Sept. 8, 1959 W. T. HARRIS 2,903,673

ACOUSTICAL IMPEDANCE-MATCHING TRANSDUCER

Filed Jan. 6, 1954

FIG. 5.

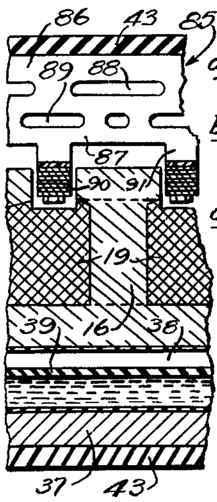


FIG. 1.

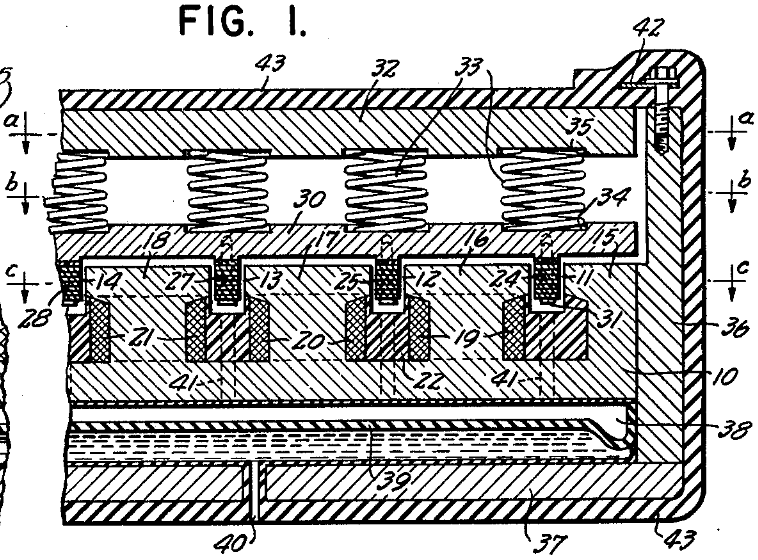


FIG. 2.

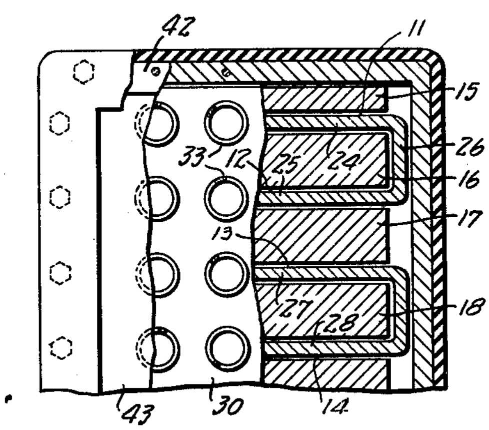


FIG. 4.

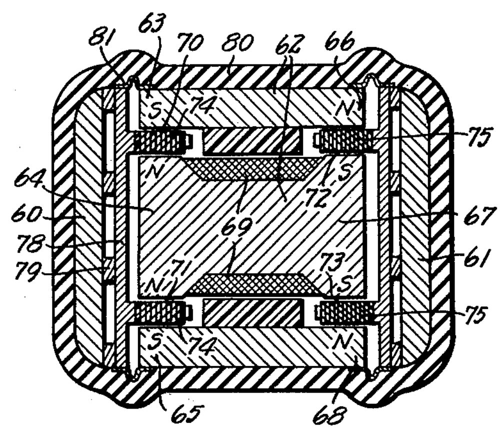


FIG. 3.

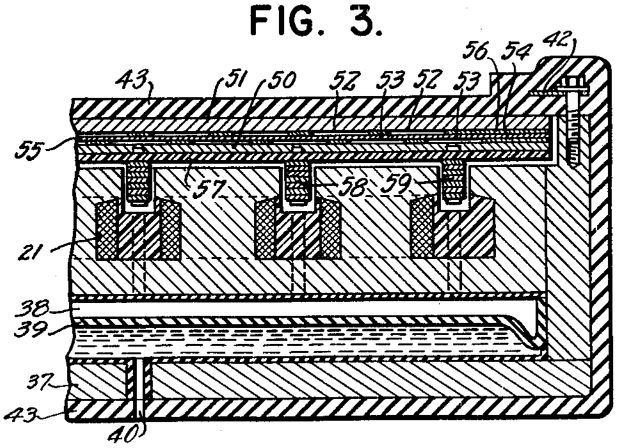
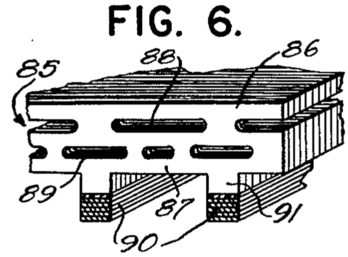


FIG. 6.



