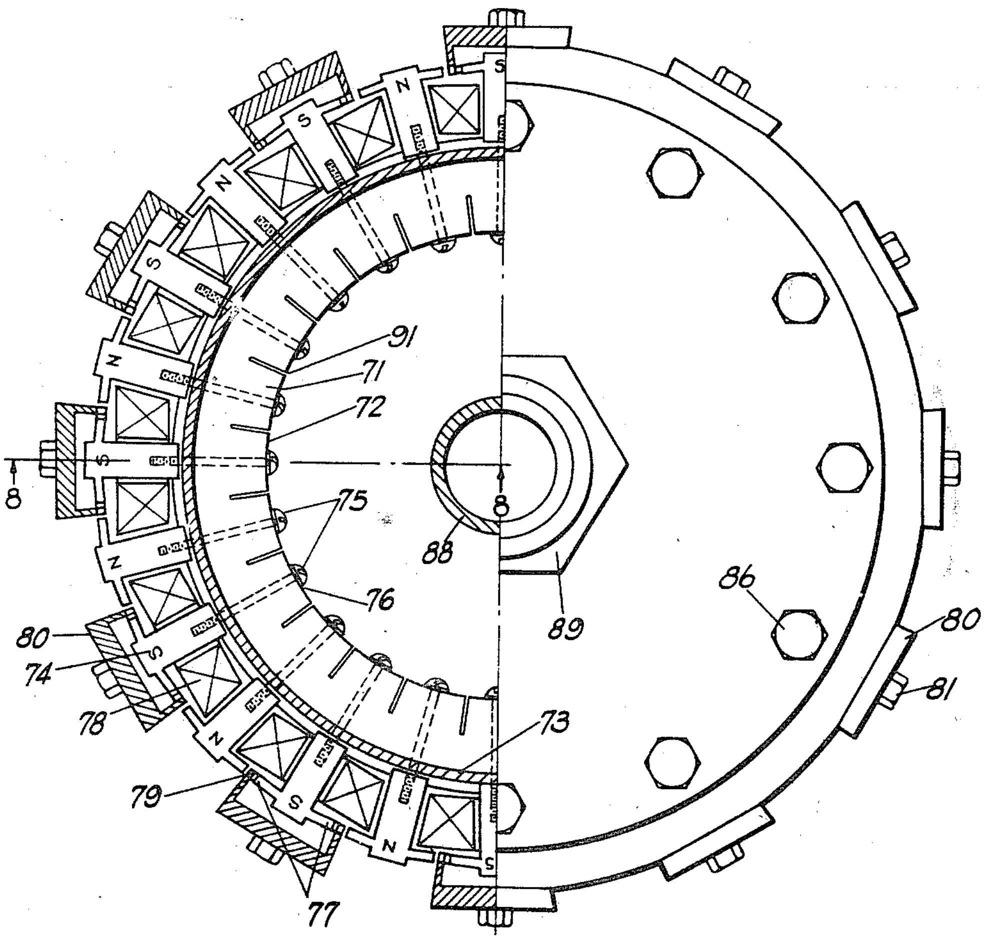

FIG. 7

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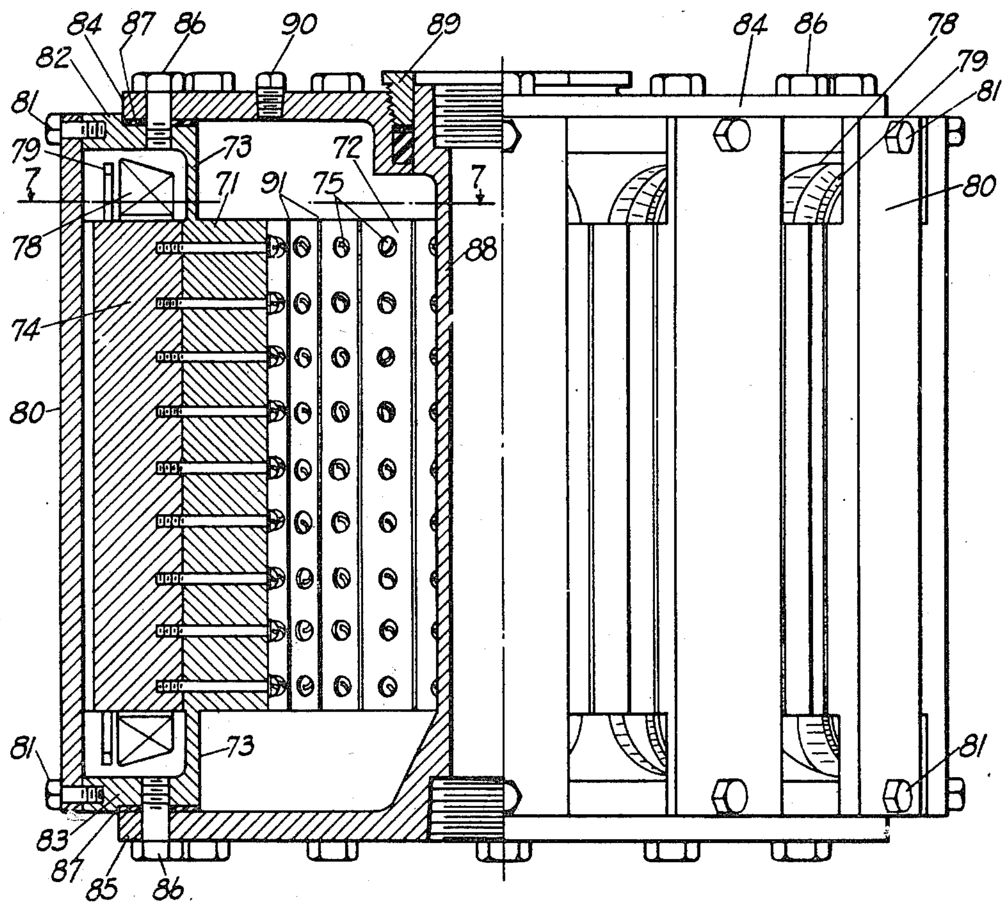

FIG. 8

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UNITED STATES PATENT OFFICE

2,419,196

ELECTROACOUSTIC TRANSDUCER

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Application May 3, 1940, Serial No. 333,157

17 Claims. (Cl. 177—386)

The present invention relates to electroacoustic transducers. More particularly the present invention relates to a device for sending and receiving compressional waves in a liquid medium and especially for waves of supersonic frequency. Still more particularly the present invention relates to a device of the type described which is operated electromagnetically.

The various features and objects of the invention as well as the construction of the same will best be understood from the following description taken in connection with the accompanying drawings in which Fig. 1 is a plan view of one modification of my invention with the cover in section, as indicated by the line I—I of Fig. 2; Fig. 2 is a transverse section taken along the line II—II in Fig. 1; Fig. 2a is an enlargement of a detail shown in Fig. 2; Fig. 3 is an end elevation of the device shown in Fig. 1 with the housing elements in section; Fig. 4 is a transverse midsection of a modification of the device shown in Figs. 1 to 3; Fig. 5 is a further modification of my invention, the left half being a section taken along the line V—V in Fig. 6 and the right half being a plan view; Fig. 6 presents the same modification as that shown in Fig. 5, the left half being a transverse midsection along the line VI—VI in Fig. 5 and the right half being an elevation; Fig. 7 shows a further modification of my invention, the left half being a section along the line VII—VII in Fig. 8 and the right half being a plan view; and Fig. 8 is another illustration of the modification shown in Fig. 7, the left half being a transverse midsection along the line VIII—VIII in Fig. 7 and the right half being an elevation.

