July 12, 1955 W. T. HARRIS 2,713,127

VARIABLE POSITION TRANSDUCER

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FIG. 1.

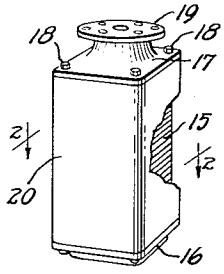



FIG. 2.

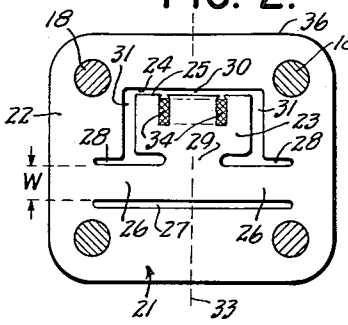



FIG. 3.

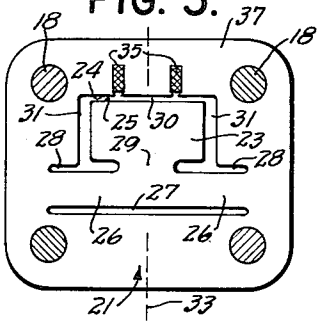



FIG. 4.

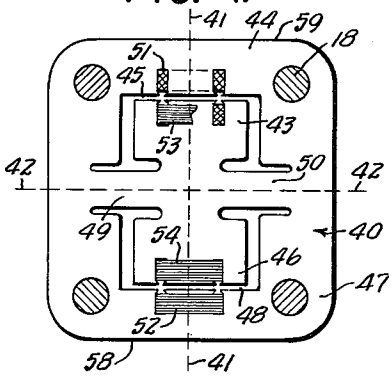



FIG. 6.

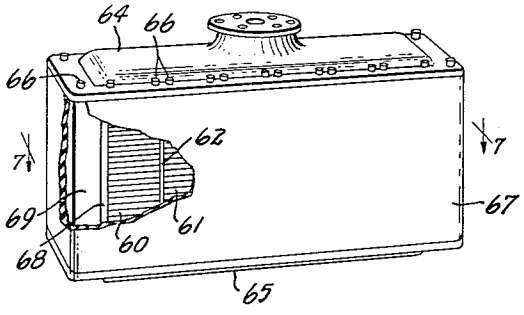



FIG. 7.

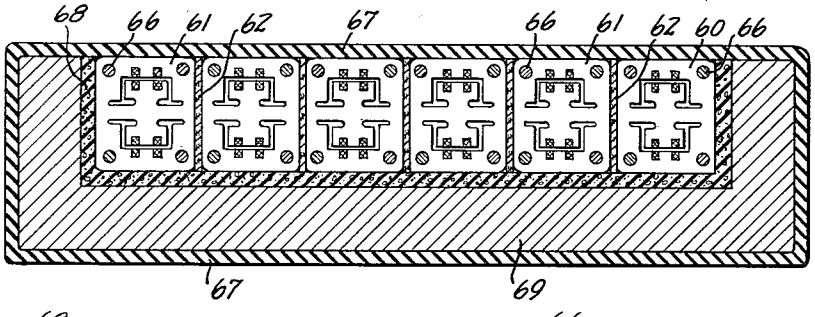



FIG. 8.

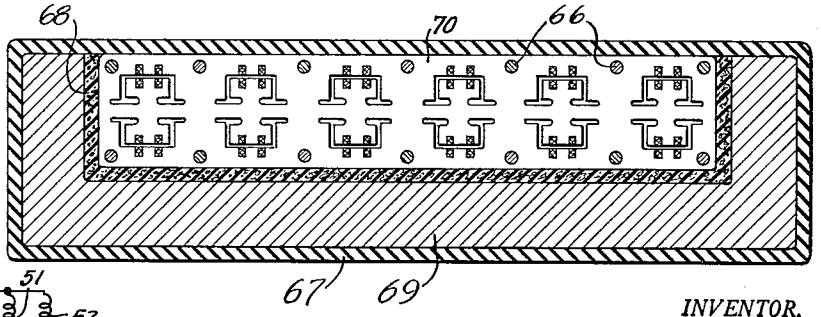
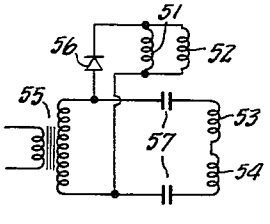



FIG. 5.




