United States Patent

[11] 3,569,886

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[54] **MAGNETIC CORE STRUCTURES**
11 Claims, 10 Drawing Figs.

[52] **U.S. Cl.** **336/217**
[51] **Int. Cl.** **H01f 27/24**
[50] **Field of Search** 336/216, 217, 233, 234

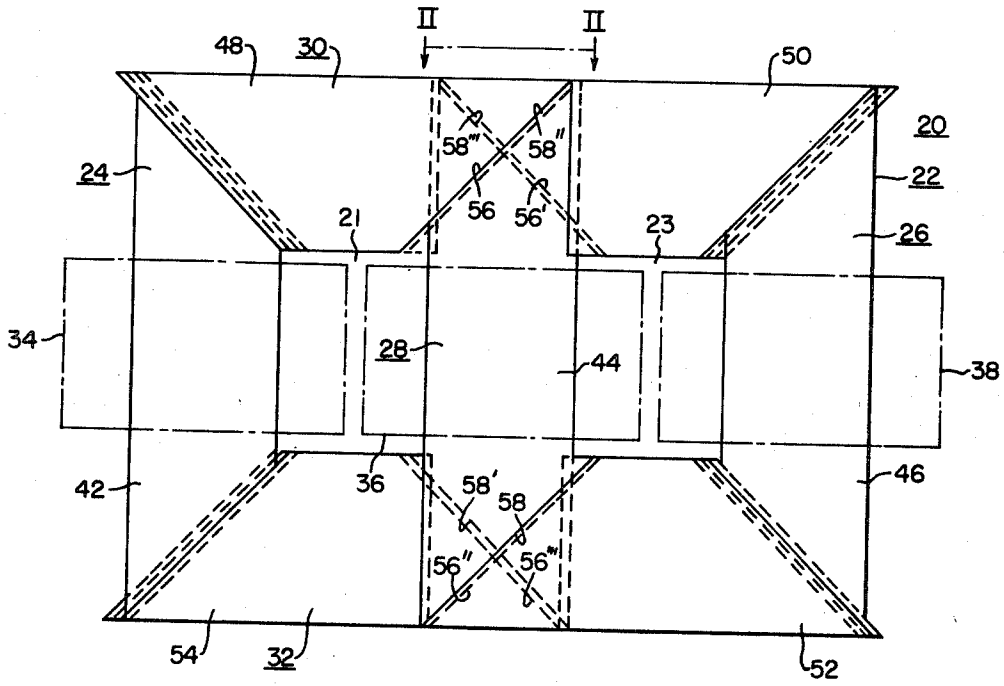
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ABSTRACT: A three-legged magnetic core structure having a plurality of stacked layers of metallic laminations, including two outer leg laminations, an inner leg lamination, and joining upper and lower yoke laminations. Each layer of laminations is of like construction, utilizing laminations of like configuration and dimensions, with the layers being oriented differently to provide three layers between repeating joints. The joints at the outer corners of the magnetic core are mitered, and the joints between the yoke and inner leg lamination include a mitered and a square joint at each end of the inner leg lamination. The inner leg lamination has one end narrowed where it joins a yoke lamination with a square joint, to provide the required joint distribution between the inner leg lamination and adjoining yoke laminations.



3 Sheets-Sheet 1

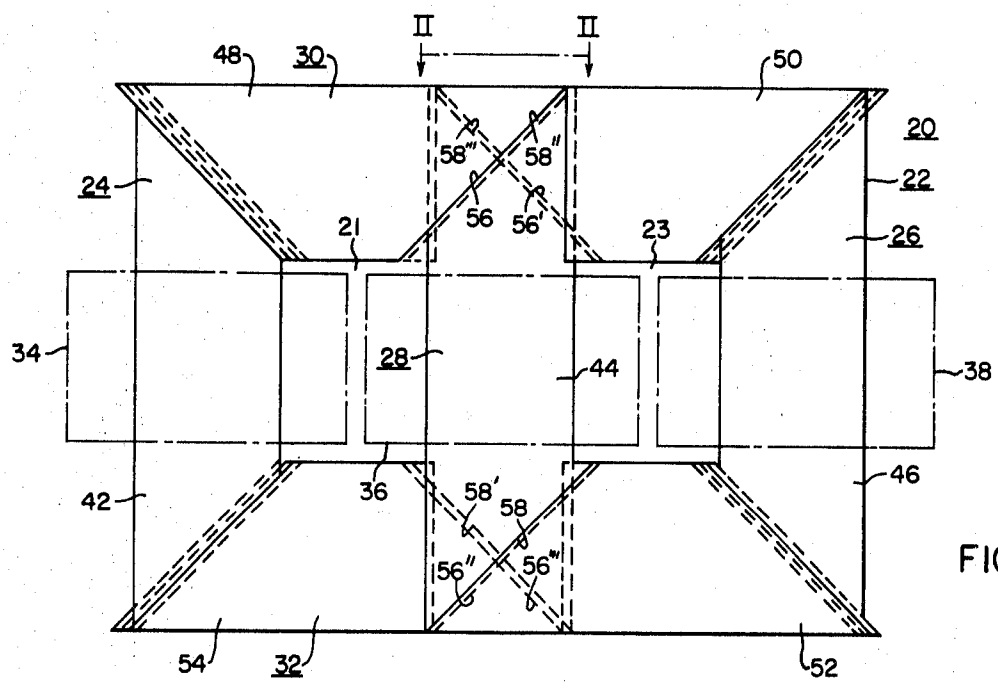


FIG.1.

