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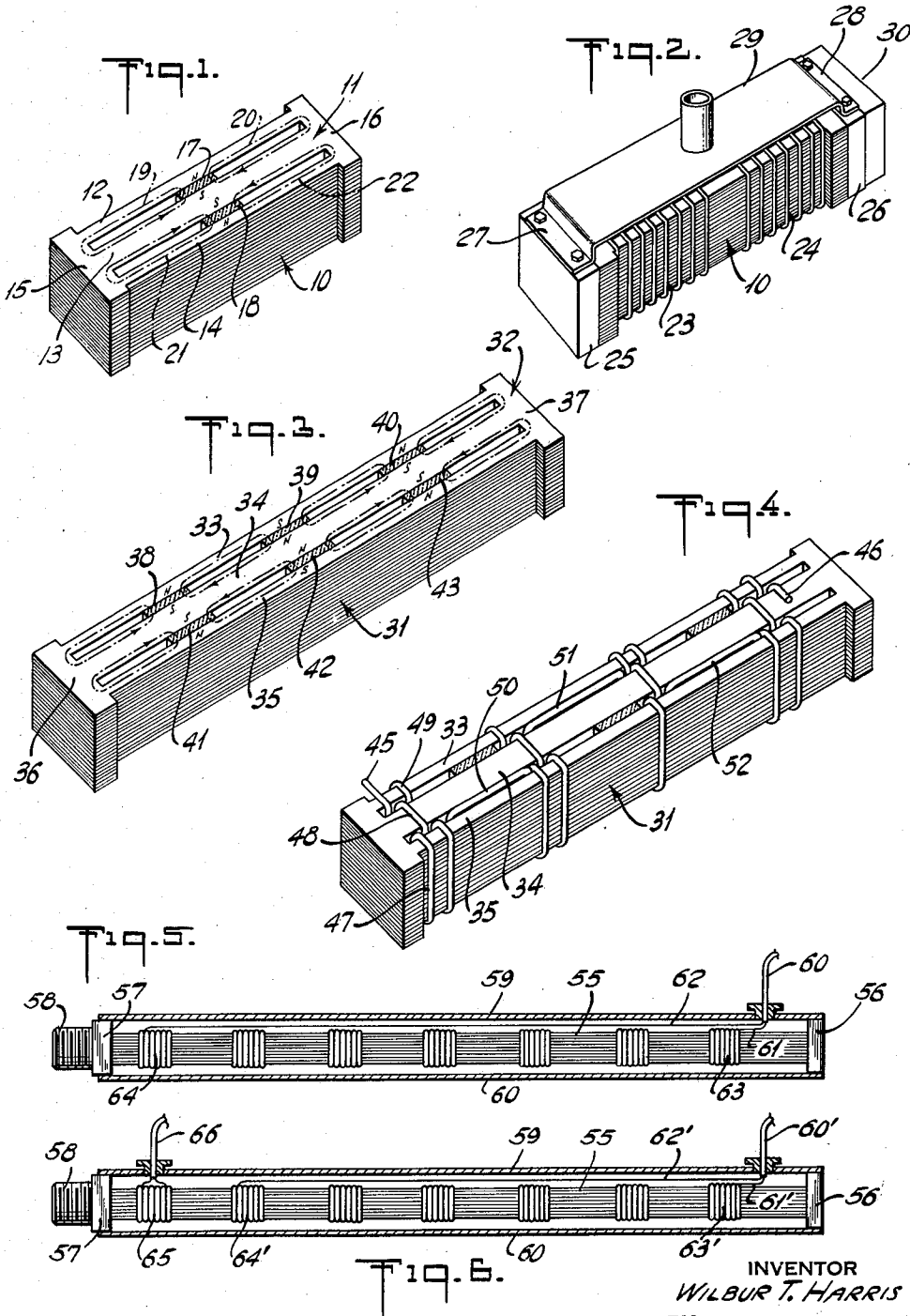
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LOW-FREQUENCY MAGNETOSTRICTIVE TRANSDUCER

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2 Sheets-Sheet 1



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Fig. 7.

