Aug. 20, 1946. B. E. STEVENS 2,406,045

INDUCTANCE DEVICE

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FIG. 1

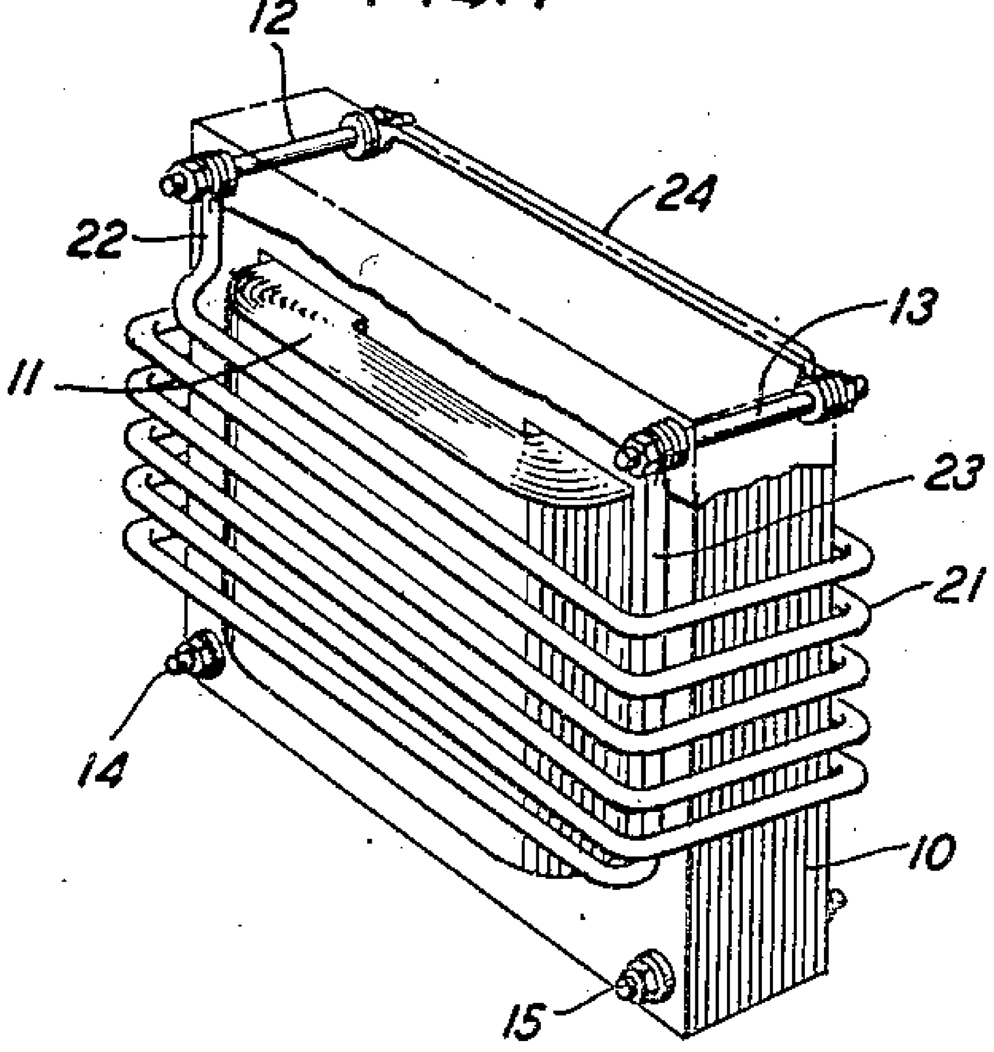