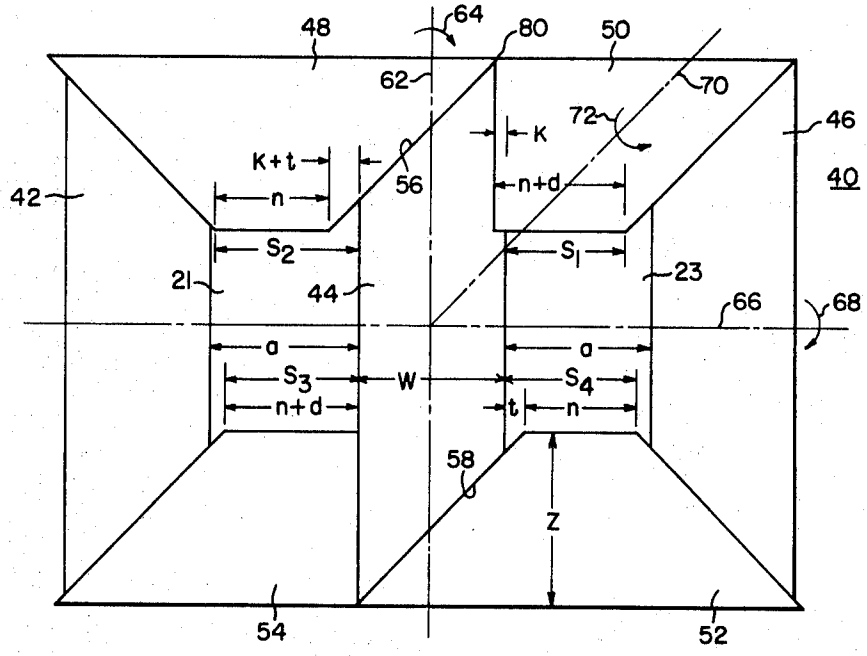


FIG.3.

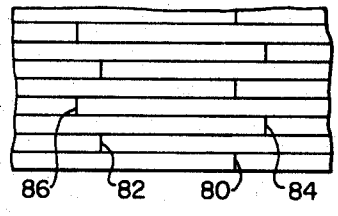


FIG.2.

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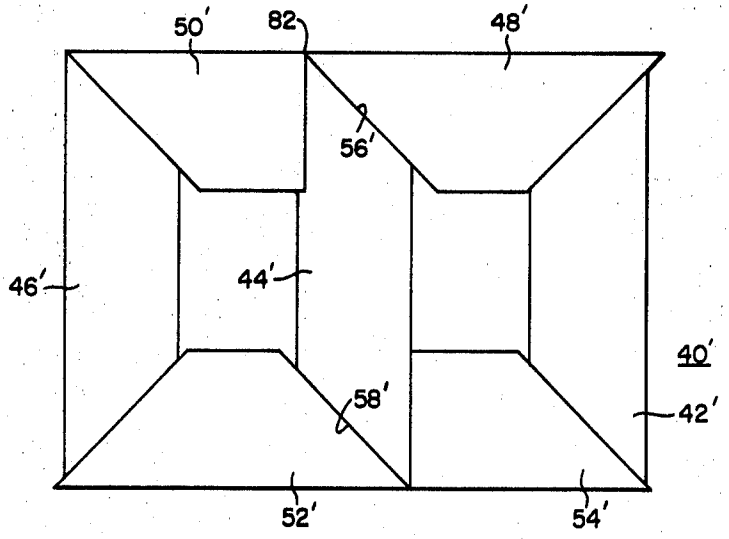


FIG. 4.

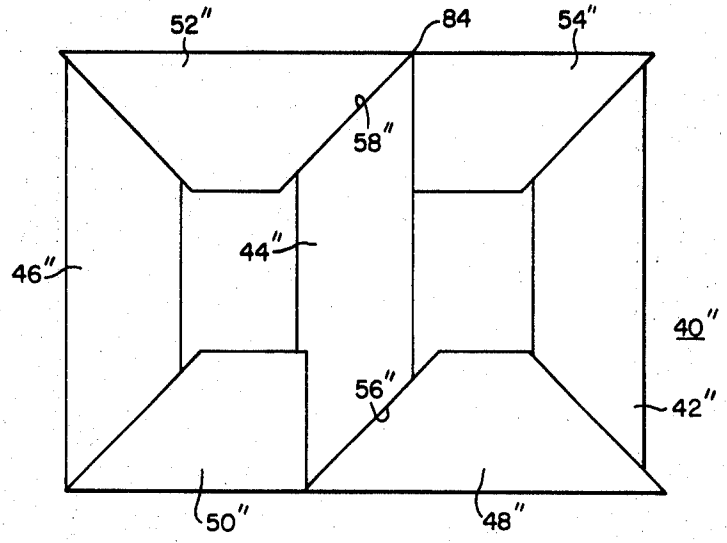


FIG. 5.