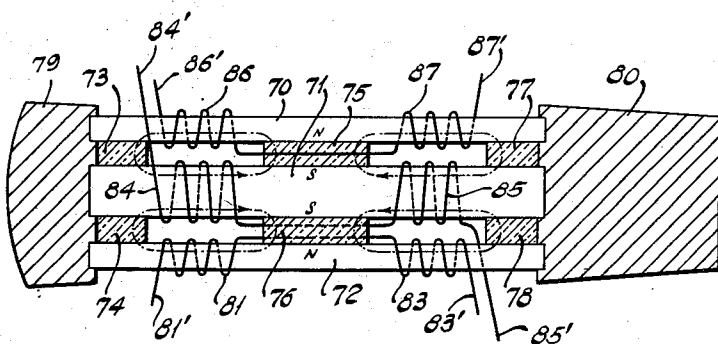
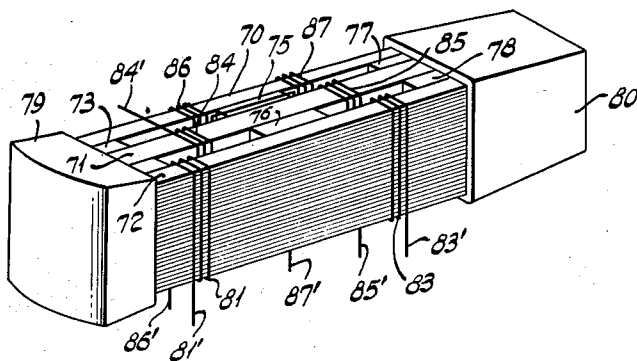


Fig. 8.

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LOW-FREQUENCY MAGNETOSTRICTIVE TRANSDUCER

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Application January 30, 1956, Serial No. 562,271

14 Claims. (Cl. 310—26)

My invention relates to electromechanical transducers of the type having application to acoustic transmission and reception and to vibratory tools; it is also applicable to transducer elements, as for underwater acoustic application and for employment in plurality in array configurations. This invention incorporates improvements and modifications with respect to copending applications Serial No. 475,462, filed December 15, 1954, Serial No. 558,947, filed January 13, 1956, and Serial No. 559,657, filed January 17, 1956.

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

It is another object to provide a transducer construction of improved inherent efficiency and applicable particularly to relatively low-frequency operation.

It is a further object to provide a magnetostrictive transducer construction meeting the above objects and enabling substantial economies in the use of magnetostrictive material.

It is a still further object to provide a transducer construction meeting the above objects and inherently adaptable to relatively inexpensive assembly techniques.

It is also an object to provide a transducer meeting the above objects and featuring plural closed magnetic flux-conducting paths, and yet permitting the development of electrical windings by means of conventional coil winding techniques.

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 simplified view in perspective illustrating a magnetostrictive core incorporating features of the invention;

Fig. 2 is a similar view of a completed assembly incorporating the core of Fig. 1 and of a type having particular application to industrial sonic cleaning as when immersed in a liquid medium;

Fig. 3 is a perspective view of a modified core according to the invention;

Fig. 4 is a similar view illustrating the development of a winding linked to the core of Fig. 3;

Figs. 5 and 6 are end views of arrays of transducer elements of the general variety illustrated in Fig. 4, the difference between Figs. 5 and 6 being solely in the details of winding connections;

Fig. 7 is a simplified view in perspective illustrating a magnetostrictive element having a core representing a further modification of the constructions of Figs. 1 and 3; and

Fig. 8 is a horizontal sectional view in the plane 8—8 of Fig. 7.