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VARIABLE POSITION TRANSDUCER

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FIG. 9.

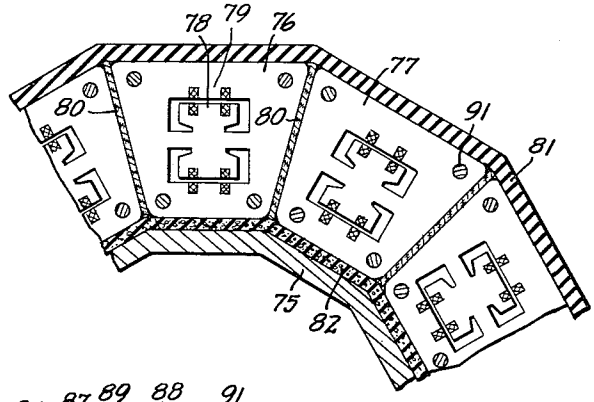



FIG. 10.

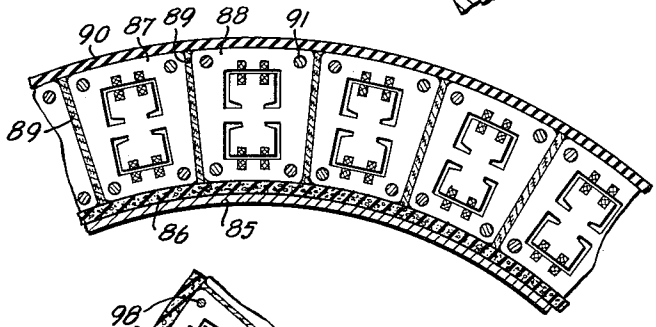



FIG. 11.

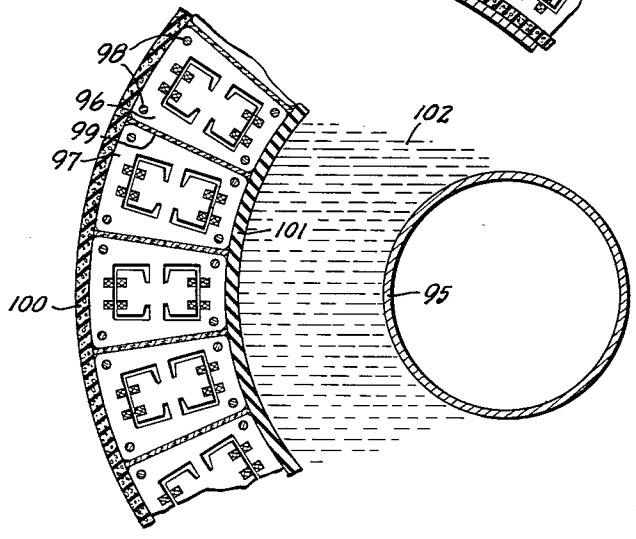
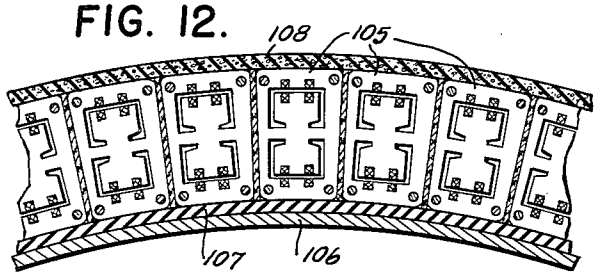



FIG. 12.




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United States Patent Office 2,713,127 Patented July 12, 1955



2,713,127

# VARIABLE POSITION TRANSDUCER

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

Application May 9, 1952, Serial No. 287,077

28 Claims. (Cl. 310—15)

My invention relates to electro-acoustic transducers of high-power conversion capacity, having particular application in the frequency range of from 1 to 15 kilocycles per second.

Conventional transducers employ piezoelectric and magnetostrictive effects, but these effects do not provide a convenient means for producing high-power resonant projectors in the frequency range below 10 kc./s. While there is some possibility of producing such projectors for operation at frequencies as low as 5 kc./s., as by using laminated magnetostrictive stacks, or loaded crystal resonators or loaded barium-titanate resonators, these forms are all poorly suited for use in the range below 10 to 15 kc./s. Magnetostrictive types in this range become rather bulky and expensive and tend to achieve a maximum efficiency in the order of 25 per cent, due to excessive eddy currents and to the relatively great magnetic and mechanical hysteresis of annealed nickel. In crystal transducers, crystal size becomes large even at 10 ks./s.; other necessary features of crystal transducers lead to relatively high cost and poor availability. In the case of barium titanate, large transducers have not yet been built to produce adequate dependability, reproducibility, and stability.

