Jan. 1, 1957 W. T. HARRIS 2,776,416

COMPENSATED WINDING

Filed Jan. 22, 1954

2 Sheets-Sheet 1

FIG. 1.

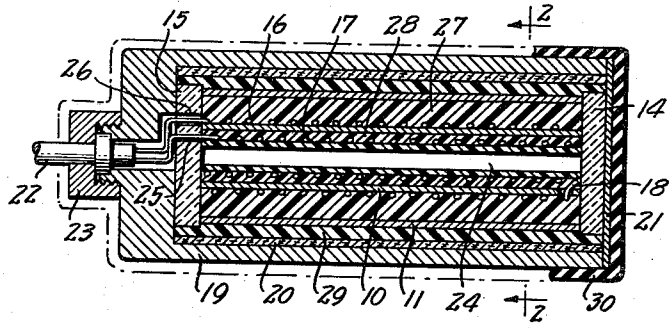


FIG. 2.

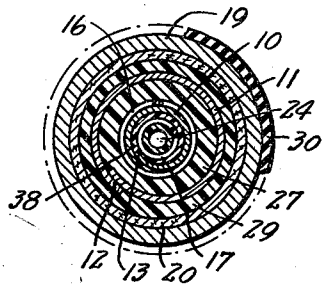


FIG. 3.

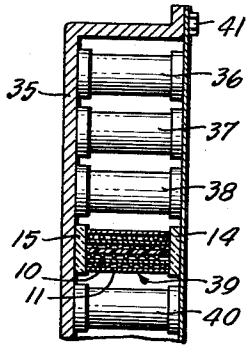


FIG. 4.

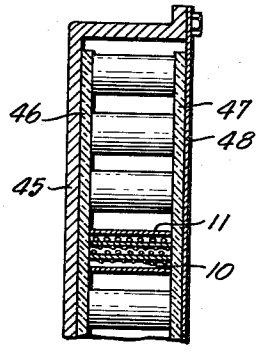


FIG. 7.

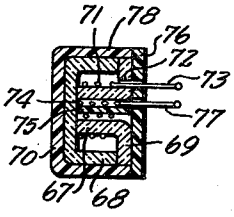


FIG. 5.

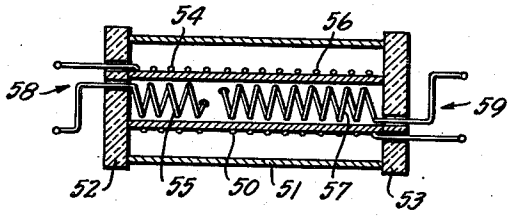


FIG. 6.

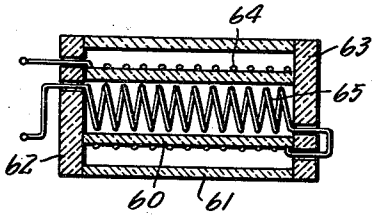
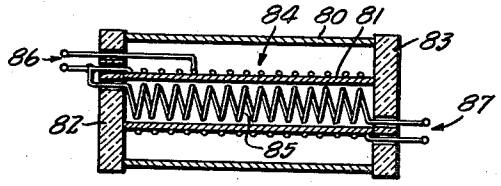


FIG. 8.



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COMPENSATED WINDING

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FIG. 9.

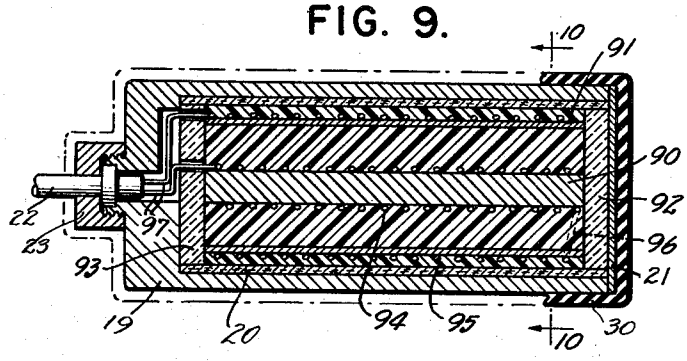


FIG. 10.

