

April 5, 1960

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2,931,993

MAGNETIC CORE

Filed April 18, 1956

5 Sheets-Sheet 1

Fig. 1

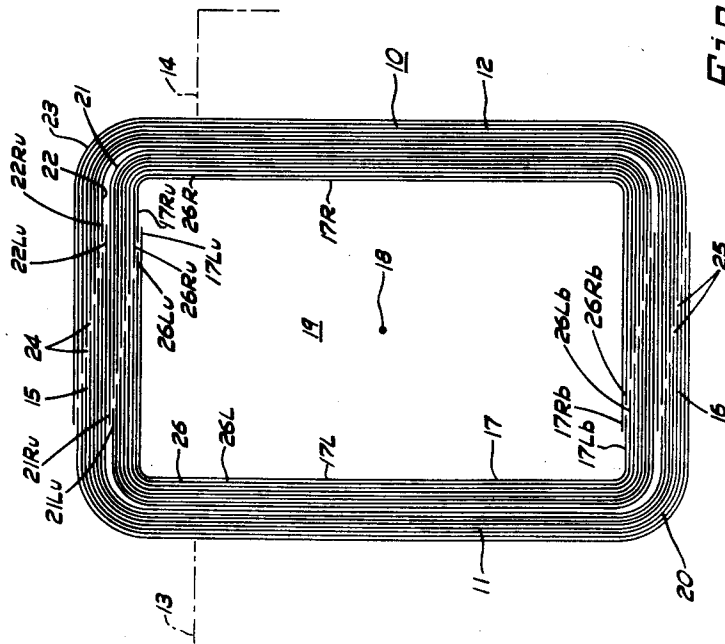
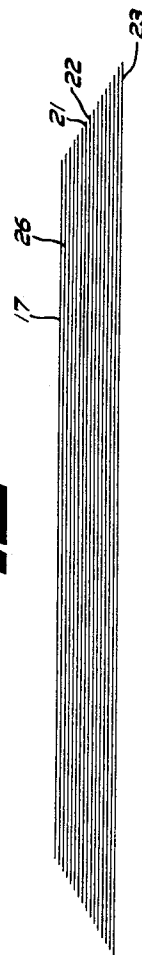


Fig. 2



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Fig. 5

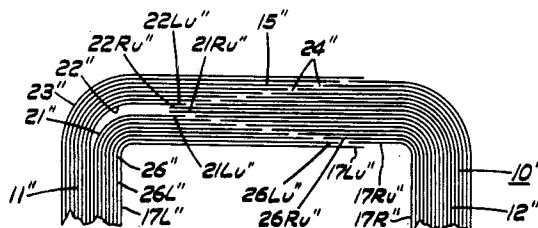


Fig. 6

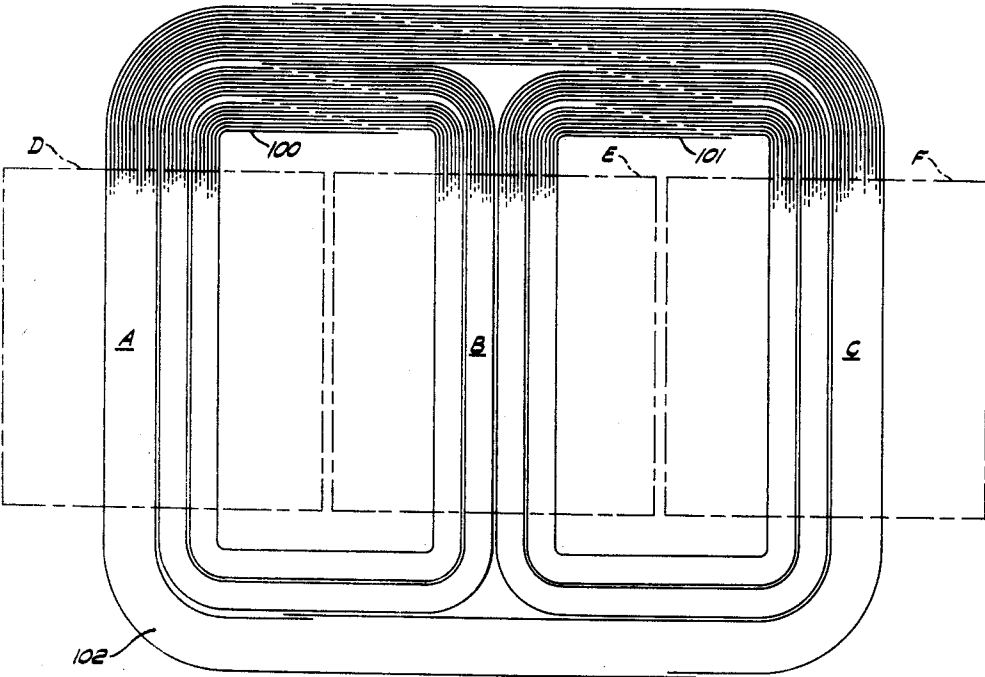
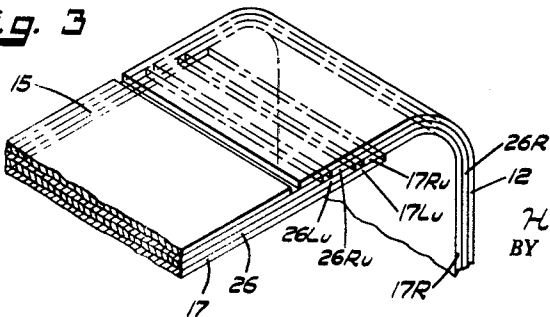


Fig. 3



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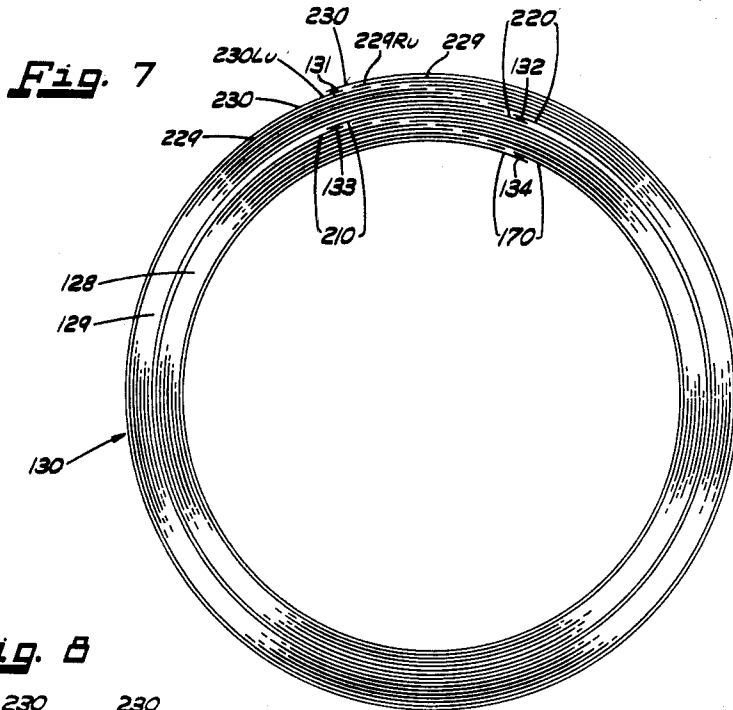