FIG. 2

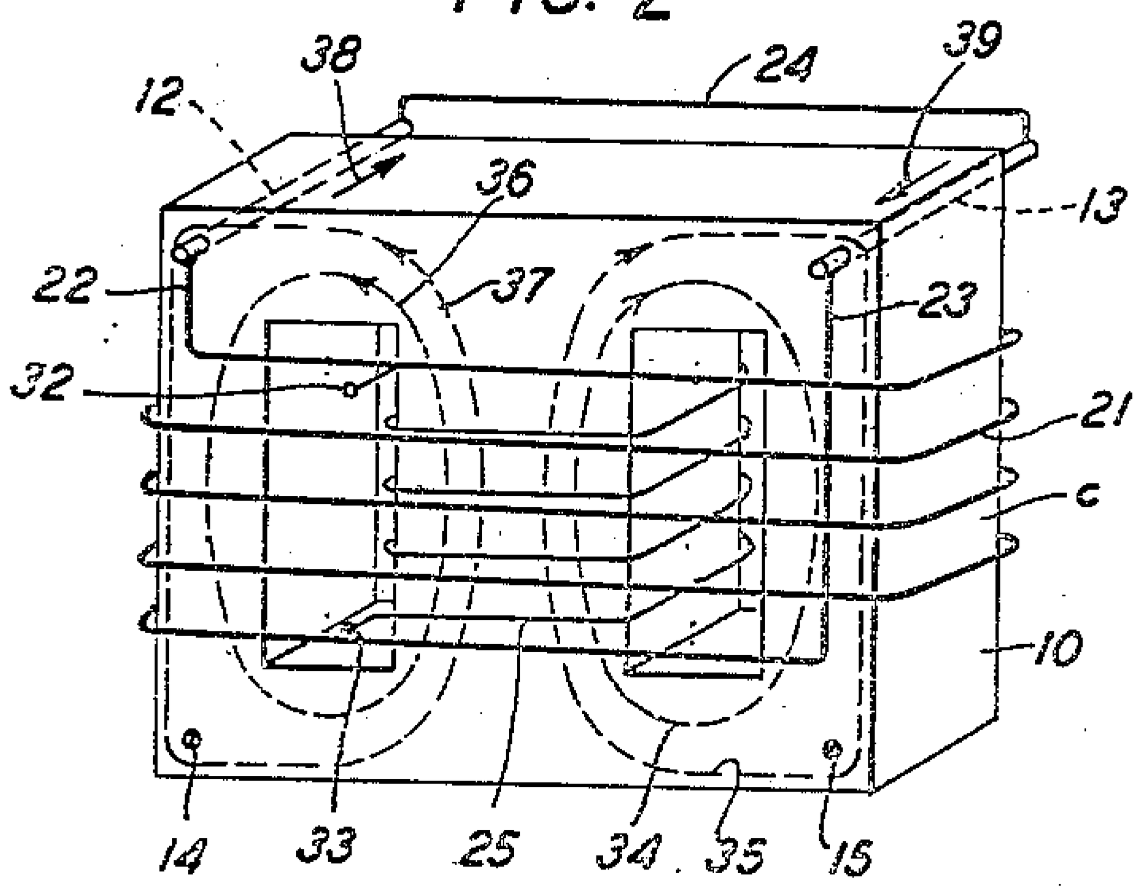

FIG. 4

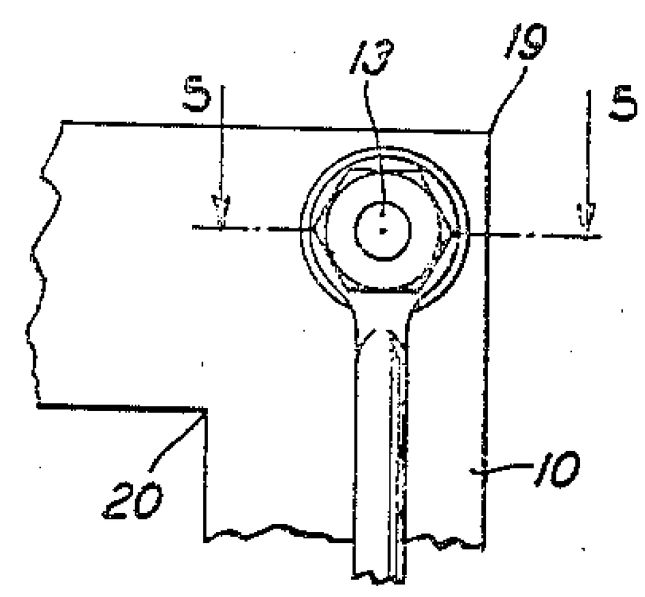

FIG. 5

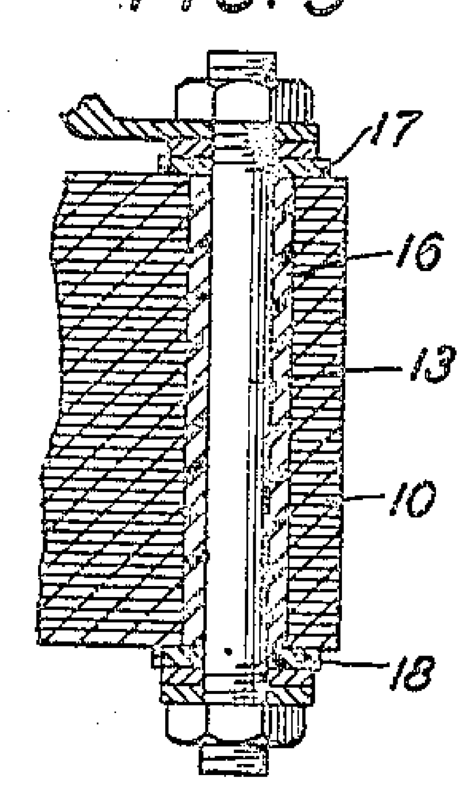