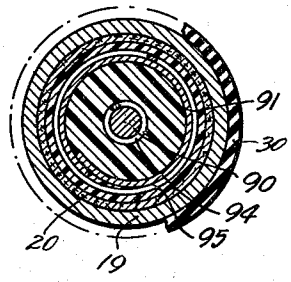


FIG. 11.

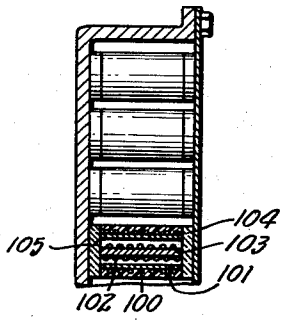


FIG. 12.

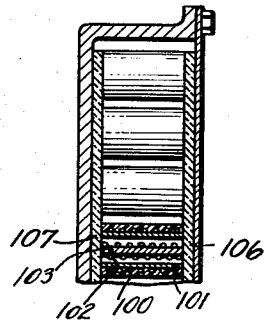


FIG. 16.

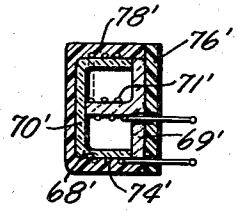


FIG. 13.

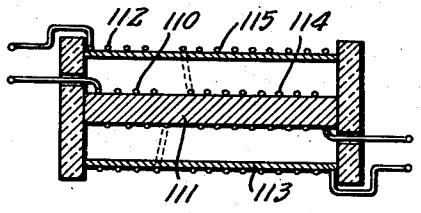


FIG. 14.

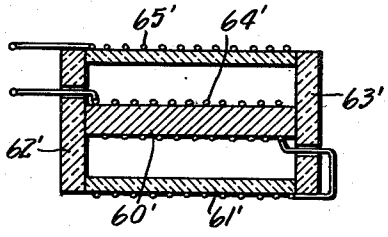
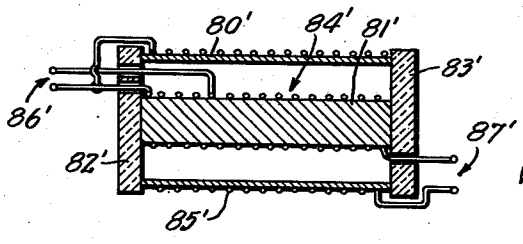


FIG. 15.



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COMPENSATED WINDING

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Application January 22, 1954, Serial No. 405,614

20 Claims. (Cl. 340—11)

My invention relates to an improved core and winding construction for electro-magnetic circuit elements and is of application to electro-acoustic transducers, to electro-magnetic inductors, to transformers, and the like. This application is a continuation-in-part of my copending application Serial No. 318,720, filed November 4, 1952.

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

It is a specific object to provide an improved core and winding construction having the basic virtues of toroidally wound cores without requiring the elaborate fabrication techniques necessary with toroidal windings.

It is another specific object to provide an improved construction of the character indicated in which stray hum and other pickup may be completely and inherently compensated for and, therefore, effectively neutralized.

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 longitudinal sectional view through an electro-acoustic transducer incorporating features of the invention;

Fig. 2 is a sectional view in the plane 2—2 of Fig. 1;

Figs. 3 and 4 are simplified fragmentary views partially in section and illustrating alternate employments of my transducer in electro-acoustic arrays;

Figs. 5 to 8 are simplified longitudinal sectional views of alternate circuit elements incorporating features of the invention.

Figs. 9 to 16 are views corresponding respectively to Figs. 1 to 8 but illustrating another basic winding arrangement.

