Jan. 17, 1961 R. P. THOMPSON ET AL 2,968,087

METHOD OF CONSTRUCTING MAGNETIC CORES

Filed April 19, 1955 3 Sheets-Sheet 1

Fig. 1

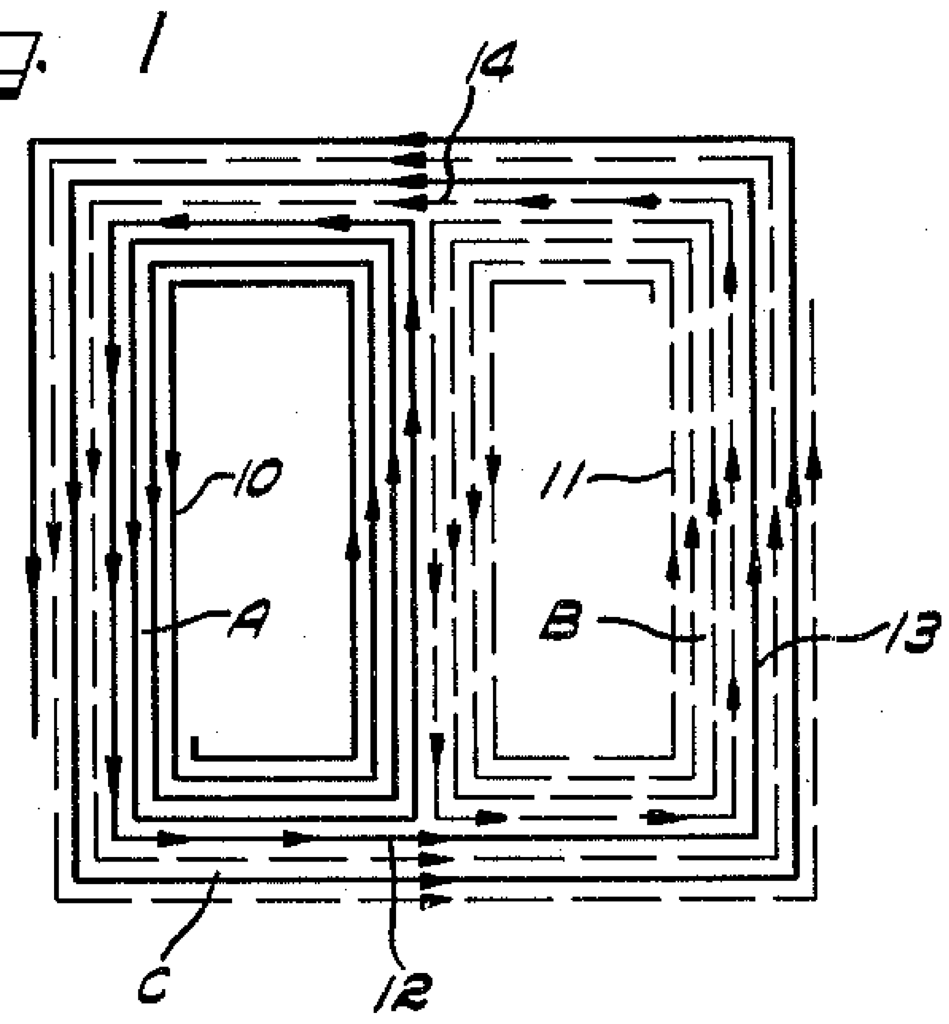


Fig. 2

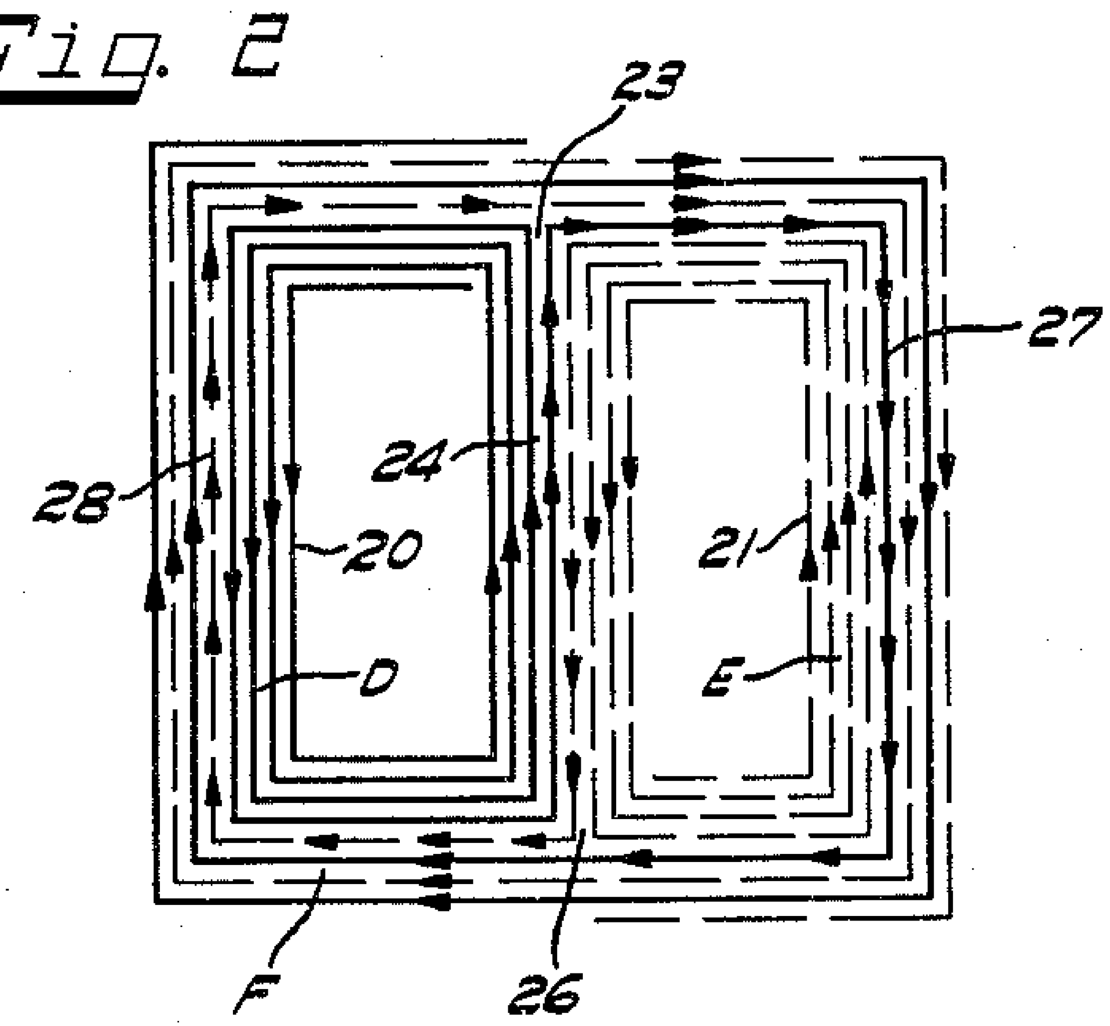
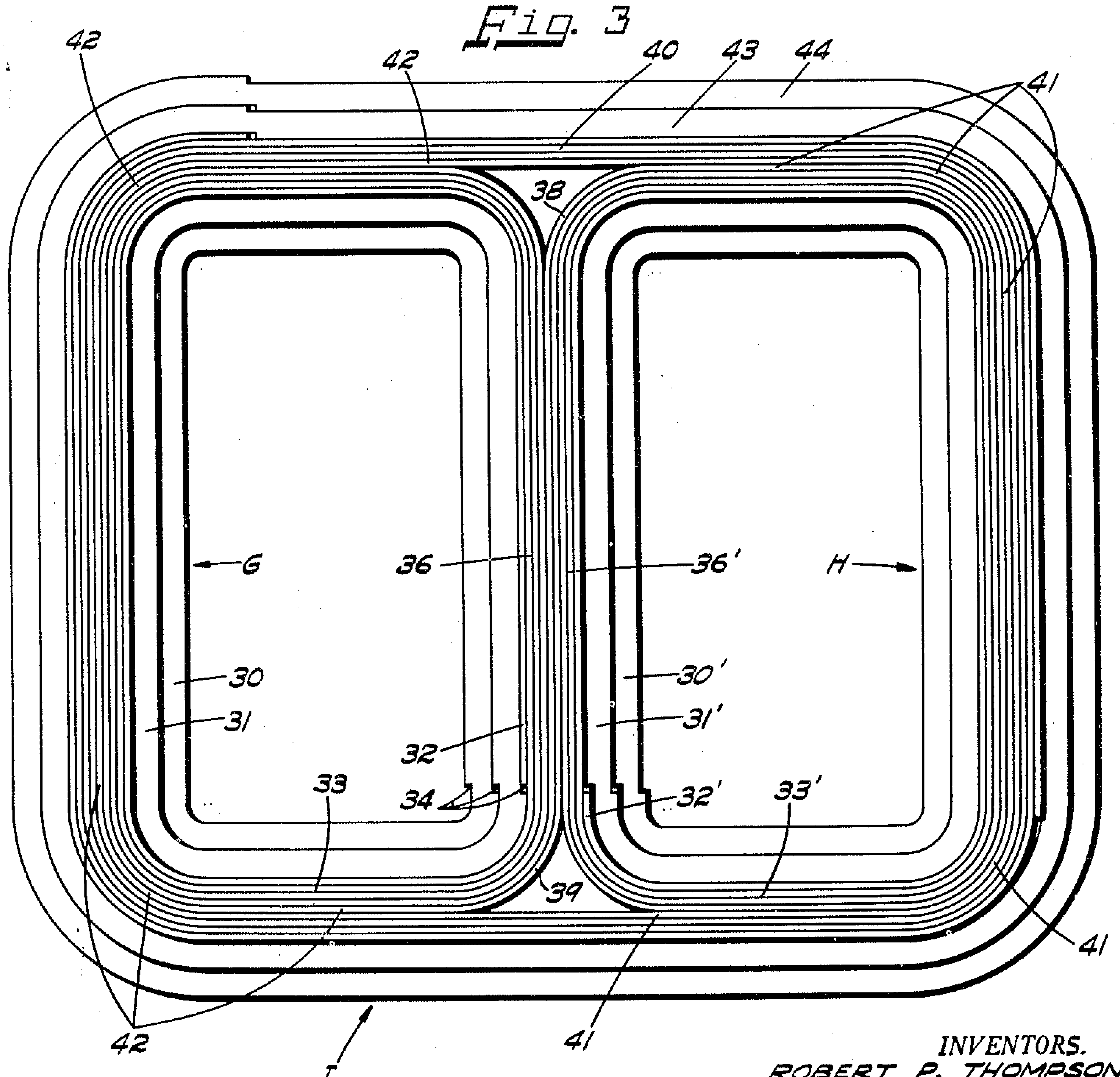


