

March 31, 1959

W. T. HARRIS

2,880,404

COMPACT RESONANT SONAR TRANSDUCER

Filed May 13, 1955

2 Sheets-Sheet 1

FIG. 2.

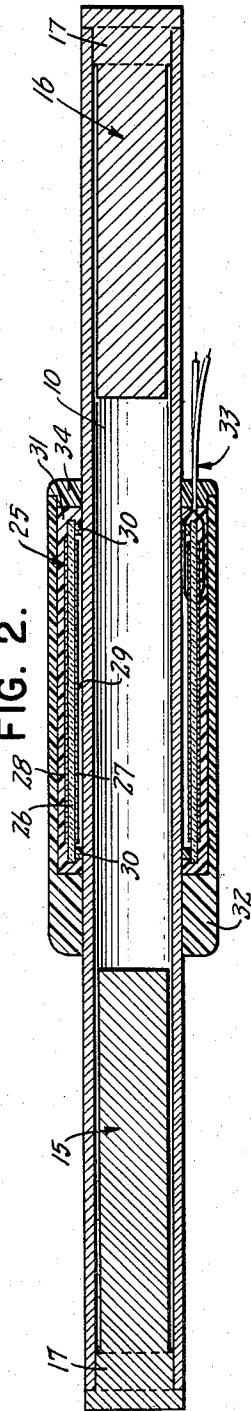


FIG. 3.

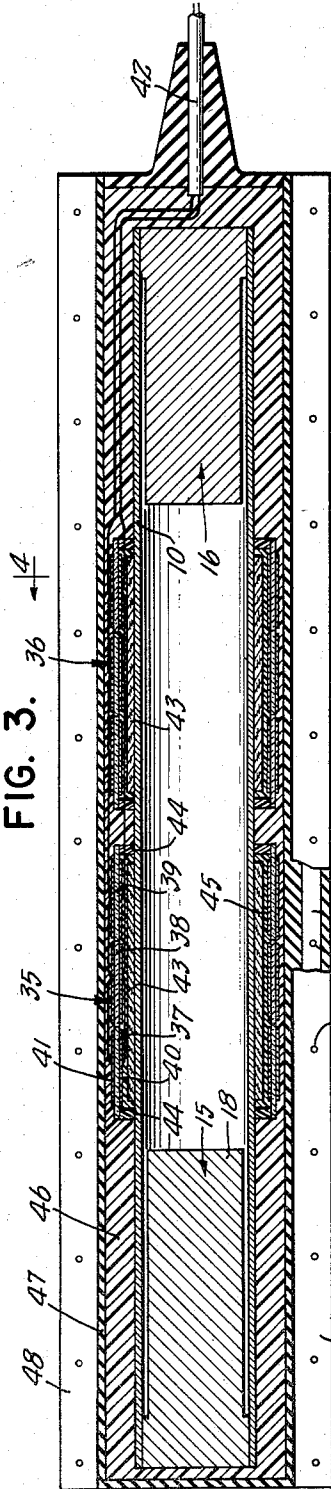
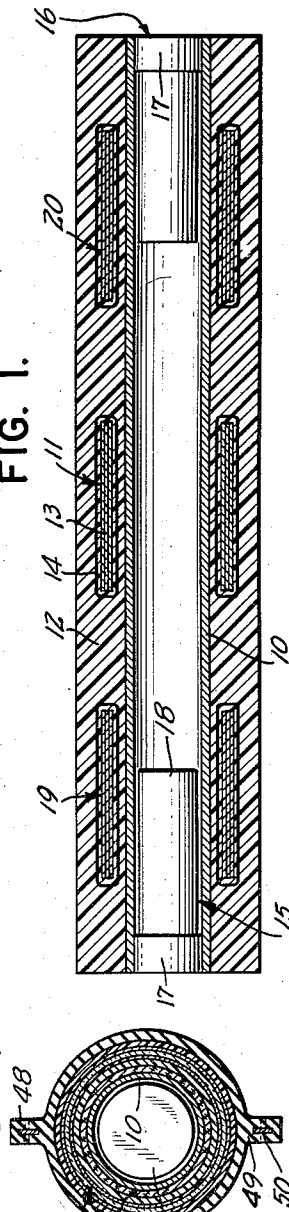


FIG. 1.