Briefly stated, my invention contemplates a new core and winding construction employing what may be termed a toroidal core, thereby providing a generally toroidal flux path; a first, or signal winding, is coupled to the core path and to the stray-flux path, and a second, or compensating winding, is coupled to the stray-flux path to the exclusion of or effectively independently of the core path. The first and second windings may have substantially the same number of turns and may be connected in opposition, so that any coupling to the stray-flux path will be completely neutralized, and coupling to the core will, in effect, be exclusively promoted. In the general form represented by Figs. 1 to 8, the second or compensating winding is physically located radially inside the toroidal flux path and, therefore, radially inside the first or signal winding; in the general form represented by Figs. 9 to 16, the second or compensating winding is physically located radially outside the torodal flux path and, therefore, radially outside the first or signal winding.

In application to electro-acoustic transducers, the core may be of magnetostrictive material, at least in those parts of the core in which magnetostrictive elongations are desired. Thus, in one subgeneric form of the invention, the toroidal core may comprise two generally concentric elongated cylindrical magnetostrictive members with magnetic means radially closing and interconnecting the ends of said cylinders to define the toroidal flux path. In application to circuit elements, the same general core construction may be employed, or the cylindrical members may be integrally formed with end-flange means, in order to permit completion of the toroidal path when the cylindrical members are assembled to each other. By way of illustrating circuit-element applications, I shall also describe transformer and inductor constructions.

Referring to Figs. 1 and 2 of the drawings, my invention is shown in application to an electro-acoustic transducer specifically designed for underwater use. As indicated generally above, the construction features a core providing a generally toroidal flux path; in the form shown, said core happens to be built up from a plurality of elements designed to promote principal acoustic response generally along the axis of the toroid. The core elements may thus comprise inner and outer tubular members 10—11 of magnetostrictive material, as, for example sheet-metal alloy of a composition known to the trade as Permendur. The sheets may be relatively thin and overlapped at their longitudinally extending edges, as at 12—13, after applying a thin layer of insulation between the overlapping areas in order to reduce circulating eddy currents. The toroidal path may be completed by means of end closure caps 14—15 of magnetic material in magnetic-flux-conducting relation with both cylinders 10—11. For simplicity of fabrication, I have shown the end members 14—15 to be circular discs of magnetic ceramic material, such as a ferrite.

In accordance with a feature of the invention, two windings are employed in particular relation with the core means described. Such windings may include a first or signal winding 16 linked to the core and also to the stray-flux path (passing through the entire transducer and, therefore, through the center of the toroid, i. e. within the inner cylinder 10); at a given instant, flux circulating in the toroidal-core path may be viewed as directed from left-to-right axially along the inner cylinder 10, then radially outward in end cap 14, then right-to-left axially along the outer cylinder 11, and finally radially inward in end cap 15. The second or compensating winding 17 is wholly linked to the stray-flux path to the exclusion of the core path and may, therefore, be contained within the inner tubular member 10. In order to achieve full compensation for stray flux, the number of turns on the two windings 16—17 is preferably the same, and these windings are connected in opposition, as suggested by the portion 18 of the conductor material interconnecting the right end of the two windings through a small opening in the tubular member 10.

The entire transducer may be contained within a housing 19, which may be a metal casting, and pressure-release means 20, such as a layer of cork or air-filled rubber, may line the excavated interior of the housing 19 and, therefore, peripherally envelop the toroidal core. Diaphragm means 21 may flexibly seal off the housing opening, and leads to the two windings may be carried out the closed end of the housing, as to a lead cable 22 passing through a suitable end fitting 23.

It will be seen that the described construction lends itself to relatively simple fabrication with common coil-winding machines and techniques; for example, the inner winding 17 may be applied as a continuous helix on a cylindrical form, such as a cardboard roll or a plastic rod or tube, as shown at 24. In a separate and equally simple operation, the outer winding 16 may be applied as a single continuous helix over the periphery of the inner tubular member 10; of course, to preserve insulation, the wire itself may be insulated as, for example,

enamel-coated, or the cylinder 10 may be coated with insulating material before applying the winding 16.