Fig. 3



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METHOD OF CONSTRUCTING MAGNETIC CORES

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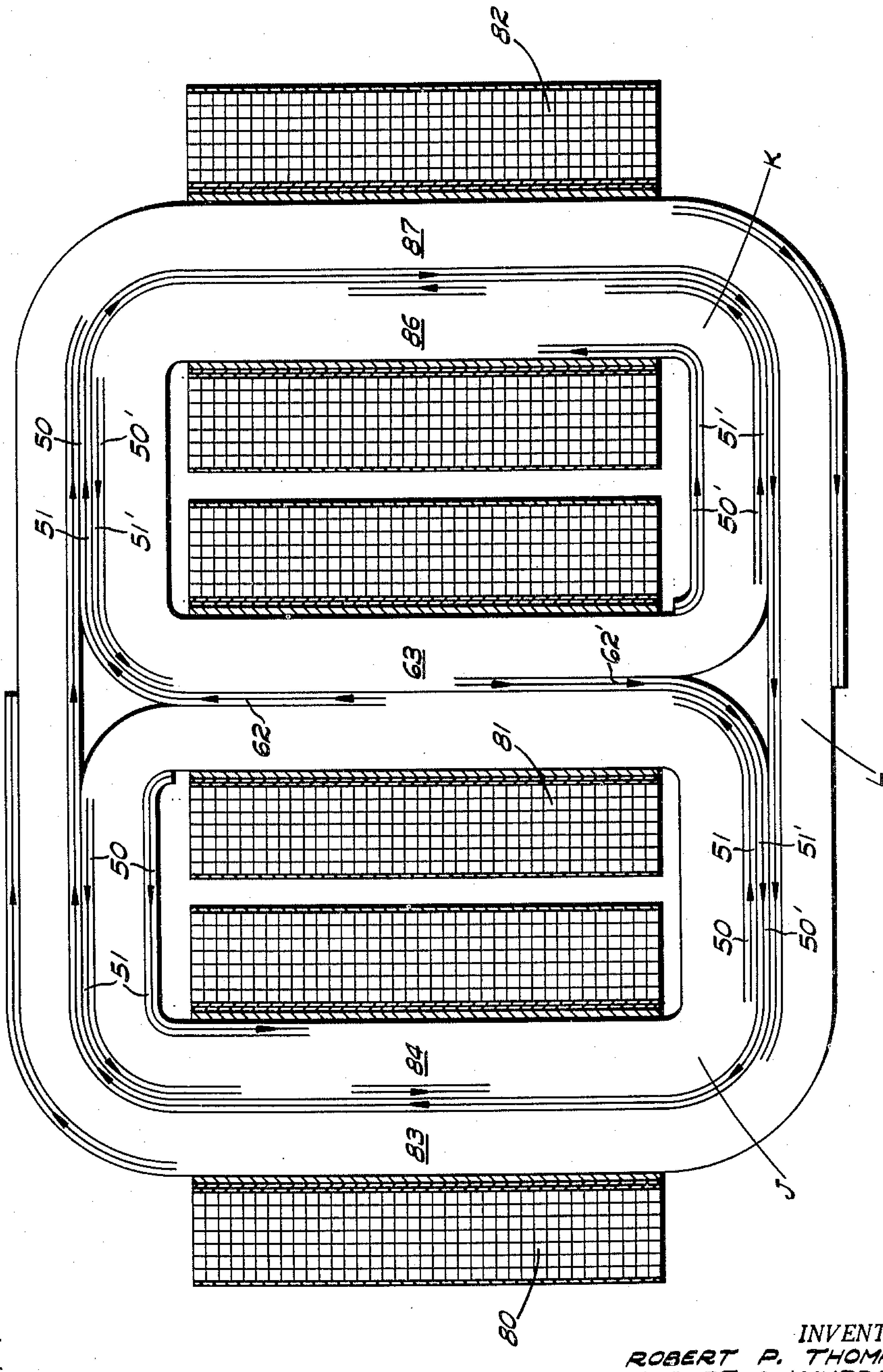

Fig. 4

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METHOD OF CONSTRUCTING MAGNETIC CORES

