Sept. 24, 1946. J. K. HODNETTE 2,408,212

ELECTRICAL INDUCTION APPARATUS

Original Filed July 20, 1943

Fig. 1.

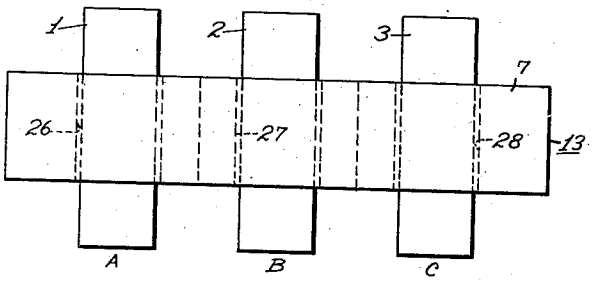


Fig. 5.

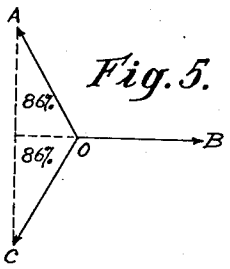


Fig. 2.

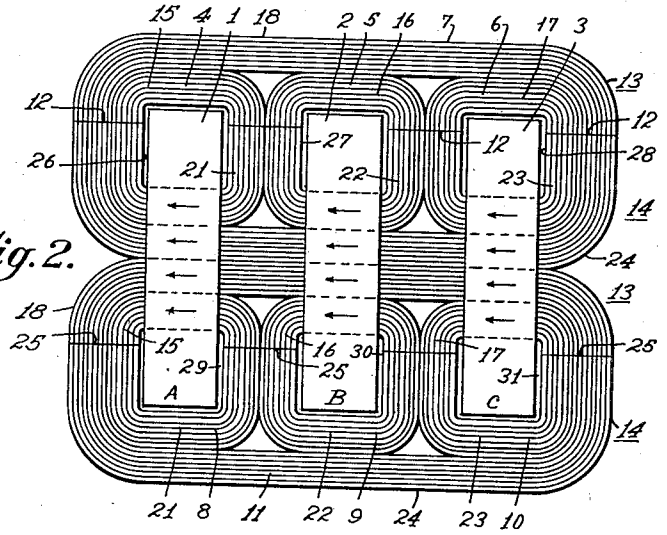


Fig. 6.

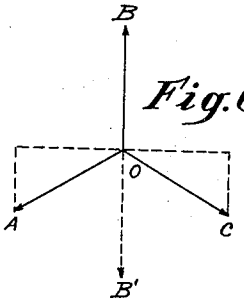


Fig. 3.

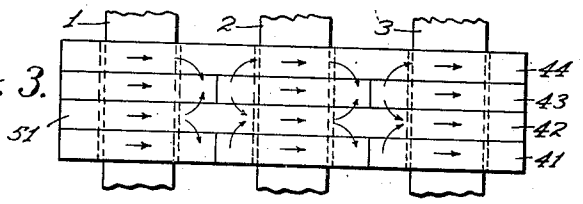
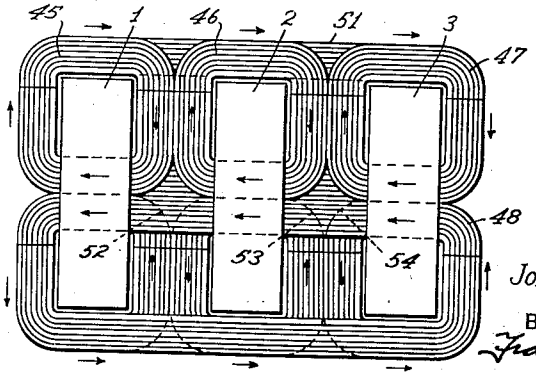


Fig. 4.



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2,408,212

ELECTRICAL INDUCTION APPARATUS

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Original application July 20, 1943, Serial No. 495,421. Divided and this application July 18, 1944, Serial No. 545,487

6 Claims. (Cl. 175—356)

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My invention relates to electrical induction apparatus, such as transformers, and particularly to the core or magnetic circuit structure thereof and to the method of making the same. More particularly, my invention relates to the core structures of polyphase induction apparatus used with alternating-current polyphase electrical circuits in which separate sets of phase windings are provided for connection to the separate phases of the polyphase circuit.

