Jan. 21, 1958 W. T. HARRIS 2,820,912

MAGNETOELASTIC TRANSDUCER

Filed Oct. 1, 1953

Fig. 1.

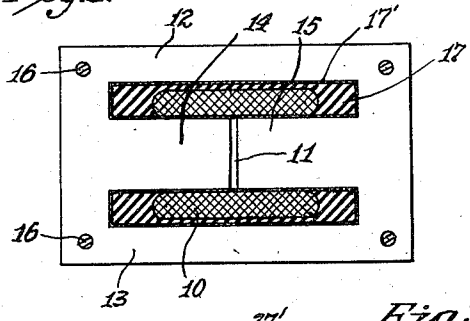


Fig. 2.

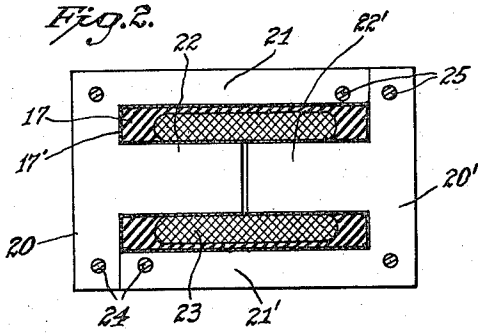


Fig. 3.

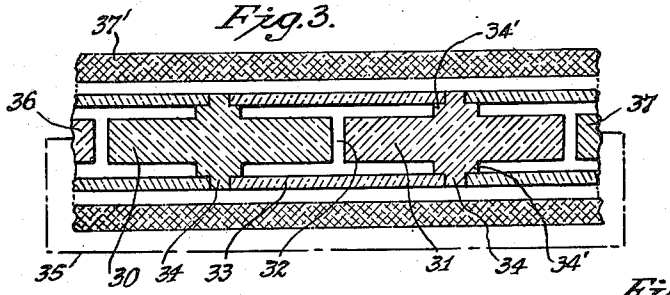


Fig. 4.

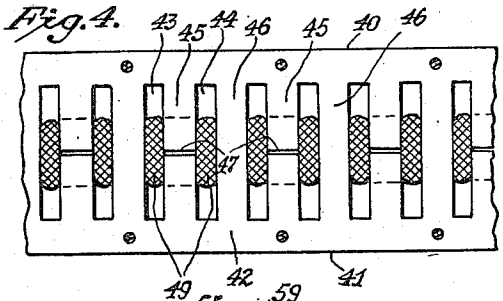


Fig. 5.

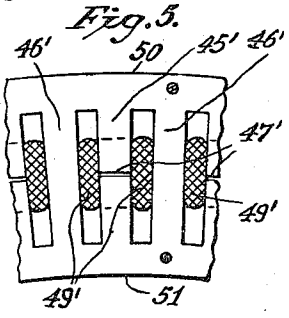


Fig. 6.

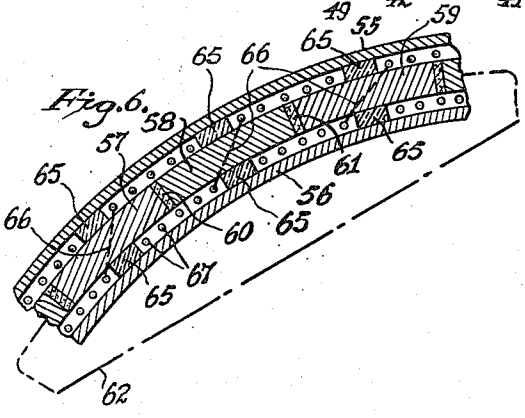
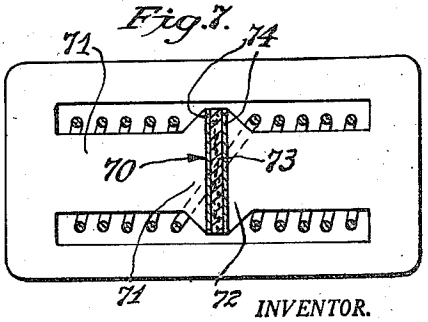


Fig. 7.



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2,820,912

MAGNETOELASTIC TRANSDUCER

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Application October 1, 1953, Serial No. 383,563

27 Claims. (Cl. 310—26)

My invention relates to electromagnetic acoustic transducers and, in particular, to those applicable to high-efficiency low-frequency use.