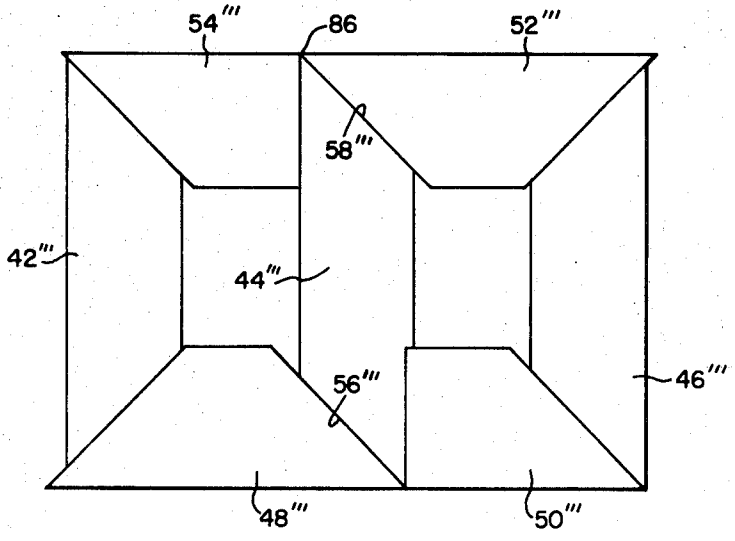


FIG. 6.

3 Sheets-Sheet 3

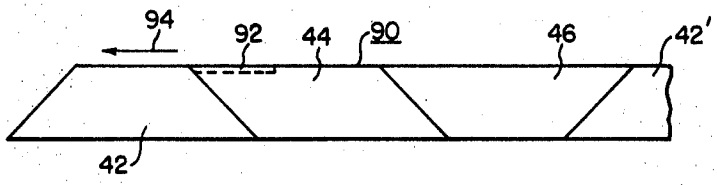


FIG. 7.

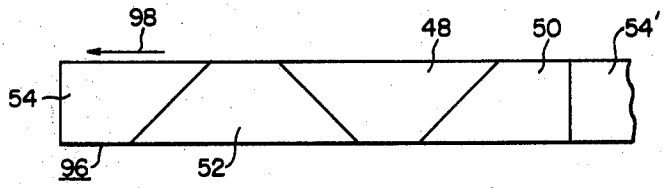


FIG. 8.

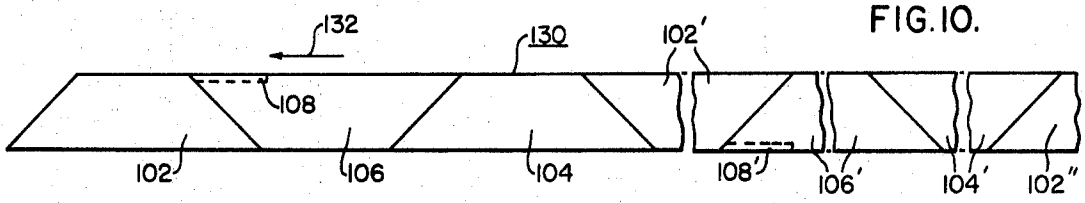


FIG. 10.

