Jan. 23, 1962 W. T. HARRIS 3,018,465

COMPLIANT ACOUSTIC RADIATING MEANS

Filed May 4, 1954

FIG. 1.

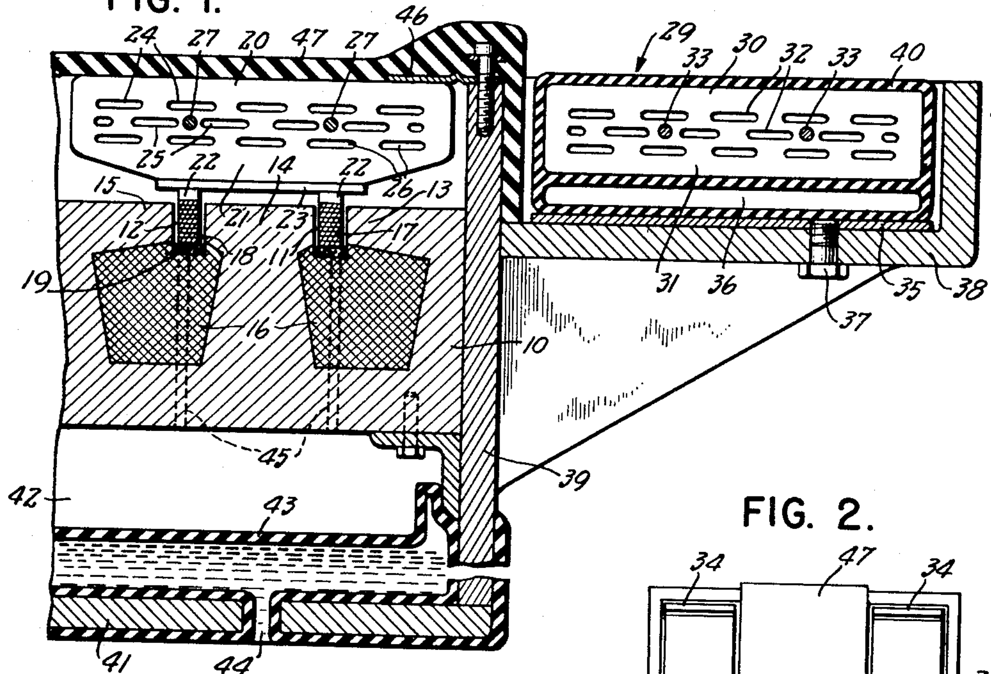


FIG. 2.

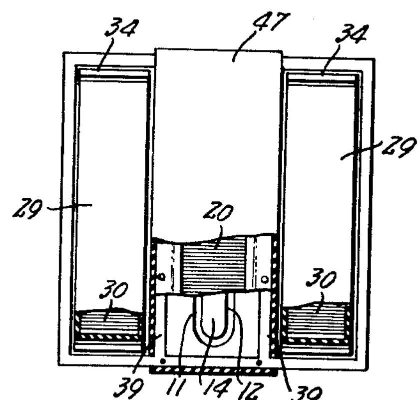


FIG. 3.

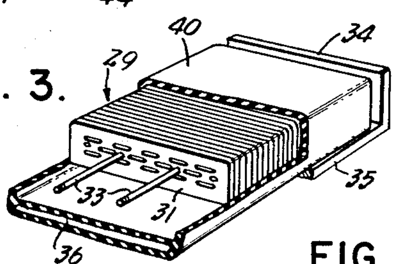
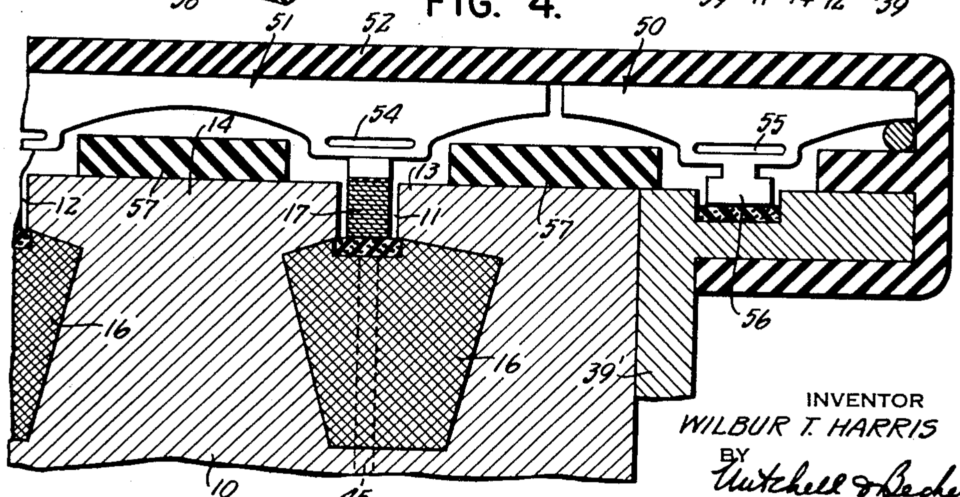


FIG. 4.



