

Aug. 4, 1959

A. M. FOX ET AL

2,898,565

MAGNETIC CORE

Filed July 2, 1954

3 Sheets-Sheet 1

Fig. 1

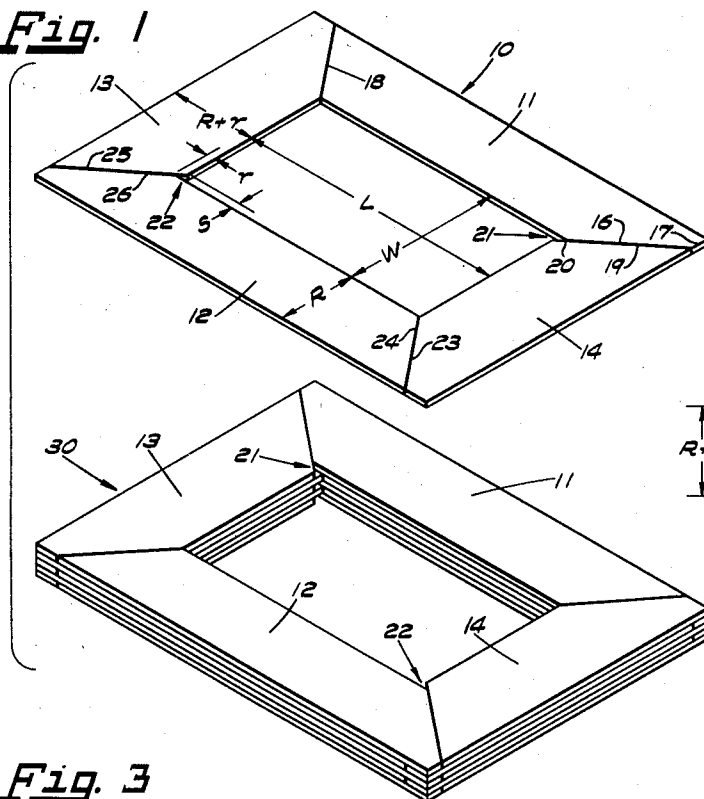


Fig. 2

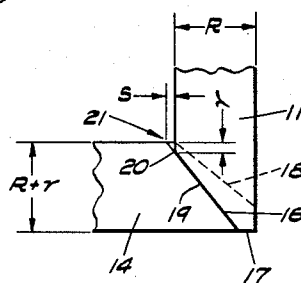
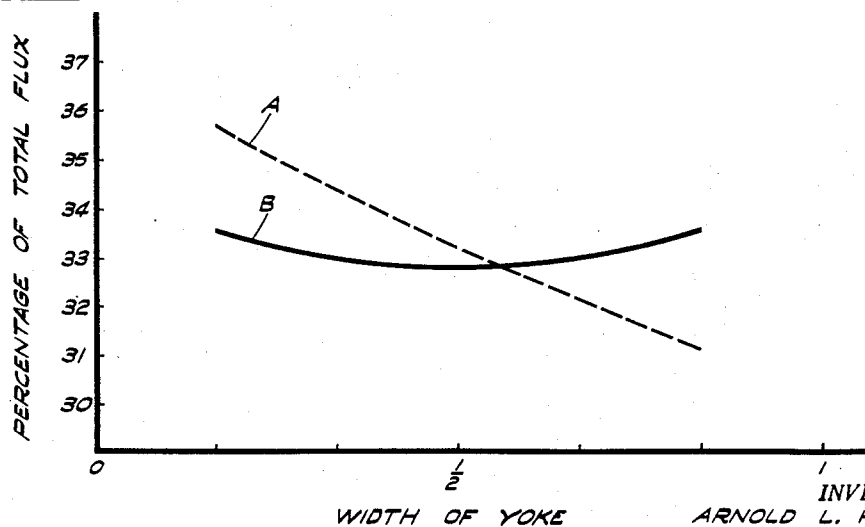


Fig. 3



INVENTORS.
ARNOLD L. HORELICK
ARNOLD M. FOX
BY *Lee W. Kaiser*
ATTORNEY

Aug. 4, 1959

A. M. FOX ET AL
MAGNETIC CORE

2,898,565

Filed July 2, 1954

3 Sheets-Sheet 3

Fig. 7

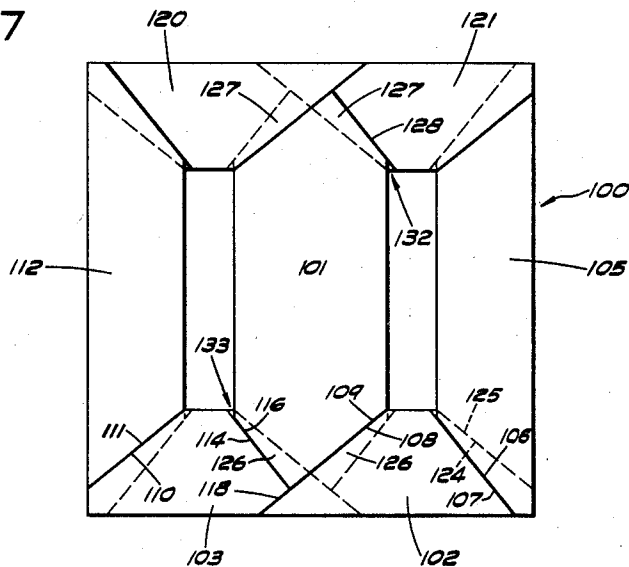
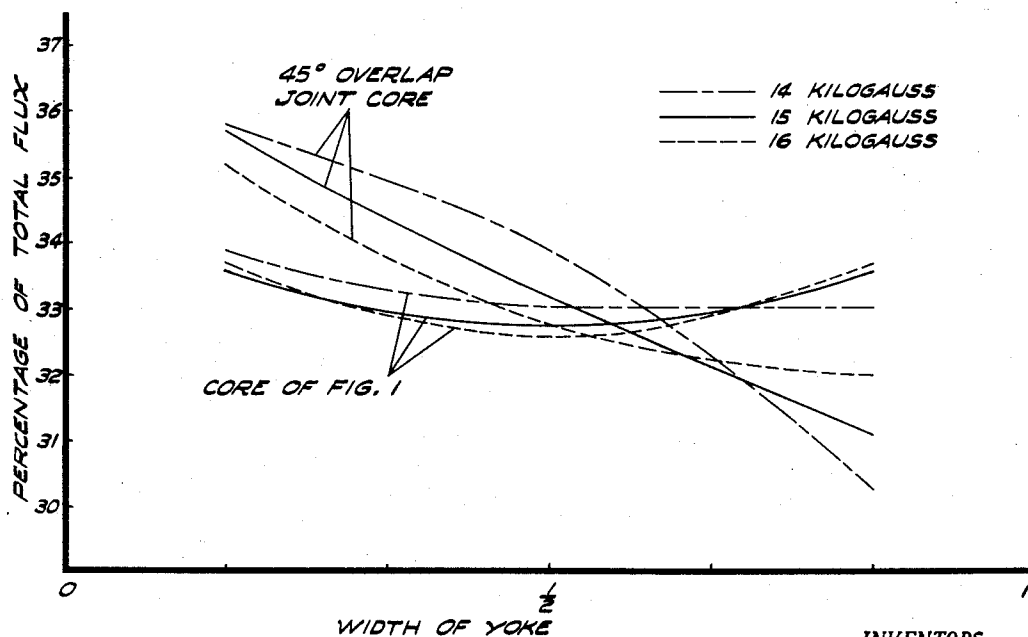


Fig. 8



INVENTORS.
ARNOLD L. HORELICK
ARNOLD M. FOX
BY *Lee H. Kaiser*
ATTORNEY

1

2,898,565

MAGNETIC CORE

Arnold M. Fox, Pittsburgh, and Arnold L. Horelick, Bridgeville, Pa., assignors to McGraw-Edison Company, a corporation of Delaware

Application July 2, 1954, Serial No. 440,883

3 Claims. (Cl. 336—217)

This invention relates to magnetic core structures for electrical induction apparatus such as transformers and reactors, and especially to laminated magnetic core structures in which a stack of thin sheets, or laminations, of magnetic material is built up to form a core.

In conventional construction of electrical induction apparatus such as transformers it is common practice to employ a core structure which is built up of a stack of thin sheets or laminations of magnetic material which in the simplest form of core consists of rectangular pieces arranged to form two leg portions and two yoke portions defining a rectangular window. Usually the laminations are cut or punched from sheets of high grade cold rolled silicon steel to secure the desirable qualities of high permeability and low core loss at the flux densities at which the apparatus will be operated. It is known that the rolling process produces a grain structure extending in the direction in which the sheets are rolled and further that the path of least reluctance is generally in the direction in which the sheets have been rolled. For optimum magnetic characteristics, it is thus desirable that the laminations be of oriented steel so that the flux path is in the direction of rolling even at the corners.

For ordinary nonoriented magnetic steels the individual laminations are usually rectangular, L-shaped, or E-shaped, and the laminations are usually stacked with square-cut butt joints and with the joints in alternating layers staggered. For example, each outside corner may be defined by the end of a leg portion in one layer and the end of a yoke portion in an adjacent layer. This construction is suitable for transformer cores employing nonoriented steel wherein the permeability and losses are not much different perpendicular to the direction of rolling than parallel to it, but such construction is unsatisfactory for oriented steel having much higher permeability and much lower losses when the lines of magnetic flux pass through the material in the direction of rolling than when lines of magnetic flux pass through the material in other directions. It will be apparent that L-shaped and E-shaped laminations cannot be punched from oriented steel sheets so that the most favorable magnetic direction extends parallel with the flux path in all parts of the laminations. Even with the common type of core consisting of rectangular laminations cut from oriented steel and stacked at right angles to each other, the core flux must pass crosswise of the preferred grain orientation at the ends of the laminations in passing from a leg portion to a yoke portion, and due to crosswise flow of flux at the corners of the core relatively high losses occur at these points.

A construction for cores having oriented steels which permits the flux to follow the direction of easiest magnetization even at the corners involves cutting the adjoining edges of the laminations at a diagonal to provide a mitered joint at each corner. Experiments prove that the losses in a core having such mitered joints are considerably lower than in a core having conventional square-cut butt and lap joints, but such construction wherein

2

the corner joints are coincident with the diagonals running through the inner and outer apices of the corners has the disadvantages that all of such joints are in substantial registry so that no interleaving of the laminations results and elaborate clamping means are required. In addition, the fact that there is no interleaving of laminations introduces the danger of gaps at the butt joints which would increase the reluctance of the core.

Diagonal cut, or mitered, joints are known in which the junctions of all adjoining edges at the outer corners of a core extend along straight lines at substantially 45 degrees to the lineal edges of the laminations with the junctions in adjoining layers being offset to provide an area of overlap bounded by substantially parallel planes coincident with the adjoining edges. Such diagonal cut joint has the advantage that the cross section of the joint is increased, as compared with a square-cut joint, by approximately 40 percent, and in the case of oriented steel cores, the direction of magnetization conforms with the preferred grain orientation substantially throughout the corners. However, even this construction is not ideal in that the magnetic flux is not distributed uniformly throughout a given cross section through the core. The mean length of magnetic flux path is smaller adjacent the winding window than in paths radially outward therefrom, causing the flux to crowd to the shorter perimeter of the core. This concentration of flux is accentuated at the corner joints wherein the flux must cross over to adjacent laminations. Considering one line of joints, in an extreme case all of the flux at the joints passes into the adjoining laminations and the flux density in those laminations would be doubled, a condition which is almost impossible at normal flux densities between 13 and 15 kilogauss per square centimeter. This crowding of flux at the inside corner joints is further aggravated by the high densities used with oriented steels.

The heating due to circulation of eddy currents is proportional to approximately the square of the maximum flux density, and it is apparent that the concentration of flux along the shorter perimeter of the core increases the danger of overheating and the formation of hot spots at the inner corners of the core.

This unequal distribution of magnetic flux throughout the cross section of the core also increases the noise level of the core. The passage of the flux at the joint to adjacent laminar layers introduces mechanical forces which can be shown to be proportional to the square of the flux density. It is well known that the concentration of the flux at the edge of the butt gaps of an interleaved joint is an important factor in causing the laminar vibrations which raise the noise level of a magnetic core, and it is apparent that crowding of the flux to the shortest perimeter of the core further increases the noise level.

It is an object of the invention to provide a laminated magnetic core which will have minimum reluctance at the corners of the core and which will have substantially uniform distribution of flux throughout any cross section of the core.

It is a further object of the invention to provide a laminated magnetic core which will have a minimum resistance to flow of flux at the corners of the core and which will obviate the danger of hot spots at the corner of the core heretofore caused by the crowding of flux to the shortest perimeter of the core.

A still further object of the invention is to provide an improved corner construction of a laminated magnetic core wherein the reluctance of the joint varies to an extent and in a direction to cause uniform flux distribution throughout a cross section of the core.

Another object of the invention is to provide an improved corner construction of a laminated core which

3

will considerably reduce the laminar vibrations and thus lower the noise level of the magnetic core.

Still another object of the invention is to provide an improved corner construction for a laminated magnetic core which will provide greater frictional engagement and mechanical support between laminations than in conventional cores having overlap, mitered corner joints.

In conventional interleaved, mitered corner joints wherein the planes of the edges defining the joints extend along straight lines at substantially 45 degrees to the lineal edges of the laminations and the planes defining the joints in adjoining layers are offset from each other, triangular voids are inherently formed at the inside corners of the core. The dimensions of these triangular voids are directly proportional to the distance that the joints in adjoining layers are offset from each other. As the size of the transformer increases, the amount of offset must increase proportionally to provide adequate frictional engagement between laminations and mechanical support at the corners of the core. As a consequence, the size of these triangular voids in conventional cores increases with increase in the size of the core.

A further object of the invention is to provide an improved interleaved, mitered joint corner construction for a laminated magnetic core which provides greater mechanical engagement between laminations than in prior art constructions and still permits triangular voids of minimum size and constant dimension at the inside corners regardless of the size of the magnetic core.

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

In the drawing:

Fig. 1 is an exploded perspective view of layers of assembled laminations forming a rectangular core constructed in accordance with an embodiment of the invention;

Fig. 2 is a partial plan view of the embodiment of Fig. 1 showing the improved corner construction of the invention;

Fig. 3 is a curve showing the uniform flux distribution in the core of the invention in comparison to a conventional core at a given magnetic flux density;

Fig. 4 illustrates another curve which will be employed in the description of the invention;

Fig. 5 is an exploded perspective view of a three legged, three phase core which is constructed in accordance with an embodiment of the invention;

Fig. 6 is a partial plan view of the embodiment at Fig. 5 showing the joint between the center leg and the yoke;

Fig. 7 is a plan view of a three legged core for a single phase, shell type transformer which is provided with an embodiment of the invention; and

Fig. 8 illustrates still another curve which will be employed in the description of the invention.

Referring to Figs. 1 and 2, a magnetic core of rectangular configuration embodying the improved corner construction of the invention is illustrated as having a plurality of layers of stacked laminations. Each layer includes a plurality of laminations having preferred grain orientation parallel to the length thereof and with the laminations closely fitted at their ends forming butt joints. In the rectangular core illustrated in Fig. 1, a layer 10 includes leg laminations 11 and 12 along the longer of the sides of the rectangular winding window and yoke laminations 13 and 14 along the shorter of the sides. The leg laminations 11 and 12 are alike and the yoke laminations 13 and 14 are alike. The width of the yoke laminations 13 and 14 is slightly greater than that of the leg laminations 11 and 12, the width of the latter being indicated by the dimension R and the width of the former

4

by the dimension $R+r$. As will be explained in detail hereinafter, the dimension r is a constant in the illustrated core regardless of core size and determines one dimension of the triangular voids 21 and 22 at diagonally opposite inside corners of the core.

Any suitable number of lamination layers may be used depending upon the size of the core desired. It will be appreciated that the laminations of oriented steel could be punched or sheared from a continuous magnetic strip so that the ends are at a 45 degree angle to the length thereof and thus provide a mitered corner construction wherein substantially none of the flux must pass crosswise of the preferred grain orientation. However, as explained hereinbefore, inasmuch as all of the joints are in substantial registry in such a construction, there is no interleaving of the laminations to provide mechanical support, and elaborate clamping means are required. Further, the fact that there is no interleaving introduces the danger of higher reluctance joints due to gaps at the butt joints.

In the core corner construction of the invention, the laminations are constructed and assembled so that substantially none of the magnetic flux must pass crosswise of the preferred grain orientation, and the edges of the laminations which form the joints in one layer are offset from the joints formed in adjoining layers to provide overlapping. Such interleaving of the edges of leg laminations and yoke laminations provides mechanical support and tightness of the corner joint. In addition, the construction is such as to provide a joint wherein the reluctance varies to an extent and in a direction to cause substantially uniform flux distribution throughout a cross section of the core. Another feature of the improved corner construction of the invention is that the laminations do not necessarily have to be punched from sheet material but rather the ends of the laminations may be sheared from a continuous strip of oriented magnetic steel on an oscillating head shear cutoff device.

In the specification and the appended claims, the longitudinal axis of the leg portions of the core is referred to as the "longitudinal axis" and the longitudinal axis of the yoke portions of the core is connoted the "lateral axis."

In the preferred embodiment the dimension r is one half inch, and the yoke laminations 13 and 14 are one half inch wider than the leg laminations 11 and 12 regardless of the size of the core. The leg lamination 11 is formed with an end 16 which is at an angle of less than 45 degrees with the longitudinal axis of the assembled laminations, and in the preferred construction the edge 16 is cut at an angle of substantially 41 degrees with the longitudinal axis. It will be appreciated that the edge 16 can be sheared from a continuous magnetic strip and the pointed portion sheared off perpendicular to the longitudinal axis of the strip to provide the edge 17 at the outer periphery of the core. The other end 18 of the leg lamination 11 makes an angle of greater than 45 degrees with the longitudinal axis, and in a preferred construction the end 18 is cut at an angle of substantially 49 degrees with the longitudinal axis. The leg lamination 12 is identical to the leg lamination 11, it only being oppositely disposed in assembled condition with respect to the leg lamination 11. The arrangement of the leg laminations 11 and 12 and yoke laminations 13 and 14 form a winding window having a width W and a length L . The inner edge of the leg laminations 11 and 12 is of a length $L+r$, or, in other words, the length of the inner edge of the leg laminations 11 and 12 is always greater than L by the constant r by which the width of the yoke laminations 13 and 14 exceeds the width of the leg laminations 11 and 12. As stated hereinbefore, this dimension r is one half inch in the preferred embodiment of the invention for all sizes of the core.

In order to provide a tight butt joint with the edge

16 of leg lamination 11, the adjacent end 19 of the yoke lamination 14 is cut at an angle which is greater than 45 degrees with the lateral axis of the assembled laminations, and this angle is complementary to the angular cut of the edge 16 with the longitudinal axis. In a preferred construction the edge 19 makes an angle of substantially 49 degrees with the lateral axis and the edge 16 makes an angle of substantially 41 degrees with the longitudinal axis.

Greater mechanical support of the laminations is obtained and the size of the triangular void is kept to a minimum and maintained constant in dimension regardless of the size of the core by having the plane of the butt joint intersect the plane of the inner edge of the leg lamination at a distance not greater than the dimension r from the inner corner. In the embodiment illustrated the plane of the butt joint defined by the abutting edges 16 and 19 passes through the apex 20 of an imaginary corner which would be formed if the yoke laminations 13 and 14 were also of the width R . In other words, an imaginary corner 20 formed by leg laminations of width R and yoke laminations also of width R and at a distance r from the inner corner of the core determines one point of the straight line butt joint in the illustrated embodiment regardless of the angle of the edge 19 with the lateral axis. Thus the length of one side of the triangular void 21 at the upper right hand inner corner of the core is always the dimension r . The inner edge of the yoke laminations 14 is of a length $W-s$, where s is dependent upon the angle the edge 19 makes with the lateral axis of the assembled laminations. In the preferred embodiment wherein this angle is substantially 49 degrees, the dimension s is approximately $\frac{7}{16}$ of an inch. The dimension s is the amount the inner edge of the yoke lamination outlining the window is offset from the inner corner. The dimension s is thus the length of the side of the void 21 parallel to the lateral axis, and it is apparent that this void is constant in size for a given angle of edge 19 relative to the lateral axis regardless of the size of the core.

The opposite end of the yoke lamination 14 has an edge surface 23 which is cut at an angle of less than 45 degrees to the lateral axis of the assembled laminations. The leg lamination 12 is similar to but oppositely disposed from the leg lamination 11, and it has an edge 24 cut at an angle greater than 45 degrees with the longitudinal axis and complementary to the angle which the surface 23 makes with the lateral axis, thereby forming a tight butt joint between the adjoining edges 23 and 24. The yoke laminations 13 and 14 are alike but oppositely disposed, and yoke lamination 13 has an edge 25 cut at the same angle, greater than 45 degrees to the lateral axis as the edge 19. This angle is complementary to the angle, less than 45 degrees, to the longitudinal axis at which the edge 26 of the leg lamination 12 is cut to effect a tight butt joint at the lower left hand corner of layer 10. Due to the width of the yoke lamination 13 being greater than that of the leg lamination 12, a triangular void 22 having sides of lengths s and r is provided in the lower left hand corner of layer 10 diagonally opposite from the void 21. It will be noted in layer 10 that the adjoining edges between laminations 11 and 13 extend from an inner corner of the window to a point along the outer edge of the leg offset from the outside corner, and that at the opposite end of the lamination 11 the butt joint formed by the abutting edges 16 and 19 extends from a point along the inner edge of the yoke offset from the inner corner by an amount s to a point along the outer edge of the yoke offset from the outer corner. It will also be noted that diagonally opposite corners of layer 10 are alike.

An adjacent layer 30 of laminations similar to those employed to form the layer 10 is assembled so that the individual laminations are oppositely arranged or re-

versed with respect to the layer 10. It will be noted that in layer 30 the location of the adjoining edges are reversed from those of layer 10 so that in the upper left and lower right hand corners the junction starts at a point along the inner edge of the yoke offset from the inner corner by a distance s and extends to a point on the outer edge of the yoke offset from the outer corner thereof, whereas in the lower left and upper right hand corners the junction starts at the inner corner and extends to a point along the outer edge of the leg offset from the outer corner. With this construction the joint at each of the corners of the layer 30 is offset from the joint at the corresponding corners of the layer 10 so as to provide overlapping of the various laminations of each layer with the laminations in an adjoining layer. All of the butt joints are in the form of a straight line running from the vicinity of an inner corner to the vicinity of the corresponding outer corner of the assembled laminations. It will be appreciated that the triangular voids 21 and 22 appear in the upper right and lower left hand corners in layer 10 and in the layer 30 are oppositely disposed in the upper left and lower right hand corners.

Although the lamination layers in Fig. 1 are shown with adjoining layers oppositely arranged, it is to be understood that any desired number of layers may be stacked so that the joints thereof are in registry and such layers may be alternated with an equal number of oppositely disposed layers with joints in registry. In actual practice it is usual to arrange the layers in sets of three with the joints of the layers in registry. It will be seen that with a plurality of layers of laminations constructed and assembled in the manner described, only a minimum of the flux will pass crosswise of the grain. It will be appreciated that the width of overlap at the corner increases in a radially outward direction. This overlaps which tapers in a direction across the laminations in combination with other features of construction provides many desirable features for the magnetic core of the invention.

The above described construction having overlapping which increases in a radially outward direction provides greater mechanical support for the interleaved laminations in comparison to prior art overlapped, mitered corner construction wherein the width of the overlap is substantially constant, thus substantially preventing separation of the laminations. Further, this overlapping which tapers in a direction crosswise of the laminations, in combination with the triangular voids at the corners of the core, provides substantially uniform flux distribution throughout a cross section of the core.

The reluctance of the flux path of shorter perimeter in a conventional core is lower than a flux path of longer perimeter, thereby causing the flux to crowd to the inner perimeter of the core. This may be better appreciated when it is realized that in a typical core having a winding leg of ten inch width, the mean length of flux path in the inner $\frac{1}{3}$, center $\frac{1}{3}$, and outer $\frac{1}{3}$ of the core may vary approximately in the ratio of 13:20:27. Concentration of flux at the inner corners due to greater reluctance of the longer perimeter paths is accentuated at the gaps in an interleaved joint wherein most of the flux must pass to adjoining laminations with the result that the area of iron at the joint is considerably less than in the remainder of the core, and this crowding of the flux to the inner perimeters of the core is further increased with oriented steels.

Crowding of the magnetic flux to the inner corners introduces the danger of hot spots at the inner corners of the core. It is well known that eddy current heating is approximately proportional to the square of the maximum flux density, and it is apparent that when the flux is nonuniformly distributed due to greater reluctance of the longer perimeter paths, the maximum flux density is raised a corresponding amount at the inner corners and

introduces the danger of overheating. A second disadvantage of the crowding of the flux to the shorter perimeter of the core is an increase in noise level of the transformer. It is well known that the passage of flux to adjoining laminations causes mechanical forces which can be shown to be proportional to the square of the flux density. It is this concentration of flux which is an important factor in causing the laminar vibrations which raise the noise level of the magnetic core. It will be apparent that the crowding of the flux to the shortest perimeter further raises the magnetic flux density and thus increases the forces and vibrations of the laminar members.

The fact that the magnetic flux is crowded to the shorter perimeter of a conventional core having a mitered overlap joint is shown in the curve of Fig. 3 which is plotted for a single magnetic flux density. The test results for this curve were obtained by linking test coils with various fractions of the cross sectional width of the core to permit measurement of the percentage of the total flux flowing therein. The curve A shows that only approximately 31% of the total flux passed through the outer one third of the conventional core whereas approximately 36% of the total flux flowed through the inner one third of the core, i.e., through the one third having the shortest perimeter. It will be appreciated that if the curve is extrapolated to the inner edge of the core, it will show still greater concentration of magnetic flux. Curve B shows that in the core of the invention the flux distribution is substantially uniform throughout the cross section of the core, in other words, that approximately 33% of the total flux passed through the outer one third of the core, approximately 33% of the total flux passed through the middle one third of the core, and approximately 33% passed through the core one third having the shortest perimeter. The desirable results of reduction in noise level and elimination of the danger of hot spots at the inner corners which flow from such uniform flux distribution are obvious. