Jan. 1, 1957 W. T. HARRIS 2,776,417

COMPENSATED WINDING

Filed Nov. 4, 1952

FIG. 1.

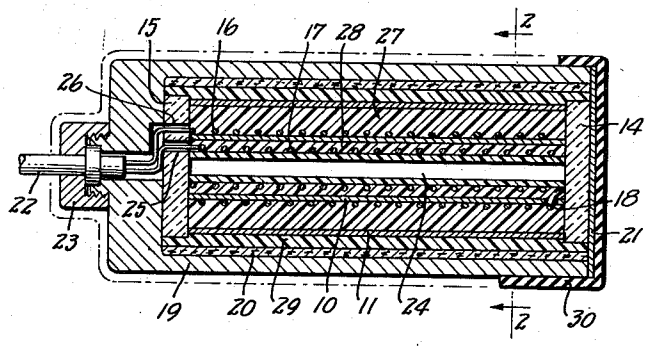


FIG. 2.

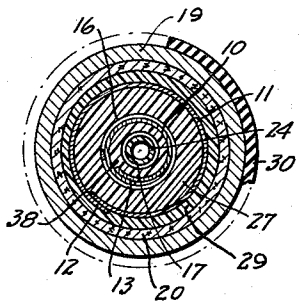


FIG. 3.

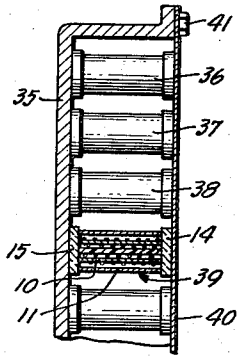


FIG. 4.

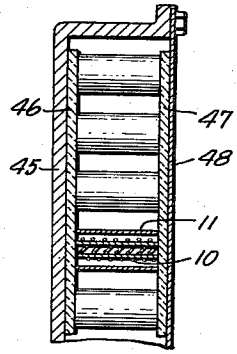


FIG. 7.

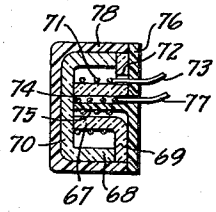


FIG. 5.

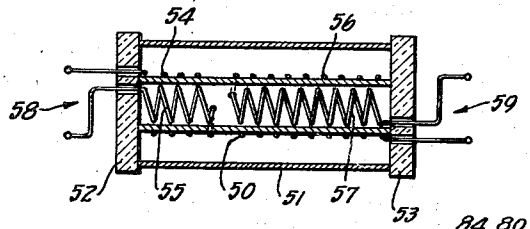


FIG. 6.

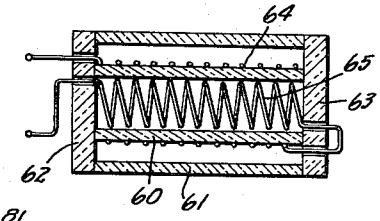
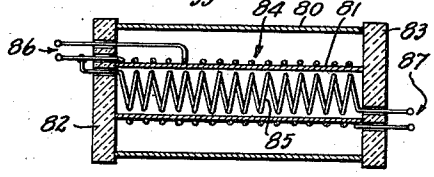


FIG. 8.



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COMPENSATED WINDING

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18 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.

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; and

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

Briefly stated, my invention contemplates a new core and winding construction employing what may be termed a toroidal core with a first, or signal winding, coupled to the core path and to the stray-flux path, and with a second, or compensating winding, coupled to the stray-flux path to the exclusion 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 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 general form of the invention, the toroidal core may comprise two generally concentric elongated tubular 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 tubular members may be integrally formed with end-flange means to complete the toroidal path when tubular members are assembled to each other. By way of illustrating circuit-element applications, I shall also describe a transformer construction and an inductor construction.

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 toroidal core which happens in the form shown 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 comprising substantially 49 percent iron, 49 percent cobalt and 2 percent vanadium. 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 center of the toroid, i. e. within the inner cylinder 10; 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 cores 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 cores 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 including inner and outer tubular members 50—51, between end-closure pieces 52—53. A first signal winding 54 is linked to the core 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 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 is made entirely of magnetic ceramic material. Thus, inner and outer tubular members 60—61 may be ceramic cylinders, and the toroidal paths may be completed by ceramic end plates 62—63. The signal and compensating windings 64—65 may be coupled to the core and to the stray-flux paths, as described above. The device of Fig. 6 will be seen to represent a good electroacoustic 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 is made up of two parts which may be said to include inner and outer tubular members 67—68 with cooperating end flanges 69—70 to complete the toroid. 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 may be established by cylinders 80—81, capped by end plates 82—83. A signal winding 84 may be linked to the core and to the stray flux, and a compensating winding 85 may be linked to the stray flux to the exclusion of the core. 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 winding 84, and output leads 87 may be connected across the full 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.

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 hollow core of magnetic material defining an annular space within said core, said core having a central opening on the axis thereof, a first winding within said annular space and developed generally along said axis, whereby a generally toroidal flux path may be established in said core, and a second winding within said opening and developed generally along said axis, whereby upon differential connection of said windings stray-field effects common to both windings may be substantially eliminated.

2. In a device of the character indicated, magnetic-core means establishing a continuous generally toroidal path, said core means having a central opening on the axis thereof, a first winding linked to said path and developed generally along said axis, whereby said first winding is also linked to the stray-flux path through the axis of said core means, and a second winding within said opening and developed generally along said axis and therefore linked only to said stray-flux path, said windings being differentially connected, whereby stray-field effects common to both windings may be substantially eliminated.

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 axially extending parts of said core 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 developed generally on the axis of said first winding and wholly within the inner of said cylinders, and closure means of magnetic material radially interconnecting the ends of said inner and outer cylinders, whereby a toroidal flux path is defined with said first winding linked to said flux path and with said second winding independent of said path.

7. In a device of the character indicated, two elongated magnetostrictive tubular 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 within the inner 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 tubular 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 tubular 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 tubular 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 tubular member, and an inwardly extending radial flange at the other end of the outer tubular member.

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

12. In a multiple-element transducer of the character indicated, a plurality of cores of magneto-strictive 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 inside said toroidal flux path and linked solely to the stray-flux path, and diaphragm means common to the thrust faces of all said elements.

13. A transducer according to claim 12, 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.

14. A transducer according to claim 12, 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 constitutes said diaphragm means.

15. An electro-acoustic transducer, comprising a magnetic core including magneto-strictive means at least in axially extending parts thereof and establishing a generally toroidal flux path, said core having a central axially extending opening therein, a first winding coupled to said core and developed generally along the axis of said core, a second winding differentially connected to said first winding and developed generally along said axis within said opening, and pressure-release means circumferentially enveloping the periphery of said core.

16. In a transducer of the character indicated, a relatively rigid housing having an excavated interior opening to one end thereof, a magnetic core establishing a generally toroidal flux path and including magnetostrictive means in the parts of said core which extend axially out of said opening, said core having a central axially extending opening therein, a first winding linked to said core and developed generally along the axis of said core, a second winding differentially connected to said first winding and developed generally along said axis within said central opening, pressure-release means radially isolating said core from said housing, and a diaphragm in intimate axially directed pressure-transmitting relation with that end of said core which faces out of said housing opening.

17. A transducer according to claim 14, in which a second similar piece of magnetic material closes the other ends of all said core units in common.

18. 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 and radially within 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.

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