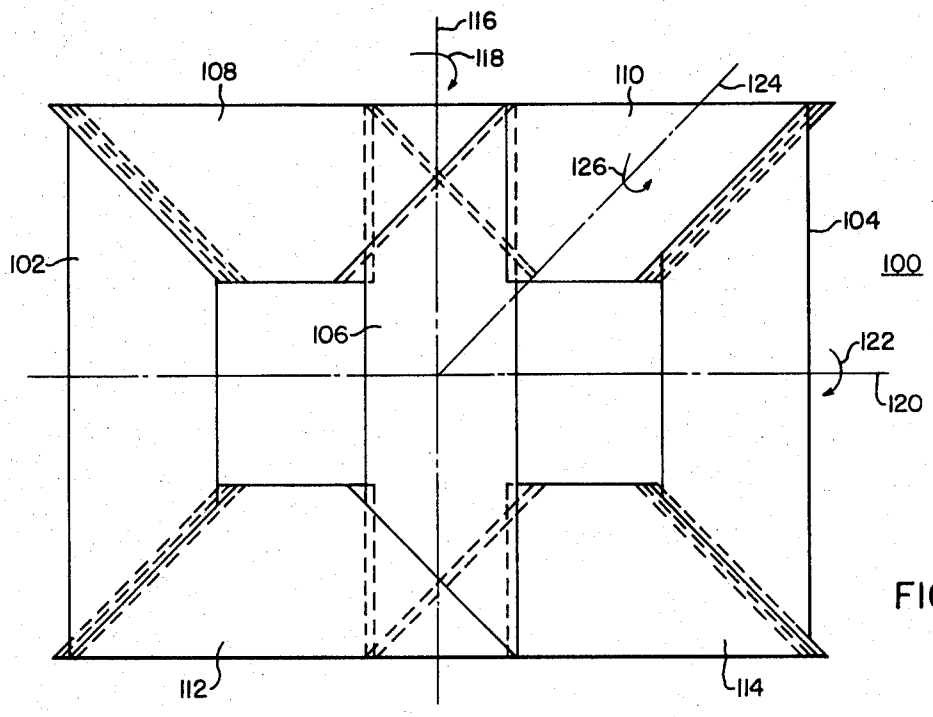


FIG. 9.

MAGNETIC CORE STRUCTURES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates in general to electrical inductive apparatus, such as transformers and reactors, and more specifically to magnetic core structures for electrical inductive apparatus.

2. Description of the Prior Art

Three-legged magnetic core structures of the stacked type conventionally utilize mitered or diagonal joints between the outer leg and yoke laminations, and between the inner leg lamination and adjoining yoke laminations, such as taught by U.S. Pat. No. 2,300,964, which is assigned to the same assignee as the present application. Further, it has been found that by staggering or stepping the joints from layer to layer, with two or more laminations separating repeating joints, that the core losses may be substantially reduced compared with the butt-lap pattern wherein only one lamination separates repeating joints. An example of stepped-lap construction is disclosed in U.S. Pat. No. 3,153,215, which is assigned to the same assignee as the present application.

The conventional three-legged magnetic core, in order to obtain all mitered or diagonal joints, provides two diagonal cuts on each end of the inner leg lamination, forming a spear or V-shaped point on each end of this lamination. The shearing of the ends of the inner leg lamination to a V-shape has the disadvantage of producing scrap, which amounts to about 4 percent of the total core weight. It also has the disadvantage of complicating automated production of the laminations, as the double cut on each end of the inner leg lamination cannot be accomplished by a single oscillating shear, as are the cuts for the remaining laminations, requiring a separate operation for each end of the inner leg lamination.

Attempts to eliminate the V-shaped ends of the inner leg lamination, by utilizing a single diagonal cut on each end of this lamination, results in creating a mitered and a square joint between each end of the inner leg lamination and adjoining yoke laminations. While this structure lends itself to automatic shearing of the laminations from a strip of magnetic material, with negligible scrap, the square joints increase the core losses when used in a structure wherein the inner leg lamination is merely rotated 180° about a predetermined axis from layer to layer, producing an X-like pattern, with one lamination between repeating joints in the same plane. The X joint pattern at the inner leg, in addition to lending itself to automatic shearing in a substantially scrapless manner, also increases the mechanical strength of the magnetic core and results in a more complete joint closure above and below the inner leg lamination, compared with magnetic cores which have inner legs having the V-shaped points at the extreme ends thereof.

U.S. Pat. No. 3,283,281, which is assigned to the same assignee as the present application, discloses that magnetic cores may utilize square joints with negligible impairment of magnetic performance, if the number of square joints per layer does not exceed two, and there are at least two intervening layers of laminations before the joint repeats in the same plane. Pat. No. 3,283,281 discloses practical embodiments of this concept, utilizing at least three different punching layers in the basic pattern. The number of different lamination shapes and dimensions, and the number of different punching layers required for the basic pattern determines the complexity involved in manufacturing and stacking the magnetic core, and therefore has a direct influence on the manufacturing cost of the core. Thus, it would be desirable to provide a new and improved three-legged magnetic core structure which facilitates automatic shearing with negligible scrap, which has mitered joints except for two square joints per layer of laminations, and which has at least two layers separating repeating joints in the same plane. Further, the manufacturing and assembly of the magnetic core should be facilitated by requiring a minimum number of different lamination shapes, and a minimum number of different basic punching layers.

SUMMARY OF THE INVENTION

Briefly, the present invention is a new and improved three-legged magnetic core structure of the stacked type, having laminations which may be cut with an oscillating shear in an automated manner, with substantially no scrap. Further, it has the mechanical strength advantages of the X joint pattern at the junction of the inner leg lamination with the adjoining yoke laminations, without the usual disadvantages of square joints relative to magnetic performance, as it has three layers of laminations between repeating joints in the same plane. Only one basic layer construction is used, with each layer having seven laminations of five different configurations. Each layer of laminations is of like construction, with the basic layer pattern being such that by rotating the basic layer 180° about three different axes, the joints will be distributed into different planes. The required distribution of the joints between the inner leg lamination and adjoining yoke laminations, from layer-to-layer, is achieved by narrowing the width of one end of the inner leg lamination, where the inner leg lamination joins a yoke lamination with a square joint.