Fig. 8

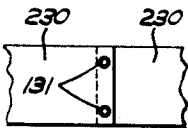
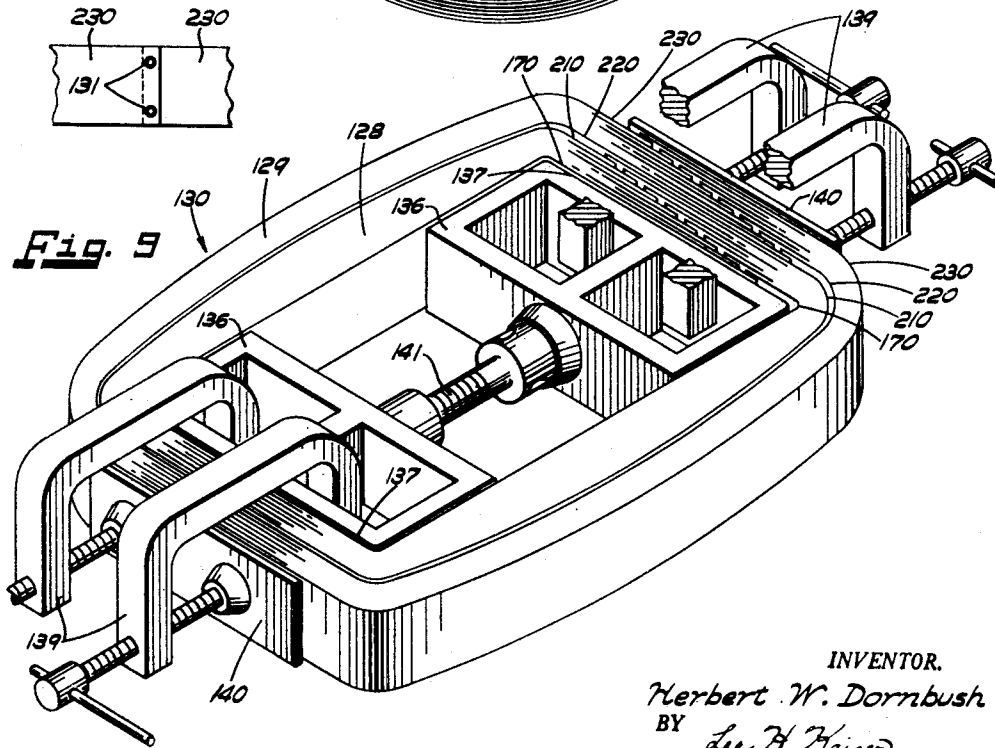


Fig. 9



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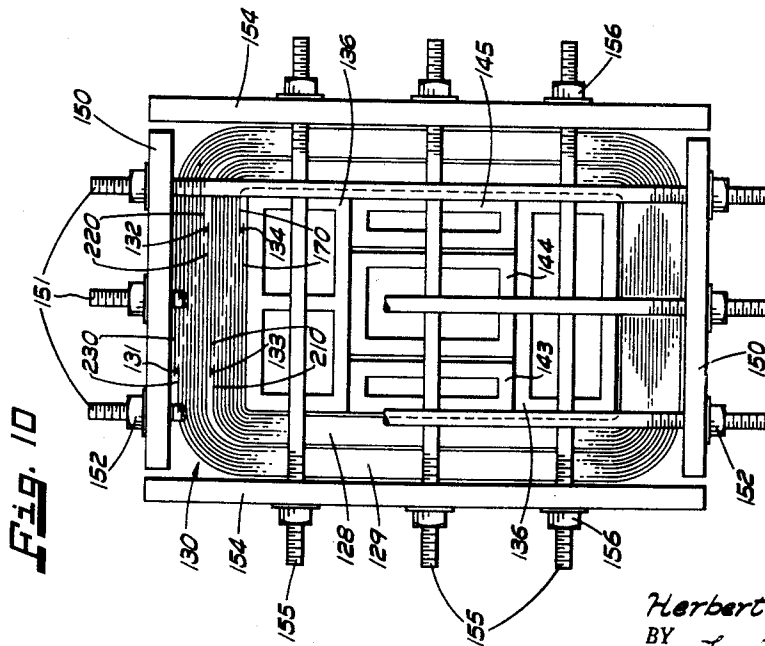
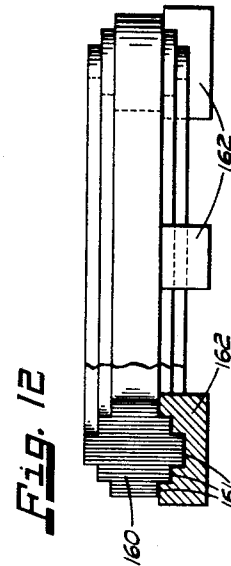
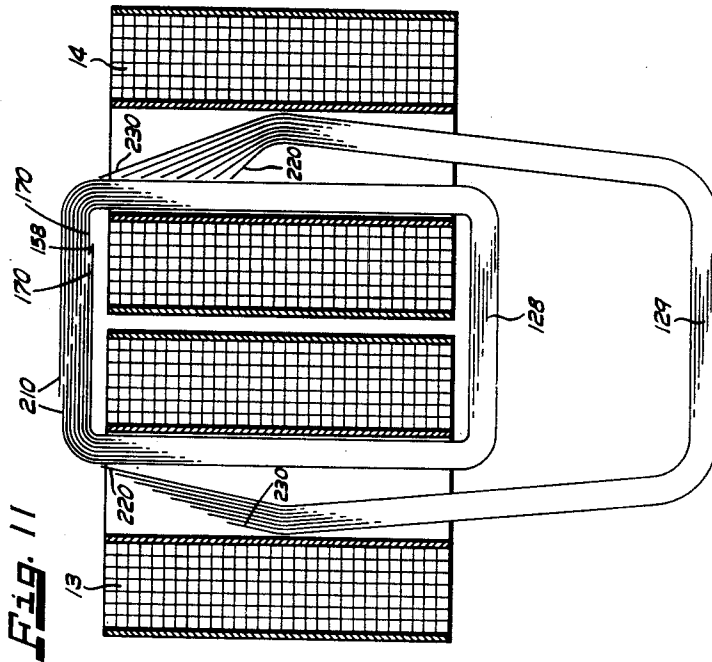
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Fig. 14