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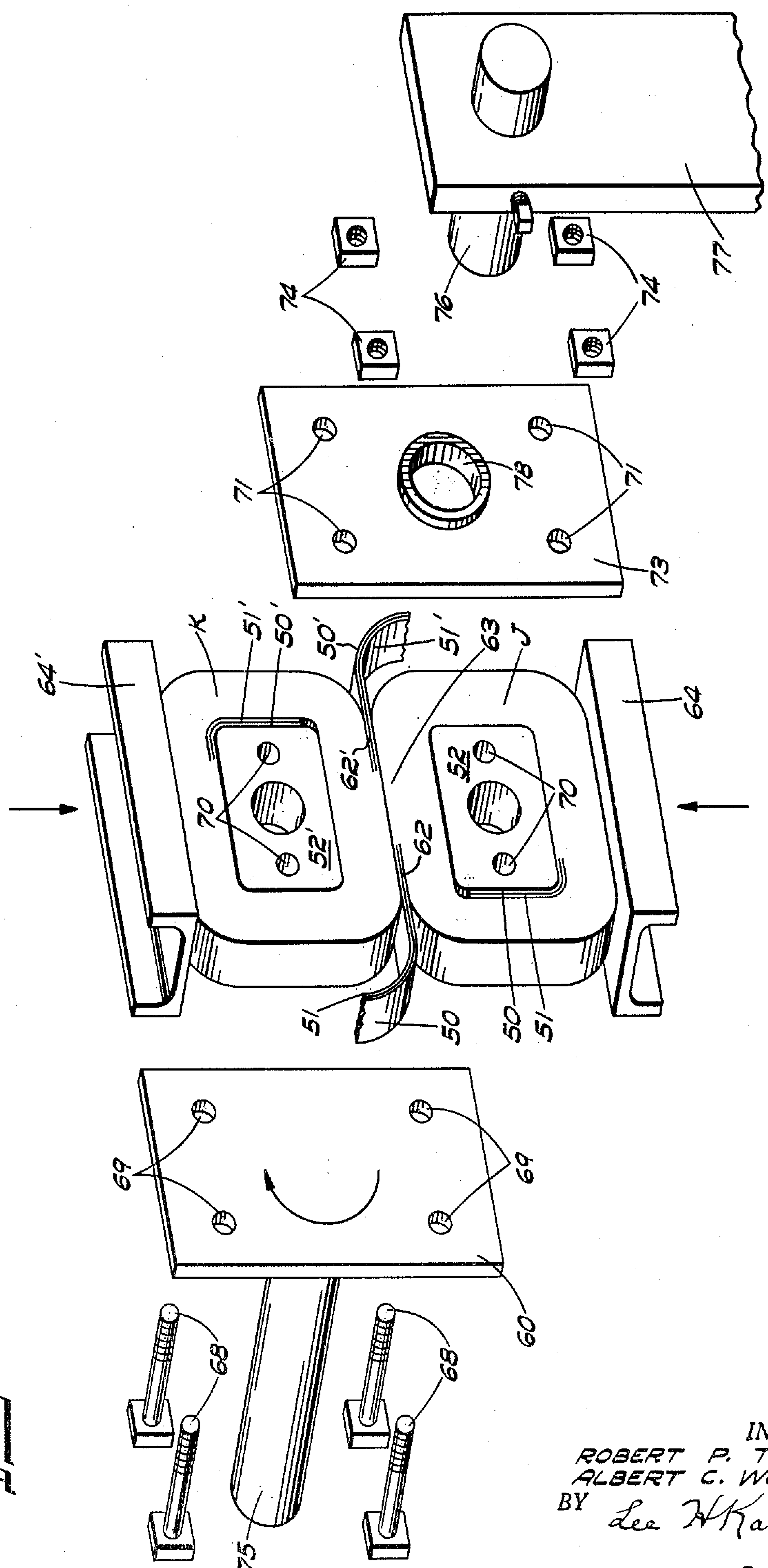

Fig. 5

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METHOD OF CONSTRUCTING MAGNETIC CORES

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3 Claims. (Cl. 29—155.57)

This invention relates to electrical induction apparatus such as transformers, and particularly to the magnetic core thereof and the method of constructing it. More particularly, the invention is directed to magnetic cores of polyphase induction apparatus used in polyphase alternating current circuits in which separate phase windings are provided for connection to the different phases of the polyphase circuit.

This invention is an improvement over the polyphase transformer and its method construction disclosed in the copending application of John L. Anderson and James G. Everhart, Serial No. 422,374, filed April 12, 1954, and assigned to the assignee of the subject invention. The core of the Anderson et al. application in its preferred form comprises two inner closed core loops, each formed of magnetic strip material spirally wound flatwise, disposed in abutting relation and surrounded by an outer closed core loop wound from magnetic strip material which is continuous with the magnetic strip material of the inner loops. The abutting sides of the two inner core loops constitute the center winding leg of the three phase core. Each of the two outer winding legs of the three phase core is formed by an outer side of one of the inner core loops and the side of the outer core loop adjacent thereto. In such a core the inner and outer core loops are magnetically interlinked by low reluctance iron paths.

It is an object of the present invention to provide a method of making a magnetic core in which a plurality of core loops, each spirally wound of magnetic strip material, are disposed in a multi-legged configuration comprising inner core loops surrounded by an outer core loop wound from magnetic strip material continuous with the magnetic strip material of the inner core loops as described above and wherein more effective transfer of flux between inner and outer core loops is obtained than in the core of which the present invention is an improvement.