It has been a common practice to use mechanically resonant piezoelectric or magnetostrictive structures as the active transducer elements when designing for efficient response to acoustic or vibratory energy, whether in liquid or solid media. For the higher sonic and supersonic ranges, such structures offer particular advantages; but in my copending application, Serial No. 287,077, filed May 9, 1952, now Patent 2,713,127, I have shown how my concept of variable-position transducers may open the way for more efficient response at the lower frequencies.

Piezoelectric resonators are relatively efficient as converters of electrical energy into acoustic energy, but are not well suited to some applications because of high cost, fragility, or sensitivity to elevated temperatures; barium titanate, rochelle salt, and ammonium dihydrogen phosphate transducers are illustrative of those suffering from these objections. Likewise, magnetostrictive transducers suffer serious handicaps, such as high cost, consumption of strategic materials (i. e. nickel or cobalt) and somewhat limited efficiency conversion efficiencies greater than about twenty percent are not easily achieved.

It is, accordingly, an object tof this invention to provide improved transducers of the character indicated.

Another object is to produce higher efficiency electromagnetic transducers without increasing the consumption of strategic materials.

It is a specific object to provide electromagnetic transducers achieving improved efficiencies through reliance on elastic rather than magnetostrictive properties of the core.

It is a general object to provide a new organization of parts for the construction of electromagnetic transducers, but possessing marked advantages over purely magnetostrictive transducers, as well as over other known and functionally comparable transducers; in this connection, it is also an object to provide a rugged structure capable of radiating at relatively elevated power levels.

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 cross-sectional view of a transducer incorporating features of the invention and revealing the plan view of one of the laminations of the core thereof;

Fig. 2 is a view similar to Fig. 1, but illustrating a modified core construction;

Fig. 3 is a longitudinal sectional view of a further modified core construction;

Figs. 4 and 5 are fragmentary views generally similar to Figs. 1 and 2, but illustrating modified core constructions lending themselves to excitation by an array of windings;

Fig. 6 is a fragmentary cross-sectional view of a transducer employing an array of core elements of the invention; and

Fig. 7 is a view similar to Fig. 1, but illustrating a further modified core.

Briefly stated, my invention contemplates electro-magnetic transducers employing a new priniciple which utilizes elastic, rather than magnetostrictive properties of the core; in order to avoid confusion, I term this principle the magnetoelastic property of the structure. According to this principle, lengthwise contraction results when current is passed through a coil coupled to my core, which may be but is preferably not of a material possessing good magnetostrictive properties; contraction results primarily from magnetic forces at a gap in a central part of the flux path excited by the coil. The magnetoelastic effect may dwarf any concurrent magnetostrictive effect, to the extent that it makes little difference whether the magnetostrictive effect slightly reinforces or slightly negatives the predominating magnetoelastic effect. This magnetoelastic propery is to be clearly distinguished from a purely magnetostrictive effect, which relies solely upon a property of the material itself, rather than on magnetic forces contributed at a gap, in order to produce the elongations or contractions of the excited core material.

Referring to Fig. 1 of the drawings, my invention is shown in application to a magnetoelastic transducer embodying an electric winding 10 coupled to a closed-loop magnetic path having a flux gap 11 therein. In the form shown, the magnetic path is defined as two loops with a common center leg. Thus, the magnetic core may comprise two outer legs 12—13 and a center leg having portions 14—15 on opposite sides of the gap 11. In order to promote the efficient distribution and sharing of flux, the overall cross-section of the center leg 14—15 may be substantially the sum of the cross-sections of the outer legs 12—13 and, in the form shown, the width of the center leg 14—15 is substantially twice the individual widths of the outer legs 12—13. The winding 10 is preferably linked to the core means on both sides of the gap 11, as in the symmetrical disposition shown. A complete transducer may comprise a stack of laminations as described and of overall height extending out of the plane of the drawing, depending upon the desired performance. All laminations may be aligned and held in compressed and permanently fixed relation by plastic bonding and by means of tie bolts, as at 16. For efficient radiation in fluid media, the gap 11 should be unified, or should be filled with an acoustic absorber such as cork or sponge rubber; but for ruggedness I prefer that all other voids be filled or potted with non-magnetic material, as with a rubber of plastic filler, designated 17, making sure to relieve the clamping effect of the plastic, as by means of a cork or the like liner 17'.