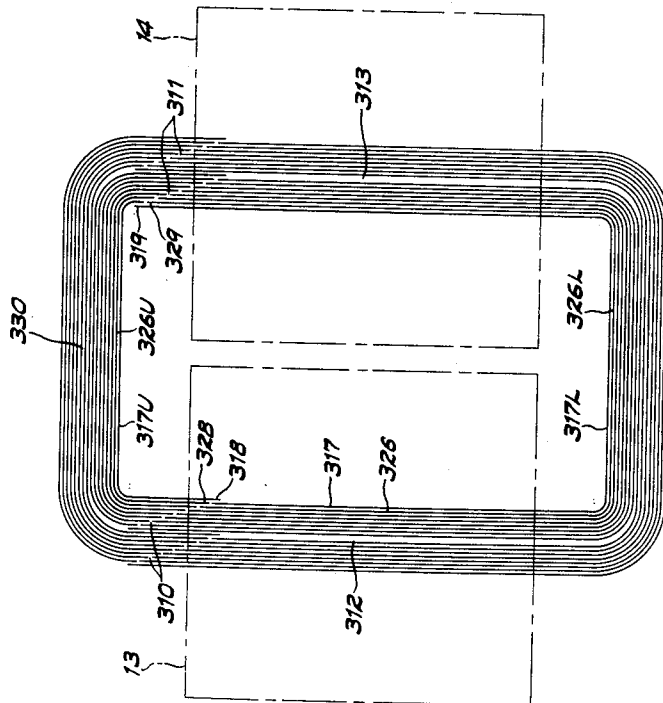
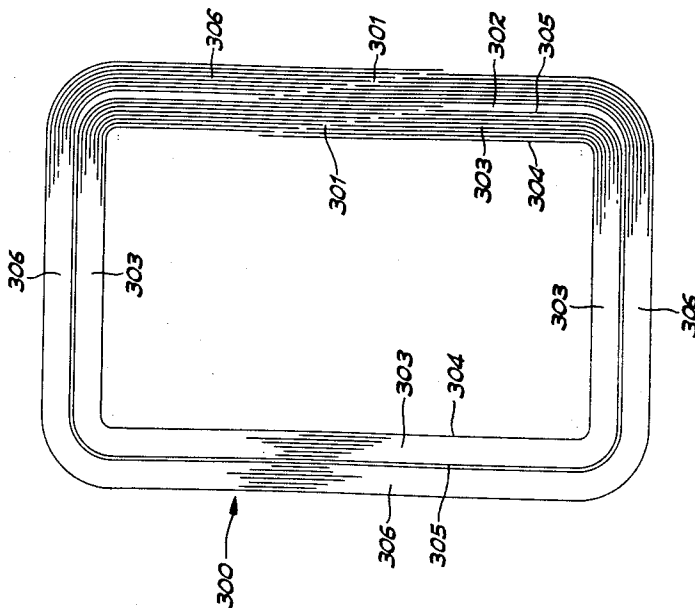


Fig. 13



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2,931,993

MAGNETIC CORE

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Application April 18, 1956, Serial No. 579,052

12 Claims. (Cl. 336—217)

This invention relates to magnetic cores for stationary induction apparatus and in particular to a magnetic core having progressively displaced, interfitted lap joints and to its method of construction.

The present application is a continuation in part of my copending applications, Ser. Nos. 353,397 and 493,532, filed May 6, 1953, and March 10, 1955, respectively, now abandoned, and having the same assignee as the present invention.

Heretofore, in the construction of certain lap joint magnetic cores such as the kind illustrated in my United States Patent No. 2,489,625, having the same assignee as the present invention, the lap joints of the turns have been placed in radial alignment. As a consequence, in making such a core, while the winding legs particularly have been compact, the interleaving of the lamination ends and the alignment of the lap joints has occasioned a relatively open core structure in the core side containing the aligned lap joints. Consequently, for cores like the illustrated example, relatively more core strip metal was required, which was relatively expensive especially when using oriented grain steel strip of the kind usually supplied with an insulating coating thereon for transformer cores. Closely related to the present invention is the magnetic core illustrated in Fig. 16 of U.S. Patent No. 2,614,158 to Sefton et al., having the same assignee as the present invention, wherein respective pairs of adjoining turns are disposed with the intermediate turn ends in one layer, but the resulting core also has radial alignment of the lap joints and a relatively open core structure on the top and bottom necessitating additional core steel for the core build-up. In addition, in such prior core construction the alignment of the lap joints involved care in the interleaving of the lamination ends to provide an individual lap joint in each turn, particularly when a plurality of turns were inserted simultaneously through the window of an electrical winding. Further, such a relatively open core structure necessitates larger transformer tanks and a greater quantity of dielectric liquid, with corresponding trouble and expense.

In the core construction of the present invention such difficulties are markedly reduced or overcome. In my invention the advantages of a magnetic lap joint in each magnetic turn are retained while using much less core strip metal and providing a thickness in the core side containing the joints practically the same as the thickness of the adjoining core sides. Moreover, the magnetic core of my invention seems to have a further favorable magnetic quality because of my new progressive lap joint construction, for example, tending to suppress irregularities in flux distribution among laminations in the core.

It is an object of the invention to provide a magnetic core having lap joints and method of construction wherein the core side having the lap joints is not appreciably thicker than the remaining core sides.

It is a further object of the invention to provide a closed magnetic core having lap joints and method of construction

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therefor wherein the mean length of magnetic turn is a minimum.

Another object of the invention is to provide a closed magnetic core having lap joints and method of construction therefor which requires a minimum amount of steel.

A still further object of the invention is to provide a closed magnetic core having lap joints and method of construction therefor wherein the laminations may be collectively inserted through the window of an electrical winding and the laminations inherently assume the desired overlapped relation without the necessity of an operator interleaving the lamination ends.

Other objects and advantages of the invention will be apparent from the following description when taken in conjunction with the accompanying drawing wherein:

Fig. 1 is a profile view of one embodiment of the core of the invention;

Fig. 2 is a view of a preferred mode of providing a series of core strips of progressively different lengths, before shaping, for embodiment in a core such as that illustrated in Fig. 1;

Fig. 3 is an enlarged schematic view of a part of a progressive lap joint flight as shown in the embodiment of Fig. 1;

Fig. 4 is a view of a preferred embodiment of the new magnetic core construction of the invention having a single lap joint in each core turn;

Fig. 5 is a view of one end of another embodiment of the invention wherein the direction of the lap joint flight is reversed;

Fig. 6 illustrates still another embodiment of the invention suitable for multiphase transformers;

Fig. 7 is a plan view of the laminations of Fig. 2 assembled into a closed loop with lap joints progressively displaced in accordance with a step of one embodiment of the method of constructing the core of Fig. 4;

Fig. 8 is an auxiliary view showing the ends of the outermost lamination of Fig. 7 in overlapped relation and the rivets for holding the lamination in a closed loop;

Figs. 9 and 10 illustrate method steps in shaping the laminations of Fig. 7 into the rectangular configuration of the finished core;

Fig. 11 shows the method step of inserting the laminations through the winding window of a preformed electrical winding;

Fig. 12 illustrates the blocks upon which the laminations of a cruciform-in-cross-section magnetic core are supported during the construction of the core;

Fig. 13 illustrates an embodiment of the magnetic core of the invention wherein the flights of lap joints are provided in a winding leg; and

Fig. 14 illustrates a further embodiment wherein the lap joints are provided in both winding legs, thereby permitting preformed windings to be assembled over the winding legs before the ends of the magnetic strip lengths are overlapped.

Referring to Figs. 1 to 3 of the drawing, a new magnetic core 10 may be generally rectangularly shaped so as to provide a left-hand leg 11 and a right-hand leg 12 as one pair of legs on opposite sides of core 10. One or both of legs 11 and 12 may be linked with one or more coils respectively denominated 13 and 14. The remaining pair of legs of core 10 may be dominated as an upper yoke leg 15 and a lower yoke leg 16 joining winding legs 11 and 12 to complete the magnetic path around the closed core 10. The innermost turn 17 has the shortest periphery, as will be well understood, around the central or transverse axis 18 of the window 19 bordered by turn 17. The central axis 18 is normal to the "plane" of core 10, which plane for the purpose of this description may be taken as the plane of the drawing paper on which Fig. 1 appears. However, sub-

stantially each turn in core 10 in Fig. 1 is concentric relative to the other turns and has therein two lengths of the core steel strip laminations. The sides of the respective laminations in adjoining turns are in a side-by-side arrangement. The respective laminations are preferably straight throughout the major portions of each leg up to the bends forming corners 20 in the core 10. All the laminations are parallel to axis 18. In the drawings, the lamination present in each turn, whether as one or more lengths of core strip, is usually schematically represented by a single line, although it will be recognized that in actually practicing this invention, such laminations will have the respective thickness of the core strip employed and the respective number of turns in a new magnetic core corresponding to the particular performance specifications for which the new core is being constructed. Although in this description reference is made to left and right hand and to top and bottom, it will be recognized that those terms are relative and used for purposes of this description since any core may be used in other than a vertical position or may be viewed, for example, from an opposite side.

