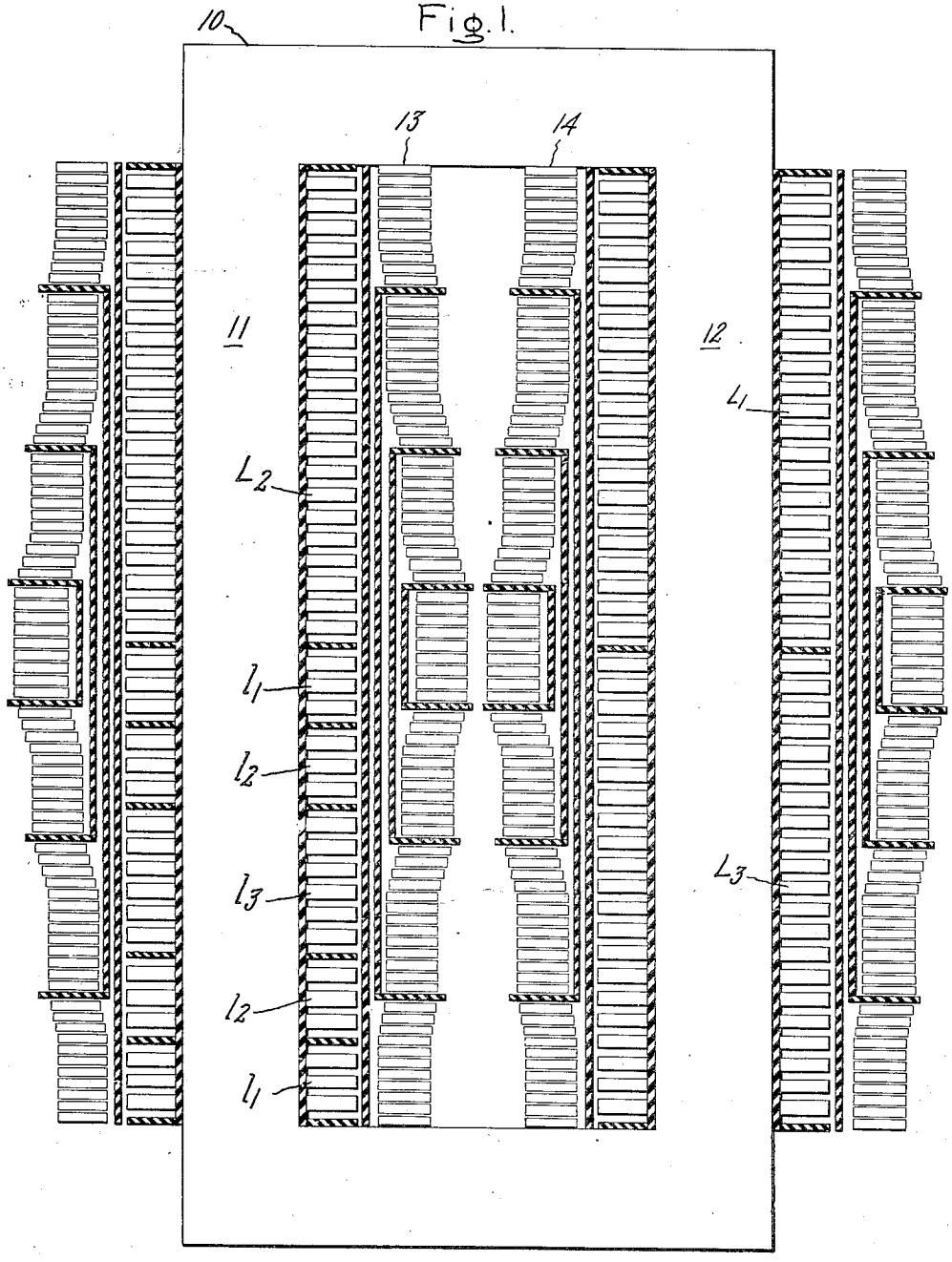
April 24, 1945. A. N. GARIN 2,374,597

ELECTRIC INDUCTION APPARATUS

Filed June 24, 1942 2 Sheets-Sheet 1

Fig. 1.