INVENTOR.
WILBUR T. HARRIS

BY *Mitchell & Bechert*

ATTORNEYS

United States Patent Office

2,903,673

Patented Sept. 8, 1959

1

2,903,673

ACOUSTICAL IMPEDANCE-MATCHING TRANSDUCER

Wilbur T. Harris, Southbury, Conn., assignor to The Harris Transducer Corporation, Woodbury, Conn., a corporation of Connecticut

Application January 6, 1954, Serial No. 402,426

22 Claims. (Cl. 340—8)

My invention relates to improved electroacoustic transducer means and in particular to electromagnetic transducers, as of the character described in greater detail in my co-pending patent application Serial No. 241,470, filed August 11, 1951.

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

It is another object to provide an improved means for coupling a transducer of the character indicated to the medium into which the transducer is to radiate or is otherwise to respond.

It is a further object to provide means for vastly improving the radiating efficiency of transducers of the character indicated.

It is a specific object to provide improved diaphragm means for coupling a movable transducer element to a radiative medium.

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

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

Fig. 2 is a fragmentary plan view on a reduced scale, with parts successively broken away and shown in the three sectional planes designated *a-b-c* in Fig. 1;

Fig. 3 is a view similar to Fig. 1 but showing a modification;

Fig. 4 is another sectional view showing a further modification; and

Figs. 5 and 6 are fragmentary sectional and perspective views, respectively, illustrating a further embodiment of the invention.

Briefly stated, my invention contemplates employment of novel diaphragm means in conjunction with the movable element of an electroacoustic transducer for providing improved impedance-matching characteristics, so that a more efficient energy transfer may be possible between the moving transducer element and the radiating medium. Such diaphragm means may be of composite or unitary construction but essentially comprises a relatively continuous radiating surface connected to the electromechanical driving mechanism through a stiffly compliable means; it is convenient to employ a driving diaphragm as part of the compliance or otherwise as a means of connecting the transducer element to the radiating surface.

In one form to be described, the driving and radiating surfaces are themselves on separate diaphragm members, and helical springs located on these members provide the desired compliance and connect these members together. In another form, the interior of a single diaphragm is effectively excavated to provide the interior weakening necessary to establish an impedance-matching compliance; this latter form may be more simply fabricated by consolidating a stack of laminations, and two general forms of laminated diaphragm are shown. In both general forms, the diaphragms are shown driven by means of electromagnetic-strip transducer elements of the character described in greater detail in the above-identified patent application, but it will be understood that the diaphragms of the invention may be driven by other vibratile transducer elements.

2

Referring to Figs. 1 and 2 of the drawings, my invention is shown in application to an electrodynamic transducer comprising magnetic-core means **10** which may be a single block of magnetic-core material, providing a grid of substantially parallel flux gaps **11—12—13—14** between spaced pole pieces **15—16—17—18**. The core **10** may be permanently magnetized, but I show a plurality of coils for polarizing the same; thus, a first coil **19** may be linked to the pole piece **16**, and further coils **20—21** to the pole pieces **17—18**, respectively. The polarity of polarization effected by the coils **19—20—21** should alternate for adjacent coils so that strong fields may be established in the gaps between adjacent pole pieces, as will be understood. In order to provide a more rugged assembly, I show fillings of plastic material, as at **22**, between turns of adjacent coils (**19—20**) in the same coil slot between adjacent pole pieces (**16—17**).

As explained more fully in the said co-pending patent application, the electrodynamic strips supported in the respective flux gaps are the driving vibratile elements of the transducer. Thus, a first coil may include strips having a first leg or stretch **24** in the gap **11** and a second leg or stretch **25** in the gap **12**, and I have shown my preference that the coil **24—25** be developed helically from strip material laminated and consolidated into a single rugged vibratile element. The loop or coil for which stretches **24—25** constitute the opposite legs may include end connections, as at **26** (Fig. 2) to complete the coil, as will be understood. A second coil, comprising opposed stretches **27—28**, may be of similar construction and may be supported in the next pair of flux gaps **13—14**.

In accordance with the invention, I provide novel diaphragm means for efficiently coupling the energy available in the moving coils **24—25** and **27—28** to the medium into which energy is to be radiated. Such diaphragm means essentially comprises a driving surface which may rigidly support the respective electrodynamic coils **24—25** and **27—28**, and a radiating surface connected to the driving surface through a suitable compliance.