FIG. 4.



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FIG. 5.

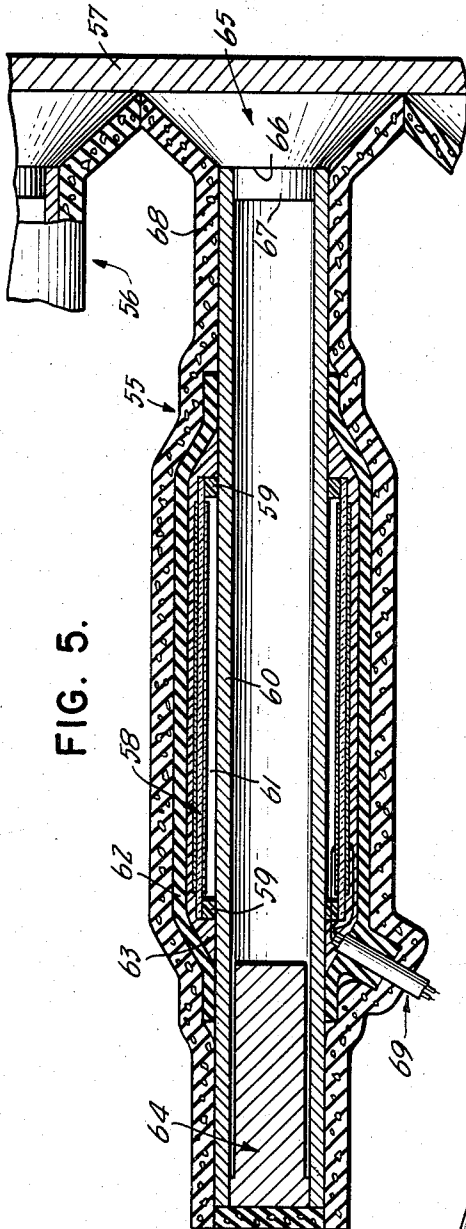


FIG. 6.

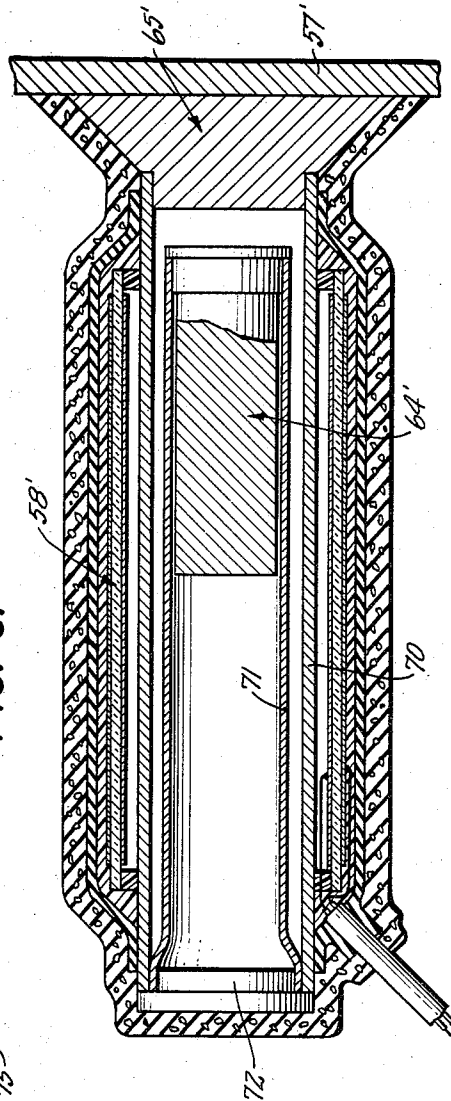
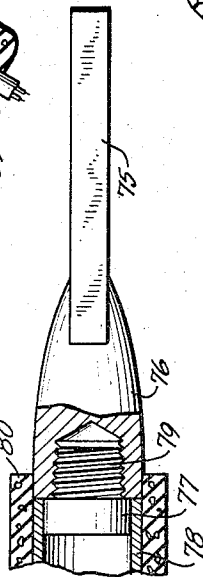


FIG. 7.