As shown in Figs. 1 to 3 a diaphragm element 1 having a radiating surface 2 is provided with a thin annular flange 3 whereby it can be clamped by the bolts 4 between a ring member 5 and a cup-shaped flanged cover member 6, a suitable watertight gasket 7 being interposed so that a watertight enclosure is formed.

Upon the back face of the diaphragm 1 and within the enclosure formed by the diaphragm and the cover member 6 there are mounted a plurality of parallel elongated vibrators 8 of magnetic material which are held to the member 1 by means of screws 9 which preferably are sunk into the face of the member 1, the resulting holes being filled by the plugs 10 to make a completely watertight joint and to provide the smooth radiating surface 2. At the upper ends of the vibrators 8 there is formed on each side a tongue or rib 11 extending for the whole length

of the member 8. These ribs 11 as seen in Fig. 2 are adapted to vibrate vertically by flexing. Their vibration is, therefore, that of a vibrating reed and they are hereinafter described as reeds.

The members 8 may be permanently magnetized but preferably are magnetized by the direct current energized polarizing coils 12 which are wound around every alternate vibrating element 8. These coils are placed in the space between the members 8 beneath the reeds 11 where they are held down upon insulating rubber strips 33 between them and member 1 by end clamping strips 34 fastened to the flange 3 by bolts 35.

The small spaces between adjacent reeds 11, therefore, become magnetic airgaps in which a very high flux density can be obtained. Positioned within the airgaps are the alternating current coils 13. These are preferably made up of insulated thin ribbon conductors wound edgewise. The coils 13 may be mounted in the airgaps in any suitable manner avoiding elasticity in the mounting so far as possible. As shown, a pair of end plates 14 and 15 are mounted by screws 17 and 17 on the flange 3. To the members 14 and 15 there is secured by the screws 18 a plate 19 having a plurality of parallel ribs 20 of non-magnetic material formed on the underside thereof. The ribs 20 are diminished in cross section at 21 to a thickness equal to the width of the conductors in coils 13 and the coil windings are cemented thereto. The end loops of the coils 13 may be further supported by being cemented to blocks 36 (Fig. 3) secured in any suitable manner to the plate 19. The width of the airgap between the reeds 11 and the width of the coils 13 are so adjusted that the windings substantially fill the entire space without, however, at any point touching the reeds. Electrical conductors (not shown) for making connections to the coils 12 and the coils 13 may be taken out of the casing through the liquid-tight stuffing tube 22.

The operation of the device is as follows: The polarizing coils 12 which may be connected in either series or parallel as desired, are supplied with direct current, thereby magnetizing the elements 8. The several coils 12 are wound in the same direction so that alternate north and south magnetic poles are formed as indicated, for example, by the letters N and S marked upon the reeds in Fig. 1 and upon the members 8 in Fig. 2. The coils 13 which may also be connected either in series or in parallel as desired are excited with an alternating current. Since the conductors of coils 13 are directly within the strong magnetic field existing between the reeds 11, there will be a reaction between these two elements tending to move the coils 13 up and down in the airgap and also tending to move the extremities of the reeds 11 up and down. The reeds 11 are highly resonant and have a definite natural frequency of vibration so that when the alternating current exciting the coils 13 coincides with the natural frequency of the reeds, the reeds will build up to a relatively large amplitude of vibration, but the coils 13 will remain practically stationary. Moreover, the height of the members 8 above the diaphragm member 1 is adjusted so that each of the members 8 together with that portion of the member 1 which is affected by it, forms a one-half wave length vibrational system at the natural frequency of vibration of the reeds 11 which is preferably made to correspond to the signaling frequency. The flexural vibration of the reeds sets up stresses in the members 8 in the vertical direction as seen in Fig. 2, these stresses being of alternate compression and elongation, whereby a vibration of the radiating surface 2 is obtained.