Turn 17 in general forms a single lamination in core 10 and may comprise two equal lengths of cold-rolled core strip metal respectively denominated 17L and 17R. In the embodiment being described, the upper end 17Ru and the lower end 17Rb of strip length 17R are on the upper sides respectively of ends 17Lu and 17Lb. The overlap area between ends 17Ru and 17Lu and between ends 17Rb and 17Lb, respectively, comprise an upper lap joint in yoke leg 15 and a lower lap joint in lower leg 16. Both of said lap joints are in turn, or lamination, 17 of core 10 and have a relatively low magnetic reluctance so as to essentially constitute turn 17 an independent and self-sufficient magnetic path for flux flow in a transformer in which core 10 may be used. Further, it may be noted that the radially outer upper end 17Ru and the radially outer lower end 17Lb of turn lamination 17 are respectively situate nearer and about the same distance from diagonally opposite corners of lamination 17. Further, those ends 17Ru and 17Lb point away from their adjacent corners and generally in the direction of the respective flights of which the lap joints formed in part by those ends are a part. In other words, the innermost flights or series of lap joints in the innermost group of laminations in core 10 extending between lamination 17 and lamination 21, inclusive, will preferably start adjacent a corner of a yoke leg so as to permit the progressive displacement of the respectively radially outer successive lap joints in the flight under discussion, to take place toward the other corner in that same yoke leg as shown in Fig. 1. A second group of laminations may comprise those between lamination 22 and lamination 23 in which a second series of flights 24 in the upper yoke leg 15 and a second series of flights 25 in the lower yoke leg 16 restart the flight pattern and extend in the same direction along their respective yoke legs. In that way, a plurality of successively outer series of flights may be provided with the displacement of the lap joints in each extending only along the respective yoke leg or legs as far as desired with both ends of all flights terminating short of the bends at the corners of the respective turns. In general, the lap joints in the new flights will generally be confined to an intermediate portion of the core side in which they occur such as a one-third length of the entire yoke leg to each side of the middle of that yoke leg.

As shown in Fig. 3, turn 26 is the lamination adjoining lamination 17 around the outer sides thereof in the same manner that substantially all of the laminations in core 10 are concentric relative to one another around axis 18. Turn 26 is made up of a left-hand length 26L and a right-hand length 26R of core steel strip and forms an upper lap joint in the overlap area between ends 26Lu and 26Ru. Similarly, in yoke leg 16 the ends 26Lb

and 26Rb have an overlap area constituting the remaining lap joint within turn 26 with the electrical and mechanical advantages of such lap joints. However, as shown in Figs. 1 and 3, the lap joint between ends 26Lu and 26Ru is the second lap joint in the first group flight and is displaced to the left of the lap joint formed between the ends 17Lu and 17Ru. Moreover, the ends 17Ru and 26Lu are in a common layer in yoke leg 15 and substantially abut. Hence, the respective ends 17Lu, 17Ru, 26Lu and 26Ru constitute but three, instead of four, radial layers parallel to axis 18, in the make-up of yoke leg 15. A new result is that yoke leg 15 and, in the embodiment of Fig. 1, yoke leg 16 are far more compact than prior constructions and a material saving is effected in the amount of core steel strip required. As shown, the next outer lamination adjoining lamination 26 around the outer sides thereof has its upper lap joint progressively displaced still further to the left and upwardly along yoke leg 15 and so on to upper lap joint in turn 21. Since the two lengths of core strip in each turn are equal and are preshaped as shown in Fig. 1, the flight in the group of turns between turns 17 and 21, along yoke leg 16, which in practice will embrace far more laminations than the numerical difference of five laminations or the illustrated showing of eight laminations, will have its successive lap joints progressively displaced downwardly and to the right. The upper and lower flights 24 and 25 respectively in the succeeding radially outer group of turns between turns 22 and 23 restart and repeat the new lap joint interfitting construction of this invention in that group. Still further groups with corresponding interfitting flights may be provided radially outwardly of and adjoining the group 22-23. In cross section the respective legs of core 10 may be rectangular or cruciform or have any other shape produced by a selection of particular turns of appropriate width as will be understood by those in the art.

The interfitting of adjoining lap joints in any flight so that there is a common layer between any two succeeding lap joints, as described in connection with the turns 17 and 26, compounds the described saving in that in three turns with three adjoining lap joints displaced as taught herein the number of layers in the lap joints region will be four in number instead of being six in number; in the case of four adjoining and progressively displaced lap joints, the eight lap joint layers will actually occupy the space of five layers as shown in Fig. 1, and so on to the end of that flight series and successive flight series, each flight having an echelon character. Moreover, in such new interfitting relation it would appear that any tendency of the flux to follow an irregular pattern or distribution seems to be inhibited apparently because in the new flight arrangement described each turn end and joint therein is so "encased" in an adjoining end or ends of an adjoining turn or turns as to provide efficient crossover paths in addition to its own main flux path through its own lap joint.

One convenient mode of constructing a core such as the one illustrated in Fig. 1 may include the use of a progressive cutting machine to shear magnetic strip into progressively different lengths as shown in Fig. 2 which may form the right-hand lengths of the laminations shown in Fig. 1. An identical bundle of strips would be cut for the left-hand lengths. Each pair of strip lengths in each progressively outer turn are longer to take care of the increase in the peripheral length of the core laminations which are positioned farther from the center. Such strip lengths may be assembled in a jig beginning with the pair of lengths in the outermost turns somewhat in the manner shown in the aforementioned United States Patent No. 2,614,158 (Figs. 5 to 8 thereof) except that provision will be made to offset the successive lap joints in each flight series as shown in the various embodiments described herein. Inasmuch as the embodiment of Fig. 1 has two lengths of core steel in each turn, or lamination,

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added provision may be made to secure the relative positions of each such length in each such turn during the stacking, blocking, binding, and annealing of the core. After such annealing the core has a permanent set as shown in Fig. 1. Following the annealing operation, the blocking and binding strips may be removed and either leg 11 or 12 or both such legs may be linked with a coil or coils as shown in the last-mentioned United States patent. In such linking, because of the set and progressive offset of succeeding lap joints in the respectively outer turns of the core, the interleaving labor of the prior aligned lap joint construction is greatly reduced, particularly in the case of a magnetic core such as that shown in Fig. 4.

Because of the greater number of pieces in the embodiment shown in Fig. 1, the construction thereof has been described first. However, the embodiment shown in Fig. 4, with a single lap joint per turn or lamination, is a preferred construction. The construction of the embodiment of Fig. 4 is generally the same in character and functioning to that provided in the embodiment of Fig. 1 except that each turn comprises but a single length of core steel strip and all of the lap joints occur along the upper yoke leg. For convenience, parts of the embodiment of Fig. 4 corresponding in construction and functioning to the parts of the core of Fig. 1, are given the same reference designations with the addition of a prime factor thereto. It may also be noted that the steps of constructing the embodiment of Fig. 4 may be similar to the construction of the Fig. 1 embodiment except that the core steel strip may initially be wound on a circular or polygonal mandrel instead of being cut by a progressive cutting machine as described above. If wound on a mandrel, the winding and radial cutting steps to provide suitable progressively greater lengths of core steel may be performed as generally described in the aforesaid Patent No. 2,614,158. In such winding, suitable spacing provision, for example, as mentioned in that patent or as shown in my aforementioned Patent No. 2,489,625 should be provided, although one of the advantages of this invention is that not as much attention has to be devoted to spacing because the increases in mean turn length between adjoining turns throughout the full thickness of the core is not as great as in prior cores, other conditions being similar. However, in stacking the turns of the embodiment of Fig. 4, such stacking will be practiced to provide the offset lap joints for the flight shown without carrying any lap joint or flight into any corner bend or any yoke leg or into any winding leg. Of course, after such stacking the steps of blocking, binding and annealing are carried out as described to provide a core permanently set as shown in Fig. 4.