Having made the two simple conventional windings 16—17, they may be interconnected at 18 in a simple soldering operation, and the leads brought out through small openings 25—26 in the rear-end plate 15 of the core. The plate 14 may then be applied, and the entire wound core assembly immersed in a potting compound so as to fill air spaces at 27—28; the potting compound at 27—28 is preferably of the sound-transmitting characteristics of the medium (e. g. water) in which the transducer is to be employed, and with vacuum-immersion the potting material may be brought into intimate pressure-transmitting relation with all exposed active internal surfaces of the transducer (i. e. surfaces of cylinders 10—11 and of end plates 14—15). The basic transducer unit may then be inserted in the housing 19, which may previously have been lined with the pressure-release material 20, and the assembly may be made completely rugged by further potting in the space 29. Finally, in order to seal off all possible crevices, a boot or coating 30 of plastic, rubber, or rubber-like material may be applied over the entire assembly, as in a dipping process.

In Figs. 3 and 4, I show alternate employments of my basic transducer construction, as in multiple-element arrays. In Fig. 3, the array comprises within a housing 35 a plurality of independent core units or transducer elements 36—37—38—39, each of which may be of essentially the same construction as that part of the structure of Figs. 1 and 2 as is fully contained within the toroidal core 10—11—14—15. It will be understood that lead connections and winding interconnections have been omitted in Fig. 3 for the sake of clarity, but that for each transducer element the leads may be brought out of the rear end in the manner described in Fig. 1, and interconnected to each other by known methods to achieve directional or other array functions. The array is completed in Fig. 3 by having all active faces 14 of the cores of transducer elements 36—37—38—39 aligned in essentially the same thrusting surface and intimately related to a common diaphragm 40, which may be peripherally bolted, as suggested at 41, to the housing 35. Lateral pressure-release means such as cork liners may effectively envelop the transducer units of Fig. 3, but for certain applications the desired lateral release may be achieved by merely not filling the spaces between these elements and, therefore, by leaving them exposed to air within the remaining volume in the housing 35.

In Fig. 4, the array is contained within a housing 45 which may be the same as that described in Fig. 3 and, again, common diaphragm means are applied over all transducer elements. However, in Fig. 4 the transducer elements are never completed until fully assembled into the array. This is because end closures for the toroidal core paths are formed at one end by a single plate 46 of magnetic material, as of magnetostrictive ceramic, and at the other end by a similar plate 47.

In assembling the array of Fig. 4, therefore, the inner and outer cylinders 10—11 may be assembled and wound and potted in the manner already described, except that end-closure plates are omitted in this preliminary assembly. Toroidal flux paths are completed only when the end plates 46—47 are applied in place. The end plates 46—47 may be retained by tie-bolts (not shown) extending therebetween, but sufficient adhesion of the assembly may result if the wound core elements 10—11 are potted with a slight excess of potting material, so that upon localized heating of the plates 46—47, when squeezed to the wound tubular members 10—11, the plastic itself will be permitted to permeate the microscopic interstices of the plates 46—47, so as to provide a sufficiently rigid bond upon setting of the plastic. Thus, in Fig. 4 the basic array is seen to be completed again by employment of common diaphragm means, and the diaphragm means in Fig. 4 may be viewed as constituting either the forward thrust plate 47, or the combination of the plate 47 with the flexible diaphragm 48.

In Fig. 5, I show an application of the principles of my invention to a circuit element which may be a transformer. The circuit element is seen to comprise a toroidal core path defined by inner and outer tubular members 50—51, between end-closure pieces 52—53. A first signal winding 54 is linked to the core path and to the stray-flux path, and a first compensating winding 55 is linked only to the stray-flux path and is connected in opposition to the signal winding 54. The described windings 54—55 represent a complete parallel with the construction of Fig. 1 and may constitute the primary of the transformer. The transformer secondary may include a signal winding 56 linked to the same core path and also to the stray-flux path, and a compensating winding 57 linked only to the stray-flux path. The secondary windings 56—57 may also be connected in opposition, and primary and secondary leads may be brought out through appropriate access holes at opposite ends of the device, as at 58—59, respectively. For complete compensation and assurance against stray pickup, I prefer that the signal and compensating windings 54—55 for the primary shall have the same number of turns, and that the secondary (signal and compensating) windings 56—57 shall also have the same number of turns, as will be understood.