It will be evident that a vibrational node will exist between the radiating surface 2 and the internal ends of the members 8. The supporting flange 3 is preferably placed as nearly as possible in the plane of the vibrational node. The ratio of the mass above the vibrational node to the mass below the vibrational node is adjusted to produce the desired amplitude of vibration at the radiating surface 2. The radiating plate 1 is for this purpose made of a considerable thickness but not greater than one-fourth of the wave length of compressional waves in the material of which it is made at the signaling frequency.

Viewed as a whole, the arrangement may be regarded as a system of three masses coupled to each other by elastic members. The mass of each reed 11 through the elasticity of the reed is coupled to the mass of its member 8, which in turn through its elasticity is coupled to the diaphragm mass 1. Since the mass of the reeds is relatively small, the coupling between the reeds and the half wavelength systems comprising members 8 and diaphragm 1 is very loose. Therefore, the reeds can build up to a relatively large vibrational amplitude. Moreover, the entire system will be sharply tuned with only one very prominent resonant frequency which is determined chiefly by the resonant frequency of the half wavelength systems comprising members 8 and diaphragm 1. The resonance of the member 8 with its radiating plate establishes the dominant resonance of the system since the mass and total elasticity of this element are much greater than that of the reed attached to it.

It will be understood, of course, that when the device is used for receiving, the operation will be reversed. Compressional waves in the medium will vibrate the plate 1 and the members 8 which, in turn, will produce flexural vibrations of the reeds 11. The consequent disturbance of the magnetic field generates an electromotive force in the coils 13.

In the modification shown in Fig. 4, which presents a sectional view like that of Fig. 2, the general arrangement of the various elements as well as their operation are substantially the same but increased efficiency of operation is obtained. This results from an increase in the flux density in the air gaps between adjacent reeds. In the construction shown in Fig. 2 most of the magnetic flux passes across the airgap between the reeds, but nevertheless a considerable amount passes through the space between one of the members 8 to the adjacent member and consequently it does not assist in the production of motion.

In the modification of Fig. 4 such leakage flux is almost entirely suppressed by placing bipolar U-shaped permanent magnets 23 to 26 with their poles supported close to the ends of the members 8 and of same polarity to the latter. A greater portion of the magnetic flux produced by the currents through the coils 12 is therefore forced to pass through the air gaps between the adjacent reeds. The permanent magnets 23 to 26 may be supported from a plate 27 by means of screws 28. The plate 27 is mounted upon end plates 20 and 30 which may be similar to the plates 14 and 15 in Fig. 2 and are likewise fastened to the flange 3 of the diaphragm element 1. The alternating current coils 13 may in this case be conveniently mounted upon elongated members 31 fastened to the several magnets by means of the screws 32. In place of using the permanent magnets 23 to 26 electromagnets could, of course, be employed, but this is undesirable where the operating elements must be placed within a watertight housing since this sets up definite limitations as to the amount of heat which can be conducted away from the structure. If the heat conditions permit the use of greater power within the unit, this should be supplied to the polarizing coils 12, and permanent magnets used for the suppression of leakage flux, for thereby a still greater flux density can be obtained.

Both of the modifications just described provide an electroacoustic transducer and have a substantially plane piston radiating surface. As is well known in the art, if the dimensions of the radiating surface are made large compared to the wave length of compressional waves in the signaling medium, the device will have a beam pattern in which the greater portion of the transmitted energy and the sensitivity pattern for reception will have their greatest magnitudes in the direction perpendicular to the radiating surface. In some cases it may be desirable to be able to radiate large amounts of energy in all directions, especially in all directions in a plane. For this purpose a radiating surface which is cylindrical and which vibrates radially is desirable.