FIG. 3

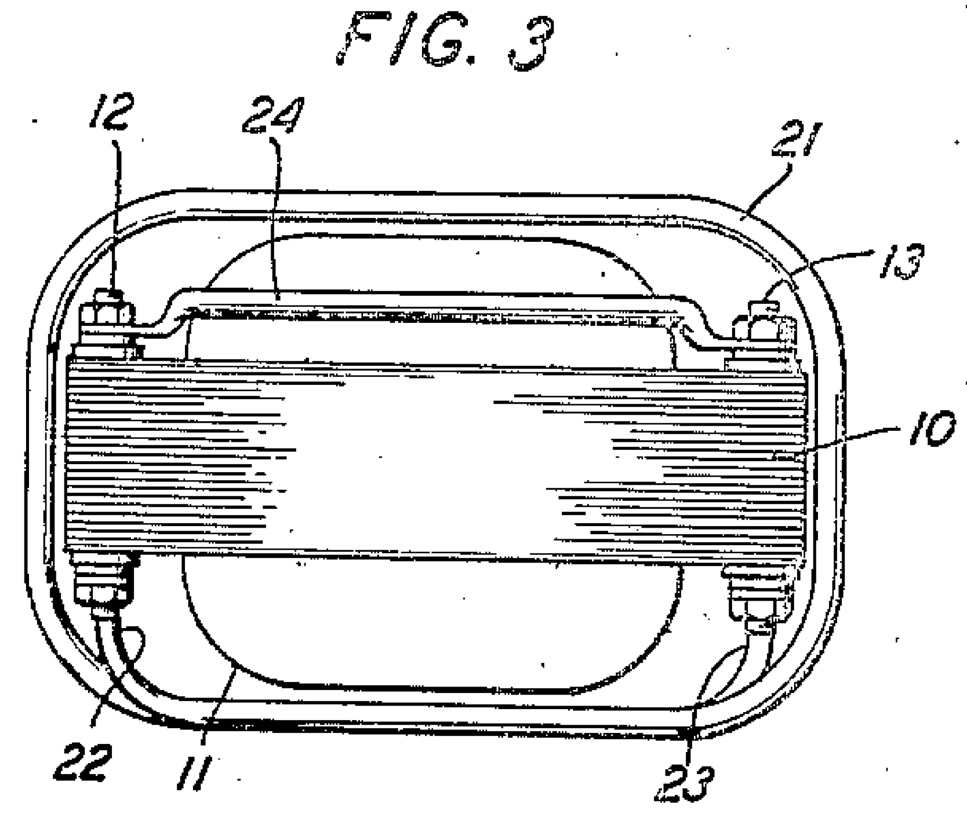

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FIG. 6

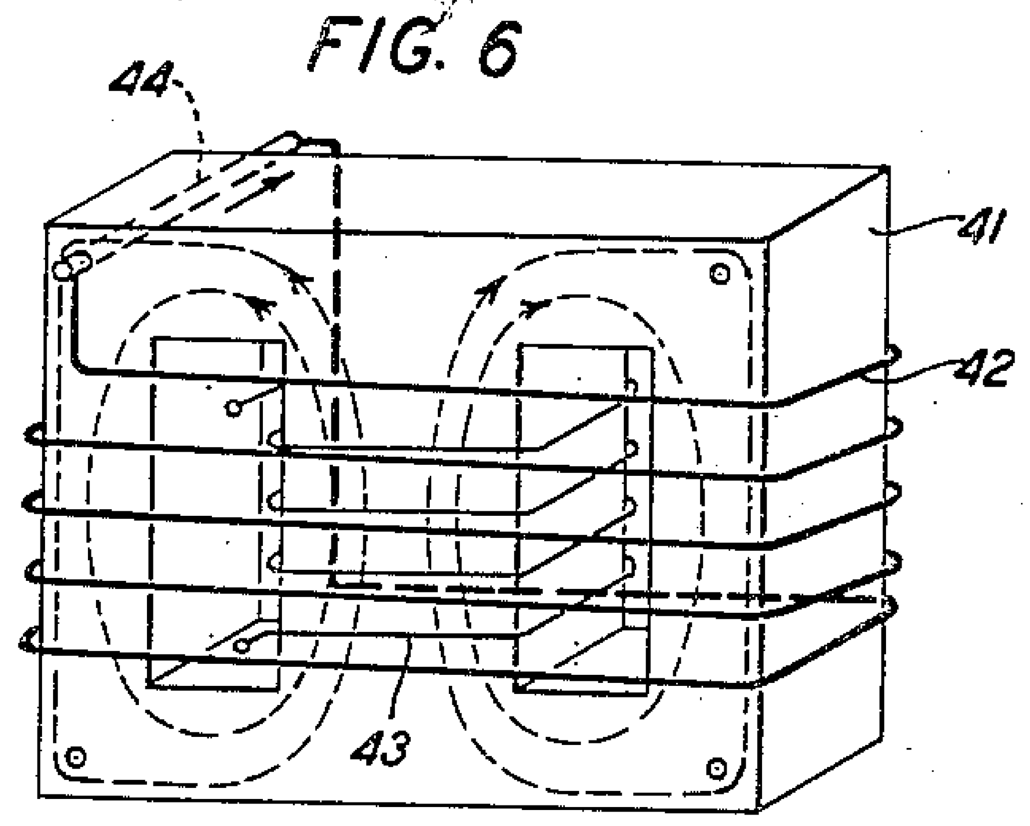