In Fig. 6, I illustrate a slight variation of the basic construction wherein the toroidal core path is defined entirely by magnetic ceramic material. Thus, inner and outer tubular members 60—61 may be ceramic cylinders, and the toroidal path may be completed by ceramic end plates 62—63. The signal and compensating windings 64—65 may be coupled to the core path and to the stray-flux path, as described above. The device of Fig. 6 will be seen to represent a good electro-acoustic transducer configuration, or merely a circuit-element inductance; and, of course, the inherent freedom of magnetic ceramics from eddy-current problems avoids the necessity of resorting to insulated overlapping ends (as at 12—13 in the construction of Figs. 1 and 2). Thus, the cylinders 60—61 may be circumferentially continuous.

In Fig. 7, I illustrate a simplified transducer or circuit-element construction, wherein the toroidal core path is defined by two parts which may be said to include inner and outer cylindrical members 67—68 with cooperating end flanges 69—70 to complete the toroidal path. Thus, the inner tubular member 67 may be integrally formed at one end with a radial outwardly extending flange 69, and the outer tubular member 68 may be integrally formed at the other end with a radial inwardly extending flange 70. It will be noted that the flange 70 extends all the way radially inwardly so as to make the part 68—70 constitute a cup with a closed bottom. Assembly may be made by applying the signal winding 71 to the outer surface of the inner tubular member 67 and by bringing one lead thereto through a small access opening 72 at the base of flange 69. The inner, or compensating winding 74, may be applied to a projection 75 integral with a plastic closure 76 for one end of the device. Leads 73—77 may both be brought out through the base of the plastic closure 76; and, if desired, a further plastic layer 78 may be applied, as by dipping, to encase the entire device or to complete its enclosure, as suggested at 78.

In Fig. 8, I illustrate another transformer embodiment, which may generally resemble the construction of Fig. 5. Thus, in Fig. 8, a toroidal magnetic core path may be established by cylinders 80—81, capped by end plates 82—83. A signal winding 84 may be linked to the core path and to the stray flux, and a compensating winding 85 may be linked to the stray flux to the exclusion of the core path. The electrical input and output connections 86—87, respectively, illustrate an autotransformer use of the described parts. Thus, input leads 86 may be connected across a small number of the turns of signal wind-

in 84, and output leads 87 may be connected across the signal winding 84. The compensating winding 85 need not be connected as an autotransformer, and I have illustrated connection of winding 85 merely in series with one output pole of the signal winding 84. With the compensating winding 85 thus connected in opposition to the signal winding output, full neutralization of stray-flux pickup may be achieved without the need to connect the compensating winding as an autotransformer.

In Figs. 9 to 16, I illustrate the other general form of the invention, as applied to structures analogous to those described in detail in connection with Figs. 1 to 8. According to this other general form of the invention, coupling of the second winding to the stray flux (to the exclusion of the toroidal core path) is accomplished externally of, or radially outside, the core structure.

Thus, in Fig. 9, the transducer may comprise a generally toroidal flux path established by axially overlapping and substantially coextensive cylindrical members 90—91 of magnetostrictive material, joined at their ends by magnetic material, such as discs 92—93 of magneticoxide ceramic. The first or signal winding 94 may be developed on the inner cylindrical member 90 and may thus be coupled to the toroidal flux path and to any stray-flux path to which the transducer may be exposed. The second or compensating winding 95 may be developed, preferably with the same number of turns as winding 94 and axially substantially co-extensive therewith, over the outer cylindrical member 91. By connecting windings 94—95 differentially, as suggested at 96, the leads 97 may respond substantially only to the flux circulated in the toroidal path. Pressure-release means, housing means, a diaphragm, and other elements of the structure of Fig. 9 may be as described for Fig. 1 and have therefore been given the same reference characters.