Briefly stated, my invention contemplates elongated magnetostrictive transducer assemblies, characterized by a plurality of spaced elongated legs joined by flux-conducting means at a plurality of longitudinally spaced lo-

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cations, whereby for any two adjacent legs, a plurality of longitudinally adjacent independent flux-conducting paths may be defined. The flux-conducting means intermediate any two longitudinally adjacent flux-conducting paths preferably accommodates flux from both paths in the same sense, and therefore adjacent paths are preferably oppositely polarized. Since the adjacent paths are oppositely polarized, the separate windings linked to the various paths must be developed in opposed senses, so that opposed flux circulation is developed in adjacent paths. In certain forms of the invention, the core is developed from a consolidated stack of like laminations in which the plural spaced legs are integrally joined at head and tail ends, with permanent magnet inserts longitudinally intermediate said ends. In another form, the separate legs are separately assembled as independent stacks of laminations, and flux-conducting inserts at the ends of the legs and at intermediate locations on the legs serve to define the plural flux-conducting paths; the latter construction permits development of windings on the legs prior to assembly of the legs to each other.

Referring to Figs. 1 and 2 of the drawings, my invention is shown in application to a transducer having a magnetostrictive core 10 comprising a consolidated stack of like laminations 11. Each lamination comprises a plurality of legs 12—13—14, which are similarly elongated and which are laterally spaced. First flux-conducting means 15 joins first corresponding ends of the legs 12—13—14, and second flux-conducting means 16 joins the other corresponding ends of the legs 12—13—14. In the form shown, the first and second flux-conducting means 15—16 are formed as integral parts of the laminations 11, and, for convenience, may be termed head and tail portions. Third flux-conducting means is employed to connect corresponding intermediate portions of adjacent pairs of legs and, in the form shown, a first flux-conducting insert 17 is bonded to the adjacent legs 12—13, and a second flux-conducting insert 18 is bonded to the adjacent legs 13—14; an epoxy resin provides a satisfactory bonding agent.

The described construction will be seen to establish plural independent flux-conducting paths, schematically indicated by the light phantom designations 19—20—21—22. Flux of adjacent paths utilizes common flux-conducting means. Thus, for example, the flux-conducting insert 17 serves flux from both longitudinally adjacent paths 19 and 20, and the left half of the center leg 13 serves flux in the adjacent paths 19—21; the width of center leg 13 is thus preferably substantially twice the individual width of either of the outer legs 12—14, the outer-leg widths being preferably equal to each other.

In order to minimize losses, I prefer that flux in adjacent paths shall be oppositely polarized so that all flux travelling in any leg or insert common to two adjacent paths may travel in the same direction. Polarizing windings may be employed for this purpose, but I prefer that the inserts 17 shall be permanently magnetized as, for example, of a suitable permanently magnetized ferrite. I have indicated by means of "N-S" legends on the face of lamination 11 that the inserts 17—18 should be oppositely oriented.

Signal-winding means preferably includes turns independently linked to all legs 12—13—14 of the core 10. The direction of turns for the respective windings should be such as to establish flux circulation in opposed sense in any two adjacent paths 19—20—21—22. This may be achieved by independently developed windings on each of the various leg sections or by means of the basket-weave type of winding described in greater detail in my said co-pending application Serial No. 475,462 and also schematically illustrated and later to be described in connection with Fig. 4. Whatever the method of wind-

ing development, the signal windings will have the appearance shown at 23—24 in Fig. 2, when assembled.

In order to economize on the use of magnetostrictive material, that is, in order to limit use of magnetostrictive material essentially only to flux-circulating parts of the device, I illustrate in Fig. 2 the employment of counterweight members 25—26 which may be termed head and tail weights respectively, and bonded to the respective longitudinal ends of the stack 10. The counterweights 25—26 need not be laminated and are preferably of non-magnetic material. For example, they may be of aluminum, non-magnetic stainless steel, zinc alloy, or of other desired alloy composition. The counterweights 25—26 are shown in Fig. 2 to provide a convenient means for mounting the transducer unit, as, for example, by bolting end flanges 27—28 of a mounting bracket 29 thereto; it will be noted that the transverse offset bracket portions adjacent flanges 27—28 may be sufficiently yieldable so as not to impair longitudinal oscillation of the complete transducer. Finally, for those applications in which radiation is not required at both ends of the device, I illustrate acoustic pressure-release material 30 (e. g., cork, wood, air-filled rubber, or the like) bonded to one longitudinal end, say the tail end 26 of the assembly.