In use, since I do not rely primarily on magnetostrictive performance, the core need not be of highly refined material designed to optimize magnetostrictive response, but may, on the other hand, be merely of ordinary silicon steel, as used in transformer laminations. While this material may possess some magnetostrictive properties, the predominant elongation or contraction produced upon exciting the core is attributable to the magnetic contraction of the poles 14—15 across the gap 11. In the case illustrated, which I shall term the magnetoelastic case, and using silicon-steel laminations with a 0.01-cm. gap 11, an incremental length change dl/l, expressed in terms of overall length of the excited leg, may be of the order of -600×10^{-6} at $B=12{,}000$ and $H=120$. For the corresponding case of a magnetostrictive elongation, as when the center leg is uninterrupted by a flux gap and in which a more favorable

magnetostrictive material (e. g. nickel) is employed, the proportional length change may be of the order of -40×10^{-6} at saturation (B=5000, H=500, approximately).

Noting that the net magnetic permeability for the silicon-steel case, including the effect of the flux gap, may be greater than the usual permeability of commercial nickel, and that the saturation flux density is three times greater, it is apparent that, on a comparable-size basis, magnetoelastic transducers can handle approximately ten times the power conversion of the nickel purely-magnetostrictive type. Further, since high-quality transformer iron has a ten-fold higher resistivity, eddy-current energy dissipation, the chief cause of low efficiency in magnetostrictive transducers, is far less important. Also, transformer iron may be cut burr-free in properly made press tools, whereas nickel is tough and ductile, and the resulting edge fins tend to produce short-circuits between laminations. Indeed, by resorting to my magnetoelastic transducer construction, the usual 20 to 25 percent efficiency for magnetostrictive transducers can be increased to substantially 75 percent, while effecting important economies.

With further reference to the specific case discussed in connection with Fig. 1, it is advantageous to make the flux gap relatively narrow, generally less than 0.005 inch. This can be accomplished economically by so designing the power-press tool that the laminations are cut in three operations or stages, which follow each other in automatic sequence: (1) cut out the spaces where the winding will be placed; (2) shear the center leg apart without making a gap; and (3) shave one of the sheared edges to produce the desired flux gap.

In further comparing my magnetoelastic transducer with magnetostrictive transducers of corresponding size, it is important to note characteristic differences which make for broad-band response. First, the resonant mode of operation occurs at a frequency substantially below the fundamental; the motion is characterized by an oscillatory inward and outward bowing of the outer legs **12—13**, and with D. C. magnetic polarization the structure can be mechanically biased to produce essentially only outward bowing, thus avoiding frequency-doubling effects, and producing a limited broad-band response in the range below the fundamental. Second, the magnetoelastic transducer basically comprises two coupled lengthwise oscillators, not just one; on a lumped-constant basis, one lengthwise oscillator may be visualized as comprising two end masses connected by longitudinally compliant outer legs **12—13**, while the other lengthwise oscillator (coupled to the first) is two-fold degenerate and is the longitudinal mode of the two halves **14—15** of the center leg. The two coupled resonant systems result in a net combined characteristic having one resonance lower in frequency than the lower of the two (when decoupled and viewed independently) and another higher resonance higher in frequency than the higher decoupled resonant frequency, and a broad high-response region between the two resulting resonances. Such an efficient broad-band response is a total impossibility with any known magnetostrictive element.

Because of the development of winding **10** in the construction of Fig. 1 may be difficult and tedious, I show in Fig. 2 an alternative construction lending itself to relatively simple manufacture. In the construction of Fig. 2, the core may in all respects resemble that of Fig. 1, except that it is made in two like halves. The two halves may be of generally E-shape with the legs facing each other and with the center leg slightly shorter than the outer legs, so that when the outer legs are anchored together, a gap of desired proportions is formed in the center leg. However, in the form shown, the two halves of the basic core laminations are of generally F-shape, comprising (in the case of the left half) what may be termed an elongated body **20**, with a transversely extending leg **21** integral with one end of the body **20**, and with a second transversely extending leg **22** integral with the center of the body, but of effective length just less than one-half the effective length of leg **21**; corresponding parts of the right-hand half of the laminations have been shown with the same reference numerals primed.