In the embodiment of Fig. 5, a zig-zag flight arrangement is shown which may be provided preferably in one yoke leg only, or in both the top and bottom yoke legs if so desired. The innermost group of turns in the embodiment of Fig. 5 and the flight or flights appertaining thereto are similar in general construction and functioning to the corresponding portion of the inner flight or flights respectively in the embodiment of Fig. 4 or Fig. 1. Hence, for convenience, the same reference designations have been employed in Fig. 5 with a double prime factor. However, the next outwardly succeeding flight in yoke leg 15'' between the turns 22'' and 23'' is reversed producing, in edge profile, a back-and-forth or zig-zag character which achieves the new features and advantages of the other embodiments disclosed herein. Thus, in the case of the outer group of turns in yoke leg 15'', end 22Lu'' is above end 22Ru'', thereby initiating the flight 24'' immediately above the lap joint provided between the ends 21Lu'' and 21Ru''. In the case of the lap joint between the ends of lamination 22'', its end 22Lu'' becomes the one which points in the direction which the new flight is to take, which is, in the case of flight 24'', upwardly and to the right. Succeeding outer groups

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beyond group 22''—23'' in a construction like Fig. 5, may continue and repeat the interfitting flight pattern established by the two innermost groups. In the event the laminations in the core of Fig. 5 are provided with flights of lap joints in the lower yoke leg which is not illustrated, then preferably such lower flights will be reversed right and left from the flights in yoke leg 15''. In that case, the innermost lower flight would extend downwardly and to the right while the next outer flight in the lower yoke leg would extend downwardly and to the left from the vicinity of the outermost lap joint in the innermost of the lower flights.

The embodiments of Figs. 1, 4, and 5 may be utilized in either single phase or multi-phase transformers. A multiphase transformer magnetic core embodying the invention is illustrated in Fig. 6 and has winding legs denoted A, B, and C, each of which may respectively be linked with one or more coils denominated D, E, and F. Inner cores 100 and 101 may be constructed in accordance with the embodiment of Fig. 4, or in accordance with one of the other embodiments, and disposed side-by-side. The outer winding legs A and C may be completed by the use of an encircling core 102 which, except for change in dimensions, may be constructed, as shown, in accordance with the embodiment of Fig. 4 hereof, or core 102 may be made in accordance with the construction shown either in Fig. 1 or Fig. 5. In a multiphase magnetic core, such as that shown in Fig. 6, the new interfitting lap joint construction disclosed herein is of even greater advantage while maintaining the superior electrical characteristics of lap joint cores utilizing wound or bent strips of grain oriented steel.

The steps of a method particularly suited for constructing the embodiment of Fig. 4 for transformers above 167 kva. rating are illustrated in Figs. 7 to 11 wherein parts corresponding to those of the embodiments of Figs. 1 to 5 are given the same reference numerals with the addition of a zero. For example, lamination 17 of Figs. 1 to 5 is shown as element 170 in Figs. 7 to 11. This method includes the step of providing a group of magnetic strip laminations of progressively increasing length similar to the laminations of Fig. 2. The laminations are assembled in a closed loop 130 with a single lap joint in each lamination and successive lap joints in a radial direction progressively displaced circumferentially. Only two groups of laminations 128 and 129, each comprising a plurality of successive laminations, are illustrated in Figs. 7 to 11, but it will be appreciated that a finished core may comprise tens, or even hundreds, of such groups. To retain the loop 130 closed the overlapped ends of the longest lamination in each group are fastened together, preferably by hollow rivets or metal grommets 131. The radially outermost group 129 is illustrated as comprising eight laminations and extends from outermost lamination 230 having the greatest peripheral length to lamination 220 which has the shortest peripheral length. Apertures are provided adjacent both ends of lamination 230 to receive rivets 131 for fastening the ends of lamination 230 in overlapped relation as shown in Fig. 8. Lamination 229 is then inserted within closed lamination 230 with the respective ends thereof overlapped and circumferentially displaced to the right of the lap joint in lamination 230 as shown in Fig. 7. In a similar manner successive radially inward laminations are inserted within the closed radially outermost laminations 230 and 229 to build up the closed loop 130 with the respective ends of the laminations overlapped and with each lap joint circumferentially displaced to the right of the next radially outer lap joint to form a flight, or series of lap joints, similar to those of the embodiments of Figs. 1 to 6. It will be appreciated that the ends 230Lu and 229Ru of the laminations 230 and 229 respectively are in a common layer and substantially abut. The flight in the group 129 of laminations 230 to 220 has its successive lap joints progressively dis-

placed downward and to the right. Preferably apertures are provided near both ends of the radially innermost lamination 220 to receive rivets 132 for securing the ends thereof in overlapped relation. The interfitting of the adjoining lap joints in the flight so that there is a common layer between any two succeeding lap joints decreases the mean length of turn in comparison to prior art cores having lap joints and provides a core side containing the joints of a thickness practically the same as the thickness of the adjoining core sides.

A second, radially inward group 128 of laminations may comprise those between lamination 210 and lamination 170 in which a second series of lap joints restart the flight pattern and extend in the same direction as the first group. Apertures are provided near the ends of the radially outermost lamination 210 to receive rivets 133 for securing the ends of lamination 210 in overlapped relation and preferably in alignment with the lap joint in lamination 230 of the outermost group 129. Successive, radially inward laminations are then inserted within closed lamination 210 with the respective ends overlapped and the lap joints circumferentially displaced to the right and downward as in the outer group 129 to further build up the closed loop 130. Preferably the ends of the radially innermost lamination 170 in this group are secured in overlapping relation by rivets 134.

In this manner a plurality of successively inner groups may be provided adjoining groups 128 with the displacement of the lap joints in each extending circumferentially only as far as desired and with ends of all flights preferably in alignment. In cross section the closed loop 130 may be rectangular as illustrated or cruciform or have any other shape by a selection of particular turns of appropriate width as will be understood by those in the art.

Although the method has been illustrated and described as overlapping the respective ends of individual laminations, the invention is not so limited and comprehends the arrangement of the laminations in sections each comprising a plurality of successive laminations and the overlapping of the respective ends of each section. Tests indicate that exciting current and core loss are not appreciably different if the ends of individual laminations are overlapped or if each section comprises two or three successive laminations and the ends of each section are overlapped.