It is a further object of the invention to provide a method of making a three-legged polyphase magnetic core which permits a greater percentage of flux from the center leg to return through the entire cross sectional area of the iron of the outer core legs than in prior art constructions.

It is a still further object of the invention to provide a method of making a three legged, polyphase magnetic core which has low reluctance iron paths at both ends of the center leg to facilitate transfer of flux between the center leg and the outer core loop.

In accordance with one aspect of the method of the invention, a pair of inner core loops are spirally wound of magnetic strip material, the two inner loops are disposed in abutting relation and with free lengths of uncut magnetic strip material continuous with the magnetic strip material of the inner core loops extending from opposite ends of the center leg formed jointly by the abutting sides of the inner loops, and the free lengths of uncut magnetic strip material are spirally wound in

parallel into a convoluted loop surrounding the inner loops in embracing relation thereto. In a core constructed in this manner low reluctance iron paths are provided at both ends of the center leg for the flux of the middle winding phase, i.e., the center winding leg, to transfer to and return from the outer core loop. Still greater flux transfer to the outer core loop is obtained by constructing a core in accordance with another aspect of the method of the invention wherein the two inner core loops are disposed with the same direction of winding and the outer core loop is wound in the opposite direction from which the inner core loops are wound. In a core constructed in this manner the magnetic ribbons from each inner loop make a complete convolution around the other inner loop before the uncut ribbons are spirally wound in parallel to form the outer core loop.

These and other objects of the invention will become more apparent upon consideration of the following detailed description when taken in connection with the accompanying drawing in which:

Fig. 1 is a view schematically illustrating the direction of winding the magnetic strip material in the magnetic core of the aforementioned application, Serial No. 422,374;

Fig. 2 is a view schematically illustrating the direction of winding the magnetic strip material in the preferred embodiment of the invention;

Fig. 3 is an elevation view of an embodiment of the invention having cruciform cross section;

Fig. 4 is an elevation view of an alternative embodiment of the invention wherein the outer core loop is formed from a plurality of magnetic ribbons from each inner core loop; and

Fig. 5 is a view of apparatus for winding the outer core loop of the embodiment of Fig. 4.

Referring to the drawing and more particularly to Fig. 1 which schematically illustrates the method of constructing the magnetic core of the aforesaid application, Serial No. 422,374, of which the present invention is an improvement, it will be noted that the magnetic core is shown as comprising two inner loop portions, indicated generally by the reference characters A and B, and an outer loop portion indicated generally by the reference character C surrounding the inner core portions A and B and wound from the magnetic ribbons of the two inner loop portions A and B. In the method of constructing the core of Fig. 1, a single continuous ribbon **10** of magnetic strip material having preferred grain orientation lengthwise thereof is spirally wound flatwise to form the inner loop portion A, and a single continuous ribbon **11** of magnetic strip material having preferred grain orientation lengthwise thereof is similarly spirally wound flatwise to form the inner loop portion B. The magnetic ribbons **10** and **11** are not severed after the inner core portions A and B are completed, and the portions A and B are disposed with adjacent sides abutting and the free lengths of uncut magnetic ribbons **10** and **11** are spirally wound in parallel into the convoluted loop C surrounding the inner core loops A and B in embracing relation thereto. It will be noted that the magnetic ribbon **10** leaves the inner core loop A at point **12** and continues for half a convolution **13** around the inner loop portion B to the point **14** where the magnetic ribbon **11** leaves the inner loop portion B, and the two ribbons **10** and **11** then continue in parallel about the inner core loops A and B to form the outer core loop C.

The inner loops of the core of the present invention are constructed in a manner identical to that described for Fig. 1, and in the preferred embodiment of the method of the present invention illustrated schematically in Fig. 2, a single continuous ribbon **20** of magnetic strip material having preferred grain orientation lengthwise thereof is spirally wound flatwise to form an inner loop portion D, and a single continuous ribbon 21 of magnetic strip material having preferred grain orientation lengthwise thereof is similarly spirally wound flatwise to form the inner loop portion E. The magnetic ribbons 20 and 21 are not severed, and the inner core portions D and E are disposed with adjacent sides abutting and so that the direction of winding both inner core portions D and E is the same, being counterclockwise as shown in Fig. 2, and further so that the free length of uncut magnetic ribbon 20 leaves inner core portion D at one end 23 of the center leg 24 formed by the adjacent sides of the inner core portions D and E and the free length of uncut magnetic ribbon 21 leaves the inner core portion E at the opposite end 26 of the center leg 24. The free lengths of uncut magnetic ribbons 20 and 21 are then spirally wound flatwise in parallel and in the opposite direction from which the inner core portions D and E are wound, i.e., clockwise as shown in Fig. 2, into a convoluted loop F surrounding the abutting inner loops D and E in embracing relation thereto. It will be noted that as a result of the step of disposing the inner loops D and E with the free lengths of uncut magnetic ribbon extending from the opposite ends of the center core leg formed jointly by the abutting sides of the inner loops, a direct iron path is provided by the ribbon 20 at the upper end 23 of the middle phase winding leg for transfer of flux to outer core section F and similarly that magnetic ribbon 21 provides a low reluctance iron path at the lower end 26 of the middle phase winding leg to permit flux transfer between the center leg and the outer core portion F. Further, as a result of the step of positioning the inner loops D and E so that their direction of winding is the same and winding the uncut lengths of ribbons 20 and 21 in the opposite direction from which the inner core portions D and E are wound, the magnetic ribbon 20 continues in a complete convolution 27 around inner core portion E before the ribbons 20 and 21 are in parallel and also the magnetic ribbon 21 similarly continues in a complete convolution 28 around inner portion D. Tests show that this latter construction provides an appreciable increase in the magnitude of the magnetic flux transferred to the outer core portion F.