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COMPLIANT ACOUSTIC RADIATING MEANS

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25 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 copending applications, Serial No. 241,470, filed August 11, 1951 now Patent No. 2,978, 671, and Serial No. 402,426, filed January 6, 1954 now Patent No. 2,903,673.

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

It is another object to provide 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 improved diaphragm means for transducers of the character indicated, whereby the effective radiating area of driving parts of the transducer is substantially enlarged.

It is a specific object to provide parasitically radiating means as a functional part of a transducer 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 fragmentary sectional view of a transducer incorporating features of the invention;

FIG. 2 is a plan view of the transducer of FIG. 1, on a reduced scale and partly broken-away;

FIG. 3 is a fragmentary perspective view of a parasitic diaphragm employed in the transducer of FIGS. 1 and 2; and

FIG. 4 is a view similar to FIG. 1 and illustrating a modification.

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 more efficient energy transfer may be possible between the moving transducer element and the radiating medium. Specifically, for the type of compliant diaphragm disclosed in my said application Serial No. 402,426 now Patent No. 2,903,673, I have discovered that the construction lends itself to provision of a parasitically resonant structure which may be continuous with or adjacent to the electromagnetically driven area. Thus, one continuous large-area diaphragm may comprise a radiating surface, with a backing surface connected thereto by uniformly compliant structure, so as to permit oscillation between said surfaces when a part of the backing area is driven. The driven part of the diaphragm area may be excited a wavelength or a substantial fraction of a wavelength laterally away from the outer limit of the diaphragm means, and still the entire diaphragm means will resonate, the outer part parasitically and in an appropriate phase relation with the driven part.

In the forms to be described, I find it convenient to employ separate driving and parasitic diaphragms. In one case, the parasitic-diaphragm structure, complete with sealing and sound-decoupling (or reflecting) backing, may be removably secured to an otherwise fully assembled transducer. In the other form, the parasitic diaphragm

is assembled and sealed as an integral part of the entire transducer construction.

Referring to FIGS. 1 to 3 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** between spaced pole pieces **13—14—15**. The core **10** may be permanently magnetized, but I show coil means **16** for polarizing the same. For a more rugged assembly, any space between the coils **16** and the core openings for accommodating the same may be filled with plastic material, but, for simpilicity, I have simply shaded the entire coil openings as being occupied by winding **16**.

As more fully explained in the said copending patent applications, the electrodynamic strips supported in the respective flux gaps are the driving vibratile elements of the transducer. Thus, a coil may comprise a first leg or stretch **17** in the gap **11** and a second leg or stretch **18** in the gap **12**. The coil **17—18** may be the first of a plurality of similar structures extending to the left of that shown in FIG. 1; but, in FIG. 2, I indicate that the transducer may comprise merely the single coil **17—18**. This coil **17—18** may be developed helically from strip material, such as soft bus-bar stock, laminated and consolidated into a single rugged vibratile element. Coil **17—18** may be yieldably supported by pads **19** of acoustically low-impedance material, such as air-filled rubber.

The diaphragm means for coupling the energy available in the moving coil **17—18** to the medium into which the energy is to be radiated may comprise essentially a radiating surface **20** and a driving or backing surface **21**, said surfaces being connected to each other through a suitable compliance. The coil **17—18** may be directly supported on the back surface **21**, but, in the form shown, I facilitate assembly by mounting the coil **17—18** on a suitably shaped raised part or pedestal **22**, which may be of insulating material and formed as a part of or secured to a mounting plate **23**. The plate **23** may be secured, as by bonding, to the backing surface **21**.