Pressure is then applied against surfaces of the periphery of the closed loop 130 to shape the laminations to the configuration of the finished core. Although the desired shape for some cores is obtained by applying pressure only against the inner periphery of the closed loop 130, in the illustrated method for constructing larger size cores, pressure is applied against both the inner and the outer periphery and a five piece mold is used to shape the annular closed loop 130 into approximate rectangular configuration. As seen in Fig. 9 two rectangular end mold pieces 136, preferably 8-shaped, are inserted within the axial window in the annular loop 130. The longer side 137 of one end mold piece 136 is disposed adjacent the inner periphery of the portion of the closed loop 130 containing the lap joints and the other end mold piece 136 is positioned diametrically opposite thereto. C-clamps 139 each having one leg acting against the outer periphery of the closed loop 130 and the other leg abutting against an inner surface of an 8-shaped end mold piece 136 are then tightened to draw the end mold pieces 136 against the inner periphery of the loop 130 and flatten the laminations against the longer side 137 thereof. Preferably a plate 140 approximately as long as side 137 of piece 136 is interposed between the C-clamps 139 and the external periphery of the core to prevent damage to the outermost laminations and to distribute the applied pressure. Hydraulic or other pressure means, preferably a jack screw 141, is then utilized to diametrically separate the end mold pieces 136 until the desired core

window dimensions are obtained and thus cause the laminations to assume an approximately rectangular shape.

After the 8-shaped end mold pieces 136 have been spread apart by the jack screw 141, rectangular center mold blocks 143, 144 and 145 (see Fig. 10) are inserted between the end mold pieces 136 to hold the laminations in approximately rectangular shape with the desired core window dimension before the jack screw 141 is removed. It will be appreciated that with a core comprising a large number of lamination groups, tension will be greatest in the radially innermost group 128 causing the laminations of this group to assume an almost exact rectangular shape whereas the tension in the groups outward therefrom will progressively decrease in a radially outward direction. An attempt has been made in Fig. 9 to illustrate this condition, although with only the few laminations shown an almost exact rectangular shape would probably be attained in all of the groups.

Pressure is then applied against the external periphery of the closed loop 130 to shape the laminations to the rectangular configuration of the finished structure. As shown in Fig. 10, end plates 150 disposed against the external periphery of the loop 130 opposite the 8-shaped end mold pieces 136 are connected by threaded tie rods 151 both above and below the core, and nuts 152 engaging the threaded tie rods 151 are tightened to apply external pressure against the yokes of the core. Side plates 154 disposed against the winding legs of the core are connected by threaded tie rods 155, also both above and below the closed loop 130, and nuts 156 are tightened on the threaded tie rods 155 to clamp the winding legs of the core between the center mold pieces 143 and 145 and the side plates 154. In order to remove all deleterious strains and give the laminations a permanent set in the position they will occupy in the final core, the laminations comprising the core structure illustrated in Fig. 10 are then given a suitable strain-relief anneal, preferably by heating in a suitable atmosphere to a temperature of approximately 1500 degrees F. The laminations take a permanent set as a result of the annealing and thereafter remain in place without the necessity for binding or compression.

After annealing, the laminations are stacked a second time in linking the core with a preformed winding. The end plates 150 and side plates 154 are removed and the mold pieces 136, 143, 144 and 145 are removed from the window in the core. The rivets 131, 132, 133 and 134 securing the ends of the innermost and outermost laminations in each group are then broken. In the second stacking operation the core is built up radially outward. The step of assembling the core with preformed transformer windings is illustrated in Fig. 11. In order to assemble a core type transformer, preformed windings 13 and 14 are disposed side-by-side. One of these windings may be the primary and the other the secondary, or the primary and secondary winding may be divided into two groups. The innermost lamination group 128 of the core is first separated from the remaining lamination groups and its lapped ends opened slightly. The ends of the laminations comprising the group 128 are then collectively inserted through the central openings in the windings 13 and 14. It will be observed that slight bending of the laminations in the yoke leg of the core is necessary to permit this insertion, but the deformation does not exceed the elastic limit and consequently, the magnetic properties of the magnetic strip material are not impaired. When the open ends of the group 128 have been passed entirely through the openings of the windings 13 and 14 they inherently assume the overlapping relation in which they were annealed. In prior art methods of construction it was necessary for an operator to shuffle the ends of the lamination lengths into individually overlapping relation. Because the laminations are permanently set with the joints peripherally staggered it is possible

to collectively assemble the entire group 128 of laminations in one operation without requiring an operator to peripherally displace the lap joints and to shuffle the lamination ends into overlapping relation beyond the far edge of the preformed winding.

In order to provide added mechanical strength, the ends of the innermost lamination 170 are riveted in overlapped relation after being linked with the preformed windings 13 and 14. As illustrated in Fig. 11 the innermost group 128 of laminations has been linked with the windings 13 and 14 as above described, the overlapped ends of lamination 170 have been secured by rivets 158, and the second group 129 is being threaded through the openings in the windings 13 and 14 so that the lap joints occur in the yoke of the core containing the lap joints of the innermost group 128. Although only two groups 128 and 129 of laminations are illustrated, it will be appreciated that any desired number of lamination groups each having a flight of peripherally displaced lap joints may be utilized to build up a finished core substantially identical to that illustrated in Fig. 4. If desired, the ends of the radially innermost or the radially outermost lamination in each group, or both, may be riveted to hold the laminations securely in position.

Although the method has been described and illustrated for the construction of a core having a rectangular cross section, it will be appreciated that by the selection of laminations of appropriate width, a cross section of cruciform or any desired shape may be provided. When a cruciform-in-cross section core 160 is constructed in accordance with the present invention, the various lamination widths thereof are supported on the steps 161 of stepped support blocks 162 peripherally spaced apart beneath the core as shown in Fig. 12.

Magnetic cores embodying the invention for transformers having ratings of 5000 kva. have been constructed in accordance with the method illustrated in Figs. 7-12 and successfully operated. It will be appreciated that if every group of laminations comprises n laminations, the radial thickness of the core side containing the lap joints is increased by only the thickness of one magnetic ribbon for every n laminations. Thus, if each joint has a one-half inch overlap and a series of ten overlap joints in one group are staggered over a peripheral length of five inches, the radial thickness of the core side containing the lap joints is only one-tenth thicker than the adjoining core sides. Thus, the mean length of lamination of the magnetic cores of the present invention is decreased considerably in comparison to conventional cores. Inherent with the decrease in mean length of turn is a reduction in the amount of core steel while retaining the low reluctance and low core loss advantages of a magnetic lap joint in each core turn.

Advantage is taken of the minimum radial buildup of the disclosed interfitting lap joints in the embodiment of magnetic core 300 illustrated in Fig. 13 wherein the flights 301 of peripherally displaced lap joints occur in a winding leg 302 of the core 300. The innermost group 303 comprises the whole turn laminations between lamination 304 and lamination 305, and the series of lap joints 301 between lamination ends extends downward and to the right; similarly the flight 301 of lap joints between the respective ends of the whole turn laminations of the radially outward group 306 extend downward and to the right. Inasmuch as the thickness of winding leg 302 is increased by only one lamination for every n laminations in each group 303 or 306, the space factor within the window of any winding encircling leg 302 is not substantially different from that of other embodiments of the invention.

The embodiment of the invention illustrated in Fig. 14 permits the electrical windings to be assembled over the winding legs rather than requiring the insertion of the laminations through the window of an electrical winding as in the embodiments of Figs. 1, 4, 5, and 6. Flights 310

and 311 of lap joints occur substantially above the electrical coils 13 and 14 in the winding legs 312 and 313 respectively. Each lamination includes two lengths of magnetic strip in a manner analogous to the embodiment of Fig. 1. Radially innermost lamination 317 comprises two lengths of cold-rolled magnetic strip denoted 317U and 317L. Strip lengths 317U and 317L overlap in a first joint 318 in winding leg 312 and in a second joint 319 in winding leg 313. The next radially outer lamination 326 also comprises two lengths of magnetic strip 326U and 326L which overlap in a first joint 328 displaced peripherally upward from lap joint 318 and also in a second joint 329 displaced peripherally downward from lap joint 319. The end of strip length 326L partially forming lap joint 329 is in the same layer as the end of strip length 317U which partially forms lap joint 319. Similarly the end of strip length 326U which partially forms lap joint 328 is in the same layer as the end of strip length 317L which partially forms lap joint 318. In this manner the flights 310 of lap joints as shown in the drawing extend upward and to the left and the flights 311 of lap joints extend downward and to the right.