Fig. 3 illustrates a cruciform-in-cross section magnetic core constructed in accordance with the invention schematically shown in Fig. 2 and comprises two inner loop portions indicated generally by the reference characters G and H and an outer continuous loop portion indicated generally by the reference character I surrounding the inner core portions G and H and wound from magnetic ribbons continuous with the magnetic ribbons from the inner loop portions G and H. Each of the inner loop portions G and H is formed by winding a closed core of magnetic ribbon. Although any suitable magnetic strip material may be utilized, it is preferable to utilize silicon steel having a preferred grain orientation lengthwise of the strip.

The inner loop portions G and H are both formed in an identical manner and only portion G will be described, the parts of the inner core portion H being given the same reference numerals as elements of portion G to which they are similar with the addition of the prime (′) designation. Although each inner loop portion may be formed from a single continuous ribbon spirally wound flatwise to provide a rectangular cross section, in the embodiment illustrated in Fig. 3 various widths of magnetic strip are utilized to build up cruciform-in-cross section inner portions G and H. A magnetic ribbon of suitable width is first spirally wound flatwise to provide a closed core section 30 of desired thickness. Inasmuch as the inner two sections of core portions G and H and the outer two sections of core portion I are similar to prior art construction, the convolutions of these sections have been omitted to clarify the drawing and direct attention to the principal novelty of the invention. The winding is preferably on a rectangular mandrel, although it is within the scope of the invention to wind on a circular mandrel and thereafter shape the core section to rectangular configuration. A magnetic ribbon of greater width is then wound over the ribbon of the inner section 30 to form a closed core section 31. Thereafter a magnetic ribbon 32 of still greater width is wound around the convolutions of the core section 31 to form a closed core section 33. The ribbon 32 is not severed after the desired number of turns have been wound.

It is well known in the art that in the winding of a core section, the inner and outer ends of the magnetic ribbon may be brazed, tack welded, or otherwise secured as indicated by the reference numeral 34 and further that the ends of successive magnetic ribbons may be joined by welding or brazing, if desired. However, it has been found satisfactory to laterally slit each ribbon near its end across a portion of its width, and to "dovetail" the slit ends in a manner analogous to a blind-halved lap joint.

In accordance with the preferred embodiment of the method of the invention, two closed, substantially rectangular, inner core portions, or loops, G and H each having a free length of uncut magnetic ribbon 32 and 32′ respectively continuous with the magnetic strip of the sections 33 and 33′ are disposed with their longer sides 36 and 36′ abutting and with the direction of winding the same, being counterclockwise as shown in Fig. 3, and with the free length of uncut ribbon 32 leaving the center leg formed by the two abutting sides 36 and 36′ at a point 38 at the upper end of the center leg and the free length of uncut ribbon 32′ leaving the lower end of the center leg at point 39. Although the uncut ribbons 32 and 32′ can be wound manually to form the outer core portion I, they are preferably mounted on a common base 60 shown in Fig. 5 and described hereinafter in connection with the embodiment of Fig. 4. The uncut ribbons 32 and 32′ are then spirally wound in parallel in the opposite direction from which the inner core portions G and H are wound, being clockwise in Fig. 3, to form a convoluted closed core section 40 of desired thickness surrounding the inner core portions G and H with the two ribbons 32 and 32′ in parallel in each spiral layer. Preferably this spiral winding of the two ribbons 32 and 32′ in parallel is accomplished by rotating the base 60 in the opposite direction from which the inner core portions G and H are wound.

The effect of winding the uncut lengths of magnetic strip 32 and 32′ in the opposite direction from which the inner core portions G and H are wound is to complete a closed flux path around the other inner loop portion before the winding of the outer loop portion is initiated and further to provide an iron path at each end of the center leg to permit transfer of flux between the center leg and the outer loop portion I of the core. It will be noted that the ribbon 32 after it leaves the inner core portion G at point 38 is then continued in the opposite direction, i.e., clockwise, in a complete convolution 41 around the inner loop portion H before the two ribbons 32 and 32′ are paralleled and spirally wound together clockwise to form core section 41 of the outer loop portion F. Similarly the outer laminar convolution of the counterclockwise wound ribbon 32′ is continued in the opposite direction, i.e., clockwise, after it leaves the lower end of the center leg at point 39 in a complete convolution 42 around the inner loop portion G before the two ribbons 32 and 32′ are paralleled and spirally wound clockwise together to form the core section 40 of the outer core loop.