The compliance connecting the two surfaces or diaphragms **20—21** may be a matrix of springs or may be defined by staggered slotted laminations running parallel to the radiating surface **20**. However, in the form shown, I indicate my preference for a unitary diaphragm construction in which the surfaces **20—21** and the compliant connection are all integrally formed. In this construction, the diaphragm means comprises a consolidated stack of transverse laminations, one of which is shown in full in FIG. 1. The compliance is derived from local weakening occasioned by a staggered orientation of slots **24** in one row, with respect to slots **25** in another row, and, if desired, with respect to slots **26** in a third row, depending upon the compliance needed for particular applications. The consolidated stack may be rigidly bonded together and secured, as by longitudinally extending tie rods or bolts **27**, and the compliant means will be understood to provide a plurality of spaced compliant connections between surfaces **20—21** distributed over the effective areas of these surfaces.

In accordance with the invention, the diaphragm means, which may be of the composite construction described at **20—21**, may be of substantially more extensive effective area than that subtended by the driving elements **17—18**, and yet the entire diaphragm means may appear to the medium as a radiator, thus providing improved impedance-matching or coupling to the medium and avoiding losses due to spill-over near the lateral limits of the driving elements.

In the form shown in FIG. 1, I have divided the diaphragm means into discrete parts, thereby providing physical separation between the driven diaphragm **20—21** and what may be termed a parasitic diaphragm or baffle **29**. In order that the parasitic diaphragm **29** shall resonate with substantially the same characteristics as the driving diaphragm, the parasitic construction may be generally similar. Thus, diaphragm **29** may comprise a radiating surface or member **30** and a backing surface or member **31**, connected by compliant means comprising staggered rows of slots **32**. The laminated nature of the parasitic diaphragm construction will be apparent from FIG. 3. Tie bolts **33** may extend the full length to hold the consolidated stack permanently assembled and, if desired, to secure the same to the end flange **34** of a mounting plate **35**. The base plate **35** is preferably spaced from the backing surface or member **31**, and this space includes an air pocket **36**, thereby substantially duplicating the conditions existing on the non-radiating side of the driving diaphragm **20**. The baffle structure **29** may be a complete subassembly removably secured as by bolt means **37** to a part **38** of the frame or housing **39** for the transducer assembly. The air pocket **36** may be defined by a bag of acoustically transparent material, such as rubber, neoprene or the like, forming part of a boot **40** encasing the laminated structure. Both the driving diaphragm and the parasitic diaphragm may be of laminated metal or plastic, depending upon the compliance characteristics required.

To complete the transducer, the magnetic-core means **10** may be secured against side plates of the transducer housing **39** and spaced from back plates **41** so as to define with the back of the core means **10** a pressure-equalizing cavity **42** for rendering the response of the transducer less depth-dependent. For pressure-equalizing purposes, a cavity **42** may contain an inflatable bag **43**, as of neoprene or the like, and the space between the bag **43** and the back plate **41** may be freely flooded by means of a bleed opening **44**. I have suggested by dashed outlines **45** that fluid-communication passages may be located at the ends of the elongated gaps **11—12** to provide free pressure communication between these gaps and the space **42** over the pressure-equalizing bag **43**. To render the transducer impervious to moisture, the entire device may be heavily coated with rubber, neoprene or the like, and locally flexible reinforcement means **46** may protect the outer rubber casing or boot **47** at the overlap between fixed and moving parts **20—39**. At least for the area over diaphragm **20**, boot **43** will be understood to be of sound-transmitting character.

In operation, the diaphragm **20** will function as described in my said copending application Serial Number 402,426, now Patent No. 2,903,673. At the same time, the parasitic diaphragm or baffle **29**, possessing, as it does, a moderate or high mechanical Q, will abstract from the medium excited by diaphragm **20** energy at or near the resonant frequency; and, because the resonant characteristics of the two diaphragms **20—29** are preferably substantially the same, the parasitic diaphragm **29** will reradiate as it resonates sympathetically and substantially in phase with the diaphragm **20**. The presence of the diaphragm or baffle **29** thus serves to increase the resistance which the medium presents to the driven diaphragm **20** to a value approaching that appropriate to the total combined area of the diaphragm **20** and baffle **29**.

In FIG. 4, I show a slight modification which may exhibit characteristics which are in substantially all respects similar to those described for the case of FIGS. 1 to 3. The principal difference between the two structures is that in FIG. 4 the parasitic diaphragm **50** and the radiating or driven diaphragm **51** are mounted in close side-by-side adjacency without any interposed barrier. This construction necessitates assembling the parasitic diaphragm **50** in the same structure as the main body of the transducer, and encasing both diaphragms **50—51** with common seal or boot means **52**. In the arrangement of FIG. 4, the compliant connection between A.C. coil means **17** and the driving diaphragm is afforded by a single slotting **54** of the diaphragm laminations at each point of thrust application. In order to preserve similar resonant characteristics in the parasitic diaphragm **50**, I show a similar slotting at **55** at the point of compliant connection to a backing plate or counterweight member **56**. Member **56** may constitute the mass equivalent to coil means **17**, and it reacts with the radiating face of parasitic diaphragm **50**, through the compliant connection.