Figs. 5 and 6 show a modification of my invention which provides such a radiating surface. In these figures the radiating element 41 having a cylindrical radiating surface 42 and provided at its ends with a nodal flange 43 has mounted on its inner face a plurality of elongated vibrating elements 44, all mounted with their long dimensions parallel to the axis of the cylinder and projecting radially from the internal surface of the member 41. The elements 44 are secured to the element 41 by means of screws 45 which are sunk into the outer face of the element 41, the resulting holes being made watertight by the plugs 46. The members 44 are similar to the members 8 in the modifications previously described and have formed along their sides near their inner ends the vibratory reeds 47. The elements 44 and the reeds 47 are magnetized by direct current polarizing coils 48 forming magnetic poles as indicated by the letters N and S. The alternating current coils 49 are cemented to the arms or U-shaped non-magnetic metal channels 50 whereby they are supported within the air gaps between adjacent reeds. The elements 50 are held in position by being screwed by the screws 51 to upper and lower ring members 52 and 53. The rings 52 and 53 also serve to hold the polarizing coils 48 in place as can be seen from Fig. 6. The two ends of the cylindrical structure are closed by cover plates 54 and 55 which are held in place by the bolts 56 which also serve to hold the rings 52 and 53 in place against the end flanges 57 which may be formed at the extremities of the flanged portions 43 of the member 41. In assembling the unit the coils 48 are positioned within the cylinder 41, then the members 44 are inserted and fastened by the screws 45. The rings 52 and 53 are then put into place and the members 50 carrying the alternating current coils 49 are placed in position where they are held by the screws 51. Finally the cover members 54 and 55 are put in place.

The interior of the structure is made watertight by means of the gaskets 58, 59, 60 and 61. Leads from the polarizing coils 48 and from the alternating current coils 49 are brought out from the interior of the structure through the watertight stuffing tube 62. The entire unit may, therefore, be immersed in the signaling medium.

The operation of the device is substantially the same as that of the preceding modifications. The strong magnetic field existing between adjacent reeds and in which the alternating current coils 49 are positioned brings about a reaction with the alternating field of these coils so that the reeds 47 are set into flexural vibration which is transmitted and converted into vibration of the members 44 and 41 in a radial direction so that compressional waves are transmitted from the entire external surface of the cylinder in all directions. If the height of the cylinder 41 be made large compared with the wave length of compressional waves in the signaling medium at the signaling frequency, the radiation will be concentrated in a plane perpendicular to the axis of the unit. If desired, the external surface of the cylinder 41 may be slotted between adjacent members 44 as indicated at 63. This will give the material between the slotted sections an opportunity to cooperate with the longitudinal bar for individual motion of each section, and it tends also to permit a larger free amplitude of the radiating surface.

The further modification of my invention which is shown in Figs. 7 and 8 is the reverse of that shown in Figs. 5 and 6 in that the radiation of compressional wave energy is directed toward the central axis of the unit where it may be applied to the treatment of liquids or other substances. Here the internal cylinder 71 having a radiating surface 72 has mounted on its external surface a plurality of vibrators 74 by means of screws 75 which may be made watertight by the lead washers 76. The elements 74 as in the other modifications are provided with reeds 77 which are magnetized with the aid of the direct current polarizing coils 78. In the air gaps between adjacent reeds there are mounted alternating current coils 79 supported on U-shaped non-magnetic metal channels 80 which are fastened by the bolts 81 to reverse flanges 82 and 83 extending from the narrow flanged portions 73 of the member 71. The interior of the unit is closed by the cover plates 84 and 85 which are also bolted to the ring 82 by the bolts 86, gaskets 87 being interposed to make the joint watertight. A centrally located pipe 88 which may be made integral with one of the cover plates, if desired, for example, the cover plate 85, is fitted into an aperture in the other cover plate 84 by means of a watertight gland 89. This pipe may be used to conduct liquids to be treated through the central portion of the oscillator where it will be subjected to intense compressional wave vibration. The space between the pipe 88 and the radiating surface 72 is filled with a compressional wave-conducting liquid, such as water or oil, which may be introduced by removing the plug 90. The operation of this device is similar to that of the modifications previously discussed. In this modification also, however, it may be desirable to slot the radiating surface 72 as shown, for example, at 91.