In Fig. 3, I illustrate modification of the type of core construction illustrated in Fig. 1, the modification being in a manner permitting a more elongated magnetostrictive body, as for application to lower frequencies. The core 31 of Figs. 3 and 4 may nevertheless closely resemble that of Fig. 1. Thus, the basic lamination 32 from which the stack 31 is developed may again comprise spaced elongated legs 33—34—35 with flux-conducting means 36—37 joining the corresponding ends. In Figs. 3 and 4, however, I provide even greater pluralities of longitudinally adjacent flux paths, as developed by bonding (at plural longitudinally spaced locations) separate flux-conducting inserts 38—39—40 for the slot between adjacent legs 33—34, and 41—42—43 for the slot between adjacent legs 34—35. All inserts 38—39 . . . 43 are preferably permanent-magnet ferrite blocks, and bonding is preferably accomplished by means of a solvent-free agent, such as an epoxy resin. No legends have been applied to the various independent flux paths developed by the described construction, but the directional arrows indicate the opposed polarization of adjacent paths, and the winding means is preferably developed to circulate flux in adjacent paths in opposite directions.

As indicated generally above, the winding means may involve independent sets of turns linked to the respective legs of the various flux paths. However, in Fig. 4, the winding, which is shown in simplified schematic form, may be developed from a single conductor extending between leads 45—46 and may employ the basket-weave development described in greater detail in my said co-pending application Serial No. 475,462. Thus, beginning at the lead 45, the winding may first enter over the top of leg 33 and run down the slot between legs 33 and 34, across the bottom of leg 34, up the slot between legs 34—35, across the top (at 47) and around and beneath the leg 35, across (at 48) the top of leg 34, down the slot between legs 33—34, across the bottom of leg 33, and around and over (at 49) the top of leg 33, and so on. Similar basket-weave developments may be followed for the linkage to legs 33—34—35 in the space longitudinally between inserts 38—39 and inserts 41—42, and so on; however, since adjacent flux paths must be excited in opposite sense, the direction of basket-weave development longitudinally between inserts 38—39 and 41—42 is opposite to that described at 47—48—49. Connection between these two successive basket-weave developments is illustrated at 50, where the conductor wraps around and therefore hides the insert 41. A similar connection 51 connects the basket-weave develop-

ment between inserts 38—39 and 41—42, to the basket-weave development between inserts 39—40 and 42—43, these two adjacent basket-weave developments being in opposed-phase relation. Finally, a connection 52 couples the last two basket-weave developments (again in opposed-phase relation), and the entire winding ends with the lead 46.

For all the forms thus far described, the polarization of flux paths and the excitation coupling thereto is such as to promote in-phase magnetostrictive elongations for all parts of all legs so that the transducer may elongate and longitudinally resonate as a whole. Because the flux paths are short, there is negligible leakage along closely adjacent stretches of any one path, and highly efficient electromechanical energy conversion is achieved.

In Figs. 5 and 6, I illustrate application of my magnetostrictive transducer construction to arrays employing a plurality of like core elements 55 in side-by-side relation. The views of Figs. 5 and 6 are end views so that only one such element 55 is visible. Nevertheless, it will be understood that the head and tail ends of all elements 55 of the array may be bonded to common head and tail members 56—57, and the latter may include a threaded or otherwise formed adapter means 58 for attachment to a mounting bracket (not shown). For protection, relatively flexible side panels 59—60 may be secured to the head and tail members 56—57; the enclosed space may be liquid-filled, or may be free-flooded with the liquid medium in which the transducer is to be operated.

In the arrangement of Fig. 5, a single lead-in supply 60 serves all windings between longitudinally adjacent flux paths, so that the conductors 61—62 are shown connected at the ends of the end windings 63—64. On the other hand, in Fig. 6, the lead-in supply 60' includes conductors 61'—62' serving all but one of the windings, namely, from the end winding 63' to the winding 64' next to the last winding 65. The last winding 65 is shown with independent lead connections 66 which may be used for feed-back purposes in a self-excited transducer, employed as described in greater detail in my co-pending application Serial No. 524,545, filed July 26, 1955.