Other parts of the structure of FIG. 4 may resemble those described for FIG. 1, and at **45** I suggest that the construction of FIG. 4 lends itself to pressure-compensating or depth-compensating treatment. It will be noted that the passage **45** is, in reality, freely communicable with the air space on the backside of parasitic diaphragm **50**, so that both the radiating and the parasitic diaphragm are uniformly corrected for depth-dependence. In order to mechanically locate coils **17** against damage, I show cushions **57** of yieldable material located laterally between points of thrust application to the respective diaphragm parts.

In the description thus far, and whatever the embodiment of the invention, I have generally referred to my composite diaphragms as including opposite surfaces connected by a compliance; these parts may also be viewed from the aspect such that the compliant connections extend between two particular reacting masses. Thus, in FIG. 1, the radiating members or masses **20—30** are compliantly connected to their corresponding driving or backing members or masses **21—17—18** and **31**, respectively. Also, since the radiating members **20—30** and **50—51** are thick and stiff and laterally extensive, and since they function as pistons essentially in a single plane, I find it convenient to refer to them as planar radiating slabs. In every case, the planar radiating slab is compliantly connected to a reacting counterweight, which in FIG. 4 is substantially only member **56** or coil **17**, and which in FIG. 1 is either the backing member **31** or member **21** (plus coil **17—18**), as will be understood.

It will be seen that I have described relatively simple means for increasing the effective radiating or response area of a given transducer construction. The presence of the parasitic diaphragm permits the driven diaphragm to bear substantially all the resistance of the medium and to relieve the driven diaphragm from reactive components of coupling to the medium. The baffle construction may be fully pressure-compensated for operation at varying depths and, in the specific form of FIG. 1, the separate unitary construction of the baffle **29** makes possible ready replacement of baffles **29** of slightly different resonant characteristics in order to produce given desired results.

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 combination, for underwater acoustic radiation, diaphragm means comprising two spaced surfaces and a compliance therebetween, and electromechanical means in driving relation with one of said surfaces at a location laterally remote from one edge of said diaphragm means, whereby said edge and the other surface of said diaphragm means near said edge may be essentially uncoupled to said electromechanical means except through the liquid acoustic medium but may nevertheless resonate parasitically.

2. In combination, for underwater acoustic radiation, diaphragm means comprising adjacent driven and undriven surfaces, each of said diaphragm means further comprising separate backing surfaces coupled to said first-mentioned surfaces by separate compliances, each of said diaphragm means being resonant at substantially the same frequency, and electromechanical means in driving relation with the backing surface for said driven diaphragm.

3. In combination, adjacent electrically-responsive and parasitic diaphragm means of generally similar construction, each said diaphragm means comprising relatively stiff yieldable material with an effectively continuous radiating surface and with an effectively continuous backing surface, the body of said diaphragm means having a plurality of spaced laterally distributed cavities therein defining a plurality of laterally spaced uniform compliant connections between said surfaces, whereby said body between said surfaces may be stiffly compliant, and electrodynamic means coupled to said responsive diaphragm means.

4. In a transducer for underwater acoustic radiation, magnetic-core means defining a plurality of spaced elongated gaps, a movable strip of conducting material including opposed legs in the respective fields of two of said gaps, a first diaphragm including a radiating surface exposed to the radiating medium and coupled to said strip through a stiff-spring compliance, and a second diaphragm adjacent said first diaphragm and comprising a radiating surface exposed to the medium and substantially in the plane of said first-mentioned radiating surface, and a reaction mass behind the radiating surface of said second diaphragm and connected thereto through a stiff-spring compliance.

5. A transducer according to claim 4, in which a third diaphragm similar to said second diaphragm is mounted adjacent said first diaphragm at a location laterally opposed to said second diaphragm.

6. In combination, for underwater acoustic radiation, transducer-housing means acoustically open on a radiating side thereof, magnetic-core means contained within said housing means and defining on said open side a plurality of spaced elongated gaps, a movable strip of conductive material including opposed legs in the respective fields of two of said gaps, a compliant resonant radiating diaphragm driven by said movable strip and covering an area of the open side of said housing and exposed to the radiating medium, and a parasitic compliant resonant diaphragm of resonant properties substantially matching those of said driving diaphragm and exposed to the medium in remaining open area on the open side of said housing.