The reeds in the various arrangements described above may be vibrated by means of piezoelectric crystals instead of electromagnetically. Suitable arrangements of this kind are shown and claimed in my copending application Serial No. 333,158, filed May 3, 1940. As there shown the crystals may, for example, be cemented on one surface of the reeds with a vibrational axis parallel to the reed surface so that vibrations are transferred between reeds and crystals by shearing action.

Having now described my invention, I claim:

1. An electroacoustic transducer comprising a radiating plate, means forming therewith a plurality of longitudinal vibrators, said vibrators being positioned side by side and having flexurally vibratable reeds extending transversely therefrom, the reeds on adjacent vibrators being positioned opposite each other with a small space between them, electromagnetic coil means for magnetizing said vibrators in alternate polarity and thereby establishing a magnetic field across said space between opposite reeds and coil means positioned within said space.

2. An electroacoustic transducer comprising a radiating plate, means forming therewith a plurality of longitudinal vibrators, said vibrators being positioned side by side and having flexurally vibratable reeds extending transversely therefrom, the reeds on adjacent vibrators being positioned opposite each other with a small space between them, electromagnetic coil means for magnetizing said vibrators in alternate polarity and thereby establishing a magnetic field across said space between opposite reeds, means for suppressing magnetic leakage from the poles formed by said vibrators and coil means positioned within said space.

3. An electroacoustic transducer comprising a radiating plate, means forming therewith a plurality of longitudinal vibrators, said vibrators being positioned side by side and having flexurally vibratable reeds extending transversely therefrom, the reeds on adjacent vibrators being positioned opposite each other with a small space between them, electromagnetic coil means for magnetizing said vibrators in alternate polarity and thereby establishing a magnetic field across said space between opposite reeds, means including a plurality of permanent magnets positioned to oppose magnetic leakage from the poles formed by said vibrators and coil means positioned within said space.

4. An electroacoustic transducer comprising a radiating plate having formed thereon a plurality of elements elongated in a dimension parallel to the surface of said plate and longitudinally vibratable in directions perpendicular to said plate, said elements having elongated flexurally vibratable reeds extending transversely therefrom and means for vibrating said reeds.

5. An electroacoustic transducer comprising a radiating plate having formed thereon a plu-

rality of elements longitudinally vibratable in directions perpendicular to said plate, said elements positioned side by side and having flexurally vibratable reeds extending transversely therefrom, the reeds on adjacent elements being positioned opposite each other with a small space between them, means providing a magnetic field across said space from one reed to the opposite reed and coil means positioned within said space.

6. An electroacoustic transducer comprising a cylindrical radiating member, having formed thereon a plurality of elements vibratable in directions substantially perpendicular to the axis of said cylinder, said elements having flexurally vibratable reeds extending transversely therefrom and means for vibrating said reeds.

7. An electroacoustic transducer comprising a cylindrical radiating member, means forming therewith a plurality of vibrators adapted to vibrate in directions substantially perpendicular to the axis of said cylinder at a predetermined natural frequency, said vibrators having flexurally vibratable reeds extending transversely therefrom and having a natural frequency of vibration corresponding to that of said vibrators and means for vibrating said reeds.

8. An electroacoustic transducer comprising a cylindrical radiating member having formed thereon a plurality of elements vibratable in directions substantially perpendicular to the axis of said cylinder, said elements being positioned side by side and having flexurally vibratable reeds extending transversely therefrom, the reeds on adjacent elements being positioned opposite each other with a small space between them, means providing a magnetic field across said space from one reed to the opposite reed and coil means positioned within said space.

9. An electroacoustic transducer comprising a cylindrical radiating member having an external radiating surface and having formed on its internal surface a plurality of elements vibratable in directions substantially perpendicular to the axis of said cylinder, said elements being positioned side by said and having flexurally vibratable reeds extending transversely therefrom, the reeds on adjacent elements being positioned opposite each other with a small space between them, means providing a magnetic field across said space from one reed to the opposite reed and coil means positioned within said space.