It is, accordingly, an object of the invention to provide a substantially improved construction for high-power application in the range indicated.

It is another object to provide an improved transducer of high efficiency, and basically versatile as to shape, application and electric impedance.

It is a further object to provide a transducer construction meeting the above objects and lending itself to mass production and to the use of relatively non-critical materials.

It is also an object to achieve certain special purpose arrays with transducer elements of the above character.

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 perspective view of a fully assembled transducer incorporating features of the invention;

Fig. 2 is a plan view of a transducer lamination, which may be one of the laminations in the stack contained within the transducer of Fig. 1;

Fig. 3 is a view similar to Fig. 2 but illustrating an alternative lamination;

Fig. 4 is a view of still another lamination;

Fig. 5 is an electrical diagram schematically indicating a means for exciting stacks of laminations as in Figs. 2, 3, and 4;

Fig. 6 is a perspective view of another fully assembled transducer according to the invention;

Fig. 7 is an enlarged sectional view in the plane 7—7 of Fig. 6;

Fig. 8 is a view similar to Fig. 7, but illustrating a modified, integral construction for the transducer of Fig. 6; and



Figs. 9 to 12 are fragmentary sectional views illustrating special-purpose applications of principles of the invention.

Briefly stated, my invention contemplates a transducer operating on a basically different concept from those characterizing operation of conventional magnetostrictive, piezoelectric or electrostrictive devices. These conventional devices are operative because of alternating volume changes, but my device operates on the principle of what I call "position-change." My transducer employs two reacting masses which, for simplicity of concept, may be termed an armature mass and a stator mass (although by "stator" I do not imply that the particular element is "static" in any sense of the word), with stiffly yieldable means connecting such masses to each other for yieldable relative movement along essentially a single axis. The mass of the armature and the stiffness of the yieldable connecting means comprise an oscillator system which reacts against the stator to accelerate the stator in the medium. Excitation means, reacting between these masses and along this axis, establish and maintain the mechanical oscillations.

In the specific forms herein disclosed, my transducer comprises a stack of laminations, each of which integrally incorporates the reacting masses as well as the yieldable means connecting these masses. The reacting masses are disposed for relative movement so as to open or close a gap in the magnetic material of the lamination, and a circuit for conduction of magnetic flux is defined by the gap and by the reacting masses and by the yieldable connecting means. Electric coupling to this path will produce or reflect mechanical relative displacements of the respective masses. Various special-purpose results may be obtained by changing the proportions and symmetries of the parts, but I prefer a construction in which two armatures react against one stator in a push-pull operation.

Referring to Fig. 1 of the drawings, my invention is shown in application to a relatively simple assembly comprising a stack **15** of laminations, bonded together with a suitable resin, and tied between end-cover members **16**—**17** by means of elongated bolts **18**, clamping the covers **16** and **17** against the stack. The upper cover member **17** may include a flange **19** for attachment to mounting means as needed for particular applications, and electrical leads to the transducer may be brought through a central opening in the flange connector **19**. For protection of the exposed edges of the laminations, I prefer to encase the assembly in a jacket **20** of resilient sound-transmitting means, such as rubber or rubber-like material.

In Figs. 2 and 3, I illustrate simplified versions of laminations for use in the stack **15**. In Fig. 2, each lamination **21** comprises a stamping of magnetic material, such as silicon steel or transformer iron, with such a formation of slots as to define what may be termed essentially a stator area **22** enclosing an armature area **23**. These areas may have opposed pole faces **24**—**25**, respectively, and may be yieldably joined to each other remote from the pole faces, as by connecting means **26**. The connecting means **26** is shown to comprise two transversely extending strips or ribbons of width W, proportioned in accordance with the desired frequency response of the device. An elongated slot **27** serves to isolate the armature mass from the stator mass and to define one side of the connecting means **26**, while two corresponding but shorter slots **28** define the other sides of the connecting means **26**; the lamination material between slots **28** provides a central stem **29**, whereby the armature mass may be integrally joined to the connecting means **26**. The slot **30** between pole faces **24**—**25** is preferably as narrow as possible, consistent

with the desired freedom of relative movement between armature and stator masses, and this slot may communicate with the slots 28 by way of slots 31, isolating the relatively movable masses 22—23.