BRIEF DESCRIPTION OF THE DRAWINGS

Further advantages and uses of the invention will become more apparent when considered in view of the following detailed description and drawings, in which:

FIG. 1 is an elevational view of a transformer having a magnetic core constructed according to an embodiment of the invention;

FIG. 2 is a fragmentary view of the joint pattern between the inner leg and upper yoke laminations of the magnetic core shown in FIG. 1, taken in the direction of the arrows II–II;

FIGS. 3, 4, 5 and 6 illustrate the layers of a basic group of laminations of the magnetic core shown in FIG. 1;

FIGS. 7 and 8 illustrate a method of cutting the leg and yoke laminations, respectively, for the magnetic core shown in FIG. 1;

FIG. 9 is an elevational view of a magnetic core constructed according to another embodiment of the invention; and

FIG. 10 illustrates a method of cutting the leg laminations for the magnetic core shown in FIG. 9.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, and FIG. 1 in particular, there is shown a transformer 20 having a three-legged magnetic core assembly 22 constructed according to an embodiment of the invention. Magnetic core 22 includes first and second outer leg members 24 and 26, an inner leg member 28, an upper yoke member 30, and a lower yoke member 32. Phase winding assemblies 34, 36 and 38, shown in phantom, are disposed about leg members 24, 28 and 26, respectively. As illustrated, transformer 20 is of the core-form type, with FIG. 1 being an elevational view, but by changing the relative proportions of the leg members, magnetic core 22 may be of the single-phase, shell-form type, having the winding portions disposed about the inner leg member 28. In the shell-form embodiment of the invention, the view of the magnetic core shown in FIG. 1 would be a plan view.

In general, magnetic core 22 includes a plurality of stacked layers of laminations formed from magnetic strip material having at least one preferred direction of magnetic orientation lengthwise of the material or substantially parallel with the sides of the strip material. The laminations which form the various layers included in the magnetic core structure 22 are assembled with their adjoining edges substantially aligned to form a substantially rectangular core having two rectangular windows or openings 21 and 23 for receiving the phase windings. Each layer of laminations includes three-leg laminations, and yoke laminations which connect the ends of the leg laminations to form a rectangular core having substantially rectangular openings. All of the joints formed between the various yoke and leg laminations are distributed such that when the various layers of which the magnetic core 22 is

formed are superposed, there are at least three laminations separating repeating joints in the same plane.

In order to provide a substantially scrapless three-legged magnetic core which lends itself to automatic shearing of the core laminations, two square joints per layer are utilized, which also provides advantages in the ease of joint closure adjacent the inner leg and a strong core mechanically. The usually higher losses associated with square joints are overcome by distributing the joints to provide three lamination layers between repeating joints. The shearing of the lamination from a strip of magnetic material, and the stacking of laminations to form the magnetic core, are facilitated by reducing the number of different lamination shapes to five, and by using only one basic layer construction, arranged to distribute the joints when the basic layer is oriented into four different positions and the layers are stacked or superposed. A three-legged layer of laminations has four possible orientations, two on each side of the layer of laminations, thus producing a magnetic core structure having a basic lamination group of four stacked layers.

More specifically, magnetic core **22** includes one or more basic groups of layers of laminations, with each group including four layers of laminations providing four joint planes at the outer corners of the magnetic core as illustrated in FIG. **1** by the solid joint corner and the three joints shown by the dotted lines at each corner, with the joints at each corner being offset by a predetermined incremental dimension, such as one-eighth or one-fourth of an inch, with the dimension selected usually depending upon the physical size of the magnetic core. The actual joint-to-joint overlap, however, may be more than the selected increment, as the joints do not necessarily step progressively, such as in the stepped-lap magnetic core disclosed in the hereinbefore-mentioned U.S. Pat.

Eight different joint planes, four for the mitered joint and four for the square joint, are provided above and below the inner leg member **28**. This is essential to the good magnetic performance of the magnetic core, and is made possible by stepping or narrowing one end of each inner leg lamination, where the inner leg lamination joins a yoke lamination with a square joint. In order to facilitate complete joint closure between the inner leg and yoke lamination, and to provide a strong joint mechanically, the orientation of the layers of a basic group is such that the joint-to-joint pattern provides a succession of X joints. This is illustrated more clearly in FIG. **2**, which is a fragmentary view of magnetic core **22** shown in FIG. **1**, taken in the direction of arrows **11–11**.