Conventionally magnetic strip lamination thickness is approximately .014 inch, and with approximately 72 magnetic ribbons per inch of core thickness the impossibility of illustrating all the convolutions in the drawing is obvious. Consequently, the thickness of magnetic strip is greatly exaggerated in the drawing and tends to give the impression that the joints between successive strips may cause bulges in the core portions radially outward therefrom. However, when it is considered that the lamination thickness is measured in thousandths of an inch and that such joints may be staggered peripherally, it will be appreciated that the joints do not appreciably affect the shape of the final core.

The next step is to wind a single narrower magnetic ribbon, of approximately the same width as the ribbon of sections 31 and 31′, into a convoluted closed core section 43 surrounding the core section 40. Here also the convolutions of the section 43 are omitted from the drawing. The ends of the ribbons 32 and 32′ are preferably staggered peripherally, and the end of the single magnetic strip from which the section 43 is wound may be brazed, tack welded, or otherwise secured to one or both strips 32 and 32′, or may be joined thereto by slitting the magnetic ribbons near their ends across a position of their width and dovetailing the slit portions. Thereafter, a narrow magnetic ribbon having a width approximately equal to that of the ribbons forming the core sections 30 and 30′ is wound into a closed core section 44 surrounding the section 43 and its end is tack welded, brazed or secured by a peripheral clamping band (not shown) encircling the outer loop I.

It is to be noted that the magnetic core has a central leg formed by the abutting straight sides of the inner core loops G and H and has two outer legs formed by the straight sides of the inner loops G and H and the adjacent, spaced straight sides of the outer loop I.

The entire core is then annealed to remove all stresses due to working of the magnetic ribbon during winding. After annealing there is no further working, machining, or bending of any of the magnetic ribbons and consequently there is no strain imparted to any portion of the core which would otherwise adversely affect the characteristics of the transformer. Conducting winding assemblies (not shown) are then wound on the finished annealed core in the manner shown in Fig. 4 and hereinafter described.

The core of Fig. 4 is rectangular in cross section and is constructed in accordance with the preferred embodiment of the method of the invention as schematically illustrated in Fig. 2 except that each inner loop portion is wound from a plurality of continuous magnetic strip ribbons spirally wound flatwise in parallel to form a closed core of rectangular cross section. Two continuous magnetic ribbons 50 and 51 having preferred grain orientation lengthwise thereof are spirally wound flatwise in parallel upon a rectangular mandrel 52 (see Fig. 5) to form inner core portion J which is rectangular in cross-section, and two continuous magnetic ribbons 50′ and 51′ having preferred grain orientation lengthwise thereof are similarly spirally wound flatwise in parallel upon a rectangular mandrel 52′ to form inner core portion K which is also rectangular in cross section. The ribbons 50, 50′, 51 and 51′ are not severed but are left as uncut free lengths extending from the inner core portions J and K. The mandrels 52 and 52′ with the inner loop portions J and K thereon are mounted upon base 60 so that the longer sides thereof are abutting and their direction of winding is the same, being shown as counterclockwise in Fig. 4, and with the outer convolution 62 of ribbons 50 and 51 leaving inner core loop J at one end of the center leg 63 formed jointly by the abutting sides of the inner loop portions J and K and the outer convolutions 62′ of ribbons 50′ and 51′ leaving inner loop portion K at the opposite end of the center leg 63. Channels 64 and 64′ are disposed against the outer sides of inner loop portions J and K, and pressure is exerted against the channels 64 and 64′ to hold the inner core portions J and K tightly together. Bolts 68 are then inserted through clearance holes 69 in the base 60, through clearance holes 70 in the mandrels 52 and 52′, and through clearance holes 71 in a backing plate 73, and nuts 74 are threaded on the bolts 68 and tightened to mount the mandrels 52 and 52′ securely to the base 60.

The base 60 is integral with a rotatable shaft 75, and a stub shaft 76 rigidly secured to a support 77 is rotatably journaled within a bearing 78 carried by the backing plate 73. The shafts 75 and 76 thus rotatably support the mandrels 52 and 52′ with the inner core portions J and K thereon, and after the channels 64 and 64′ are removed, the shaft 75 is rotated in a direction opposite to that in which the inner core portions J and K are wound to spirally wind the uncut lengths of magnetic ribbons 50, 51, 50′ and 51′ into a closed outer core portion L tightly and closely embracing the abutting inner portions J and K. The four parallel ribbons 50, 51, 50′ and 51′ are continued to form a closed outer core loop L having approximately the same thickness as the inner loops J and K. The ends of the magnetic ribbons 50, 51, 50′ and 51′ are secured by brazing, welding, or by a peripheral clamping band encircling the outer core loop L.

The effect of disposing the inner core loops so that the uncut free lengths of magnetic ribbon 50, 51 and 50′, 51′ extend from opposite ends of the center core leg formed jointly by the abutting sides of the inner core loops and winding said uncut lengths of magnetic ribbon in the opposite direction from which the inner core loops J and K are wound is that the outer laminar convolutions 62 and 62′ of ribbons 50, 51, 50′ and 51′ leave loops J and K at the upper and lower ends respectively of the center leg 63 to permit flux transfer through a direct iron path into the outer core loop L at both ends of the center leg, and further that the magnetic ribbons 50, 51, 50′ and 51′ continue for a complete convolution around the opposite inner core loop before they are paralleled and spirally wound to form outer core loop L.