7. The combination of claim 6, in which a dividing wall of said housing extends between said diaphragms.

8. The combination of claim 7, in which an acoustically transparent boot covers the radiating surface of said driving diaphragm and extends into sealing contact with said dividing wall to the exclusion of said parasitic diaphragm, said parasitic diaphragm being removably secured as a unit to said housing independently of said radiating diaphragm.

9. The combination of claim 6, in which said diaphragms are mutually adjacent without any barrier therebetween.

10. The combination of claim 6, in which a single continuous boot of acoustically transparent material covers the radiating surfaces of both said driving and parasitic diaphragms.

11. As an article of manufacture, a compliant parasitic diaphragm for directionally responsive liquid-immersed application, comprising substantially coextensive driving and backing surfaces connected to each other by stiffly compliant means, acoustically transparent means encasing said diaphragm and defining an air-filled pocket on the backside of said diaphragm and substantially coextensive therewith.

12. As an article of manufacture, a compliant parasitic diaphragm comprising driving and backing surfaces connected to each other by compliant means, acoustically transparent means encasing said diaphragm and defining an air-filled pocket on the backside of said diaphragm and substantially coextensive therewith, said driving surface and said compliance and said backing surface being defined by a consolidated stack of transverse laminations with aligned slotted openings so as to establish compliant areas between said surfaces.

13. In an underwater 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 diaphragm comprising a driving surface fixedly carrying said moving coil and a radiating surface connected to said driving surface through a stiff compliance, 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, and a baffle comprising a driving surface alongside the driving surface of said diaphragm and a backing surface of mass substantially equal to that of said driving surface and connected to said driving surface through a stiff compliance substantially matching that of said diaphragm.

14. A transducer according to claim 13, and an air-filled bag of yieldable material immediately behind the backing surface of said baffle.

15. A transducer according to claim 13, in which free fluid-communication with said bag and within said transducer is substantially coextensive with the backing surfaces of both said diaphragm and said baffle.

16. As an article of manufacture, a compliant parasitic diaphragm comprising driving and backing surfaces connected to each other by compliant means, said surfaces and compliant means being defined by a consolidated stack of transverse laminations with aligned slotted openings, said slotted openings extending in lateral rows, there being a plurality of rows with the slots of adjacent rows in laterally staggered relation, and an acoustically decoupling pocket coextensive with said backing surface.

17. An article according to claim 16, and including mounting means connected to longitudinal ends of said stack at a location intermediate said driving and backing surfaces.

18. An article according to claim 16, in which said mounting means includes a tie rod passing through said stack and projecting out both ends thereof.

19. In combination, two diaphragms supported in side-by-side adjacency, one of said diaphragms comprising a radiating surface and a backing surface connected thereto by a compliance, and electromechanical means coupled to the other of said diaphragms and responsive to a frequency of the order of magnitude of the resonant frequency of said one diaphragm.

20. In combination, a primary electromagnetically driven resonant radiator for underwater radiation, and a juxtaposed secondary resonant radiator structurally separate from and unconnected to said primary radiator, said radiators being resonant at substantially the same frequency and both being exposed to an external medium, whereby said secondary radiator may radiate through coupling through the medium when said primary radiator is driven at substantially said frequency.

21. In combination, for underwater use, a primary driven radiator including a planar radiating slab, and a juxtaposed secondary resonant radiator resonant at the driven frequency of the primary radiator and including a planar radiating slab adjacent and substantially coplanar with said first-mentioned radiating slab.

22. A secondary underwater radiator, comprising a planar radiating slab coupled to a counterweight by com-

pliant means, and an air compliance behind said counterweight to decouple the same.

23. In combination, for underwater use, a primary planar radiating slab and a secondary planar radiating slab in side-by-side substantially coplanar relation, separate counterweights independently connected to the backs of said slabs by compliant means, and air-compliance means behind said counterweights to decouple the same, the counterweight for said primary slab including a driving element.

24. The combination of claim 23, in which said driving element is an electrodynamic coil.

25. In combination, for underwater use, elongated planar radiating-slab means, separate counterweights independently connected to the back of said slab means at spaced locations by compliant means, an air-compliance means behind said counterweights to decouple the same, one of said counterweights including a driving element.

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