The described structure will be appreciated as defining a symmetrical arrangement of circuit paths for circulation of magnetic flux, symmetrically on both sides of a longitudinal axis of symmetry 33. Each path may include the gap 30, the armature mass 23, one of the connecting means 26, and the corresponding outer part of the stator mass 22. It is preferred that each such path shall reach saturation so as to cause the use of more restricted flux paths, still symmetrical about the axis 33, and each spanning the gap 30 twice, at spaced locations along the pole faces 24—25, as will be made more clear.

In accordance with the invention, I provide excitation means reacting between the armature and stator masses, so as to produce relative movement of the pole faces along the axis of symmetry 33. Such means may involve an electromagnetic coupling to the possible flux paths, and I prefer that such coupling be made at a point where one coupling may link both paths. The described lamination may be permanently polarized on the axis of symmetry 33, and a signal winding 34 in slots formed in one of the pole faces (say, in the armature pole face 25 in Fig. 2, and in the stator pole face 24 in Fig. 3) may provide the desired results when alternating current of the desired frequency is fed to such signal winding. With each swing of the alternating excitation, the pole faces will be correspondingly attracted or repulsed, with the result that the forward lamination edge (36—37, as the case may be) will constitute a radiating face. If polarization is used to avoid frequency-doubling effects, that is, with the D.-C. flux greater than the maximum A.-C. flux, attraction of the pole faces will vary, but repulsion will not occur.

In the described structure, it will be noted that placement of the winding slots intermediate the ends of the pole faces may force the pole faces to define two gaps for each of the more restricted flux paths. Thus, in addition to the large path (through gap 30, stator 22, armature 23, and connecting means 26), both pole faces 24—25 cooperate with winding 34 to define two restricted flux paths symmetrical about axis 33. Each such restricted path passes first across gap 30 and through winding 34 and second across gap 30 and externally of winding 34. To achieve this more restricted flux path, I prefer not only that the coil slots shall be well within the outer limits of the pole faces (as at locations substantially half way from the axis 33 to the outer pole face limits), but that the coil slots shall not be so deep as to impair flux circulation through the lamination material immediately behind the bottoms of the coil slots.

If the laminations of Figs. 2 and 3 are not permanently magnetized, the desired polarization may be achieved by introduction of a direct-current component in the signal applied to winding 34 or 35, as the case may be. Alternatively, each of the winding designations 34 and 35, as shown in the drawings, may be understood to be schematically representative of two separate windings in each of the pole faces shown, the polarizing current being applied to one winding and the signal current being applied to the other winding, in each case.

In Fig. 4, I illustrate a lamination 40 of a type which I consider to be preferable over those shown and described in connection with Figs. 2 and 3. The arrangement of Fig. 4 will be seen to be not only symmetrical about an axis 41, along which displacements take place, but also generally symmetrical about a central transverse axis 42. Thus, the lamination 40 may be said to comprise two motor parts, each complete with its armature and stator masses. One motor may comprise an armature mass 43, surrounded by a stator mass 44, and opposing pole faces may define a gap 45 at the upper end of the stator, in the sense of the drawings. The other motor may be in all respects similar and comprise an armature mass 46, surrounded by a stator mass 47, both masses having opposed pole faces, defining a gap 48. The slotted arrangements for the lamination 40 may be as described in Fig. 2 with a central slot such as the slot 27 defining the transverse center of symmetry, so that each of the motors may, independent of the other, involve its own integral connection between armature and stator. However, in the preferred form shown, the transverse axis of symmetry is about common connecting means for the two armatures to their respective stator masses. Thus, connecting means 49—50, having widths appropriate to the design frequency, may integrally connect both armatures 43—46 in common to both stators 44—47, as will be seen.