The transducer arrays of Figs. 11 and 12 generally resemble those of Figs. 3 and 4, except that to illustrate the other general form of the invention the second or compensating winding 100 has been developed radially outside the outer cylindrical member 101, and the first or signal winding 102, although radially inside the compensating winding 100, is still coupled to the toroidal flux path by way of the inner cylindrical member 103. In Fig. 11, the individual transducer elements are formed with complete magnetic circuits, completed in each instance by separate magnetic end discs 104—105; whereas, in Fig. 12, magnetic end plates 106—107 complete the toroidal flux paths of a plurality of transducer elements in common.

In Fig. 13, I illustrate the plane transformer case in which a primary signal winding 110 is developed about the inner cylindrical core member 111, and in which the primary compensating winding 112 is developed about the outer cylindrical core member 113. Corresponding signal and compensating secondary windings 114 and 115 are developed about the same cylindrical members 111—113 and, except for the relative radial relation of the various windings, the construction and functioning of the transformer of Fig. 13 resembles that of Fig. 5.

In Figs. 14 and 15, the reversed placement of the compensating winding with respect to the signal winding has been effected in a manner completely analogous to that described in Fig. 13, and therefore the parts in Figs. 14 and 15 which correspond respectively to those in Figs. 6 and 8 have been given the same reference characters, with primed notation.

The circuit element of Fig. 16 is generally similar to that of Fig. 7, except again that the second or compensating winding 74' has been developed outside the outer limits of the core member 68'. The first or signal winding 71' is linked to the toroidal flux path established by flanged cylindrical members 69'—70', and the full assembly is sealed as a unit by a plastic potting, suggested at 76'—78'.

It will be seen that I have described a basically simple winding-and-core construction lending itself to mass-production techniques which are already well understood and for which there is a relative abundance of machinery. My construction avoids the undesirable properties (i. e. susceptibility to stray flux) characteristic of helically-wound constructions made with such existing techniques and machinery. While it has been possible in the past to avoid these undesirable characteristics by resorting to complex fabrication methods and expensive machinery, my construction avoids the need for such complexity and expense.

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. In a device of the character indicated, a toroidal core path defining an annular space within said core path, a first winding contained within said annular space and coupled to said core path and to the stray flux, and a second winding differentially connected to said first winding and wound radially outside the body of said core and therefore coupled to the stray flux to the exclusion of said core path.

2. In a device of the character indicated, core-body means containing and defining a continuous toroidal magnetic-flux path, a first winding linked to said path, whereby said first winding is also linked to the stray-flux path in which said core means may be immersed, and a second winding differentially connected to said first winding, the axis of said second winding being substantially coaxial with that of said first winding and said second winding being linked to said stray-flux path to the exclusion of said core path.

3. A device according to claim 2, in which the number of turns of each of said windings is substantially the same.

4. A device according to claim 2, in which said core means includes a magnetic ceramic.

5. A device according to claim 2, in which parts of said core means extending axially of said toroidal path are of magnetostrictive material.

6. In a device of the character indicated, two substantially concentric elongated cylinders of magnetic material, a first winding enveloping the inner of said cylinders and within the outer of said cylinders, a second winding wholly enveloping the outer of said cylinders, and closure means of magnetic material radially interconnecting the ends of said inner and outer cylinders, whereby a toroidal core path is defined with said first winding linked to said core path and to the stray-flux path in which said device may be immersed and with said second winding linked to said stray-flux path to the exclusion of said core path.

7. In a device of the character indicated, two elongated magnetostrictive generally cylindrical members one within the other and magnetically interconnected at their corresponding ends, whereby a generally toroidal flux path is thereby defined, a first winding in the radial space between said members and therefore coupled to said flux path, and a second winding radially outside the outer of said members and therefore not coupled to said flux path, whereby upon differential connection of said windings stray-field effects common to both windings may be substantially eliminated.