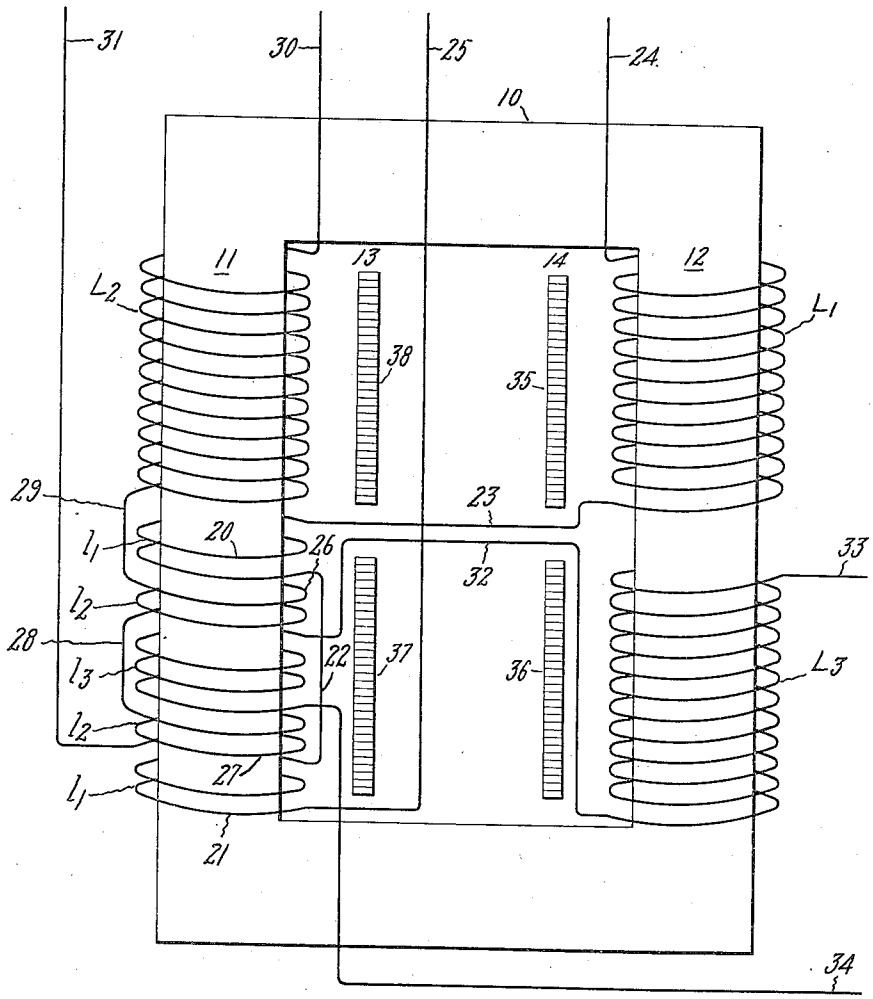
Inventor:
Alexis N. Garin,
by Harry E. Dunham
His Attorney.

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Fig. 2.



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UNITED STATES PATENT OFFICE

2,374,597

ELECTRIC INDUCTION APPARATUS

Alexis N. Garin, Pittsfield, Mass., assignor to General Electric Company, a corporation of New York

Application June 24, 1942, Serial No. 448,261

5 Claims. (Cl. 175—362)

My invention relates to electric induction apparatus, and although not limited thereto has particular application to split winding transformers.

In the design of electric induction apparatus, such as transformers having a plurality of windings, it is sometimes necessary to split one of the windings into a plurality of circuits. Whenever this is done, especially when the circuits are of the same voltage rating, it is desirable that these circuits should possess symmetrical impedance characteristics, that is, the impedances between any two circuits of the split winding should be approximately equal and the impedances between any circuit of the split winding and the other winding should also be approximately equal. Physical symmetry in the arrangement and location of circuits of a split winding is the most convenient method of obtaining symmetrical impedance characteristics. Thus, the usual way of obtaining symmetrical impedance characteristics is to have the number and location of the various circuits correspond with the physical symmetry of the apparatus. Split windings which include two circuits may have symmetrical impedance characteristics because of the "two-way" symmetry of typical normal transformer construction whether of core or shell type, and with concentric or interleaved windings, since the two legs of a two-legged design, or the two halves of a leg of a design having one leg per phase, either normally are, or can be made symmetrical.