The construction of Fig. 2 lends itself to the separate winding of coil **23** and to the subassembly of the two halves of the core as separate consolidated stacks. Control of the size of the flux gap presents no substantial problem, since this is a matter of proper tool dimensioning; however, great care must be taken, when consolidating the unit, that plastic is not allowed to run into the flux gap. An acceptable method of assembly is first to consolidate with a plastic bonding agent two F stacks in suitable jigs, and then to clean off the consolidated stacks by filing or milling any deposits from surfaces that abut, as well as from the flux-gap surfaces. The consolidated coil assembly **23** may then be placed on one F, and the other F fitted in place. The device may finally be fastened together by a compression band or by straps and rivets, as, for example, end straps extending between tie bolts **24** and between tie bolts **25**, respectively.

For consolidating the laminations I prefer to spray the laminations individually, taking care that parts near the flux gap are shielded, and employing a thin solution of a high-temperature-curing epoxy resin. The sprayed pieces dry quickly and can be separately handled and stored. When later assembled in presses and baked, the sprayed pieces bond into a solid structure.

In Fig. 3, I show that my invention is not inherently limited to laminated or to multiple-leg core constructions, as suggested in Figs. 1 and 2; in fact, in Fig. 3 I show what I term a basic magnetoelastic core construction for insertion in any desired flux path. The basic construction of Fig. 3 involves a plurality of like core elements **30**, which may be cylindrical, flat, square, or otherwise formed, but having a section with the appearance shown. The core element **30** may be of magnetostrictive material, and I have illustrated by the sectioning my preference for a high coercive-strength material, which may be one of the ferricoxide ceramics known as ferrites. The elements **30—31** are preferably arranged in end-to-end relation with gaps (as at **32**) of desired proportions between adjacent ends, and non-magnetic means may be employed to space the elements **30—31**. In the form shown, relatively rigid spacers such as ceramic blades or tubes **33**, as the case may be, are set in direct longitudinally spacing abutment with outwardly projecting flanges **34** at the central portions of the elements **30—31**; and shoulders **34'** at flanges **34** may provide proper transverse or radial locating support for spacers **33**. The spacers may be bonded, as by thermosetting plastic means, to the supporting shoulders for the magnetostrictive elements **30—31**, and a completed end-to-end asembly of any desired number of elements may readily be fabricated. By means of the dot-dash line **35**, I suggest a continuous flux loop utilizing the described multiple-element assembly as a part thereof; the line **35** will also be understood to suggest that the rest of this flux loop or magnetic circuit may include further successions of elements **30—31**. By exciting one of the elements **30—31**, as by coil means of limited length, and by picking off a signal at a remote element, as by a further coil of limited length coupled to a remote element **30—31**, I provide adaptation of my multi-section core to delay-lay functions; but, in the form shown, the phantom-outline coil **37'** schematically suggests that, for other purposes, a plurality of elements **30—31** may be energized by a single coil.

In Figs. 4 and 5, I show application of the principles of my invention to a multiple-winding transducer in which the windings may be connected by known methods in order to develop array properties in the transducer face.

In Fig. 4, the effective transducer faces may be on opposite sides 40—41 of the lamination 42, and the lamination 42 will be understood to be one of a plurality, in a stack extending out of the plane of the drawing. Lamination 42 may be characterized by a plurality of longitudinally spaced, transversely extending pairs of slots 43—44, extending short of the sides 40—41 and defining a plurality of legs 45—46 between slots. In accordance with the invention, gaps 47 for promotion of magnetoelastic effects may be formed by properly slitting alternate legs 45, leaving the other legs 46 continuous and integral with the rest of the core. Separate electrical windings 49 may be coupled to the slitted legs 45 in the manner discussed in connection with Figs. 1 and 2. It will be appreciated that the characteristic elongation described in connection with Figs. 1 and 2 will be achieved in the configuration of Fig. 4, resulting in a front-to-back or thickness-mode oscillation of the transducer. Such a transducer would, of course, have bidirectional response properties, but by application of sound-absorbing means (such as an air-filled rubber pad) to one of the faces 40—41 in a known manner, unidirectional response may be obtained, as will be understood.

In Fig. 5, the structure is basically the same as that described in Fig. 4, except that the opposed faces 50—51 of the transducer are arcuate, as in a cylindrical array of windings. Since the parts of Fig. 5 correspond essentially with those of Fig. 4, they have been given the same reference numerals, with prime indications. It will be clear that when excited, the transducer of Fig. 5 may radiate or respond radially inwardly if sound-absorbent material, such as cork or air-filled rubber is laid over the outside, that is, over the surface 50 of the transducer; if the same sort of layer is applied to the inner surface 51, then radiation or response will be directed radially outwardly.