In Figs. 7 and 8, I illustrate application of the principles of my invention to a magnetostrictive transducer element in which coil windings may be developed on core-leg sections prior to assembly of the core legs to each other. Thus, the core legs 70—71—72 may comprise independent stacks of uniform strips of magnetostrictive material, the width of the strips of leg 71 being substantially twice the individual widths of outer legs 70—72, because, of course, the central leg 71 serves laterally adjacent flux paths. First flux-conducting means 73—74 connects first corresponding ends of the legs 70—71—72; second flux-conducting means 75—76, at longitudinally spaced but corresponding locations, connects adjacent legs 70—71 and 71—72; and third flux-conducting means 77—78 connects the legs 70—71—72 at a third longitudinal location.

Since the connecting means 73—74 . . . 78 are not relied upon for longitudinal magnetostrictive elongation, they may be independent elements of magnetic flux-conducting material not having particular magnetostrictive properties. Accordingly, the end elements 73—74 and 77—78 may be of ferrite ceramic, and the intermediate inserts or blocks 75—76 between longitudinally adjacent flux paths are preferably ferrite permanent magnets. Blocks 75—76 should be of thickness (determining lateral spacing of stacks 70—71 and 71—72) sufficient to supply the required magnetomotive force and of width (longitudinally along the legs 70—71—72) sufficient to pass the required magnetic flux. The ferrite blocks 73—74—77—78 should be magnetically soft and have high permeability, high saturation flux density, and low coercive force.

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The mechanical assembly of Figs. 7 and 8 is completed by applying a solid head weight 79 to one longitudinal end and a solid tail weight 80 to the other longitudinal end. Each of the weights 79—80 may be precision cast with a recess or cavity (or plural recesses or cavities) formed to closely receive the projecting ends of the legs 70—71—72, and the assembly is retained by bonding in the relation shown. The head element 79 is preferably of light metal, such as aluminum, and the tail weight 80 is preferably of relatively heavy metal, such as a zinc alloy.

As explained above, electrical windings may be assembled to the respective legs 70—71—72 prior to the assembly of the legs to each other. Thus, winding 81 on the left end of leg 72 may be developed at a first longitudinal location and winding 83 may be developed (in the opposite sense) at a second longitudinal location; both windings 81—83 may be developed from the same conductor, and joined by connector 82, with external connections available at lead ends 81'—83'. Both winding developments may be made on conventional helical coil-winding apparatus in a single chucked position of leg 72, and prior to assembly of leg 72 to the rest of the transducer. In a similar manner, separate opposed-phase windings 84—85, with leads 84'—85', may be developed as a sub-assembly on leg 71; and opposed-phase windings 86—87, with leads 86'—87', may be developed as a sub-assembly on leg 70. In assembling the wound legs to each other (at spacer blocks 73—74 . . . 78) and in electrically interconnecting the winding leads, care must be taken that the adjacent windings 81—84 are oppositely wound or oppositely energized and that the adjacent windings 84—86 are oppositely wound or energized. The leads may be interconnected in series or in parallel in a manner determining the desired relative direction of flux circulation, as indicated by the phantom arrows in Fig. 8.