However, three, four, or five-way physical symmetry required for split winding transformers with three, four, or five circuits in the split winding may or may not be compatible with normal transformer construction. For instance, the two-legged, concentric, line-in-the-middle design has inherently two-way symmetry and may have four-way symmetry, but does not have three-way or five-way symmetry. The three-group interleaved design has inherently two-way symmetry and may have three-way and six-way symmetry, but does not have four-way or five-way symmetry.

It is, therefore, an object of my invention to provide a structure which will have substantially symmetrical impedance characteristics for a multiple circuit electric induction apparatus where the number of circuits does not correspond to the physical symmetry of the apparatus.

Another object of my invention is to provide an electric induction apparatus having three circuits in the secondary winding with substantially symmetrical impedances from the primary to the three secondary windings taken individually or in pairs, and also to provide substantially symmetrical impedances between the secondary windings.

Further objects and advantages of my invention will become apparent from the following description referring to the accompanying drawings, and the features of novelty which characterize my invention will be pointed out with particularity in the claims annexed to and forming a part of this specification.

In the drawings Fig. 1 is a sectional side elevation of a transformer which is provided with an embodiment of my invention, and Fig. 2 diagrammatically illustrates the relative relationships of the secondary windings which form the split circuit of the structure illustrated in Fig. 1.

In the arrangement illustrated in the drawings, I have illustrated my invention as applied to a single phase three-circuit split winding transformer, but it is to be understood that my invention has application to any other suitable electric induction apparatus where the number of circuits does not conveniently lend itself to the physical symmetry of the apparatus. In order to provide substantially symmetrical impedances between the various windings, a major portion of each of the three circuits is placed in one of three of the quadrants or parts of the apparatus, a portion of each of the three circuits being placed in the remaining fourth quadrant or another part. In order to further contribute to the symmetry of the impedance characteristics, the portions of the three circuits in the fourth quadrant are so disposed with respect to each other as to counteract any unsymmetrical relationship between the major portion of the circuits in the first three quadrants. A quadrant or part or section of the core is considered as that portion which is bounded by two perpendicular planes each passing through the physical center of the core, one plane being in line with the longitudinal axis and the other plane being in line with the lateral axis. In the drawings the core, when it is assumed two perpendicular planes pass through the physical center, has four physically similar parts or quadrants or sections.

Referring more particularly to Fig. 1 of the drawings I have illustrated a transformer having a core member 10 with winding legs 11 and 12. Around the winding legs 11 and 12 are placed primary winding portions 13 and 14, respectively, which may be the high voltage winding of the apparatus. Concentric with the winding 14 and in an upper part or upper quadrant of the appa-

ratus there is placed a winding or group L_1. In the upper left hand quadrant of the apparatus and surrounding the winding leg 11 is placed a second winding circuit or group of windings L_2, and surrounding the lower part of the winding leg 12 or in a third quadrant is the third secondary winding circuit L_3. The winding sections L_1, L_2, and L_3 may be the secondary or low voltage windings and they may have the same relative number of coils. In order, therefore, to contribute to the symmetrical impedance characteristics of the low voltage windings having three circuits, a major portion of each of the circuits is placed in some of the parts of the apparatus, such as in three or four quadrants or parts of the electric apparatus.

It is to be understood that the impedances between each of the windings L_1, L_2, and L_3 are substantially symmetrical with respect to the adjacent portion of the high voltage windings 13 and 14 by providing the geometrical mean distances of the major portion of the circuit with respect to the high voltage windings to be the same. The calculation of reactances by the geometrical mean distance is described in various publications, such as: Electricity and Magnetism—Clerk Maxwell—volume II (1873), Absolute Measurements in Electricity and Magnetism—A. Gray—vol. II (1893), On the G. M. D. of Rectangular Areas and the Calculation of Self-Inductance—E. B. Rosa—, Bulletin of the Bureau of Standards—volume 3, 1907.