In Fig. 6, I show application of my basic magnetoelastic configuration to a cylindrical transducer which may radiate radially inwardly or radially outwardly, depending upon the connection of parts. For an outwardly radiating device, the radiating surface would be a continuous loop or cylindrical wall 55 of elastic material, and I prefer in the form shown that the wall 55 be of aluminum. For radially inward radiation, another similar wall 56 may be employed, and it is convenient, regardless of the inward or outward direction of propagation, to construct the transducer with both inner and outer walls 55—56. Longitudinally coextensive with the walls 55—56 and disposed radially therebetween, I provide a circumferentially extending plurality of ferromagnetic elements 57—58—59 which may be oriented parallel to the axis of the transducer and in closely spaced end-to-end relation so as to define small longitudinally extending gaps 60—61 between elements. By means of the dot-dash line 62, I schematically suggest that the arcuate fragment displayed in detail in Fig. 6 may be circumferentially continuous, and that a continuous magnetic circuit or flux path may be established through all ferromagnetic elements 57—58—59 and the gaps 60—61 therebetween.

In order to support the elements 57—58—59, I have shown relatively stiff spacer blocks 65 which may be axially or longitudinally coextensive with the elements 57—58—59 and which serve to space central portions of such elements radially with respect to the two radiating walls 55—56. I prefer that these spacer blocks be bonded both to the walls and to the ferromagnetic elements, and I prefer to employ ceramic material for these blocks. Also, to facilitate assembly, but yet not to impair underwater acoustic response, I have shown the use of cork or other pressure-release spacers in the gaps 60—61 between elements. By means of heavy dashed-line connections 66, I indicate that electrical windings, individual turns of which are suggested at 67, may be coupled to the ferromagnetic material on both sides of the various gaps 60—61 and that these windings may in turn be

serially connected to each other for the full circumferential extent of the transducer. Of course, it will be understood that the transducer may be excited upon breaking one of these connections and placing the signal generator, or receiver, as the case may be, in series with all windings. If desired, the voids between ferromagnetic elements and the inner and outer walls 55—56 may be potted (as discussed in connection with Fig. 1) in order to assure ruggedness of the assembly.

In use, electromagnetic excitation of the circumferentially extending flux path will result in simultaneous elongation or contraction, as the case may be, of all ferromagnetic elements 56—57—59, as accentuated by the magnetoelastic phenomenon that is characteristic of the invention. Because of the cylindrical nature of the configuration, these elongations will be accompanied by fluctuating radial pressures or forces applied to the spacer blocks 65, which in turn may serve as pistons driving spaced parts of the respective walls 55—56. If predominantly radially inward propagation is desired, the application of a pressure-release blanket, as of air-foam rubber, to the outer wall 55 will serve to accentuate radially inward radiation; in like manner, radially outward response may be promoted by means of a similar blanket on the inner surface of the inner wall 56.

In Fig. 7, I illustrate that my basic construction lends itself to permanent polarizing, even when the laminations of a structure as in Figs. 1, 2, 4, and 5 are of relatively low-coercive-force material, as for example, the ordinary silicon steel used for transformer cores. In Fig. 7, permanent polarization is achieved by partially filling a widened or enlarged flux gap 70 in the center leg 71-72 with a transversely extending slab 73 of high-coercive-force material, such as a magnetic-oxide ceramic. Of course, in placing the slab 73 in the gap 70, great care must be taken to leave a sufficient residual gap for magnetoelastic contraction and to assure such spacing as will avoid harm to the ceramic 73. For protection of the ceramic 73, I have illustrated the employment of relatively thin pressure-release layers 74, which may be of cardboard or cork, cemented to opposite sides of the ceramic 73 before insertion as a preassembled sandwich in the gap 70.

Although the gap-insert configuration of Fig. 7 may in certain cases provide permanent polarization, together with important economies in lamination material, the structures of Figs. 1, 2, 4 and 5 will be understood to lend themselves to permanent polarization upon resort to the relatively expensive expedient of employing ferromagnetic materials with sufficiently high coercive force, and in that event no special permanent polarizing means need be employed; moreover, as long as the flux gaps are made sufficiently narrow, satisfactory polarization may be achieved with laminations of only moderate coercive-force materials, thus permitting the use of high-permeability materials for the lamination.