The construction of magnetic core **22** may most easily be understood by examining a basic layer of laminations, and then noting how the basic layer is oriented to provide the other layers of a basic group. The basic layer is shown in FIG. **3**, with the reference numeral **40**, and it corresponds to the top layer of laminations of the magnetic core **22** shown in FIG. **1**. Basic layer **40** includes first and second outer leg laminations **42** and **46**, respectively, a center or inner leg lamination **44**, first and second upper yoke laminations **48** and **50**, and first and second lower yolk laminations **52** and **54**, respectively. The ends of the first and second outer leg laminations **42** and **46** are each cut diagonally, preferably at an angle of substantially 45° with respect to the direction of magnetic orientation of the strip material from which the laminations are cut. Each end of the inner leg lamination **44** has a single diagonal cut, also preferably at an angle of substantially 45° to the edges of the strip, forming edges **56** and **58**, which, in this embodiment, are parallel with one another, forming the inner leg lamination into a parallelogram configuration.

In order to distribute the joints between the inner leg lamination **44** and the adjoining yoke lamination into different planes, in the basic group of four layers of laminations, one end of the inner leg lamination **44** is narrowed by a predetermined dimension, such as by one-fourth, three-eighths, or one-half of an inch, by a step which starts at one of the extreme ends of the lamination and extends inwardly parallel to the side or edge of the lamination, extending for at least the distance of the yoke width dimension. Thus, inner leg lamination **44** is narrowed by a dimension K at its end adjacent the upper yoke lamination **50**, but it would be equally effective to narrow the end adjacent the lower yoke lamination **54**. It is important, however, that only one end be narrowed.

The ends of the first upper and first lower yoke laminations **48** and **52**, respectively, are each cut diagonally with respect to the sides of the lamination, forming a substantially trapezoidal configuration, and the second upper and second lower yoke laminations **50** and **52**, respectively, each have one end cut diagonally with respect to the sides of the laminations, and the other ends are cut perpendicular to the sides of the laminations. It is important to note that the first upper and first lower yoke laminations are of similar configuration and dimensions, and that the second upper and second lower yoke laminations are of similar configuration and dimension, thus reducing the number of different lamination shapes to five for the basic layer **40**.

In the assembly of the basic layer **40** the various yoke and leg laminations are assembled to form a rectangular configuration having two substantially rectangular windows **21** and **23**. The leg laminations are disposed in spaced parallel relation, with the yoke laminations joining the ends of the leg laminations to complete the rectangular configuration. All of the joints between the leg and yoke laminations are mitered, except for a square joint between the narrowed portion of the inner leg lamination **44** and the upper yoke lamination **50**, and a square joint between inner leg lamination **44** and the lower leg lamination **54**.

A rectangular three-legged layer of laminations has four possible orientations, two on each side of the layer. All four of these orientations are used to provide maximum joint distribution for a single basic layer of laminations. The mitered joints between the outer leg and yoke laminations are arranged such that as the basic layer is placed into the possible orientations, the outer corner joints, at each outer corner of the core, will be incrementally offset into four different planes. The incremental narrowing of one end of the inner leg lamination accomplishes this result for both the mitered and square joints between the inner leg and adjoining j yoke laminations. The strongest joint mechanically, and the best joint closure above and below the inner leg lamination, will be obtained by disposing the mitered joints of the inner leg lamination of one layer, perpendicular to the mitered joints of the preceding layer. In other words, the next layer of laminations immediately adjacent layer **40** is shown in FIG. **3**, should be obtained by rotating the basic layer 180° about axis **62**, which is an axis disposed longitudinally through the inner leg lamination **44** in the plane of the lamination, with its rotation about the axis being indicated by arrow **64**. Or, the basic layer **40** may be rotated 180° about axis **66**, as indicated by arrow **68**, which axis is perpendicular to the leg laminations in the plane of the laminations. Rotating the basic layer **40** about either axis **64** or axis **68**, turns the basic layer of laminations over to its opposite side. Assuming that the second layer orientation is in rotational symmetry with the first layer about axis **62**, this layer would have the arrangement shown in FIG. **4**, with the same reference numerals being used in FIGS. **3** and **4** to indicate like laminations, with the reference numeral for the second layer and its laminations having a single prime mark to distinguish them from the first layer and its laminations.

The third layer of laminations should now return the diagonal joints above and below the inner leg lamination to the direction of the first layer, but incrementally offset from the mitered joints of the first layer. This orientation is achieved by rotating the first layer 180° about an axis **70**, as indicated by arrow **72**, which axis is perpendicular to the plane of the inner leg lamination **44**. The third layer of laminations is shown in FIG. **5**, and it has the same reference numerals as the first layer, with the addition of double prime marks to distinguish the laminations from the first layer.

The fourth layer of the basic group is shown in FIG. **6**, and it is in rotational symmetry with the first layer **40** about the

remaining axis **66**. The fourth layer has the same reference numerals as the first layer **40**, with the addition of triple prime marks.