It will be seen that I have described an improved transducer construction particularly applicable to low-frequency use wherein it is important to maintain utmost efficiency and assurance against flux leakage between closely adjacent legs of any given flux path. My basic construction is inherently applicable to any length, and the employment of plural longitudinally adjacent independent flux paths assures against flux losses. In spite of the apparent complexity of structure, it is nevertheless applicable to relatively inexpensive assembly because, as indicated particularly in connection with Figs. 7 and 8, conventional coil-winding techniques are applicable prior to assembly of wound sub-assemblies. Long transducer elements may be housed inside metal tubes with end closures to make oscillators for drilling, shake tables, lapping devices, and the like; in the latter connection, Figs. 5 and 6 may be viewed as essentially longitudinal sectional views through the tubular housing in which parts labelled 59—60 are essentially the same tubular housing part. The high amplitudes developed at low frequencies are advantageous in very long transducers of the type shown in Figs. 5 and 6, and as indicated particularly in connection with Fig. 6, the construction lends itself to self-excited operation. For liquid-immersed applications where unidirectional response is needed, one end may be shielded by compliant means, such as a double-walled metal cover with air between the walls or by means of an absorbent or pressure-release pad, as at 30 in Fig. 2. Also, for liquid-immersed applications, and if corrosion-resistant materials are employed, including, for example, windings developed with polytetrafluoroethylene-insulated conductors, my invention permits the use of unhoused constructions, or, alternatively, constructions in which the housings are flooded, as will be understood.

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 described in the claims which follow.

I claim:

1. An electromechanical transducer, comprising two

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separate laterally spaced elongated legs of magnetostrictive material, separate blocks of magnetic flux-conducting material magnetically connecting corresponding end portions of said legs, a further block of magnetic flux-conducting material magnetically connecting corresponding intermediate portions of said legs, said intermediate block being a permanent magnet and therefore establishing polarized flux-conducting paths on the one hand through said legs and said intermediate block and the block at one end, and on the other hand through said legs and said intermediate block and the block at the other end, and winding means linked separately to said paths along said legs and in a polarity to circulate flux in opposite directions in said paths.

2. An electromechanical transducer, comprising two separate laterally spaced elongated legs, each leg comprising a consolidated stack of like longitudinally extending magnetostrictive strips, separate blocks of magnetic flux-conducting material magnetically connecting corresponding end portions of said legs, a further block of magnetic flux-conducting material magnetically connecting corresponding intermediate portions of said legs, said intermediate block being a permanent magnet and therefore establishing polarized flux-conducting paths on the one hand through said legs and said intermediate block and the block at one end, and on the other hand through said legs and said intermediate block and the block at the other end, and winding means linked separately to said paths along said legs and in a polarity to circulate flux in opposite directions in said paths.

3. An electromechanical transducer, comprising three separate laterally spaced elongated legs, each leg comprising a consolidated stack of like but separate longitudinally extending magnetostrictive strips, a first pair of separate magnetic flux-conducting blocks magnetically connecting corresponding end portions of said legs, a second pair of magnetic flux-conducting blocks magnetically connecting corresponding intermediate portions of said legs, a third pair of magnetic flux-conducting blocks magnetically connecting the other corresponding ends of said legs, whereby separate flux paths may be established between adjacent blocks and adjacent legs, means oppositely polarizing adjacent flux paths, and winding means linked to said flux paths along said legs and in a sense to develop circulating flux of opposite polarity in adjacent flux paths, whereby the instantaneous flux in those portions of the intermediate leg which are common to two adjacent flux paths may always flow in the same direction, and whereby the instantaneous flux passing through any single one of said intermediate blocks may always be in the same direction for each of the two adjacent flux paths served thereby.

4. A transducer according to claim 3, in which the outer legs are of equal width and are each substantially one-half the width of the intermediate leg.

5. An electromechanical transducer comprising three laterally spaced elongated legs, each leg comprising a separate consolidated stack of like longitudinally extending magnetostrictive strips, a first pair of separate blocks of magnetic flux-conducting material magnetically connecting first corresponding end portions of said legs, a second pair of separate blocks of magnetic flux-conducting material magnetically connecting further corresponding portions of said legs at a location longitudinally spaced from said first corresponding portions, the blocks of one of said pairs being permanently magnetized and oriented to establish opposed polarity in the respective flux-conducting paths defined on the one hand by a first two adjacent legs and by the magnetic blocks spacing the same and on the other hand by the other two adjacent legs and the magnetic blocks spacing the same, and separate windings coupled to the legs of said separate paths in a sense to circulate flux in opposite directions in adjacent of said separate paths.