As noted above, any magnetostrictive effects concurrent with my magnetoelastic effects may reinforce or partially negative the magnetoelastic effects, depending on the sign of the magnetostrictive constant of the material. With material (such as nickel) having a negative constant, the magnetostrictive and magnetoelastic effects will aid each other, producing desirable results at the expense of strategic materials. However, for transformer steel, for which the magnetostrictive constant is positive (and therefore antagonistic to magnetoelastic action), the overall performance may still be preferred over that of a nickel core because of the higher permeability, higher saturation-flux density, and higher electrical resistivity obtainable.

It will be seen that I have described basically simple constructions characterized by relatively high efficiency, particularly for response to pressure fluctuations in fluids or in solids. My use of the magnetoelastic principle pro-

vides increased power-conversion potentialities, which may be in the order of at least ten times those achieved with purely magnetostrictive configurations made with the best magnetostrictive materials. Furthermore, I achieve my improved performance with a minimum use of scarce materials.

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

I claim:

1. In a transducer of the character indicated, a three-legged ferromagnetic core with an open gap in the center leg, said gap being substantially shorter than the spacing of said center leg from either of the other legs, and an electrical winding coupled to said center leg.

2. A transducer according to claim 1, in which said gap is intermediate the ends of said center leg, and in which said winding is coupled to said center leg on both sides of said gap.

3. A transducer according to claim 1, in which the minimum cross-sectional area of said center leg is substantially twice the minimum cross-sectional area of the outer legs of said core.

4. A transducer according to claim 1, in which the effective minimum cross-sectional area of said center leg is substantially equal to the sum of the minimum effective cross-sectional areas of the outer legs of said core.

5. In a transducer of the character indicated, a core defined between opposed spaced sides and having a plurality of internal slots extending between said sides but short of said sides to define a plurality of spaced legs extending between said sides, alternate of said legs having gaps therein, and winding means supported in slots adjacent each gap and linked to the legs having gaps.

6. A transducer according to claim 5, in which the opposed sides of said core are substantially flat and parallel.

7. A transducer according to claim 5, in which said opposed sides are substantially arcuate about the same center so that acoustic response may extend radially of said center.

8. In a transducer of the character indicated, a closed magnetic circuit including a core of ferromagnetic material and having a gap therein, magnetizing means in said gap and of an effective thickness less than the width of said gap, and electric winding means linked to said ferromagnetic material.

9. A transducer according to claim 8, in which said magnetizing means is a permanent magnet.

10. A transducer according to claim 8, in which said magnetizing means is a high-coercive-force material.

11. A transducer according to claim 10, in which said material is a magnetic-oxide ceramic.

12. In a transducer of the character indicated, a closed magnetic loop of elements of ferromagnetic material spaced in end-to-end adjacency to define a plurality of spaced gaps, and electric winding means linked to said ferromagnetic material on opposite sides of said gaps.

13. In a transducer of the character indicated, a loop of non-magnetic material defining a radiating wall, a plurality of closely spaced ferromagnetic elements substantially coextensive with said loop on one radial side thereof, relatively rigid supporting means supporting central portions of said elements in radially spaced relation with said loop, and electric winding means coupled to said ferromagnetic elements on both sides of the gaps defined by the spacing between elements.

14. In a transducer of the character indicated, a cylindrical radiating wall, a plurality of ferromagnetic elements in closely spaced relation with each other and longitudinally substantially coextensive with said wall, rigid supporting means spacing the central portions of said elements radially inwardly of said wall, and electric winding means coupled to said ferromagnetic elements

on opposite sides of the gaps defined by the spaces therebetween.

15. In a transducer of the character indicated, a cylindrical radiating wall, a plurality of ferromagnetic elements in closely spaced relation with each other and longitudinally substantially coextensive with said wall, rigid supporting means spacing the central portions of said elements radially outwardly of said wall, and electric winding means coupled to said ferromagnetic elements on opposite sides of the gaps defined by the spaces therebetween.

16. As an article of manufacture, a magnetoelastic core subassembly comprising a plurality of elongated elements of ferromagnetic material, and non-magnetic means relatively rigidly spacing central portions of said elements and aligning the ends of said elements to define gaps therebetween in an end-to-end alignment of said elements.

17. As an article of manufacture, a magnetoelastic core comprising a plurality of elongated ferromagnetic core elements, each of said core elements having an enlarged central shoulder extending transversely of the longitudinal axis thereof, and rigid non-magnetic spacers supporting said elements in end-to-end relation with a gap between adjacent ends and in direct longitudinal thrust-sustaining abutment with said shoulders.