Thus, the second, third and fourth layers are in 180° rotational symmetry with the first layer **40** about axes **62**, **70** and **66**, respectively, but as hereinbefore pointed out, it would be equally suitable to use a sequence which includes axes **68**, **70** and **62**, respectively, for the second, third and fourth layers. By using the sequence about axes **62**, **70** and **66**, respectively, as illustrated in the FIGS., the ends of the inner leg laminations at the upper yoke appear as shown in FIG. **2**, with excellent distribution into four different planes, with the joints in the upper yoke appearing at **80** in the first layer, **82** in the second layer, **84** in the third layer, and **86** in the fourth layer.

As hereinbefore stated, the joints at the four outer corners of the magnetic core are distributed into four different planes in the basic group of laminations. A method for choosing dimensions to stagger the joint lines into four different planes is as follows, using the letters shown in FIG. **3**. Specifically, each window **21** and **23** has a width dimension a, the width of the yoke lamination is z, and the width of the leg lamination is w. The inward step on the inner leg lamination is k, the shorter side of the yoke laminations **48** and **52** is n, and the shorter side of yoke laminations **50** and **54** is $n+d$. The dimensions S_1, S_2, S_3 and S_4 are the dimensions from the start of the mitered edges of the yoke laminations, which edges cooperate with similarly cut edges of the outer leg laminations to form the outer corner joints, to the nearest side or edge of the inner leg lamination, with S_1, S_2, S_3 and S_4 being these dimension for yoke laminations **50**, **48**, **54** and **52**, respectively. The following equations may then be written for the dimensions S_1, S_2, S_3 and S_4:

$$S_1 = n + d - k \qquad \text{or } S_1 - n = d - k$$

$$S_2 = n + k + t \qquad \text{or } S_2 - n = k + t$$

$$S_3 = n + d \qquad \text{or } S_3 - n = d$$

$$S_4 = n + t \qquad \text{or } S_4 - n = t$$

It should be noted at $z = w = t$. The values of d, k and t are selected so the right-hand sides of the four equations listed above are different. The value of t will usually be 0, one-half, or 1 inch. Some practical good combinations are listed in Table **1**.

TABLE I

t	1	1	1	½	0
k	¼	⅜	½	½	¼
d	¾	⅝	½	¼	¾
d−k	½	¼	0	0	½
k+t	1¼	1⅜	1½	¾	¼
d	¾	⅝	½	¼	¾
t	1	1	1	½	0

The laminations for magnetic core **22** shown in FIG. **1** may be formed in a substantially scrapless manner as shown in FIGS. **7** and **8**. FIG. **7** illustrates the cutting of the first outer, inner and second outer leg laminations **42**, **44** and **46**, respectively, from a strip **90** of magnetic material. The inward step or narrowing of one end of the inner leg lamination **44** is illustrated by the dotted line **92**, with this small piece being the only scrap generated. The strip **90** advances in the direction of arrow **94**, thus facilitating the forming of cut **92**, as it will be on the leading edge of the inner leg lamination.

FIG. **8** illustrates the cutting of the yoke lamination from a strip **96** of magnetic material, by advancing the strip in the direction of arrow **98**. As illustrated, the lower yoke laminations **54** and **52** may be cut first, and then the upper yoke laminations **48** and **50**, but since the upper and lower yoke laminations **48** and **52** are similar, the sequence may be reversed if desired.

While it is preferable to make the inner leg lamination **44** in the configuration of a parallelogram, as it facilitates the automatic shearing of the leg laminations, the advantages of the invention may also be obtained by constructing the inner leg lamination in the shape of a trapezoid. One end of the inner leg lamination will also be narrowed in this embodiment, to distribute the joints above and below the inner leg lamination into different planes, in a basic group of laminations. This embodiment of the invention is shown in FIG. **9**, illustrating a magnetic core **100** having a basic layer which includes first and second outer leg laminations **102** and **104**, an inner leg lamination **106**, first and second upper yoke laminations **108** and **110**, and first and second lower yoke laminations **112** and **114**. The second layer may be obtained by rotating the first or basic layer 180° about axis **116**, as illustrated by arrow **118**, with axis **116** being disposed longitudinally through the inner leg lamination **106** in the plane of the lamination. This arrangement "crosses" or places the mitered joints of the first and second layers at substantially right angles to one another, both above and below the inner leg laminations. Or, the basic layer may be rotated 180° about axis **124**, as indicated by arrow **126**, which axis is disposed perpendicular to the plane of the inner leg lamination **106**. If the second layer is in rotational symmetry with the first layer about axis **116**, the third layer will be in rotational symmetry with the first layer about axis **120**, as indicated by arrow **122**, with axis **120** being perpendicular to the leg laminations, in the plane of the leg laminations, and the fourth layer will be in rotational symmetry with the first layer about axis **124**. If the second layer is in rotational symmetry with the first layer about axis **124**, the third layer will be in rotational symmetry with the first layer about axis **120**, and the fourth layer will be in rotational symmetry with the first layer about axis **116**.