In the form shown in Fig. 1, the driving surface is part of a first or driving diaphragm member **30** to which the various legs of the moving coils are rigidly secured through suitable insulating means (not shown); I have schematically suggested this secured relation by means of anchoring bolts, as at **31**. The radiating surface may comprise a second or radiating diaphragm **32** for direct coupling to the medium into which radiation is to be effected. In Fig. 1, the compliance connecting the two diaphragms **30—32** comprises a grid or matrix of spring connections **33**, which, as will be seen in Fig. 2, preferably uniformly cover substantially the entire radiating area of the diaphragm means. In order to locate the various springs **33** each of the diaphragms **32—33** may be locally recessed, as at **34—35**.

To complete the transducer, the magnetic-core means **10** may be secured in a rugged housing comprising side plates **36** and a back plate **37**, preferably defining with the back of the magnetic-core means **10** a pressure-equalizing cavity **38** for rendering the response of the transducer less depth-dependent. For pressure-equalizing purposes, the cavity **38** may contain an inflatable bag **39**, as of neoprene or the like, and the space between the bag 39 and the backplate 37 may be freely flooded by means of a bleed opening 40. I have suggested by lightly dashed outlines 41 that fluid-communicative passages may be located at the ends of the elongated gaps to provide free pressure communication between the gaps 11—12—13 and the space over the other side of the pressure-equalizing bag 39. For rendering the transducer impervious to moisture, as when submerged at relatively great depth in water, the entire device may be coated heavily with rubber, neoprene or the like, and locally flexibly reinforcement means 42 may protect the outer rubber casing or boot 43 at the overlap between fixed and moving parts 32—36; at least for the area over diaphragm 32, boot 43 will be understood to be preferably of sound-transmitting character.

The operation of the described diaphragm construction will be better understood from a simplified illustration for a hypothetical square diaphragm, one-foot square. Ordinarily, efficiencies of the order of 1 percent at 100 cycles/sec., and 12.5 percent at 1 kc./sec., would be expected when driving such a diaphragm in water, using readily attainable magnetic-field strengths and coil structures; these low efficiencies result from the fact that the impedance of the medium is so high that the diaphragm forces developed by the coils produce excessively small displacements, and hence small amounts of radiative dissipation. On the other hand, with the introduction of a compliance to provide a reactance, and if the mass of the driving diaphragm 30 and coils (24—25, 27—28) is small compared to the total reactive mass of the radiating medium, then the limitations are changed markedly; actually, the reactive mass may be in the order of 50 times the driving mass. With the double diaphragm and intervening compliance, the $\int Fdx$ product of coil force and in-phase motion, which determines radiated energy, can be much larger because larger motions are possible, without resort to extremely stiff springs. Under resonant conditions, the amplitude of displacement of diaphragm 30 may build up sufficiently to drive the load (diaphragm 32 plus the water or other medium), with a displacement magnification reflecting the ratio of the reactive masses. The result is substantially improved efficiency at resonance, coupled with useful improvement in broad-band efficiencies off resonance.

In Fig. 3, I show a slightly modified construction in which the diaphragm means including the compliance is of unitary construction. The diaphragm may still comprise essentially a driving face or member 50 and a radiating face or member 51, but the compliance may be provided by locally excavated openings or slots 52 at one depth in the diaphragm or at a plurality of depths, as shown in the case of slots 53, which, for greater compliance, may overlap the slots 52. Even though the diaphragm shown may be made from a single piece of material, I find it much more convenient to construct the diaphragm by consolidating a stack of variously slotted and unslotted laminations. Thus, the driving surface or member 50 may constitute the first lamination and may extend preferably continuously across the radiating section of the transducer. The slots 53 may be defined in a single slotted lamination 54 located immediately adjacent and between the lamination 50 and a next lamination 55 running continuously across the transducer. In like manner, the slots 52 may be formed in a further lamination 56 sandwiched between the continuous laminations 51—55. For insulating purposes, the driving lamination 50 may be covered or coated with a plastic lamination 57 against which the moving-coil elements 58—59 may be directly secured, as will be understood. Polarization, excitation, pressure-equalization, and protection against water seepage may be effected in the manner and by the means described in connection with Figs. 1 and 2.