FIG. 7

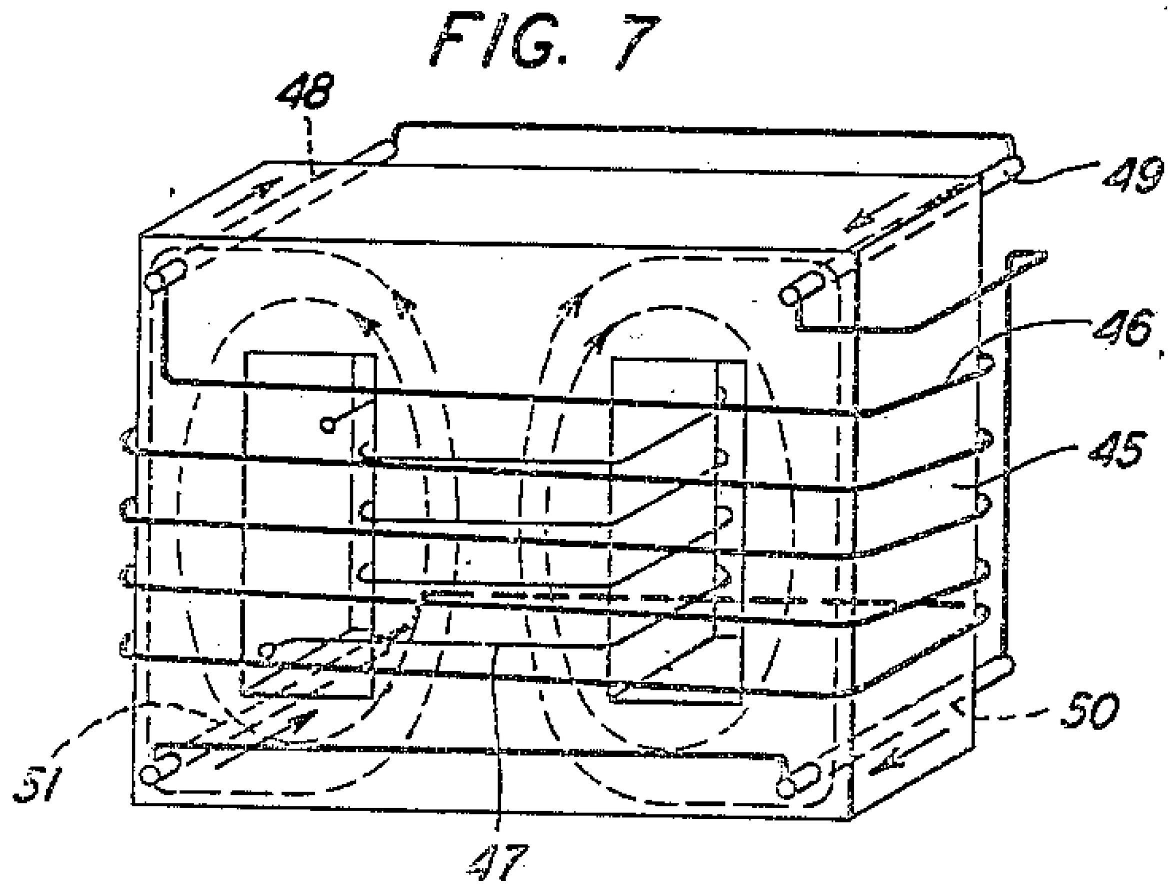


FIG. 8

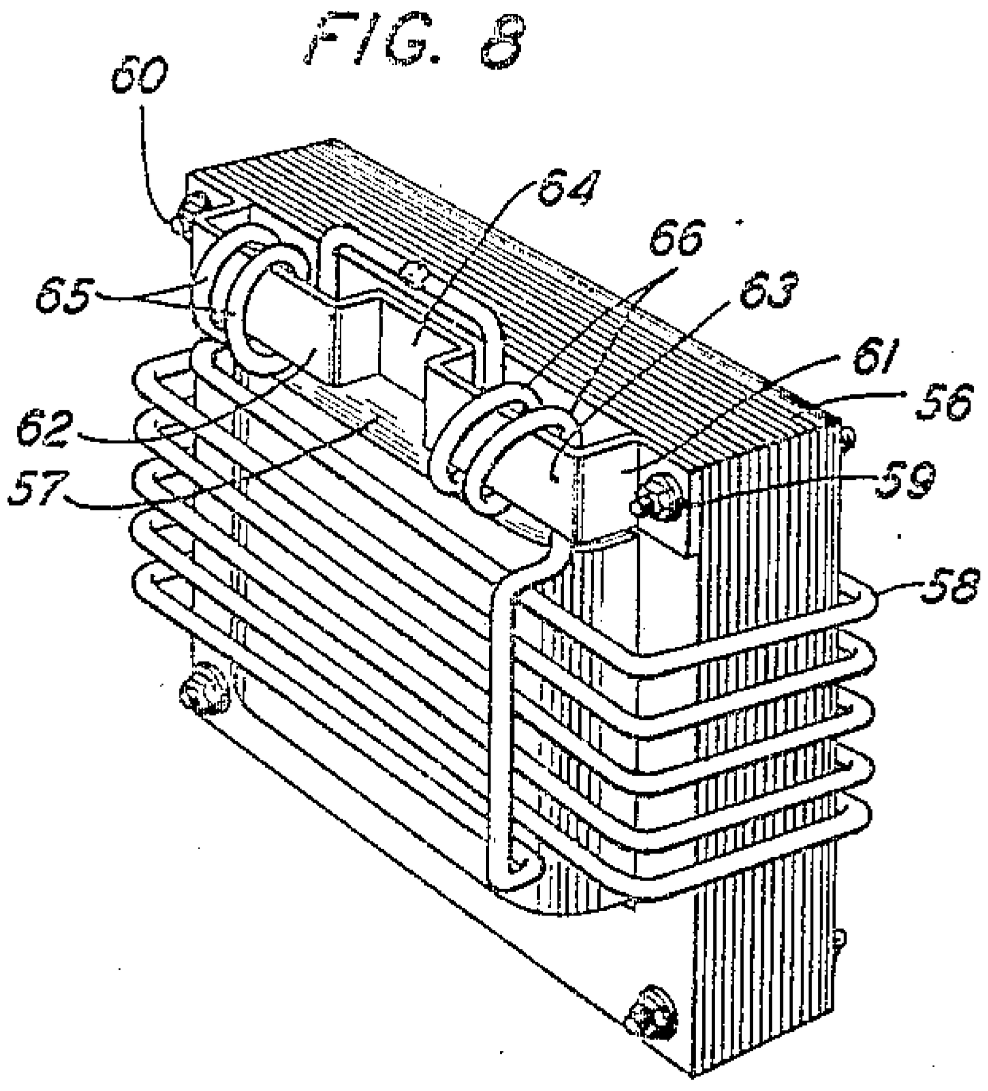
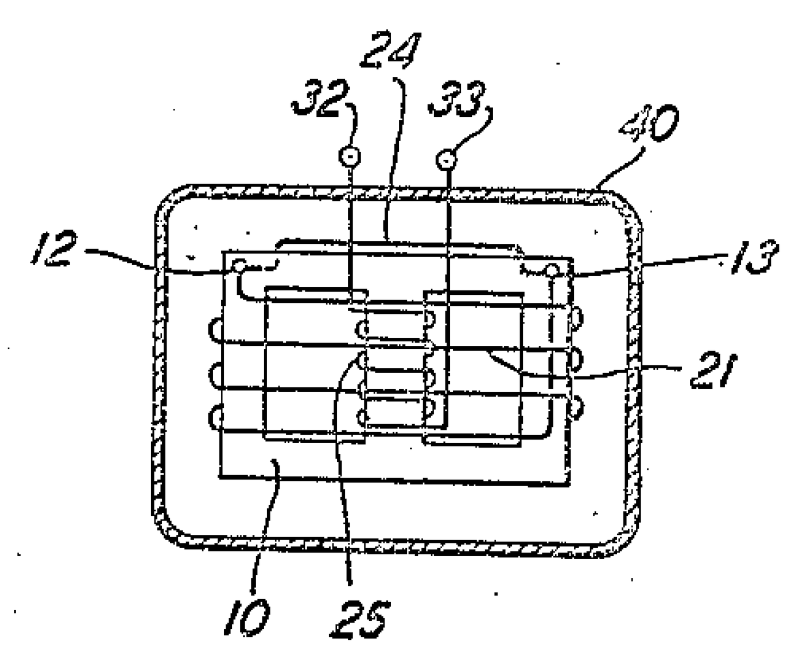