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2,880,404

COMPACT RESONANT SONAR TRANSDUCER

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Application May 13, 1955, Serial No. 508,074

22 Claims. (Cl. 340—11)

My invention relates to electromechanical transducers and in particular to structures wherein mechanical resonance dominates performance.

It is an object of the invention to provide an improved transducer construction of the character indicated.

It is another object to provide transducer constructions of high efficiency for low-frequency underwater application.

It is a further object to achieve the above objects with a structure inherently making for a compact assembly.

It is a specific object to provide an efficient tool-driving mechanism with a structure of the character indicated.

Other objects and various further features of novelty and invention will be pointed out or will occur to those skilled in the art from a reading of the following specification in conjunction with the accompanying drawings. In said drawings, which show, for illustrative purposes only, preferred forms of the invention:

Fig. 1 is a longitudinal sectional view through a transducer incorporating features of the invention;

Figs. 2 and 3 are views similar to Fig. 1, but illustrating modifications;

Fig. 4 is a sectional view taken in the plane 4—4 of Fig. 3;

Figs. 5 and 6 are further longitudinal sectional views illustrating alternative embodiments; and

Fig. 7 is a fragmentary side elevation, partly broken away and shown in longitudinal section to illustrate a further modification.

Briefly stated, my invention involves what I call a Poisson's ratio coupling between an electromechanical transducer element and a resonant structure in such manner that electrical performance is dominated by mechanical properties of such structure. In this application, I am concerned with mechanically resonant structures, involving the longitudinally resonant mode of an elongated metal cylinder or tube. The electromechanical transducer element may be tubular and in substantially concentric axially overlapping relation with the tube, and a secure bond is provided between axially spaced parts of the transducer element and the mechanically resonant tube. When the transducer tube element is excited, any tendency thereof to elongate or to contract is then directly transmitted to the resonant tube, the transmitting force being primarily characterized by an alternating longitudinal spread or a radial squeeze; at frequencies approaching mechanical resonance, substantial power may be available for radiation, for tool driving, or for other purposes. My transducers can be caused to deliver useful power either substantially in the radial plane normal to the axis of the transducer, or longitudinally.

Referring to Fig. 1 of the drawings, my invention is shown in application to a transducer comprising an elongated metal tube 10 with a tubular electromechanical transducer element 11 in substantially concentric axially overlapping relation with said tube. Means 12

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solidly bonds at least axially spaced parts of said transducer element 11 to the tube 10.

The transducer element 10 happens to be of the toroidally wound magnetostrictive variety, comprising a core 13 of magnetostrictive material, with a toroidal winding 14 coupled thereto. Upon excitation of the winding 14, the core 13 is caused to contract and expand radially; and, by virtue of the bond between the core 14 and the tube 10, a localized region of the tube 10 is correspondingly elongated and contracted axially due to the radial stricture and expansion through Poisson's ratio coupling between radial and longitudinal deformation. At resonance, the entire tube 10 will elongate and contract as if it had been excited for its entire length, and efficient electroacoustic conversion occurs. If the ends of the tube 10 are closed off, as shown, some radiation will occur at the ends because of their motion, but the predominant radiation will be that due to radial motion and therefore, for the form shown, the response will be primarily in the radial plane normal to the axis of the tube 10.

Because of the property of magnetostrictive material to increase in length for electrically induced radial contraction, it is desirable that the bonds between the core 13 and the tube 10 shall be continuous for the longitudinal length of overlap. To provide a rugged structure, a single potting 12 may fully encase the transducer element 11 and the entire adjacent region of the tube 10.

If the structure is solely as thus far described, low-frequency performance can only be achieved for unnecessarily great lengths of tube 10. In accordance with the invention, I make possible a substantially more compact structure by loading the ends of tube 10 with counterweights 15—16. Each counterweight is shown to comprise a base portion 17 secured to the end of the tube 10 and preferably closing off the same. A body portion 18 extends longitudinally inwardly within the tube 10 and in clearance relation therewith. As thus constructed, the mechanical structure 10—15—16 may be described as a half wave-length tube internally folded at the ends.