18. As an article of manufacture, a magnetoelastic transducer lamination of ferromagnetic material comprising three legs defining two slots adjacent a center leg, said center leg having a flux gap therein and being of an effective width substantially twice that of each of the outer legs, said gap being substantially less than the width of either of said slots, whereby said center leg including said gap may form an important part of a magnetic circuit when an electric winding is coupled thereto.

19. As an article of manufacture, a magnetoelastic transducer lamination of generally F shape, comprising an elongated body, a first leg extending integrally from one end of said body and transversely therefrom, and a second leg extending substantially parallel to said first leg from the center of said body and to an extent slightly less than one-half the length of said first leg, whereby two such laminations may be fitted together to define a three-legged core with a gap in the center leg.

20. In a transducer of the character indicated, two mechanically coupled mechanical oscillators of magnetic-flux-conducting material, said first oscillator comprising two end masses with an elongated longitudinally compliant leg connecting said end masses, said second oscillator comprising an elongated longitudinally compliant leg directly connected to one of said masses to the exclusion of the other, the compliant axes of said legs being similarly oriented, said second-mentioned leg being coupled to the other of said masses by means including a magnetic-flux gap, and means establishing varying magnetic flux in said second-mentioned leg.

21. In a transducer of the character indicated, a magnetic circuit comprising two mechanically coupled mechanical oscillators of magnetizable material, said first oscillator comprising two end masses with an elongated longitudinally compliant leg connecting said end masses, said second oscillator comprising an elongated longitudinally compliant leg connected to one of said masses to the exclusion of the other and completing the magnetic circuit to said other end mass through a magnetic-flux gap, and an electrical coupling to said circuit for establishing magnetic-flux variations in said second-mentioned leg and across said gap.

22. In a transducer of the character indicated, a magnetic circuit comprising two mechanically coupled mechanical oscillators of magnetizable material, said first oscillator comprising two end masses with an elongated longitudinally compliant leg connecting said end masses, said second oscillator comprising two elongated longitudinally compliant legs connected respectively to said

end masses and extending toward each other to define a generally central magnetic-flux gap, and an electrical coupling to said circuit for establishing magnetic-flux variations through the two legs and gap of said second oscillator.

23. In a transducer of the character indicated, a magnetic core comprising a consolidated stack of like laminations of ferro-magnetic material, each lamination including three legs joined to each other at opposite ends and defining openings between legs, the center leg having a magnetic-flux gap therein of spacing substantially less than the width of said center leg, the open span of said gap being sufficient to permit free longitudinal oscillation of the poles at said gap, and a winding passing through said openings and coupled to said center leg.

24. A transducer according to claim 23, in which said gap is centrally located on said center leg.

25. A transducer lamination, comprising a single sheet of ferro-magnetic material having two spaced, like, and symmetrically located winding openings therein, said sheet having a thin elongated open flux gap communicating with both said winding openings, thereby defining two poles in a center leg at said gap, whereby an electric winding received in said winding openings and coupled to said center leg may be effective to create fluctuating magnetic forces at said gap, and means independent of said center leg for supporting said lamination, whereby said poles have maximum freedom for elastically restrained relative longitudinal displacement upon development of such forces.

26. A magnetoelastic transducer, comprising a consolidated stack of like ferro-magnetic laminations, each lamination having two spaced winding openings therein defining first and second flux paths around said respective

openings and in common with the part of said lamination between said openings, each lamination having a flux gap connecting said openings and defining spaced free poles on opposite sides of said gap, the width of the lamination along said gap being substantially twice the width of each said flux path external to the part between said openings, and a winding with turns passing through said openings and linked to said part between openings, whereby said winding may be effective to create fluctuating magnetic forces at said gap.

27. A magnetoelastic transducer, comprising a complete flux-path circuit of ferro-magnetic material, said circuit including two like elongated inherently longitudinally vibratile members aligned in end-to-end relation, said members being closely spaced and supported freely at their adjacent ends to define a flux gap, and a winding coupled to said flux-path circuit, whereby the longitudinal oscillatory mode of said members may directly determine the span of said gap, so that upon application of oscillatory driving energy to said winding the magnetic forces at the gap may directly stress-excite said members into longitudinal-mode oscillation.

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