FIG. 9



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UNITED STATES PATENT OFFICE

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INDUCTANCE DEVICE

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Application May 30, 1944, Serial No. 538,065

9 Claims. (Cl. 175—356)

This invention relates to an inductance device or apparatus such as power transformers and its object is to reduce the stray magnetic flux from such apparatus.

Although the invention is of general application to stationary induction apparatus it will be illustrated as applied to a power transformer having a shell-type core with the usual primary and secondary windings surrounding a leg of the core. As is well understood in the art there is a certain amount of stray magnetic flux from such a core which is generally objectionable in that it may be picked up by adjacent apparatus and gives rise to disturbing potentials in a signaling circuit.

In accordance with this invention the stray magnetic flux from such a device is substantially reduced by the use of a closed circuit auxiliary winding of one or more turns which surrounds the core and the main winding and is coaxial with the main winding and which is so arranged as to have developed therein a current of the proper magnitude, wave form and phase to set up a field which opposes the external field of the transformer. The preferred source of electromotive force for this auxiliary winding is obtained by having a portion of this auxiliary winding enclosed only by that portion of the flux path in the core which is rich in harmonics of the fundamental frequency of the stray field so that the opposing field set up by the auxiliary winding will tend to neutralize not only the fundamental frequency but the harmonics of the stray field. In a shell-type core having its main winding connected to a 60-cycle source of current to produce a magnetic flux in the core, one portion of the magnetic path in the core which will have a flux rich in harmonics is that portion of the core near an outer corner thereof where the flux path is of higher reluctance. In the preferred embodiment of the invention a portion of the auxiliary winding is made to pass through an opening in the core near an outer corner thereof and in a direction perpendicular to the plane traversed by the core flux so that the auxiliary winding is enclosed by the flux passing between said opening and the adjacent outer corner of the core. In the manufacture of such power transformers, the core is usually made up of laminations held together by clamping bolts. In practicing the present invention one or more of these bolts may be placed at the corners of the core structures and suitably insulated from the core whereby these bolts may constitute portions of the auxiliary winding above described. Such bolts should be so connected together and so connected to the auxiliary winding proper that the voltages developed in the bolts by reason of the flux traversing the core path between each bolt and the adjacent outer edge of the core are additive and are also additive with respect to the voltage developed in the turns of the auxiliary winding by the stray field whereby the field set up by the flow of current in the auxiliary winding will be in the proper direction to oppose and tend to neutralize the stray field.

The invention will be better understood by reference to the following detailed description taken in connection with the accompanying drawings in which:

Fig. 1 is a perspective view of an unpotted shell-type transformer in which the stray field is reduced by the auxiliary winding of this invention;

Fig. 2 is a schematic view of the transformer of Fig. 1 in which the electromotive force developed in the auxiliary winding is obtained from two of the clamping core bolts;

Fig. 3 is a top view of Fig. 1;

Fig. 4 is an enlarged plan view of a corner portion of the laminated core of Fig. 1;

Fig. 5 is a sectional view of the laminated core portion of Fig. 4 taken along the line 5—5 of Fig. 4;

Fig. 6 is a modification of the transformer of Fig. 1 in which only one core bolt is utilized as part of the auxiliary winding;

Fig. 7 is similar to Fig. 6 except that four core bolts are included as parts of the auxiliary winding;

Fig. 8 illustrates an alternative arrangement utilizing a different portion of the core structure for inducing current in the auxiliary winding, and

Fig. 9 illustrates the transformer of Fig. 1 enclosed in a suitable case.

Referring more particularly to Fig. 1, the transformer disclosed is of the shell-type comprising a core 10 made up of a plurality of laminations of suitable magnetic material. The main winding 11 may comprise superimposed primary and secondary windings which are wound around the middle leg of the core in the usual manner. The laminations of the core are held together by bolts 12, 13, 14 and 15 and cooperating nuts. Each of the bolts 12 and 13, is suitably insulated from the core as shown, for example, in Fig. 5 where the bolt 13 is insulated from the core 10 by means of the insulating sleeve 16 and the insulating washers 17 and 18. From Fig. 4 it will be apparent that bolt 13, for a purpose which will be described later, is located substantially closer to the outer corner 19 of the core than to the inner corner 20 thereof. Bolt 12 at another corner of the core structure is insulated from the core in a similar manner and placed in the same relative positions as bolt 13. In Fig. 1 the other clamping bolts 14 and 15 need not be insulated from the core.