In order to promote greater electroacoustic conversion, I show provision of further transducer elements 19—20 which may be similar to the element 11 and provided in axially overlapping relation with the tube 10, but axially spaced from each other. The single potting 12 encases the entire area of overlap, and, if desired, this potting may be extended as shown to the longitudinal ends of the transducer, thus making for an assembly which may be readily incorporated into low-frequency array configurations.

The arrangement of Fig. 2 in many respects resembles that of Fig. 1, and for corresponding parts the same reference numerals have been employed. The transducer element 25 of Fig. 2, is, however, of different construction, being shown as a piezoelectric ceramic tube 26, as of barium titanate, with inner and outer electrodes 27—28, which may be fused silver coats on the piezoelectric cylinder 26. Unfortunately, it is a property of piezoelectric material, such as barium titanate, to become distorted for one polarity, by an increase in length, by an increase in diameter, and by a decrease in wall thickness, whereas it would be preferable to find properties as described above for the magnetostrictive case in which an electrically induced increase in length is accompanied by an electrically induced decrease in inside diameter. Thus, unfortunately, the piezoelectric cylinder 26 will develop two electromechanical forces in opposition, and only the effective difference can be utilized.

In spite of the dimensional changes characterizing piezoelectric action, I have found that piezoelectric elements may be solidly and continuously bonded to tubular resonant structure, in which case the radial forces predom-

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inate over the squeeze forces as far as coupling to the resonant structure is concerned, and an effective transducer results; for a high-Q linear oscillator, the longitudinal drive will predominate through resonant build up (even in the presence of elemental squeeze action out of phase therewith), and Poisson coupling to the medium occurs.

In accordance with a feature of the invention, however, I prefer to maximize the difference between electrically induced forces by avoiding or minimizing radial coupling between the cylinder 25 and the tube 10, as by providing a pressure-release zone, such as a hollow air-filled annular space 29 between members 10—26. Also, I securely bond the longitudinal ends of element 26 to the tube 10 so as to transfer essentially only longitudinal movements of the element 26 to the tube 10, through shear action in the spaced bonds. In the form shown, assembly is facilitated by employment of shims 30, as of Bakelite, concentrically positioning the piezoelectric tube 26 about the mechanically resonant tube 10, and a single potting 31 of hard, sound-transmitting plastic serves not only to protect the outer electrode 28 and the entire transducer element 25, but also securely to bond the longitudinal limits of the transducer element 25 to the tube 10. As a practical matter, the described relation can be achieved by employing a mold or jacket 32 for receiving the potting material 31 to be introduced preferably under evacuated conditions. The leads 33 to the electrodes 27—28 may be brought out through a closure cap 34 constituting part of the mold for the potting 31.

The arrangement of Fig. 3 is generally similar to that of Fig. 2, except that the transducer driving elements 35—36 are provided in plurality in order to improve coupling to the resonant structure 10—15—16. Each transducer element happens, as in the case of element 35, to comprise a consolidated assembly of three piezoelectric cores 37—38—39, each preassembled with its own inner and outer electrodes (as at 40—41, for the core 37), and bonded intimately in end-to-end relation. The electrodes of all elements are connected in parallel and are brought out through leads 42 at one longitudinal end of the device.

For pressure release to decouple radial deformations of the transducer element from those of the tube 10, I show in Fig. 3 the provision of pressure-release layers 43, as of cork, cellular rubber or the like in the radial space between the transducer elements 35—36 and the tube 10. Shims 44 are shown purely for concentric supporting purposes during the potting operation, but preferably sufficient opening is provided (not shown) in the fit of the shims 44 to permit free-flooding the remaining space 45 between the transducer element 35—36 and the tube 10 with hard, sound-transmitting plastic, all in the same operation as that in which the plastic 46 is applied.