In order to contribute further to the symmetrical impedance characteristics between the three low voltage winding circuits a portion of each of the circuits is placed in the remaining apparatus parts or the fourth quadrant of the electric apparatus. As will be seen more clearly in the diagrammatic representation of Fig. 2, a portion of the first circuit, l_1, is placed in the fourth quadrant and is connected in series with the L_1 winding. Likewise a portion of the second circuit is placed in the fourth quadrant in the form of a winding l_2, and l_3 is placed in the fourth quadrant in series with the L_3 winding. Thus, the impedances between the three circuits and the adjacent high voltage windings will be substantially symmetrical.

In order to provide for substantial symmetry of the impedance characteristics of the various secondary winding circuits to each other, the minor portions of each of the circuits, l_1, l_2 and l_3, are disposed with respect to each other substantially opposite to the relative relationships of the major portion L_1, L_2, L_3. In other words, since L_1 and L_3 are relatively close together it is desirable to place the minor portions of the windings, l_1 and l_3, relatively far apart with respect to each other in the fourth quadrant. In order to accomplish this the minor portions of the winding l_1 are formed into two windings 20 and 21 connected together by a conductor 22 and which are placed at the opposite ends of the quadrant relatively far apart from the winding l_3, which is centrally disposed with respect to the fourth quadrant. Winding 20 is connected to L_1 by a conductor 23 and terminals 24 and 25 are provided for group 1.

In like manner since L_2 and L_3 are relatively far apart, their minor portions l_2 and l_3 are placed relatively close together in the fourth quadrant. However, in order that the minor portions will be symmetrical with respect to each other, l_2 is formed into two windings 26 and 27 connected together by a conductor 28 and which are placed on either side of the winding l_3, the winding l_2 being connected in series with the winding L_2. Winding 26 is connected to L_2 by a conductor 29 and terminals 30 and 31 are provided for group 2. Winding L_3 is connected to l_3 by a conductor 32 and terminals 33 and 34 are provided for group 3.

These three circuits, containing respectively, the coils (L_1+l_1), (L_2+l_2) and (L_3+l_3), may have their terminals brought out independently of each other and may be connected to independent load circuits; or the terminals may be brought to a terminal board within the transformer for series or multiple connection to provide either a voltage or a current three times the capacity of one circuit as required; or again, the three circuits may be connected permanently either in series or in parallel. In the first case above, the reactance relationship that is secured assures that the transformer will exhibit the same impedance characteristics, such as voltage regulation or short-circuit current, with respect to each load circuit under similar conditions. In the second and third cases, if connected in series, the distribution of the leakage flux of the transformer will be symmetrical; and if connected in parallel, the division of load current among the three circuits will be equal.

The primary windings 13 and 14 may be formed in any suitable manner and in Fig. 2 I have shown four groups of coils, 35, 36, 37, and 38, one being in each quadrant. These four primary windings may be connected in any suitable relationship, such as in parallel.

For best copper economy the general principle governing the distribution of total secondary turns between the major portion of the secondary winding (coils L_1, L_2, L_3) and the remainder of the winding (coils l_1, l_2, l_3) is that with all, three, circuits of the secondary winding equally loaded, the secondary ampere turns in the four quadrants of the transformer should be substantially equal, resulting in substantially equal currents in the four parallel circuits of the primary winding, each of which occupies one quadrant of the transformer, as described above. In the transformer shown in the drawings, coils L_1, L_2, L_3 have 110 turns each and coils l_1, l_2, l_3 have 28 turns each, so that the current division in the four parallel circuits of the primary winding, when all, three, circuits of the secondary winding are equally loaded, is approximately as follows:

Each of those three circuits of the primary winding which is located in the quadrants containing the L_1, L_2, L_3 coils of the secondary winding carries

$$\frac{110}{3\times110+3\times28}=26.6\%$$

of the primary line current; and the fourth circuit of the primary winding, located in the quadrant containing l_1, l_2, l_3 coils of the secondary winding, carries

$$\frac{3\times28}{3\times110+3\times28}=20.2\%$$

of the primary line current. It will be seen from these equations that the current distributed among the four primary circuits can be adjusted to any desired value by modifying the turn distribution between (L_1, L_2, L_3) and (l_1, l_2, l_3).