With the described structure, each of the motors may define its own circuit paths for the circulation of magnetic flux; or both motors may share the same circuit paths. In the former case, a circuit is defined by a gap (45 or 48), and by an armature, stator and connecting means (43, 49—50, and 44; or 46, 49—50, and 47); in the latter case, a circuit is defined by two gaps (45 and 48), two armatures (43 and 46), and one of the stators (44 or 47). In addition, more restricted paths, each twice spanning one of the gaps 45—48, may be defined, as explained in connection with the lamination of Fig. 2. Electromagnetic coupling may be made to any part of these paths, but as in the case of the arrangement of Figs. 2 and 3, I prefer to establish coupling near the pole faces, so as to assure greatest flux concentration in the vicinity of greatest relative movement of the parts. For simplicity of assembly, I provide coil slots in all pole faces, so that polarizing windings and signal windings may be separately assembled in their own slots. Thus, the windings 51—52 may receive polarizing current, and the windings 53—54 may receive signal current. It will be understood that signal windings and polarizing windings may be reversed in their positions with respect to the gaps 45—48, the only criterion being that each be wound for the desired current-handling capacities.

In Fig. 5, I illustrate typical electrical connection of the windings to a common source, as by means of a transformer 55. A rectifier 56 converts the output of transformer 55 into polarizing current for the windings 51—52, and capacitors 57 isolate direct current from the signal windings 53—54.

In operation, it will be understood that, with a proper connection of the polarizing and signal windings, a swing of applied signal voltage in one direction will cause attraction of one pair of pole faces, say to close the gap 45, and repulsion of the other pair of pole faces, say to open the gap 48. Likewise, a swing of opposite polarity will achieve the opposite result, say of opening the gap 45 and closing the gap 48. Thus, the device tends to respond in push-pull, with both armatures reinforcing each other in their reaction with their respective stators, thereby increasing the efficiency of operation. The device as described thus far may be considered to be of basic or elemental nature, but it will be seen to lend itself readily to arrayed configurations, depending upon the desired usage.

If the distance from the center of the back surface, say the surface 58, to the center of the front surface (59) is less than one-half a wave length, the directivity pattern in the plane of the lamination will be the familiar cosine pattern. If the height of the stack of laminations 40 is large, the pattern in the plane normal to the laminations 40, will have a different form, depending upon the height. If the half-perimeter dimension is greater than a half wave length, the forward lobe of the directivity pattern broadens and becomes depressed at the center of symmetry, and the directivity index becomes less than the 4.8 db characteristic of the cosine or

pressure-gradient pattern. The forward intensity becomes zero, and the pattern a "clover leaf," when the half-circumference equals a wave length. In spite of these properties, not all of which may seem desirable, it will be seen that the versatility of my device is in no sense undesirably limited; for example, the cosine pattern can be converted to a cardioid pattern or to a non-directional pattern by the application of a suitable compliance to the back surface. In larger arrays, "clover-leaf" patterns can similarly be combined to produce desirable over-all effects.

In Fig. 6, I illustrate a fully assembled transducer incorporating an array of stacks of laminations, which may be of any of the previously described forms. The unit comprises a plurality of vertical stacks, such as the stacks 60—61, assembled in side-by-side relation with a layer 62 of pressure-release material, such as cork, between adjacent elements. The stacks may be secured in assembled relation to end-cover members 64—65, by means of bolts 66 passing from top to bottom of the assembly. The entire device may be jacketed by sound-transmitting means, such as a rubber-like blanket 67, and without further structure the device will be bidirectional. If a predominant unidirectional response is desired, pressure-release material, such as air-filled rubber or the like 68, may be applied as a blanket over all but the desired radiating faces. In Fig. 7, I have shown the transducer array cradled in a frame casting 69, embracing the longitudinal ends of the assembly and covering the entire back; and the pressure-release blanket lines the casting and surrounds the transducer elements flush with the front face of the device. The rubber blanket 67 is shown to envelop both the array and the casting.

In Fig. 8, I illustrate a slight modification to show how certain simplicity and economy may be achieved, as by stamping laminations for a plurality of transducer units in common. Thus, the single lamination 70 may be used to define a large plurality of transducer elements (in the form shown, six). The slot proportions and armature and stator proportions for the respective motor units of Fig. 8 may be as described for the lamination units of Fig. 7, and the various polarizing and signal windings may also be similarly devised. In either arrangement, all signal-winding currents may be of the same magnitude, and all polarizing currents to the respective windings may be of the same magnitude; but in certain applications the response may be "tailored" by a suitably attenuated proportioning of signals applied to the respective transducer elements. Thus, signals of greatest strength may be applied to the more central elements, and the excitation energy may be of reduced magnitude at the outer transducer units.