This application is a division of my copending application Serial No. 495,421, filed July 20, 1943, for Electrical induction apparatus, and assigned to the same assignee with this application.

Many commercial grades of silicon steel have slightly better magnetic properties in the direction of rolling than in a direction at an angle to the direction of rolling. That is, when the lines of magnetic flux pass through the steel substantially in the direction of rolling, the core loss is less and the permeability of the steel is higher than when the lines of magnetic flux pass at an angle to the direction of rolling, and these properties are poorest when the lines of magnetic flux are substantially perpendicular to the direction of rolling. It has been the usual practice in building core structures for use in distribution or power transformers to employ stacks of layers of thin sheets or laminations of magnetic material shaped as L-plates. These L-plates are stamped or punched from sheets of silicon steel, and it is necessary that a compromise in the direction of cutting be made which gives poorer magnetic qualities than those in the optimum direction.

It has been discovered that, by a proper control of cold rolling and annealing silicon steel, a preferred orientation of the grains in the direction of rolling may be effected in which the permeability of the steel is considerably higher at operating densities, say 13 to 18 kilogausses, than the permeability of commercial grades of hot rolled silicon steel at the same magnetic densities. Likewise, the watts loss per unit volume or unit weight at operating densities is lower than for commercial grades of hot rolled silicon steel at the same density when magnetized in the direction of rolling.

It will be seen, therefore, that if the magnetic circuit loops of a core are formed of a continuous ribbon of sheet steel having preferred orientation of the grains in the direction of rolling the strip, that is, in the direction in which the lines of magnetic flux pass through the strip, a core having high permeability and low watts loss will result.

There are also many advantages in utilizing

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preformed current coils for the windings of an induction apparatus, among which are the application of high-frequency testing and the inspection of the individual unassembled coils. These coils are wound on separate temporary formers or mandrels, and are then assembled together with the magnetic core structure of the transformer or other induction apparatus with the required insulation and spacers. When continuously wound cores have been proposed or utilized for use with preformed coils, these cores have been cut and provided with butt joints at the cut surfaces in order to provide for ready assembly of the core parts about the preformed coils. Until recently, however, magnetic core structures having butt joints have been characterized by high iron losses and high excitation currents which prevent their successful operation at high magnetic densities, such as are otherwise possible when improved magnetically oriented magnetic steels are used.

In my copending application Serial No. 401,699, filed July 10, 1941, for Induction apparatus, and assigned to the same assignee as this application, a core structure is disclosed that is formed of successive layers of magnetic sheet material wound layer upon layer and bonded together by filling the successive layers or turns of magnetic sheet material with bonding or filling material, thereby providing a solid or non-yielding laminated structure having a firm interlayer support for all portions of the layers of sheet steel which is beneficial in producing a true and relatively unburred cut surface forming the faces of the butt joints.

In Patent No. 2,293,951, filed by J. B. Seastone and C. C. Horstman, issued August 25, 1942, for Induction apparatus and method of core construction therefor, and assigned to the same assignee as this application, a further development in the formation of low loss butt joints is disclosed in which chemically inert bonding material is applied to the laminations, the core is cut, worked and etched to remove parts which could electrically connect adjacent laminations. In practicing the present invention, the teachings of my earlier filed copending application and the teachings of the Seastone and Horstman patent in the formation of butt joints may be employed to increase the efficiency of the use of the steel.

It is an object of the present invention to provide a low loss core structure for use in polyphase electrical apparatus in which a plurality of core loops of magnetic material are employed, and each formed from a sheet of magnetic ma-

terial wound flatwise layer upon layer as above-described and in which the separate core loops provide separate magnetic circuit paths.

It is a further object of the invention to provide a low loss core structure of the above-indicated character in which a plurality of core loops extend through the circuit conducting windings associated with each phase of the apparatus.

The invention accordingly is disclosed in the embodiments thereof shown in the accompanying drawing, and comprises the features of construction, combination of elements and arrangement of parts which will be exemplified in the constructions hereinafter set forth, and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawing, in which:

Figs. 1 and 2 are plan and side elevational views, respectively, of a core and coil assembly organized in accordance with the invention;

Figs. 3 and 4 are plan and side elevational views, respectively, of another embodiment of the invention; and,

Figs. 5 and 6 are vector diagrams.

Referring to the drawing, Figs. 1, 2, 3 and 4 show three-phase transformer structures of the shell type in which three phase winding structures 1, 2 and 3 are arranged along the same axis, and a portion of the core passes centrally through the windows in all three winding structures and returns parallel to the winding axis on the outside of the winding.

In Figs. 1 and 2 the core comprises two similar upper and lower halves as viewed in Fig. 2, the upper half including loops 4, 5 and 6 positioned about each of the three phase winding structures 1, 2 and 3, respectively, and an outer loop 7 about all three of the inner loops 4, 5 and 6, and, similarly, the lower half of the core structure includes three inner core loops 8, 9 and 10 positioned respectively about the winding turns of the three phase winding structures 1, 2 and 3, and an outer loop 11 that is positioned about all three of the inner loops 8, 9 and 10. With this arrangement of the core loops there exists a plurality of core loop members extending through the windows in each of the three sets of windings 1, 2 and 3. These core loop members include the winding leg portions of the two longer loops 7 and 11 which extend through the windows of all three winding structures 1, 2 and 3 and includes also the winding leg portion of each of the smaller core loops 4, 5, 6, 8, 9 and 10, each of which extends through a window of one set only of the three winding structures 1, 2 and 3.

Each of the several core loops 4 to 11, inclusive, consists of a plurality of layers of turns of a strip of magnetic material wound continuously to provide a plurality of laminations or sheets of steel. After the loops 4, 5 and 6 have been wound to provide the necessary number of turns, and the associated outer loop 7 enclosing the three smaller loops has likewise been wound to provide the necessary number of turns, the several loops are cut along the line 12 to provide upper and lower loop sections 13 and 14. The upper section 13 includes three U-shaped members 15, 16 and 17 corresponding to the upper portions of the three smaller core loops 4, 5 and 6, and a U-shaped member 18 corresponding to the upper portion of the longer loop 7 surrounding the

three smaller loops. Likewise, the lower section 14 includes three U-shaped members 21, 22 and 23 corresponding to the lower portions of the loop members 4, 5 and 6 and a U-shaped member 24 corresponding to the lower portion of the loop member 7. In each of the U-shaped members the laminations are bent flatwise at the bends of the U, the cut ends presenting a plurality of flat faces at the butt joint surfaces 12.

Either during the winding operation or thereafter, prior to cutting the core loops along the lines 12 to form the butt joints, the layers of magnetic material are bonded together by insulating and bonding material adhering to the opposite sides of each of the several turns or laminations comprising the core and are heat treated so that the group of laminations are yieldably, but rigidly, attached, so that when cut along the line 12, solid U-shaped pieces result which may be reassembled about the pre-formed coil structures 1, 2 and 3. The particular treatment may correspond in detail to that disclosed in my above-mentioned copending application and in the above-mentioned Seastone and Horstman patent.

The lower half of the core as viewed in Fig. 2 comprises the smaller core loops 8, 9 and 10 and the larger core loop 11 are wound, bonded together and cut along the lines 25 in the same manner above described for the upper half of the core structure, as viewed in Fig. 2, cutting the smaller core loops into upper U-shaped member portions 15, 16 and 17, and lower U-shaped portions 21, 22 and 23, and cutting the longer loop 9 into upper and lower portions 18 and 24, respectively, as described above with respect to the upper half of the core structure as viewed in Fig. 2.

It is common practice, in shell type transformers, to reverse the polarity of the middle one of the three-phase windings so that the flux passing between the coil groups can be reduced. With the polarity of phase B reversed, a greater proportion of the total flux passes through a path about a single window only about the coil group of each phase. As shown in Figure 2, there are six windows, 26, 27, and 28 in the upper half of the core structure and windows 29, 30 and 31 in the lower half of the core structure. The windows 26 and 29 accommodate the primary and secondary windings of phase A; the windows 27 and 30 accommodate the windings of phase B; and the windows 28 and 31 accommodate the windings of phase C.

Figure 5 is a vector diagram showing the phase relation between the magnetizing currents or magnetic flux in each of the three phases of the three-phase circuit, the magnetizing currents in the separate phases being indicated by the vectors A, B and C, respectively, all meeting at a common point O. The time phase relation between the magnetizing currents in the three phases will be 120° as shown, and the instantaneous current in any phase will be represented by the vertical distance between the outer end of the vector and the point O. In the instantaneous position shown in the diagram in Figure 5, the vertical projection of the vector B is zero and the projections of the vectors A and C are 86% of the maximum value, which maximum value is represented by the length of the vector, the projections of the two vectors being in opposite directions.

Referring to Fig. 2, and assuming the instantaneous flux relation in the three phases to be that represented by the vector diagram in Fig. 5,

the flux induced in the core by the phase windings A will be in one direction and the flux induced in the phase winding C will be in the opposite direction, and phase B will induce zero flux in the core. Since the flux induced in loops 7 and 11 by the phase windings A and C are in opposite directions, they will cancel out, leaving zero flux in these two outer loops of the core structure, the remaining flux passing through the four inner loops 4, 6, 8 and 10. There will be no instantaneous flux in loops 5 and 9 since in phase B the flux is zero.

Again assuming that the vector relation between the flux in the three-phase windings A, B and C is as shown in Fig. 6 with respect to which the arrows are shown in Figure 2 on the several portions of the core passing through the phase winding structures, with flux in phase windings A, B and C passing in the same direction, shown to the left in Figure 2, and flux in phase B being in the direction shown by the dotted vector B', resulting from reversing the polarity of this phase. It will also be noticed that the three vectors A, B and C are of equal length and equally displaced, and with the vector B reversed the direction of the flux in the three phases will be in the same direction in the winding leg portions of the two outer loops 7 and 11 for the instantaneous vector relation shown in the Fig. 6. Flux in the three loops 4, 5 and 6 will circulate in a clockwise direction in the several loops, and will circulate in the three loops 8, 9 and 10 in a counterclockwise direction for the instantaneous vector relation assumed.

Figs. 3 and 4 show a core structure that is, in general, similar to that shown in Figs. 1 and 2 except that instead of the core loops being wound from a strip of steel having a width corresponding to the desired width of the finished core, it is built up of several layers 41, 42, 43 and 44 as best shown in Fig. 3 and the loops are so arranged that in one layer, such as the first layer 41, three of the smaller loops 45, 46 and 47 each pass through the window of the associated phase winding structures 1, 2 and 3, a single loop passing through only one winding structure window, and in the same layer 41 the lower portion or remaining half of the core in that layer is formed of a winding loop 48 that extends through the windows in all three phase winding structures 1, 2 and 3 and returns along the outside of all three of these winding structures. In the next adjacent layer 42, the arrangement of the relatively smaller loops and the larger loop is reversed, the longer loop 51 being shown above the three smaller loops 52, 53 and 54. The dimensions of the several loops are such that the inner and outer edges of the loops are in alignment as they pass within the window of the several winding structures 1, 2 and 3, and also in the area passing the outer edge of the winding, so that the edges of the loops in the adjacent layers are adjacent each other in these areas. The core may be made up of any even number of such layers of larger and smaller loops. In Fig. 3, four such layers are shown, the layer 43 being a duplicate of the layer 41, and the layer 44 being a duplicate of layer 42. The arrangement of the larger and smaller loops shown in Figs. 3 and 4 is somewhat more efficient in the use of core material than that shown in Figs. 1 and 2, since, because the smaller and larger loops have their adjacent edges side by side in adjacent layers, flux may readily pass from a smaller to a larger loop and vice versa through the adjoining edges between the several layers. That is to say, a part of the flux induced in the winding leg portion of one of the longer loops in one winding structure which is opposite in direction or different in magnitude to the flux induced within another winding structure in another portion of the same core loop, will pass into the adjacent smaller loop. Also a portion of the flux induced in the smaller loops will likewise pass into the adjacent longer loops, so that the portions of the longer loops passing along the outer edges of the winding structures will carry a portion of the flux induced in the smaller loop.

The arrows shown in Fig. 4 indicate the direction in which the flux tends to pass for the condition represented by the vector diagram in Fig. 6, and the arrows in Fig. 3 correspond to those shown in Fig. 4 and include also arrows between the windings 2 and 3 showing the manner in which the flux passes from the loops in one layer to the loops in another layer, so that the longer loops passing through the windows in all three windings will distribute the flux between the smaller loops.

Since modifications in the structures shown may be made within the scope of my invention, I do not wish to be limited otherwise than by the scope of the appended claims.

I claim as my invention:

1. In a three-phase induction apparatus having a winding structure comprising three sets of windings, each set adapted to be connected to one of the three phases of an electric circuit, said three sets of windings being arranged in a row with their axis in alignment, a core structure comprising a plurality of core loops each formed of magnetic sheet material wound flatwise, the spaces between the successive layers of magnetic sheet material being filled with a substantially non-flowable, non-volatile, molded, solid material for solidly supporting the several layers of material against relative movement, each loop being cut to form closely fitting butt joints on opposite sides thereof and to provide separable core sections, the core structure comprising a plurality of core loop members, certain of said core loop members extending through a window of one set of windings only, and other core loop members adjacent thereto extending through the windows of all sets of windings.

2. In a three-phase induction apparatus having a winding structure comprising three sets of windings, each set adapted to be connected to one of the three phases of an electric circuit, said three sets of windings being arranged in a row with their axis in alignment, a core structure comprising a plurality of core loops each formed of magnetic sheet material wound flatwise, the spaces between the successive layers of magnetic sheet material being filled with a substantially non-flowable, non-volatile, molded, solid material for solidly supporting the several layers of material against relative movement, each loop being cut to form closely fitting butt joints on opposite sides thereof and to provide separable core sections, the core structure comprising a plurality of core loop members, certain of said core loop members extending through a window of one set of windings only, and other core loop members adjacent thereto extending through the windows of all sets of windings, the core loops in adjacent layers being so dimensioned that the inner and outer edges of the loops are in alignment on opposite sides of the loops for portions of their respective core turns.

3. In a three-phase induction apparatus having a winding structure comprising three sets of windings, each set adapted to be connected to one of the three phases of an electric circuit, said three sets of windings being arranged in a row with their axis in alignment, a core structure comprising a plurality of core loops each formed of magnetic sheet material wound flatwise, the spaces between the successive layers of magnetic sheet material being filled with a substantially non-flowable, non-volatile, molded, solid material for solidly supporting the several layers of material against relative movement, each loop being cut to form closely fitting butt joints on opposite sides thereof and to provide separable core sections, the core structure comprising a plurality of core loops, certain of said core loops of relatively lesser size being in alignment and each extending through a window in one set of windings only, and certain other of said core loops of relatively greater size extending about a group of the above-named core loops of relatively lesser size and through all the windows in said several sets of windings.

4. In a three-phase induction apparatus having a winding structure comprising three sets of windings, each set adapted to be connected to one of the three phases of an electric circuit, said three sets of windings being arranged in a row with their axis in alignment, a core structure comprising a plurality of core loops each formed of magnetic sheet material wound flatwise, the core structure comprising a plurality of core loop members, certain of said core loop members extending through a window of one set of windings only, and other core loop members adjacent thereto extending through the windows of all sets of windings.

5. In a three-phase induction apparatus having a winding structure comprising three sets of windings, each set adapted to be connected to one of the three phases of an electric circuit, said three sets of windings being arranged in a row with their axis in alignment, a core structure comprising a plurality of core loops each formed of magnetic sheet material wound flatwise, the core structure comprising a plurality of core loop members, certain of said core loop members extending through a window of one set of windings only, and other core loop members adjacent thereto extending through the windows of all sets of windings, the adjacent core loops being so dimensioned that the inner and outer edges of the loops are in alignment on opposite sides of the loops for portions of their respective core turns.

6. In a three-phase induction apparatus having a winding structure comprising three sets of windings, each set adapted to be connected to one of the three phases of an electric circuit, said three sets of windings being arranged in a row with their axis in alignment, a core structure comprising a plurality of core loops each formed of magnetic sheet material wound flatwise, the core structure comprising a plurality of core loops, certain of said core loops of relatively lesser size being in alignment and each extending through a window in one set of windings only and certain other of said core loops of relatively greater size extending about a group of the above-named core loops of relatively lesser size and through all the windows in said several sets of windings.

JOHN K. HODNETTE.