In reality the ends of the laminations are only overlapped approximately one-half inch, and consequently the series 310 and 311 of lap joints occupy a much smaller portion of the peripheral length of the winding legs 312 and 313 in an actual core than that represented in Fig. 14.

The magnetic strip lengths 317U, 326U, etc., in upper yoke 330 are assembled in overlapped relation with the strip lengths 317L, 326L, etc., after the electrical windings 13 and 14 have been inserted over the winding legs 312 and 313, and it will be appreciated that no bending of the laminations occurs which would disturb the grain orientation of the annealed and permanently set laminations 317, 326, etc.

In still another embodiment of the invention not shown in the drawing each lamination includes two lap joints, both in the same yoke with the joints occurring adjacent opposite corners of the core. In other words, two flights of lap joints occur in each group of laminations, the flight being in the same yoke and adjacent opposite corners of the core. In this embodiment also the electrical coils can be placed on the winding legs before the lamination lengths are assembled in overlapped relation.

While there have been shown and described preferred practices of the invention, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention, and it is intended by the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention. The appended claims are intended to cover the aforementioned embodiment wherein the laminations are arranged in sections each comprising a plurality of radially successive laminations all having the same length, and the phrase "lamination length" used in certain of the claims is intended to cover either a single lamination or a plurality of laminations all having the same length.

It is claimed:

1. A magnetic core for stationary induction apparatus comprising, in combination, a plurality of concentric groups of lamination lengths of magnetic material forming a closed four-sided magnetic core having a pair of opposed legs and a pair of opposed relatively shorter yokes, one of said legs being a winding leg, each of said groups comprising a plurality of radially successive lamination lengths, each lamination length constituting a closed magnetic circuit and having its ends overlapped a relatively short distance in one of said yokes, substantially all of said lamination lengths having those improved strain-free properties characteristic of magnetic material relief-annealed subsequent to mechanical working, radially successive lap joints in each of said groups being circumferentially displaced along one of said yokes and hav-

ing one end of each adjoining pair of lap joints disposed in a common layer with the end of one lamination length in said layer discontinuous from the end of the other lamination length in said layer to provide an interfitting flight of lap joints in said one yoke, whereby the lamination lengths of each group may be separated at their overlapped ends and collectively inserted through the window of an electrical winding and said lamination lengths inherently assume said overlapping relation.

2. A closed magnetic core for stationary induction apparatus comprising, in combination, a plurality of radially nested, flatwise curved laminations of magnetic material having a preferred grain orientation lengthwise thereof, substantially all of said laminations having those improved strain-free properties characteristic of magnetic material relief-annealed subsequent to mechanical working and having a permanent set of rectangular configuration with four sides joined at approximately right angle corners to form a hollow core having oppositely disposed sides and relatively shorter, oppositely disposed ends, one of the sides of said core being a winding leg, each one of said laminations being of longer length than the additive length of said sides and ends of said magnetic core measured circumferentially at said one of said laminations, said laminations being in solid contact along substantially their entire length with the corner bends compactly nested together and each lamination having the ends thereof overlapped a relatively short distance in one of the ends of said core, the lap joints of radially successive laminations being progressively displaced peripherally along a substantial portion of the circumferential length of said one end of said core and the outermost end of each lamination being in the same layer as, but discontinuous from, the innermost end of the lamination radially outward therefrom to provide an interfitting flight of lap joints along said one end, whereby said laminations may be collectively inserted through the window of an electrical winding and said laminations inherently resume said overlapping relation:

3. In combination, a closed magnetic core having four sides surrounding a window and comprising a plurality of concentric groups of laminations of magnetic material, each group including a plurality of radially successive laminations, each lamination comprising a whole turn in said core and substantially all of said laminations having those improved strain-free properties characteristic of magnetic material relief-annealed subsequent to mechanical working and having a permanent set of rectangular configuration with four sides joined at approximately right angle corners to form a hollow, closed core having oppositely disposed legs and oppositely disposed, relatively shorter yokes, one of said legs being a winding leg, said laminations of each group being in solid contact along substantially their entire length with the corner bends compactly nested together and each lamination of said group having its ends overlapped a relatively short distance in one of said yokes, radially successive lap joints in each group being progressively displaced in a circumferential direction along a substantial portion of the length of one of said yokes and the radially outermost end of each lamination being in the same layer as, but discontinuous from, the radially innermost end of the lamination radially outward therefrom to provide an interfitting flight of lap joints in said group along said one yoke, whereby the laminations of each group may be separated at their overlapped ends and collectively inserted through the window of an electrical winding to link said one leg with said winding and said laminations inherently assume said overlapping relation, the interfitting lap joints in radially successive groups being similarly arranged and displaced along at least one yoke of said core.

4. A magnetic core for stationary induction apparatus comprising, in combination, a plurality of radially nested, lengthwise bent lamination lengths of magnetic material each having a preferred grain orientation lengthwise there-

of, said lamination lengths having those improved strain-free properties characteristic of magnetic material relief-annealed subsequent to mechanical working and having a permanent set of four-sided configuration to form a closed, hollow magnetic core having a pair of opposed legs and a pair of opposed, relatively shorter yokes surrounding a window, one of said legs being a winding leg, each of said lamination lengths constituting a whole turn in said core and having its ends overlapped a relatively short distance in one of said yokes, radially successive lap joints being progressively displaced in a circumferential direction along said one yoke and having one end of each adjoining pair of lap joints disposed in a common layer in said one yoke with the end of one lamination length in said layer discontinuous from the end of the other lamination length in said layer, whereby said lamination lengths may be separated at their overlapped ends and collectively inserted through the window of an electrical winding and said lamination lengths inherently assume said overlapping relation.

5. Stationary induction apparatus comprising, in combination, an electrical winding having a window there-through and sides of substantially rectangular cross section surrounding said window, a closed quadrilateral magnetic core including a plurality of concentric groups of lamination lengths, said core passing through said window and closely embracing one of said sides of said winding and having a pair of opposed legs, one of which is disposed within said window, and a pair of opposed, relatively shorter yokes, said lamination lengths having those improved strain-free properties characteristic of magnetic material relief-annealed subsequent to mechanical working and having a permanent set of quadrilateral configuration, each said group including a plurality of radially successive lamination lengths in solid contact along substantially their entire length and each of which comprises a whole turn of said core and has its ends overlapped a relatively short distance in one of said yokes of said core, radially successive lap joints in each said group being progressively displaced in a circumferential direction along one of said yokes and the outermost end of each lamination length being in the same layer as but discontinuous from the radially innermost end of the lamination length radially outward therefrom to provide a flight of interfitting lap joints in said group along said one yoke.