To complete the structure for the case of an underwater transducer having primary response in the radial plane normal to the transducer axis, I have shown an outer boot 47 of sound-transmitting rubber or rubber-like material fully encasing the assembly and provided with laterally extending elongated flanges 48—49 which are preferably of the type disclosed in greater detail in my copending application Serial No. 454,712, filed September 8, 1954. Such flanges therefore preferably include metallic reinforcement means 50 contained within the body of each flange, at least at the regions where the flanges are to be secured, as at holes 51.

The structures thus far described have been characterized primarily by response in the radial plane normal to the transducer axis, but, as indicated generally above, the principles of the invention are also applicable to endwise radiation, the response in the radial plane being, in such case, minimized. In Fig. 5, I show such an application wherein the transducer device 55 is but one of a plurality of similar devices, including the device 56, mounted in laterally spaced relation and coupled to a diaphragm 57,

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for underwater acoustic radiation to the right, in the sense of the drawing. The basic structure of Fig. 5 resembles that of Fig. 2, in that a longitudinal-type transducer element 58 is of the piezoelectric variety, supported by shims 59 on a tube 60 in such manner as to provide an air-filled pressure-release volume 61 for radially decoupling the transducer element from the mechanically resonant structure. A boot or envelope of rubber or rubber-like material 62 surrounds the transducer element to define a volume within which the potting 63 may be economically applied and yet good longitudinal coupling can be achieved between the parts 58—60.

The structure of Fig. 5 also resembles that of Fig. 2, in that at least one of the counterweights 64, like counterweight 15, extends longitudinally within the tube 60. At the other end of the structure, however, the counterweight 65 serves as a piston or impedance-matching device to directly couple the end of the tube 60 to the diaphragm 57. Counterweight 65, therefore, may comprise a frusto-conical body terminating at a shoulder 66 and having an inner base 67 secured to the end of the tube 60. Inasmuch as radiation is to be promoted in the longitudinal mode and is to be minimized in the radial mode, I have provided a jacket 68 of air-filled rubber or the like to assure pressure release in all but the desired radiating direction. Leads to the transducer electrodes may be brought out through a suitable seal or gland, as at 69.

The arrangement of Fig. 6 resembles that of Fig. 5, except that it demonstrates a further saving in space through employment of the principles of the invention. Space saving is realized in a more compact mechanically resonant structure, comprising a plurality of tubes 70—71 in concentric overlapping relation and so secured at odd adjacent ends as to develop a multiply folded, longitudinally resonant, half-wave device. Since the structure shown employs but two tubes, there is but one point of interconnection, which happens to be at the rear and to be provided by a circumferential enlargement 72 on the inner tube 71, so as to facilitate a welded attachment of the two tubes. The re-entrant counterweight 64' may be secured to the free end of the inner tube 71, and the piston or impedance-transforming counterweight 65' may be secured at the free end of the outer tube 70, all in the manner discussed above for the case of Fig. 5. The transducer element 58' may be secured to the outer tube 70 as described in Fig. 5, and since all other parts of Fig. 6 resemble those of Fig. 5, the same reference numbers have been employed, with primed notation.

In Fig. 7, I illustrate that longitudinal drivers, as in Figs. 5 and 6, and employing piezoelectric driving elements or magnetostrictive driving elements (as in Fig. 1), are useful for machine-tool applications. The particular tool 75 in Fig. 7 is a lapping tool or plate carried by a tool-holder or adapter 76, having a base 77 secured to the end of the longitudinally resonant tube 78 of one of my resonators, corresponding to the tube 60 of Fig. 5 or to the tube 70 of Fig. 6. I prefer that the adapter part 76 be permanently secured to the tool 75 and that the base 77 be permanently secured to the tube 78, so that for replacement of the tool, a threaded or other detachable interfit 79 between parts 75—76 is desirable. It will be understood that the parts 75—76—77 together provide the counterweight function achieved by pistons 65—65' or by counterweight 16 in the other forms described above. In order to minimize radial radiations for the tool of Fig. 7, substantially the entire body of the same may be encased in insulating material, such as a jacket 80 of air-cell rubber.