The yoke laminations for magnetic core **100** may be cut from a strip of magnetic material as illustrated in FIG. **8** for the yoke laminations of magnetic core **22**, while the leg laminations may be cut from a strip of magnetic material as illustrated in FIG. **10**. FIG. **10** illustrates a strip **130** of magnetic material being advanced in the direction of arrow **132**, cutting outer leg lamination **102**, inner leg lamination **106**, outer leg lamination **104**, outer leg lamination **102'** for the next layer, inner leg lamination **106'** for the next layer, and outer leg lamination **104'** for the next layer. The incremental narrowing of one end of each of the inner leg laminations **106** and **106'** is indicated by dotted lines **108** and **108'**, respectively, with the narrowing occuring on the leading edge of these laminations.

In summary, there has been disclosed new and improved electrical inductive apparatus, such as transformers or reactors, which have a new and improved magnetic core structure which has the advantages of the X joint above and below the inner leg laminations of a three-legged magnetic core structure, such as ease of joint closure and the high strength of such a joint, without the disadvantages of the joint relative to magnetic performance of the core. The new and improved magnetic core structure has only five different lamination shapes per layer, and only one basic layer construction is utilized. The basic layer is placed into four different orientations, to form a basic group of laminations in which all of the joints are distributed into different planes. Therefore, three layers of laminations separate repeating joints in the same plane, to substantially improve the magnetic performance of the core, compared to magnetic cores which utilize square joints with only one layer of laminations between repeating joints in the same plane. Further, the disclosed magnetic core may be formed in a substantially scrapless manner, with the only scrap being generated by the incremental narrowing of one end of each of the inner leg laminations. The incremental narrowing is necessary in order to distribute all the joints above and below the inner leg laminations into different planes in each basic group of laminations.

Since numerous changes may be made in the above-described apparatus and different embodiments of the invention may be made without departing from the spirit thereof, it

is intended that all matter contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative, and not in a limiting sense.

I claim:

1. A magnetic core comprising:

at least one group of four stacked layers of metallic laminations;

a first layer of said at least one group including first and second outer leg laminations, an inner leg lamination, first and second upper yoke laminations which join said outer leg laminations with mitered joints, and said inner leg lamination with mitered and square joints, respectively, and first and second lower yoke laminations which join said outer leg laminations with mitered joints and said inner leg lamination with mitered and square joints, respectively; and

one end of said inner leg lamination having a step which narrows the width of the lamination where the inner leg lamination joins a yoke lamination with a square joint; each lamination of said first layer having a duplicate in each of the three removing layers of the group, with the laminations of the three remaining layers being assembled the same as the first layer, each of said layers being oriented to distribute each joint into different planes through the group.

2. The magnetic core of claim 1 wherein each of the three-remaining layers of the group is in 180° rotational symmetry with the first layer, each about a different axis of the first layer.

3. The magnetic core of claim 2 wherein the axes of the first layer about which the three-remaining layers are in rotational symmetry with are:

a. an axis which extends longitudinally through the inner leg lamination, in the plane of the lamination;

b. an axis which extends perpendicularly through the plane of the inner leg lamination; and

c. an axis which is perpendicular to the sides of the inner leg lamination, in the plane of the lamination.

4. The magnetic core of claim 3 wherein the inner leg lamination has substantially the configuration of a parallelogram, and the second, third and fourth layers are oriented relative to the first layer in the sequence a, b, and c.

5. The magnetic core of claim 3 wherein the inner leg lamination has substantially the configuration of a parallelogram, and the second, third and fourth layers are oriented, relative to the first layer, in the sequence c, b and a.

6. The magnetic core of claim 3 wherein the inner leg lamination has substantially the configuration of a trapezoid, and the second, third and fourth layers are oriented, relative to the first layer, in the sequence a, c and b.

7. The magnetic core of claim 3 wherein the inner leg lamination has substantially the configuration of a trapezoid, and the second, third and fourth layers are oriented, relative to the first layer, in the sequence b, c and a.

8. The magnetic core of claim 1 wherein the first upper and first lower yoke laminations have substantially the same configuration and dimensions, and the second upper and second lower yoke laminations have substantially the same configuration and dimensions.

9. The magnetic core of claim 8 wherein the innner leg lamination has substantially the configuration of a parallelogram, with the first upper and first lower yoke laminations joining the first and second outer leg laminations, respectively, and the second upper and second lower yoke laminations joining the second and first outer leg laminations, respectively.

10. The magnetic core of claim 8 wherein the inner leg lamination has substantially the configuration of a trapezoid, with the first upper and first lower yoke laminations joining the first outer leg lamination, and the second upper and second lower yoke laminations joining the second outer leg lamination.

11. The magnetic core of claim 1 including a plurality of groups of four layers of laminations, stacked in superposed relation, each constructed similar to the at least one group of laminations.