Conducting winding assemblies, or electrical coils 80, 81 and 82, including primary and secondary windings, are wound on the finished annealed core in any suitable manner, preferably by the apparatus disclosed in U.S. Patent 2,305,999 to Steinmayer et al. The outer straight portion 84 of inner core loop J and the abutting straight portion 83 of the outer core loop L pass through the winding window of the electrical coil 80 to form one outer core leg, the abutting back-to-back straight portions of the inner core loops and K pass through the winding window of the electrical coil 81 to form the central leg 63, and the outer straight portion 86 of the inner core loop K and the abutting straight portion 87 of the outer core loop L pass through the winding window of the electrical coil 82 to form the other outer leg. After the conducting windings have been finished, suitable wedges may be driven in place to hold the electrical coil assemblies firmly positioned with reference to their winding legs.

In prior art core constructions no iron paths were provided to interlink the inner and outer core portions, and the magnetic flux could only transfer to the outer core portion through high reluctance air paths perpendicular to the laminations. Consequently, substantially none of the flux from the middle winding phase, i.e., the center leg, transferred to the outer core portion and all of the flux from the center leg had to return through only half the available cross sectional area of the iron. In other words, substantially all the flux from the center leg returned through the inner core portions, and the iron outer core portion was not utilized as a path for the middle winding phase flux. If a winding on the center leg of such a prior art core is energized, a test coil circumjacent the outer portion only of the core shows that substantially no flux from the center leg is transferred to the outer core loop. When a coil on the center leg of a core constructed in accordance with the present invention is energized, a test coil encircling only the outer core portion indicates that an appreciable amount of the flux from the center leg transfers to the outer core loop. Further, the amount of such flux transfer in a core constructed in accordance with the present invention is considerably higher than in a core constructed in accordance with the aforementioned application Serial No. 422,374 of which the present invention is an improvement.

The invention provides a unitary polyphase transformer construction which utilizes the wound core principle and in which the inner and outer portions, or loops, of the core are directly interlinked by ferromagnetic paths. It is to be noted that there are no air gaps in the magnetic path and that low reluctance iron paths interlinking the inner and outer portions of the core have the grain of the magnetic ribbon in the direction of flux travel. The flux from any winding phase can return through the entire cross section of the other winding legs without transferring through high reluctance air paths perpendicular to the laminations as in three legged, three phase cores heretofore constructed.

Although the method of construction has been described as including the mounting of two inner core loops as an integral entity on a rotatable base to wind the outer loop, it will be appreciated that the method described is merely illustrative and that the disclosed transformer core is capable of construction by other means, e.g., the outer core loop may be wound manually, if desired. The description has been limited to a three legged, three phase transformer, but it will be appreciated that the invention comprehends any transformer, whether single phase or polyphase, of the type having lengthwise bent, concentrically stacked laminations wherein it is desirable to interlink portions of the core with low reluctance iron paths.

While only three embodiments of the invention have been illustrated and described, it will be obvious to those skilled in the art that changes and modifications can be made without departing from the invention, and therefore it is intended in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

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

1. The method of constructing a magnetic core having three parallel, spaced apart legs in a common plane, comprising the steps of spirally winding magnetic strip material flatwise to form a first inner convoluted loop, spirally winding magnetic strip material flatwise to form a second inner convoluted loop, mounting said inner loops on a common rotatable member with adjacent sides of said loops in abutting relation and so that the direction of winding both said inner loops is the same and with free lengths of uncut magnetic strip material continuous with the magnetic strip material of said inner loops extending from the opposite ends of the center leg formed jointly by the abutting sides of said inner loops, and rotating said member in a direction opposite to that in which said inner loops are wound to spirally and flatwise wind the magnetic strip material continuous with said inner loops in parallel into an outer convoluted loop surrounding said inner loops in embracing relation thereto.

2. The method of constructing a magnetic core having three parallel, spaced apart legs in a common plane, comprising the steps of spirally winding magnetic strip, material flatwise to form a first inner convoluted loop, spirally winding magnetic strip material flatwise to form a second inner convoluted loop, disposing said inner loops with adjacent sides thereof abutting and with their direction of winding the same and with free lengths of uncut magnetic strip material continuous with the magnetic strip material of said inner loops extending from the opposite ends of the center core leg formed jointly by the abutting sides of said inner loops, and spirally and flatwise winding said three lengths of uncut magnetic strip material in parallel in a direction opposite to that in which said inner loops are wound into an outer convoluted loop surrounding said inner loops in embracing relation thereto.

3. In the method of constructing a three legged magnetic core having two inner core loops wound of magnetic strip material and an outer convoluted core loop embracing said inner core loops and wound of magnetic strip material continuous with the magnetic strip material of said inner loops, the improvement which comprises the steps of disposing said inner core loops in a common plane with adjacent sides abutting and with the same direction of winding and with free lengths of uncut magnetic strip material continuous with the magnetic strip material of said two inner core loops extending from opposite ends of the center leg formed jointly by said abutting sides, holding said inner core loops in abutting coplanar relation and spirally winding said free lengths of uncut magnetic strip material in the direction opposite to that in which said inner loops are wound into a closed convoluted core surrounding said inner loops in embracing relation thereto.

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