6. A transducer according to claim 5, and including

head and tail weights bonded to the respective longitudinal ends of said legs.

7. In an electrical transducer, a core including a consolidated stack of like laminations of magnetostrictive material, each lamination including a plurality of laterally spaced elongated legs integrally formed with a head joining said legs at one end and defining an elongated slot between two adjacent legs, a first single ferrite insert in said slot and longitudinally spaced from said head and defining with said head and with said adjacent legs a first flux-conducting path, a second single ferrite insert in said slot and longitudinally spaced from said first insert on the opposite side thereof from said head and defining with said first insert and with said adjacent legs a second flux-conducting path, said first ferrite insert being permanently magnetized, whereby said flux-conducting paths are polarized in opposite directions, and winding means linked to said separate paths in a sense to circulate flux in opposite directions in said paths.

8. In an electromechanical transducer, a core including a consolidated stack of like laminations of magnetostrictive material, each lamination including a plurality of laterally spaced elongated legs integrally formed with a head joining said legs at one end and defining an elongated slot between two adjacent legs, a first single ferrite insert in said slot and longitudinally spaced from said head and defining with said head and with said adjacent legs a first flux-conducting path, a second single ferrite insert in said slot and spaced from said first insert on the opposite side thereof from said head and defining with said first insert and with said adjacent legs a second flux-conducting path, means magnetically polarizing said flux-conducting paths in opposite directions, and winding means linked to said paths in a sense circulating flux in opposite directions in said paths.

9. In an electromechanical transducer, a magnetostrictive core having a plurality of laterally spaced elongated legs extending in the same general direction, first flux-conducting means joining said legs at a first longitudinal location, second and third flux-conducting means joining said legs at second and third locations longitudinally spaced from each other and from said first location, the intermediate of said flux-conducting means being permanently magnetized, and winding means coupled to one of said legs.

10. A transducer according to claim 9, and including independent counterweights independently bonded to the respective ends of said core.

11. A transducer according to claim 10, and including mounting structure secured to both said counterweights independently of said core.

12. A transducer according to claim 10, and including acoustic pressure-release means bonded to the outer longitudinal exposed face of one counterweight to the exclusion of the other.

13. In an electromechanical transducer, an elongated

magnetostrictive core having a plurality of laterally spaced elongated legs, first flux-conducting means joining said legs at a first longitudinal location, whereby an elongated slot is defined between said legs, second flux-conducting means joining said legs at a second longitudinal location spaced from said first flux-conducting means and defining with said first flux-conducting means and with said legs a first flux-conducting path, third flux-conducting means joining said legs at a third longitudinal location and defining with said legs and with said second flux-conducting means a second flux-conducting path, fourth flux-conducting means joining said legs at a fourth location and defining with said flux-conducting means a third flux-conducting path, means oppositely polarizing adjacent of said paths, and separate winding means linked to said respective paths in a direction to circulate flux in opposite directions in adjacent paths.

14. In an electromechanical transducer, an elongated magnetostrictive core having a plurality of laterally spaced elongated legs, first flux-conducting means joining said legs at a first longitudinal location, whereby an elongated slot is defined between said legs, second flux-conducting means joining said legs at a second longitudinal location spaced from said first flux-conducting means and defining with said first flux-conducting means and with said legs a first flux-conducting path, third flux-conducting means joining said legs at a third longitudinal location and defining with said legs and with said second flux-conducting means a second flux-conducting path, fourth flux-conducting means joining said legs at a fourth location and defining with said flux-conducting means a third flux-conducting path, said second flux-conducting means comprising a permanent-magnet insert, whereby said first and second paths are oppositely polarized, said third flux-conducting means comprising a further permanent magnet insert whereby said second and third paths are oppositely polarized, said two inserts being oriented to polarize said second flux-conducting path in the same direction, first winding means including turns separately linked to a first two of said paths in a direction to circulate flux in opposite directions in the same, and second winding means independent of said first winding means and linked to the remaining of said three paths.

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