The core 10 and the main windings 11 are surrounded by a single layer multiturn auxiliary winding 21 which is wound coaxially with the main winding. As shown in Figs. 1 and 2, one terminal 22 of auxiliary winding 21 is electrically connected to the front end of bolt 12 while the other terminal 23 of winding 21 is electrically connected to the front end of bolt 13. The rear ends of bolts 12 and 13 are electrically connected by a strap 24. The strap 24 and the turns of auxiliary winding 21 are covered with a suitable insulating material. Auxiliary winding 21 with the bolts 12 and 13 and strap 24 therefore constitute a closed circuit in which an electromotive force will be induced by reason of the fact that a portion of the auxiliary winding is enclosed by that portion of the flux path in core 10 which passes between bolt 13 and the adjacent corner edge of the core and between bolt 12 and the adjacent corner edge of the core.

Referring more particularly to the schematic view of the transformer shown in Fig. 2, only the primary or magnetizing winding 25 is disclosed, while the superimposed secondary winding is omitted to simplify the drawings. Assume for the moment that the terminals 32 and 33 of primary winding 25 are connected to a 60-cycle power source and that for a given half cycle of the current therefrom the flux path in core 10 is indicated by the dotted lines 34 to 37 traveling in directions indicated by the arrows thereon. While most of the flux Φ_a will take the paths indicated by lines 34 and 36, a portion of the flux Φ_b will take the paths indicated by lines 35 and 37. Bolts 12 and 13 are within the path of the flux Φ_b which induces a voltage in them so that a current will flow if they are connected in a closed circuit. As shown in Fig. 2, the two bolts 12 and 13 are electrically connected in a closed circuit including auxiliary winding 21 and strap 24 in such a manner that the voltages developed in the two bolts are additive, the direction of current flow in the two bolts being indicated by the solid line arrows 38 and 39 of Fig. 2 for the flux direction in the core indicated in the same figure with due consideration of time-phase relations. The turns of winding 21 are wound around core 10 in such a direction that the voltage induced in winding 21 by reason of the stray field from core 10 is additive to the voltages induced in bolts 12 and 13.

The magnetizing current supplied the transformer, Fig. 2, by primary winding 25 may be largely distorted depending on the flux density at which the core is operated. This distortion arises mainly from the hysteresis in the magnetic circuit. Because of this distortion the stray field is rich in harmonics of the fundamental frequency of the current supplied to primary winding 25.

It is well known that the magnetizing current of a transformer increases rapidly with the increase of flux density in the core and that the harmonics increase at a greater rate than the fundamental. Since the external or stray field of the transformer is a function of the magnetizing current, it is essential that the current in auxiliary winding 21 change in the same manner as the magnetizing current of the transformer.

Due to the particular location of the core bolts 12 and 13 at the corners of the shell-type core 10, the electromotive force developed thereby in auxiliary winding 21 is also rich in harmonics of the fundamental frequency of the current supplied from the primary winding 25.

The following data show that the electromotive force induced in core bolts 12 and 13 is rich in harmonics of the fundamental frequency. Let *a* represent the core section lying between the core window and bolt 13; *b* the core section lying between bolt 13 and the adjacent outer corner of the core; and *c* the core section at the point marked *c* in Fig. 2. The following values are the component voltages induced in one turn on open circuit enclosing sections *a*, *b* and *c* respectively, with respect to the flux density in the center leg of the transformer:

Center leg flux density lines per sq. in.	Section	Millivolts in one turn		
		60 C. P. S.	180 C. P. S.	300 C. P. S.
70,000	*a*	465	57	14.5
63,000		425	44	9.5
56,000		385	34	5.5
70,000	*b*	78	38	7.0
63,000		60	25	4.0
56,000		45	16	2.5
70,000	*c*	535	21	10
63,000		485	20	7.4
56,000		430	20	2.4

Regarding phase relations, if the core bolt 13 is considered merely as a secondary winding of the transformer, the voltage induced in core bolt 13 would be 180 degrees out-of-phase with the voltage applied to the magnetizing winding 25 and 90 degrees out-of-phase with the external field. To obtain from the auxiliary winding 21 a field which is 180 degrees out-of-phase with respect to the external field of the transformer, it is necessary to provide sufficient reactance in the closed circuit comprising winding 21. The electrical connection of core bolts 12 and 13 with the multiturn winding 21 provides this reactance. A core bolt, such as bolt 13, is not well coupled with the primary winding 25 and can be considered in series with a leakage reactance. By drawing sufficient current from the core bolts 12 and 13 this leakage reactance is effective in producing the proper phase relation, together with that reactance provided by the multiturn winding 21. To obtain a large current only a few turns of heavy wire are used in the auxiliary winding 21 so that it has a low resistance.

In one particular embodiment where auxiliary winding 21 comprised eight turns of heavy copper wire uniformly spaced over substantially the entire core structure 10, it was found by measurement that the current in winding 21 was approximately 5 amperes.

It has been found in utilizing one embodiment of this invention that the stray field of a shell-type transformer using no metallic casing for the transformer will have its external field reduced by an amount of 10 to 14 decibels for the fundamental frequency and with a decibel loss almost as large for the harmonics when an auxiliary winding of the type illustrated in Fig. 1 is employed.