8. A device according to claim 7, in which said generally cylindrical members are axially substantially coextensive, and in which the interconnection of said members is effected by end closure members of magnetic material in intimate magnetic-flux-circulating contact circumferentially continuously of both said generally cylindrical members.

9. A device according to claim 7, in which the interconnection of said members is effected by radial-flange means carried by one of said generally cylindrical members.

10. A device according to claim 9, in which said flange means comprises an outwardly extending radial flange at one end of the inner member, and an inwardly extending radial flange at the other end of the outer member.

11. A device according to claim 7, in which said members are of magnetostrictive ceramic material.

12. An electro-acoustic transducer, comprising a magnetic core-body including magnetostrictive means at least in axially extending parts thereof, said core-body defining a generally toroidal flux path, a first winding linked to said flux path and to a stray-flux path, and a second winding differentially connected to said first winding, said second winding being unenclosed within the torus of said core-body and therefore linked to said stray-flux path to the exclusion of flux in said core-body, and pressure-release means circumferentially enveloping the periphery of said core-body.

13. In a transducer of the character indicated, a relatively rigid housing having an excavated interior opening to one end thereof, a magnetic core-body establishing a generally toroidal flux path and including magnetostrictive means in the parts of said core-body which extend axially out of said opening, a first winding linked to said core-body and to a stray-flux path, a second winding differentially connected to said first winding, said second winding being independent of effective coupling to the flux path of said core body and therefore linked to said stray-flux path to the exclusion of said core path, pressure-release means radially isolating said core-body from said housing, and a diaphragm in intimate axially directed pressure-transmitting relation with that end of said core-body which faces out of said opening.

14. In a multiple-element transducer of the character indicated, a plurality of cores of magnetostrictive material establishing for each core a generally toroidal flux path, said cores being aligned with their thrust faces substantially in a common surface, there being for each core a first windng enclosed within the torus of the core and linked to the core path and to a stray-flux path, and a second winding differentially connected to said first winding and unenclosed within the torus of the core and therefore linked solely to the stray-flux path, and diaphragm means common to the thrust faces of all said elements.

15. A transducer according to claim 13, in which said cores are completely self-contained separate and independent elements, and in which said diaphragm means is separately connected to each of said units.

16. A transducer according to claim 13, in which the thrust end of each of said cores is closed by a single piece of magnetic material common to all thrust ends of said cores and separately closing the toroidal flux paths in all of said units, whereby, said single common piece of magnetic material may constitute said diaphragm means.

17. A transducer according to claim 15, in which a second similar piece of magnetic material closes the other ends of all said core units in common.

18. In a multiple-element transducer of the character indicated, a plurality of cores of magnetostrictive material establishing for each core a generally toroidal flux path, said cores being aligned with their thrust faces substantially in a common surface, there being for each core a first winding linked to the core path and to a stray-flux path, and a second winding differentially connected to said first winding and located radially outside said toroidal flux path and linked solely to the stray-flux path, and diaphragm means common to the thrust faces of all said elements.

19. In a device of the character indicated, a core comprising two elongated magnetic ceramic cylindrical members, one within the other, magnetic ceramic elements interconnecting said ceramic members at their corresponding ends, a first winding in the radial space between said members and therefore coupled to said core, and a second winding substantially coextensive with said first winding but independent of effective coupling to said core, whereby upon differential connection of said windings stray-field effects common to both windings may be substantially eliminated.

20. In a device of the character indicated, a core comprising two elongated cylindrical members of magnetic material one within the other and magnetically interconnected at their corresponding ends, a first winding in the radial space between said members and therefore coupled to said core, and a second winding substantially axially coextensive with said first winding but independent of effective coupling to said core, whereby upon differential connection of said windings stray-field effects common to both windings may be substantially eliminated.

No references cited.