10. An electroacoustic transducer comprising a cylindrical radiating member having an internal radiating surface and having formed on its external surface a plurality of elements vibratable in directions substantially perpendicular to the axis of said cylinder, said elements being positioned side by side and having flexurally vibratable reeds extending transversely therefrom, the reeds on adjacent elements being positioned opposite each other with a small space between them, means providing a magnetic field across said space from one reed to the opposite reed and coil means positioned within said space.

11. An electroacoustic device for treating liquids with compressional waves comprising a cylindrical radiating member having an internal radiating surface and having formed on its external surface a plurality of elements vibratable in directions substantially perpendicular to the axis of said cylinder, said elements being positioned side by side and having flexurally vibratable reeds extending transversely therefrom, the reeds on adjacent elements being positioned opposite each other with a small space between

them, means providing a magnetic field across said space from one reed to the opposite reed and coil means positioned within said space, means closing the space within said cylindrical member, and means for conducting liquids to be treated along the axis of said cylinder.

12. An electroacoustic transducer comprising a radiating member, means including said member forming a plurality of half wave length vibrators, each of said vibrators being composed of said radiating member with a longitudinally vibrating element extending therefrom having a free end and a node intermediate of the ends of the means taken longitudinally, means including a plurality of reeds extending normally from said longitudinally vibrating elements at points in the vicinity of their free ends, said reeds being adapted to vibrate flexurally at the frequency corresponding to said half wave length for vibrating said vibrators and means for vibrating said reeds.

13. An electroacoustic transducer comprising a radiating member, means including said member forming a half wave length vibrator, said vibrator being composed of said radiating member with a longitudinally vibrating element extending therefrom having a free end and having a node intermediate of the ends of the means taken longitudinally, means including a reed extending normally from said longitudinally vibrating element at a point in the vicinity of the free end of the reed, said reed being adapted to vibrate flexurally at a frequency corresponding to said half wave length for vibrating said vibrator and means for vibrating said reed.

14. An electroacoustic transducer comprising a plurality of half wave length longitudinally vibratable units, each composed of a radiating element joined with a longitudinally vibrating element forming together combined elements each having a node between the ends of a combined element, said units being arranged side by side, and means for vibrating said elements including vibratory reeds formed integrally with said longitudinally vibrating elements on both sides thereof and extending perpendicularly from said sides, the reeds on adjacent elements being opposite to each other with an air gap between them and said reeds having length and thickness dimensions to give each of them a natural frequency of vibration equal to the frequency of which said elements are a half wave length, means providing a magnetic flux across said air gaps and coil means positioned in said air gaps.

15. An electroacoustic transducer comprising a radiating member, means forming therewith a plurality of half wave length vibrators, each of said vibrators being composed of said radiating member with a longitudinally vibrating element having a node intermediate of the ends of the means taken longitudinally, said longitudinally vibrating elements having flexurally vibratable reeds extending normally from the sides of said longitudinally vibrating elements near their ends and means for vibrating said reeds.

16. An electroacoustic transducer comprising a radiating member, means forming therewith a plurality of longitudinal vibrators, each of said vibrators being composed of said radiating member with a longitudinally vibrating element having a node intermediate of the ends of the means taken longitudinally, each of said vibrators having a natural frequency of vibration, said longitudinally vibrating elements of said vibrators having flexurally vibratable reeds extending normally from the sides of said longitudinal vibrators

near their ends, said reeds having the same natural frequency of vibration as said vibrators and means for vibrating said reeds.

17. An electroacoustic transducer comprising a radiating member, means forming therewith a longitudinal vibrator, said vibrator being composed of said radiating member with a longitudinally vibrating element having a node intermediate of the ends of the means taken longitudinally, said vibrator having a natural frequency of vibration and having flexurally vibratable reeds extending normally from the sides of said longitudinally vibrating element near their ends, said reeds having the same natural frequency of vibration as said vibrator and means for vibrating the said reeds.

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