However, this invention may also be advantageously employed for reducing the external field of transformers that are ordinarily enclosed in a metallic case. For example, in Fig. 9 a shell-type transformer of Fig. 1 is shown enclosed in a suitable casing 40 of magnetic material such as steel or Mumetal.

The following measurements indicate the extent to which the external field may be reduced by the employment of the auxiliary winding of this invention. As indicated, one set of measurements was taken for a transformer of the type disclosed in Fig. 1 without any auxiliary winding but with an enclosing casing of steel. Another set of measurements gives the external field for a transformer of the type in Fig. 1 including an auxiliary winding 21 electrically connected in circuit with two of the core bolts as indicated in that figure and with the transformer enclosed in the same steel case as for the first set of measurements. For the third set of measurements the conditions are the same as for the second set except that the transformer case was of Mumetal instead of steel. The voltage values given in the following tables are millivolts pick-up with a small search coil six inches from each side of the transformer indicated:

Table A—where the transformer has no auxiliary winding and is enclosed in a steel case

Frequency, C. P. S.	Bottom side	Broad side	Narrow side
60	15.0	7.7	6.7
180	11.0	5.4	4.6
300	2.8	1.5	1.2

Table B—where the transformer is enclosed in the same steel case above-mentioned but the transformer is provided with the auxiliary winding of Fig. 1

Frequency, C. P. S.	Bottom side	Broad side	Narrow side
60	1.7	1.1	1.5
180	1.7	1.4	1.8
300	.8	.5	.6

Table C—where the transformer is enclosed in a Mumetal case and is provided with the auxiliary winding of Fig. 1

Frequency, C. P. S.	Bottom side	Broad side	Narrow side
60	0.14	0.05	0.06
180	.13	.01	.08
300	.11	.03	.04

It is to be understood that the number of core bolts electrically connected in the closed circuit including the auxiliary winding depends upon the field strength desired from the auxiliary winding. In Fig. 1 two of the core bolts 12 and 13 are electrically connected as part of the auxiliary winding 21 while in the modification illustrated in Fig. 6 only one core bolt is included in circuit with the auxiliary winding and in Fig. 7 four of the core bolts are connected in circuit with the auxiliary winding.

A detailed description of the embodiments illustrated in Figs. 6 and 7 is believed unnecessary since these figures are identical with the embodiment of Fig. 2 except for the number of core bolts electrically connected in the closed circuit comprising the auxiliary winding. In Fig. 6 the laminated core 41 is surrounded by multiturn auxiliary winding 42 which is wound coaxially with the main magnetizing winding 43 and the two terminals of auxiliary winding 42 are electrically connected to the opposite ends of core bolt 44 whereby bolt 44 serves the same function as core bolt 13 to produce in auxiliary winding 42 a current of the proper magnitude, phase and wave form to reduce the external field of the transformer. In Fig. 7 the laminated core 45 is surrounded by a multiturn auxiliary winding 46 wound coaxially with the magnetizing winding 47 and the four core bolts 48, 49, 50 and 51 are electrically connected in a closed circuit comprising auxiliary winding 46 in such a manner that the electromotive forces induced in the four core bolts are additive and so connected to the auxiliary winding 46 that the current produced thereby in said winding is of the proper magnitude, phase and wave form to produce a substantial reduction in the stray field of the transformer. Bolts 44, 48, 49, 50 and 51 are insulated from the core in the same manner as described for bolt 13 of Fig. 1.

A further alternative form of the invention is disclosed in Fig. 8 where the core 56 is of the shell-type having a magnetizing winding 57 wound around the center leg of the core. A multi-turn single layer auxiliary winding 58 surrounds core 56 and is wound coaxially with the magnetizing winding 57. The core of Fig. 8 differs from the cores of the earlier figures in that the clamping bolts 59 and 60 for the core laminations also hold in place against the core structure a strip 61 of magnetic material. One portion 62 of strip 61 is located directly above one of the windows in the core structure while another portion 63 of strip 61 is located directly above the other window in the core structure; both portions 62 and 63 being spaced laterally from the core structure. The central portion 64 of strip 61 is in contact with the main core directly above the center leg of the transformer core. The flux traversing sections 62 and 63 of strip 61 will be rich in harmonics of the fundamental frequency of the stray field for the same reasons as the flux traversing section *b* of the core of Fig. 2. As shown in Fig. 8, the auxiliary winding 58 includes one or more turns wound around strip portion 62 and one or more turns wound around strip portion 63. Assuming the direction of the flux in core 56 is the same as that indicated by the dotted lines in Fig. 2, the direction the turns 65 are wound around strip 62 and the direction the turns 66 are wound around strip 63 and the direction the main portion of winding 58 is wound around core 56 are such that the electromotive force induced in turns 65 is additive with respect to the voltage induced in turns 66 and the sum of these two voltages is additive to the voltage developed in the main portion of winding 58 due to the external field of the transformer. The arrangement of Fig. 8 will, therefore, produce a substantial reduction in the external field of the transformer in the same manner and to the same extent as is secured by the earlier described embodiments of the invention.

It is also to be understood that this invention may possess still other embodiments commensurate with the scope of the appended claims.

What is claimed is:

1. An inductance device comprising a magnetic core, a main winding wound only on one portion of said core and adapted to be traversed by alternating current of a definite frequency, said core having such a configuration that a second portion of said core external to said winding is traversed by a flux rich in harmonics of the fundamental frequency of said current, and means

for reducing the stray field from said core, said means comprising a closed circuit of negligible resistance comprising an auxiliary winding surrounding said core and said main winding and coaxial with said main winding, a portion of said auxiliary winding being enclosed only by said second core portion, said auxiliary winding portion and the remainder of said auxiliary winding being so connected that the current flow in said auxiliary winding produced by the flux traversing said second core portion produces a magnetic field opposed to the stray field of said device.