It will be seen that I have described improved transducer constructions, having particular utility for underwater and machine-tool applications at audio and supersonic frequencies, extending throughout the range 100

c.p.s. to 60 kcs. Squeezer or Poisson's ratio coupling to the mechanically resonant structure is particularly effective at or near longitudinal resonance, and efficient energy conversion is achieved. By longitudinally folding the basic resonant structure, substantial space is saved for a given response frequency; and, viewed from another aspect, lower response frequencies are achievable within given space limitations.

While I have described the invention in detail for the preferred forms illustrated, it will be understood that modifications may be made within the scope of the invention as defined in the claims which follow.

I claim:

1. An electroacoustic transducer, comprising an elongated tubular longitudinally resonant structure, a tubular electromechanical transducer element in substantially concentric axially overlapping relation with said structure, and means directly and solidly bonding axially spaced parts of said transducer element to said structure.

2. An electroacoustic transducer, comprising an elongated longitudinally resonant structure including a hollow cylindrical portion intermediate the ends thereof, a cylindrical electromechanical transducer in substantially concentric axially overlapping relation with said cylindrical portion, and means directly and solidly bonding axially spaced parts of said transducer element to said structure.

3. An electroacoustic transducer, comprising an elongated longitudinally resonant structure, a tubular electromechanical transducer element in substantially concentric axially overlapping relation with said structure, and means solidly bonding said entire element to said structure for the full axial length of overlap between said element and said structure.

4. A transducer according to claim 3, in which said element comprises a tubular core of magnetostrictive material and a toroidal winding linked to said core, the bond between said element and said structure extending to said core.

5. A transducer according to claim 3, in which said element includes a tubular length of piezoelectric material with inner and outer electrodes applied thereto.

6. An electroacoustic transducer comprising an elongated cylindrical longitudinally resonant structure, a tubular electromechanical transducer element in substantially concentric overlapping relation with said structure, a circumferentially extending layer of pressure-release material radially between said element and said structure and substantially coextensive with the length of overlap but terminating short of the limits of such overlap, and means solidly bonding said element and said pressure release material to said structure and including solid bonds pressure-transmitting direct between the ends of said element and said structure, whereby the ends of said transducer element may be bonded directly to said structure to the exclusion of locations intermediate said direct bonds.

7. A transducer according to claim 6, in which said element comprises a tube of piezoelectric material, said direct bonds being direct to said piezoelectric material, and inner and outer electrodes carried by said material in the axial space between said direct bonds.

8. A transducer according to claim 7, in which said piezoelectric tube is a consolidation of generally similar tubular piezoelectric elements in rigidly bonded end-to-end relation.

9. An electroacoustic transducer, comprising elongated tubular longitudinally resonant structure, a tubular electromechanical transducer element surrounding a part of said structure, first and second shims peripherally supporting the ends of said transducer element on said structure in substantially concentric relation therewith, and bonding means solidly encasing said transducer ele-

ment and extending over said shims and to adjacent areas of said structure, whereby said transducer element is solidly bonded to said structure essentially only at the ends thereof, and whereby a pressure-release volume is defined between said structure and said transducer element at intermediate locations.

10. An electroacoustic transducer, comprising an elongated tubular longitudinally resonant structure, a plurality of tubular electromechanical transducer elements in spaced end-to-end relation along parts of the length of said structure and supported substantially concentrically therewith, and a solid potting of sound-transmitting material rigidly bonding axially spaced parts of each transducer element to said structure and otherwise fully surrounding said elements and said structure.

11. An electroacoustic transducer, comprising an elongated tubular longitudinally resonant structure, a plurality of tubular electromechanical transducer elements in spaced end-to-end relation along parts of the length of said structure and supported substantially concentrically therewith, and a solid potting of sound-transmitting material rigidly bonding each transducer element to said structure and otherwise fully surrounding said elements and said structure.

12. An electroacoustic transducer, comprising an elongated longitudinally resonant structure including a hollow cylindrical tube, first and second counterweights secured to the longitudinal ends of said tube, and a tubular electromechanical transducer element in substantially concentric axially overlapping relation with said tube, and means rigidly and solidly bonding axially spaced parts of said transducer element to said tube.