In view of the foregoing it will be seen that in order to have substantially symmetrical impedance characteristics between windings where the

number of winding circuits is different from the number of groups or parts which correspond to the physical symmetry of the apparatus, a portion or a major portion of each of the winding circuits is placed on a different winding receiving section of the core, such different winding receiving sections typically comprising all but one of the total number of such sections, and all the minor portions of said windings being placed symmetrically with respect to each other on the remaining winding receiving section of the core.

It will be evident now that my invention provides means whereby a transformer winding may be split into a desired number of electrically-symmetrical circuits when the structure of the transformer does not lend itself to subdivision into an equal number of physical-symmetrical parts, and that the desired electrical symmetry can be secured with reasonable accuracy and very conveniently with the help of the physical symmetry characteristic of the structure and involving a number of physical parts different from the number of the electrical circuits, without the necessity of resorting to laborious inductance calculations, and sometimes even with a greater accuracy than could be secured by calculation with available inductance formulas without taking advantage of such physical symmetry.

Furthermore, it is evident that this same principle applies when the number of parts involved in the physical symmetry differs from the number of circuits involved in the electrical symmetry by more than one.

Although I have shown and described a particular embodiment of my invention, my invention is not limited to the particular embodiment described; and I intend in the appended claims to cover all modifications which come within the spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In an electric induction apparatus having a core with two winding legs, first, second, and third windings adapted to form three circuits each of said windings having major and minor portions connected respectively together, said major portion of said first winding surrounding approximately one-half of one of said legs, said major portion of said second winding surrounding approximately one-half of said other leg opposite said first winding major portion, said major portion of said third winding surrounding the remaining one-half of said first core leg, each of said minor portions of said three windings surrounding the remaining one-half of said second core leg, said minor portion of said first winding having two subportions placed at opposite ends of said second core leg remaining one-half, said minor portions of said second winding having two subportions placed adjacent said subportions of said first winding subportions, and said minor portion of said third winding being placed between said subportions of said second minor winding portion.

2. A split winding transformer having at least two windings per phase, one of said windings being subdivided into a plurality of independent circuits having respective terminals which are insulated from each other, and core means for said windings having one more coil receiving section than said subdivided winding has circuits, all of said coil receiving core sections being excited by in-phase flux, said coil receiving core sections having physical symmetry, said circuits being disposed on said core means so that they have symmetrical impedance characteristics with respect to each other and with respect to the other of said windings by being subdivided respectively into major portions and minor portions, a major portion of each circuit being disposed on a different one of said coil receiving core sections, and all of said minor portions being disposed on the remaining coil receiving core section.

3. A split winding transformer having at least two windings per phase, one of said windings being subdivided into a plurality of independent circuits having respective terminals which are insulated from each other, and unitary core means for said windings having one more coil receiving section than said subdivided winding has circuits, all of said coil receiving sections being threaded by the same exciting flux, said coil receiving core sections having physical symmetry, said circuits being disposed on said core means so that they have symmetrical impedance characteristics with respect to each other and with respect to the other of said windings by being subdivided respectively into major portions and minor portions, the major and minor portions of each circuit being serially connected, a major portion of each circuit being disposed on a different one of said coil receiving core sections, the impedance characteristics of said major portions being unsymmetrical with respect to each other, and all of said minor portions being disposed on the remaining coil receiving core section, the physical relation between said minor portions being such as to produce unsymmetrical impedance characteristics therebetween which are opposite to the unsymmetrical impedance characteristics between said major portions.

4. An electrical induction apparatus having a unitary core which is symmetrical about longitudinal and lateral axes so as to have four equal quadrants, a winding having three circuits each of which has a major portion and a minor portion, the major portions of each of said circuits being disposed respectively on three of said quadrants, the minor portions of each of said circuits being disposed on the fourth quadrant so that said circuits will have substantially symmetrical impedances with respect to each other.

5. An electrical induction apparatus having a unitary core which is symmetrical about longitudinal and lateral axes so as to have four equal quadrants, a winding having three circuits each of which has a major portion and a minor portion, the major portions of said circuits being disposed respectively on three of said quadrants, the minor portions of said circuits being disposed on the fourth quadrant, said minor portions being disposed with respect to each other with relative distances different from the relative distances between said major portions so that said circuits will have substantially symmetrical impedances with respect to each other.

ALEXIS N. GARIN.