6. In the method of constructing a magnetic core of individual closed magnetic circuits, the steps comprising, in combination, providing a plurality of magnetic laminations of progressively different lengths, stacking said lamination lengths concentrically in order of length and overlapping the respective ends of each lamination length a relatively short distance to form a closed loop and progressively displacing the lap joints in a peripheral direction along the circumferential length of said closed loop so that the radially innermost lamination length end at each lap joint is discontinuous from but in a common layer with the radially outermost lamination length end of the lap joint of the succeeding radially inward closed magnetic circuit to provide a step-like flight of lap joints, shaping said lamination lengths into a four-sided core having said step-like flight of lap joints in one of the sides thereof, and annealing the core while so shaped to relieve strains in the magnetic material and to give said lamination lengths a permanent set of four-sided configuration with the ends of each lamination length overlapped, whereby the ends of said lamination lengths may be separated at said lap joints and said lamination lengths collectively inserted through the window of an electrical winding and said lamination lengths inherently assume said overlapping relation.

7. In the method of constructing a magnetic core, the steps comprising, in combination, providing a plurality of magnetic laminations of progressively different lengths, stacking said lamination lengths concentrically in order of length in groups each comprising a plurality of radi-

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ally successive lamination lengths and overlapping the ends of each lamination length to form a closed magnetic core and progressively displacing the lap joints of each said group in a circumferential direction along said closed core so that radially successive lap joints have one end of each disposed in a common layer with the end of one lamination length in said layer discontinuous from the end of the other lamination length in said layer to provide a step-like flight of lap joints in said group, positioning said groups so that said flights of lap joints are in radial alignment in at least one peripheral portion of said core, shaping said lamination lengths into a quadrilateral core having a pair of opposed legs and a pair of opposed relatively shorter yokes and with said flights of lap joints in at least one of the yokes thereof, and annealing the core while so shaped to permanently set said lamination lengths in quadrilateral configuration with overlapped ends in one of said yokes and to relieve strains in said magnetic lamination lengths.

8. In the method of constructing a magnetic core of individual closed magnetic circuits, the steps comprising, in combination, providing a plurality of magnetic laminations of progressively different lengths, stacking said lamination lengths concentrically in order of length and overlapping the ends of each lamination length a relatively short distance to form a closed core and progressively displacing the lap joints of radially successive lamination lengths in a circumferential direction along a substantial portion of the peripheral length of said closed core and so that the radially innermost lamination length end at each lap joint is in a common layer with but discontinuous from the radially outermost lamination length end of the lap joint of the succeeding radially inward lamination length to form an interfitting flight of lap joints and said lamination lengths are in solid contact along substantially their entire length, shaping said lamination lengths into a quadrilateral core having a pair of opposed legs and a pair of opposed relatively shorter yokes and with said flight of interfitting lap joints in one of the yokes, and annealing the core while so shaped to relieve strains in said lamination lengths and to permanently set said lamination lengths in quadrilateral configuration with overlapped ends, whereby the ends of said lamination lengths may be separated at said lap joints and collectively inserted through the window of an electrical winding and said lamination lengths inherently assume said overlapping relation.

9. In the method of constructing an electrical transformer, the steps comprising, in combination, providing a plurality of magnetic laminations of progressively different lengths, stacking said lamination lengths concentrically in the order of length in groups each comprising a plurality of radially successive lamination lengths and overlapping the ends of each lamination length to form a hollow magnetic core and peripherally displacing the lap joints of each said group progressively along the circumferential lengths of said core so that radially successive lap joints have one end of each disposed in a common layer with the end of one lamination length in said layer discontinuous from the end of the other lamination length in said layer to provide a step-like flight of lap joints in said group, positioning said groups so that said flights of lap joints are in radial alignment in at least one portion of the periphery of said core, shaping said lamination lengths so stacked into a quadrilateral core having a pair of opposed legs and a pair of opposed relatively shorter yokes and with the flights of lap joints in at least one of the yokes of the core, annealing the core while so shaped to relieve strains in said lamination lengths and permanently set said lamination lengths in quadrilateral shape with overlapping ends, collectively bending the lamination lengths of each of said groups at positions including the corners at the ends of said one yoke to open said lap joints and collectively inserting said lamination lengths so opened through the window

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of an electrical winding, whereby said laminations inherently assume the position in which they were annealed with the peripherally displaced lap joints reclosed to complete the linking of a leg of said core with said electrical winding.

10. In a method of constructing a magnetic core, the steps comprising, in combination, providing a plurality of magnetic strip laminations of progressively different lengths, securing the ends of the longest lamination length in overlapping relation to provide a closed magnetic turn, inserting the lamination lengths in order of decreasing length concentrically within said closed turn and overlapping the ends of each lamination length a relatively short distance to provide a hollow core and progressively displacing the lap joints in a circumferential direction along said hollow core so that the radially innermost end of each lamination length is in a common layer with but discontinuous from the radially outermost end of the succeeding radially inward lamination length to provide a step-like flight of interfitting lap joints along the periphery of said core, shaping said core into four-sided configuration with said step-like flight of interfitting lap joints in one side thereof, and annealing the core while so shaped to relieve strains in said magnetic strip lamination lengths and to give said lamination lengths a permanent set of four-sided configuration with the ends of each lamination length in overlapping relation.

11. In the method of constructing a magnetic core, the steps comprising, in combination, providing a plurality of magnetic laminations of progressively different lengths, securing the ends of the longest lamination length in overlapping relation to provide a closed magnetic turn, inserting the lamination lengths in order of decreasing length within said closed turn and overlapping the ends of each lamination length a relatively short distance to provide a hollow core of individual, closed magnetic circuits and progressively displacing said lap joints in a peripheral direction in a recurring pattern wherein the lap joints in each group comprised of a plurality of radially successive lamination lengths are displaced circumferentially in a step-like flight of lap joints along the periphery of said hollow core and so that radially successive lap joints have one end of each disposed in a common layer with the end of one lamination length in said layer discontinuous from the end of the other lamination length in said layer, positioning said groups so that said flights of lap joints are in radial alignment along at least one portion of the peripheral length of said core, applying pressure against the inner periphery of the portion of the core containing the lap joints and against the inner periphery of the portion diametrically opposed thereto to shape said lamination lengths into a quadrilateral core having opposed shorter sides forming yokes and opposed longer sides with the flights of lap joints in at least one of said yokes, and annealing the core while so shaped to relieve strains in said lamination lengths and to give said lamination lengths a permanent set of quadrilateral configuration with overlapped ends.

12. In the method of constructing a magnetic core of individual closed magnetic circuits, the steps comprising, in combination, providing a plurality of magnetic laminations of progressively different lengths, securing the ends of the longest lamination length in overlapping relation to provide a closed turn, inserting said lamination lengths in order of decreasing length within said closed turn and overlapping the ends of each lamination length a relatively short distance to provide a hollow core and peripherally displacing said lap joints in a recurring pattern wherein the lap joints in each group comprising a plurality of radially successive lamination lengths are progressively displaced peripherally in a step-like flight of lap joints along the circumference of said hollow core and so that said lamination lengths are in solid contact along substantially their entire length with the radially innermost

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lamination length end at each lap joint in a common layer with, but discontinuous from, the radially outermost end of the succeeding radially inward lamination length, positioning said groups so that said flights of lap joints are in radial alignment in at least one portion of said hollow core, shaping said core into a four-sided configuration having a pair of opposed legs one of which may be a winding leg and a pair of opposed relatively shorter yokes and with said flights of lap joints in at least one of said yokes, annealing the core while so shaped to relieve strains in said magnetic strip lamination lengths and to permanently set said lamination lengths in four-sided configuration with the ends of each lamination length overlapped, whereby said lamination lengths of each said group may be opened at their overlapped ends

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and collectively inserted through the window of an electrical winding and said lamination lengths inherently assume said overlapping relation.

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