2. An inductance device comprising a magnetic core, a main winding wound on only one portion of said core and adapted to be traversed by alternating current of a definite frequency, said core having such a configuration that a second portion of said core external to said main winding is traversed by flux in which harmonics are present with respect to the fundamental frequency in ratios of substantially the same order of magnitude as in the stray field of said device, and means for reducing the stray field from said core, said means comprising a closed circuit of negligible resistance comprising an auxiliary winding surrounding said core and said main winding and coaxial with said main winding, a portion of said auxiliary winding being enclosed only by said second core portion, said auxiliary winding portion and the remainder of said auxiliary winding being so connected that the current flow in said auxiliary winding produced by the flux traversing said second core portion produces a magnetic field which is substantially 180 degrees out-of-phase with respect to the stray field.

3. An inductance device comprising a substantially rectangular-shaped core of magnetic material defining two closed magnetic paths having a common path through a central portion of said core, a main winding on said central portion, and means for reducing the stray field from said device, said means comprising a closed circuit multiturn auxiliary winding embracing said core and with the main portion of said auxiliary winding wound coaxially with said main winding, said auxiliary winding having a portion threading through said core near an outer corner thereof in a direction substantially perpendicular to the plane of the flux through said core.

4. An inductance device comprising a substantially rectangular-shaped core of magnetic material defining two closed magnetic paths having a common path through a central portion of said core, a main winding on said central portion, and means for reducing the stray field from said device, said means comprising a closed circuit multiturn auxiliary winding embracing said core and with the main portion of said auxiliary winding wound coaxially with said main winding, said auxiliary winding having a portion threading through said core near an outer corner thereof in a direction substantially perpendicular to the plane of the flux through said core, the direction the turns of said auxiliary winding are wound on said core being such that the electromotive force developed in the portion of said auxiliary winding threaded through the core produces a current in said auxiliary winding which sets up a magnetic field opposing the stray field of said device.

5. An inductance device comprising a substantially rectangular-shaped core of laminations of magnetic material defining two closed magnetic paths having a common path through a central portion of said core, a main winding on said central portion, clamping bolts for holding said laminations together, at least one of said bolts being insulated from said laminations and passing through said laminations near an outer corner of said core, an auxiliary winding embracing said core and with the main portion of said auxiliary winding wound coaxially with said main winding, and a closed electrical circuit including said auxiliary winding and said one bolt connected in series.

6. An inductance device comprising a substantially rectangular-shaped core, a main winding on one limb of said core, a closed electrical circuit of negligible resistance comprising an auxiliary winding wound externally around said core and wound coaxially with said main winding, a portion of said auxiliary winding passing through a portion of said core external to said main winding and in a direction perpendicular to the plane of the flux traversing said core, said auxiliary winding portion being located closely adjacent an external corner of said core such that the distance between said external corner and said auxiliary winding portion is considerably less than the distance between said auxiliary winding portion and the adjacent inner corner of said core.

7. An inductance device comprising a substantially rectangular-shaped core of laminations of magnetic material, clamping bolts for holding said laminations together, a main winding on one limb of said core, an auxiliary winding embracing the entire core structure and wound coaxially with said main winding, one of said bolts passing through a portion of said core external to said main winding and being closely adjacent an external corner of said core such that the distance between said external corner and said bolt is considerably less than the distance between said bolt and the adjacent inner corner of said core, said one bolt being insulated from said laminations, and a closed circuit including said auxiliary winding and said one bolt connected in series.

8. An inductance device comprising a substantially rectangular-shaped core of laminations of magnetic material defining two closed magnetic paths having a common path through a central portion of said core, a main winding on said central portion, clamping bolts passing through said laminations for holding said laminations together, said bolts being electrically insulated from said laminations, one of said bolts being located closely adjacent one external corner of said core such that the distance between said one external corner and said one bolt is considerably less than the distance between said one bolt and the adjacent inner corner of said core, a second of said bolts being located closely adjacent a second external corner of said core such that the distance between said second external corner and said second bolt is considerably less than the distance between said second bolt and the adjacent inner corner of said core, a single layer multiturn auxiliary winding surrounding the entire core structure and wound coaxially with said main winding, the axial length of said auxiliary winding being at least equal to the axial length of said main winding, and a closed circuit of negligible resistance comprising said first bolt, said second bolt and said auxiliary winding connected in series, said first bolt and said second bolt being so connected to said auxiliary winding that the electromotive forces induced in said bolts are additive to produce a current flow through said auxiliary winding in the same direction as the current devel-

oped in said auxiliary winding due to the stray field of said device.

9. An inductance device comprising a magnetic core, a main winding wound on one section of said core and adapted to be traversed by alternating current of a definite frequency, said core external to said winding having a portion of increased cross-sectional area as compared with adjacent sections of said core, said core portion having an aperture dividing the flux traversing said core portion into two paths, one path having a higher reluctance than the other path whereby said one path is traversed by flux rich in harmonics of the fundamental frequency of said current, and means for reducing the stray field from said core, said means comprising a closed circuit of negligible resistance comprising an auxiliary winding surrounding said core and said main winding and coaxial with said main winding, a portion of said auxiliary winding threading through said aperture and enclosed only by said one flux path, said auxiliary winding portion and the remainder of said auxiliary winding being so connected that the current flow in said auxiliary winding caused by the flux traversing said one flux path produces a magnetic field opposed to the stray field of said device.

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