13. An electroacoustic transducer, comprising an elongated longitudinally resonant structure including a hollow cylindrical tube, first and second counterweights secured to the longitudinal ends of said tube, each said counterweight having a base portion secured at an end of said tube and a body portion extending inwardly of said tube and in clearance relation with the inner wall of said tube, a tubular electromechanical transducer element in substantially concentric axially overlapping relation with said tube, and means solidly bonding axially spaced parts of said transducer element to said tube.

14. An electroacoustic transducer, comprising an elongated longitudinally resonant structure including a hollow cylindrical tube, first and second counterweights secured to the longitudinal ends of said tube; one of said counterweights including a base portion secured at one end of said tube, and a body portion extending within said tube and in radial clearance relation therewith; the other of said counterweights including a base portion secured to the other end of said tube, and a diaphragm-connecting portion extending longitudinally away from said tube; a tubular electromechanical transducer element in substantially concentric axially overlapping relation with said tube, and means solidly bonding axially spaced parts of said transducer element to said tube.

15. An electroacoustic transducer, comprising an elongated longitudinally resonant structure including a hollow cylindrical tube, first and second counterweights secured to the longitudinal ends of said tube; one of said counterweights including a base portion secured at one end of said tube, and a body portion extending within said tube and in radial clearance relation therewith; the other of said counterweights including a base portion secured to the other end of said tube, and a tool extending longitudinally away from said body and directly connected to said second-mentioned base portion; a tubular electromechanical transducer element in substantially concentric axially overlapping relation with said tube, and means solidly bonding axially spaced parts of said transducer element to said tube.

16. In combination, diaphragm means extending over a radiating area, and a plurality of driving elements secured in laterally spaced relation to one side of said dia-

phragm means, each of said driving elements comprising an elongated tubular longitudinally resonant structure oriented with its longitudinal axis generally perpendicular to the point of connection thereof to said diaphragm means, a tubular electromechanical transducer element in substantially concentric axially overlapping relation with said structure, means solidly bonding axially spaced parts of said transducer element to said structure, means connecting one end of said structure directly to said diaphragm means and at the same time closing off said one end, and means closing off the other end of said structure.

17. In combination, diaphragm means extending over a radiating area, and a plurality of driving elements in driving relation with one side of said diaphragm means, each said driving element comprising an elongated longitudinally resonant tube, first and second counterweights closing off and peripherally secured to the ends of said tube, one of said counterweights including a base portion secured to said tube and a body portion defining an impedance-transforming piston extending longitudinally away from said tube and in direct driving relation with said diaphragm means, the other of said counterweights including a base portion secured to the other end of said tube and a body portion extending longitudinally within said tube and in clearance relation therewith.

18. The combination of claim 17, and including a tubular electromechanical transducer element surrounding and in substantially concentric axially overlapping relation with said tube, and means solidly bonding axially spaced parts of said transducer element to said structure.

19. The combination of claim 17, and including pressure-release means enveloping substantially all the exposed parts of said combination on the resonant side of said diaphragm means.

20. In combination, two elongated concentric tubes in axially overlapping relation, means securing said tubes to each other at one end, said tubes being otherwise spaced in radial clearance relation, first and second counterweights independently secured to and carried by the respective free ends of said tubes, a tubular electromechanical transducer element surrounding and in substantially concentric axially overlapping relation with the outer one of said tubes, and means solidly bonding axially spaced parts of said transducer element to said outer tube.

21. In combination, a plurality of elongated concentric tubes in axially overlapping relation, means securing successive of said tubes to each other at odd adjacent ends, said tubes being otherwise spaced in radial clearance relation, first and second counterweights secured to and carried by the free ends of said tubes, a tubular electromechanical transducer element surrounding and in substantially concentric axially overlapping relation with the outer one of said tubes, and means solidly bonding axially spaced parts of said transducer element to said outer tube.

22. The combination of claim 21, in which the counterweight secured to the inner of said tubes comprises a base portion so secured, and a body portion extending longitudinally within said inner tube and in radial clearance relation therewith.

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