In Fig. 9, I illustrate further flexibility in the employment of my basic transducer design. The particular configuration illustrated may be used for omnidirectional response in the plane of the transducer elements. The device may be built around a central frame member 75, which may be a polygonal casting, with separate transducer elements 76—77 applied to the respective faces of the casting. The transducer laminations are shown to be more or less trapezoidal or sector-shaped, but possessing nevertheless similar proportions insofar as the armature and stator parts 78 and 79 are concerned. Windings may also be as described in the previous arrangements, and layers of pressure-release material 80 may isolate adjacent transducer elements. A jacket 81 of sound-transmitting material may envelop the active faces of all transducer elements, and pressure-release material 82, such as air-filled rubber, may insure against inward radiation.

In Fig. 10, I illustate a portion of another transducer which may have essentially omnidirectional properties in the plane of the laminations. The device of Fig. 10, however, is generally circular, so that the entire assembly will appear cylindrical. The construction may be based on a cylindrical core or casting 85, surrounded by a blanket 86 of pressure-release material, and sector-shaped transducer elements 87—88 may be positioned around the blanket 86. As in Fig. 9, isolation layers 89 of pressure-release material, such as cork, may separate adjacent transducer elements; and a jacket 90 of sound-transmitting material, such as neoprene or the like, may encase the assembly. In both Figs. 9 and 10, the stacks of laminations may be retained in assembled relation and assembled to the entire structure by means of tie-bolts 96 to end-cover plates (not shown).

The prismatic radiators of Figs. 9 and 10 happen to illustrate the case of response radially outwardly of the transducer arrays; but it will be appreciated, from the foregoing discussion of properties of the basic push-pull lamination of Fig. 4, that my invention is equally applicable for concerted radiation inward, as illustrated in Figs. 11 and 12. In Fig. 11, I illustrate the case of focused sonic excitation of a steel pipe 95, which may be a flow tube in an industrial processing establishment. The transducer array may be cylindrical and utilize the same laminations as those described in Fig. 10. Thus, a plurality of transducer elements 96—97 may be tied by bolts 98 to end-cover plates (not shown), and isolated from each other by pressure-release means 99. An outer jacket 100 of pressure-release material may serve to attenuate outward radiation, and an inner jacket 101 of sound-transmitting material may protect all active faces of the transducer elements 96—97. Efficient coupling may be had to the flow tube 95 by filling the intervening distance between the transducer array and the tube 95, with sound-transmitting material 102, as, for example, by casting the transducer to the pipe with a sound-transmitting plastic or potting compound. However, in the form shown, I have merely filled this space with a fluid, such as water or preferably castor oil.

In the case illustrated in Fig. 12, a transducer array, comprising a plurality of sector-shaped elements 105, is applied directly to the outer surface of a pipe or vessel 106 to be excited. A layer of sound-transmitting material 107 may physically protect the transducer elements and still achieve a proper transfer of sonic power to the tube or casing 106, and sound-attenuating means such as a pressure-release blanket 108 may materially reduce outward radiation. It will be appreciated that when the respective transducer units 105 are excited, whether it be in phase or in progressively rotated phase around the circumference of the vessel or casing 106, the entire casing is caused to radiate inwardly, and the contents of vessel 106 may be subjected to severe excitation. The result may be to achieve and maintain a fine dispersion of catalytic particles, as in a cracking plant, or severe microscopic turbulence may be established to promote mixing and other results, depending upon the application.

It will be seen that I have described a basic transducer element construction of high efficiency and power-handling capabilities, particularly at relatively low frequencies. My construction is inexpensive to fabricate and is versatile as to shape, application, and electrical impedance. Its employment of iron, as distinguished from magnetostrictive materials such as annealed nickel, make for substantially reduced eddy-current and hysteresis losses. The preferred push-pull configuration provides stability of structure and performance (i. e. no mean displacement from the equilibrium position) at different power levels; it also offers linearity of response due to balancing out of effects proportional to the square of the displacement. My basic construction lends itself to design for particular properties; for example, in designing for a particular "Q" value, the armature and stator mass proportions are controlled (for equal masses, "Q" is low; for stator mass small compared to armature mass, "Q" is high). Furthermore, since the size of the device is not strictly determined by the resonant frequency, my

construction lends itself to independent designing for frequency.

While I have described the invention in detail for the preferred forms shown, 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. As an article of manufacture, a transducer lamination of magnetic material comprising a stator mass area completely surrounding an armature mass area, said mass areas having adjacent pole faces on opposite sides of said lamination defining two gaps on a common axis extending in the plane of said lamination, and yieldable means integrally connecting said stator mass area and said armature mass area symmetrically about said axis and intermediate said gaps.

2. As an article of manufacture, a transducer lamination comprising a single stator and a plurality of armatures, each of said armatures being completely surrounded by parts of said stator and there being a separate stator pole face opposite a separate pole face on each of said armatures, thereby defining a corresponding plurality of gaps, and stiffly resilient means remote from each of said gaps and integrally and yieldably connecting each of said armatures to said stator.

3. In a transducer of the character indicated, a stacked plurality of like laminations of magnetic material, each lamination integrally including a stator mass area and an armature mass area with opposed adjacent pole faces and a yieldable integral connection between such mass areas, so as to define a continuous and homogenous circuit path for magnetic flux through said gap and said mass areas and said yieldable connection, said connection being physically within the peripheral confines of said stator mass area, electric excitation means coupled to said path, whereby said mass areas may be driven with a relative movement changing said gap along an axis passing through the plane of each lamination so that, upon excitation, said stack may be displaced both in a front direction and in a back direction in the plane of such axes, and pressure-release means extending through the plane of such axes on one side of said stack to the exclusion of the other side.

4. A transducer according to claim 3, and including a covering of sound-transmitting material over the opposite side of said stack and extending through the plane of said axes.

5. A transducer array including a plurality of transducer elements, each of said elements comprising a stacked plurality of laminations of magnetic material, each lamination including a stator completely surrounding an armature, said armature and stator each having two pole faces defining spaced gaps at opposed sides of said lamination and yieldable connecting means integrally connecting said armature and stator between said gaps and symmetrically with respect to an axis passing through said gaps; whereby a first circuit path for accommodation of magnetic flux may include the said gap on one side of said lamination, as well as said connection means and the pole pieces defining said gap, and further whereby a second circuit path may be defined by the other said gaps and said connection means and the pole pieces defining said other gap, and separate electric excitation means separately linked to said paths.

6. An array according to claim 5, in which said separate excitation means include windings connected in push-pull.

7. An array according to claim 5, in which corresponding laminations of adjacent stacks are integral with each other.

8. An array according to claim 5, and including a central mounting member, said array being supported as a spaced plurality of stacks about said mounting member, and pressure-release means between said stacks and said mounting member, whereby said array may respond primarily externally of said mounting member.

9. An array according to claim 5, and including a conduit having a sound-transmitting wall, said stacks being spaced from said wall with their axes converging thereon.

10. An array according to claim 9, and including sound-transmitting means intimately coupling said stacks to said wall.

11. An array according to claim 9, and including pressure-release means surrounding said array of stacks.

12. In a transducer of the character indicated, a stacked plurality of like lamination means, and common electrical coupling to said plurality, each lamination means being of magnetic material and comprising a stator mass area completely surrounding an armature mass area, said areas being spaced at opposite sides of said lamination means at two gaps defined in each instance by a stator pole piece directly opposite an armature pole piece, whereby a circuit for passage of magnetic flux may exist through said armature mass area and said pole pieces and said gaps and one lateral side of said stator mass area, said electrical coupling linking said circuit, and means for supporting the stacked mass areas for relative displacement on an axis through said pole pieces, said last-defined means being stiffly resilient in the sense of said axis.

13. A transducer according to claim 12, in which said last-defined means is symmetrically disposed with respect to said axis.

14. A transducer according to claim 12, in which said electrical coupling is linked to a part of said circuit in said armature mass area.

15. A transducer according to claim 12, in which said electrical coupling is linked to a part of said circuit in said stator mass area.

16. In a transducer of the character indicated, a stacked plurality of like laminations means, and common electrical coupling to said plurality, each lamination means being of magnetic material and comprising a stator mass area and an armature mass area, said areas being spaced at an elongated gap defined by an elongated stator pole face directly opposite an elongated armature pole face, one of said pole faces having coil-receiving slots for said electrical coupling and intermediate the limits of said elongated gap, whereby a restricted flux path may be defined twice through said gap at the pole-face locations on opposite sides of one said coil slots, and means for yieldably supporting the stacked mass areas for relative displacement on an axis through said pole faces.

17. A transducer according to claim 16, in which both pole faces have coil-receiving slots for said electrical coupling at corresponding locations along said gap.

18. In a transducer of the character indicated, a consolidated stack of like laminations defining two oscillating systems yieldably and integrally connected in common and for otherwise free relative oscillation along a predominant axis of mechanical oscillation, one of said systems surrounding the other of said systems and electromagnetic excitation means including a gap between said systems and oriented to produce a reaction component along said axis for displacing both said systems relatively to each other and against the action of the yieldable connection.

19. In a transducer of the character indicated, integral armature-and-stator means including an array of stacks of laminations of magnetic material, each lamination of each stack including an armature mass and a stator mass with a gap therebetween, said masses being integrally joined by a connection yieldable to permit relative movement of said masses to change said gap, corresponding of said armature and stator masses and of said yieldable connections defining a circuit path for accommodation of magnetic flux, and electric-excitation means coupled

to corresponding parts of a plurality of such paths, the axes of relative movement of armature-and-stator masses in each of two adjacent stacks being substantially normal to the axis on which said two stacks are adjacent, said adjacent axes being inclined with respect to each other.

20. In a transducer of the character indicated, a stacked plurality of like laminations of magnetic material, each lamination integrally including a stator-mass area and an armature-mass area with opposed adjacent pole faces and a yieldable integral connection between such mass areas, so as to define a continuous and homogeneous circuit path for magnetic flux through said gap and said mass areas and said yieldable connection, said connection being physically within the peripheral confines of said stator-mass area, electric-excitation means coupled to said path, whereby said mass areas may be driven with a relative movement changing said gap along an axis passing through the plane of each lamination so that, upon excitation, said stack may be displaced both in a front direction and in a back direction in the plane of such axes.

21. A transducer according to claim 20, in which the pole face of one of said mass areas has a slotted opening for reception of said electric-excitation means in coupled relation to said paths.

22. A transducer according to claim 20, in which the pole faces of both of said mass areas have slotted openings for reception of separate coils of said electric-excitation means in coupled relation to said paths.

23. A transducer comprising a stator mass completely surrounding an armature mass, said masses being of magnetic material and having opposed adjacent pole faces on opposite sides of said transducer and defining two gaps on a common axis, yieldable means integrally connecting said stator mass and said armature mass symmetrically about said axis, and electric-excitation means coupled to magnetic paths including said gaps.

24. A transducer comprising a stator mass completely surrounding an armature mass, said masses being of magnetic material and having opposed adjacent pole faces on opposite sides of said transducer and defining two gaps on a common axis, yieldable means integrally connecting said stator mass and said armature mass symmetrically about said axis at a location intermediate said gaps, and means for exciting in push-pull the separate magnetic circuits established through said respective gaps and through said yieldable means.

25. In a transducer of the character indicated, a consolidated stack of laminations, each lamination comprising an armature-mass area and a stator-mass area, said stator-mass area surrounding said armature-mass area symmetrically on opposite sides of a longitudinal response axis, said armature-mass area being integrally and resiliently connected to said stator-mass area at locations symmetrically disposed with respect to said axis and yieldable predominantly along said axis, there being a flux gap between pole faces at longitudinally opposed locations on said stator-mass area and on said armature-mass area, and electric-winding means linked to said stack in a relation to establish symmetrical flux circulation on the one hand through said gap and armature-mass area via one side of said stator-mass area, and on the other hand through said gap and armature-mass area via the other side of said stator-mass area.

26. A transducer according to claim 25, in which said armature-mass areas and said stator-mass areas are provided in a transversely extending array, the longitudinal response axes of the respective elements of said array being in substantially parallel relation.

27. A transducer according to claim 25, in which said armature-mass areas and said stator-mass areas are provided in a transversely extending array, the longitudinal response axes of the respective elements of said array being inclined with respect to each other.

28. In a transducer of the character indicated, an armature body, a rigid exterior stator body surrounding said armature body, means within the peripheral confines of the stator body reactively connecting said armature body to said stator body, said bodies having through the reactive connection a natural predominant mechanical oscillating frequency in a longitudinal mode of oscillation, and means including a magnetic circuit circulating magnetic flux through said bodies and including a gap in said longitudinal mode for exciting said transducer at substantially said frequency.

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