In Fig. 4 I show a further modification in which my invention is adapted to a bi-directional transducer having radiating surfaces or members at 60—61 on opposite sides of the transducer. Nevertheless, the transducer may still comprise basic magnetic-core members 62 defining spaced pole pieces 63—64—65 on one radiating side and correspondingly spaced pole pieces 66—67—68 on the other radiating side of the transducer. The core may be permanently polarized, but I have shown a single polarization coil 69 coupled to the center yoke between pole pieces 64—67 and developing strong flux gaps at 70—71 and at 72—73, as will be understood. A first laminated-strip forming a conductive loop or dynamic coil 74 may include stretches or opposed legs in the gaps 70—71, and a second loop or coil 75 may be similarly supported in the remaining gaps 72—73. The diaphragms are connected to both of the loops respectively and may be as described in either of the preceding cases, and I have shown a composite diaphragm construction involving but a single row of compliance excavations in each case. The diaphragm which includes the radiating surface 60 may thus be built of merely three laminations, including a first continuous lamination for driving member 78, a slotted spacer lamination 79, and the radiating lamination 60. The slots of lamination 79 are preferably parallel and elongated for substantially the full length of the transducer, and the air space in each of these slots preferably communicates with other air spaces within the transducer, as for pressure-equalizing purposes, disclosed more particularly in Figs. 1 and 3, it being understood that, for the bidirectional transducer shown, the pressure-equalizing chamber or bag would be provided at a longitudinal end rather than at the back of the transducer, as in Fig. 1. The entire transducer may be encased in a boot 80 of flexible material, such as rubber or neoprene, and for extra ruggedness of support the bridges between relatively moving elements may be reenforced by flexible metal corrugations, as at 81.

In Figs. 5 and 6, I show a further embodiment of the invention in which the spring diaphragm is still of laminated construction but in which the planes of laminations are aligned with, rather than transverse to the principal response axis of the transducer. The diaphragm of Figs. 5 and 6 lends itself readily to either of the basic arrangements of Figs. 3 and 4; it is perhaps best shown in Fig. 6 as comprising a transverse stack of laminations 85. Upon consolidation as shown, the diaphragm may still be said to comprise in effect a driving surface 86 and a driven surface 87, connected by resiliently yieldable means, the resiliency being provided by one or more rows of elongated slots 88—89 in each lamination 85. For driving purposes, electrical coils 90 of strip material may be secured to driving pedestals or supports 91, forming an integral part of laminations 85. Polarization, pressure-equalizing, and sealing may be otherwise as described for Figs. 1 and 3, and therefore corresponding reference numerals are used in Fig. 5.

It will be appreciated that I have described means for more efficiently transmitting energy from a mechanically vibratile element into a radiating medium. The compliant diaphragms provide an impedance-matching transformer action which maximizes the force per unit area which can be exerted; as a result, efficiency, compactness, and cost are favorably affected.

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. In a device of the character indicated, diaphragm means comprising a driving surface and a radiating surface and a compliance therebetween, said compliance including a plurality of separate spaced spring connections between said surfaces and distributed over the areas thereof, and electromechanical means in driving relation with said driving surface.

2. In a device of the character indicated, a composite

diaphragm comprising a radiating diaphragm surface, a driving diaphragm surface, and yieldable metallic means connecting said surfaces said yieldable means having a plurality of laterally spaced connections to both said surfaces, said connections being distributed over the areas of said surfaces.

3. A device according to claim 2, in which said yieldable means comprises a plurality of separate springs yieldable generally along axes normal to said radiating and driving surfaces.

4. A device according to claim 2, in which said yieldable means comprises two spaced resiliently bendable members, and rigid spacers connecting said members at laterally spaced locations.

5. A device according to claim 4, in which said spacers are defined between adjacent slots of a slotted lamination sandwiched between said members.

6. In a device of the character indicated, diaphragm means of relatively stiffly yieldable material with an effectively continuous radiating surface and with an effectively continuous driving surface, the body of said diaphragm means having a plurality of spaced localized cavities therein, said cavities being effectively distributed over the areas of said surfaces and disposed between said surfaces, whereby said body between said surfaces may be stiffly compliant.

7. In a transducer of the character indicated, magnetic core means defining a plurality of spaced elongated gaps, a movable strip of conductive material including opposed legs in the respective fields of two of said gaps, and diaphragm means including a driving surface rigidly supporting said conductive legs, and a radiating surface coupled to said driving surface through stiff compliant means, said compliant means connecting said surfaces at a plurality of spaced locations distributed over the areas thereof.

8. A transducer according to claim 7, in which said movable strip of conductive material comprises a loop containing a plurality of turns of laminated strip material, there being a plurality of laminations in the field of each of said gaps.

9. In a transducer of the character indicated, magnetic-core means comprising a plurality of pole pieces oriented to define a plurality of spaced elongated gaps in substantially a single plane generally normal to the principal response axis of said transducer, a moving conductive coil including two opposed legs movably supported in two of said gaps, and a composite diaphragm comprising a driving surface fixedly carrying said moving coil and a radiating surface connected to said driving surface through metallic compliant means, said compliant means connecting said surfaces at a plurality of spaced locations distributed over the areas thereof, whereby said diaphragm may function essentially uniformly over the area thereof.

10. In a transducer of the character indicated, magnetic-core means comprising a plurality of pole pieces oriented to define a plurality of spaced elongated gaps in substantially a single plane generally normal to the principal response axis of said transducer, a moving conductive coil including two opposed legs movably supported in two of said gaps, a composite diaphragm comprising a driving surface fixedly carrying said moving coil and a radiating surface connected to said driving surface through a metallic compliance, and a rigid housing fixedly supporting said magnetic-core means and defining between said core means and a part of said housing a pressure-equalizing cavity with an external opening on a side other than the radiating side of said transducer, a collapsible flexible bag within said cavity and covering said opening, whereby fluid may enter said opening and fill said bag, there being a fluid-communicating opening between one of said gaps and the other side of said collapsible bag, whereby air within said transducer may be maintained under ambient fluid-pressure conditions.

11. In a transducer of the character indicated, magnetic-core means comprising spaced pole pieces defining two spaced elongated flux gaps on one side of said core means and two spaced elongated flux gaps on the other side of said core means, a first loop of conductive material including opposed legs in the respective gaps on one side of said core means, a second conductive loop of conductive material including opposed legs in the respective gaps on the other side of said core means, and two diaphragms connected respectively to both said loops, each of said diaphragms comprising a radiating surface connected to the adjacent conductive loop through a metallic compliance.

12. A transducer according to claim 11, in which the respective loops are each rigidly supported on a driving diaphragm, and in which the compliant connection includes said driving diaphragm.

13. In combination, two spaced diaphragms, one of which is resiliently bendable, an electromechanical driving connection to one of said diaphragms, and two direct connections between said diaphragms at locations laterally spaced on opposite sides of the location of said driving connection.

14. In combination, two spaced diaphragms, one of which is resiliently bendable, a direct connection between said diaphragms at one location, and electromechanical driving means including two driving connections to said one of said diaphragms, said two driving connections being on opposite sides of the location of said direct connection.

15. In a transducer of the character indicated, magnetic-core means comprising a plurality of pole pieces oriented to define a plurality of spaced elongated gaps in substantially a single plane generally normal to the principal response axis of said transducer, a moving conductive coil including two opposed legs movably supported in two of said gaps, and diaphragm comprising a radiating surface connected to said coil through metallic compliant means, said compliant means being connected to said diaphragm at a plurality of spaced locations distributed over the effective area of said diaphragm, whereby said diaphragm as a whole is effectively compliantly coupled to said coil.

16. In combination, a transducer housing including a radiating diaphragm peripherally sealed to said housing at one side thereof, an electromechanical transducer within said housing comprising a driving diaphragm facing said radiating diaphragm, and stiffly compliant metallic means connecting said driving diaphragm to said radiant diaphragm at a plurality of spaced locations distributed over the area of said diaphragms.

17. The combination of claim 16, in which said radiating diaphragm comprises a sound-transmitting boot of rubber-like material.

18. A diaphragm, comprising a consolidated stack of laminations, each lamination having a radiating edge and a driving edge and slotted between said edges, whereby for vibratile action of said edges relatively to each other the slotted construction provides a compliant connection.

19. A diaphragm according to claim 18, in which each lamination is integrally formed with a driving pedestal projecting generally normally from said driving edge for supporting an electromechanical driving element thereon.

20. A diaphragm according to claim 19, in which a slot opening in said lamination is in general alignment with said pedestal.

21. A diaphragm according to claim 19, in which said lamination is slotted at locations laterally offset from said pedestal.

22. In a device of the character indicated, a composite diaphragm comprising a radiating diaphragm surface, a driving diaphragm surface, and yieldable metallic means connecting said surfaces, said diaphragm consisting of a consolidated transversely extending stack of laminations,

each lamination having opposed edges respectively forming parts of said radiating diaphragm surface and of said driving diaphragm surface and having a slot therein between said edges.

References Cited in the file of this patent

UNITED STATES PATENTS

1,563,626	Hecht	Dec. 1, 1925
1,610,674	Hahnemann	Dec. 14, 1926
2,429,104	Olson	Oct. 14, 1947
2,561,368	Hayes	July 24, 1951

FOREIGN PATENTS

147,941	Great Britain	Sept. 15, 1921
298,382	Great Britain	Oct. 11, 1928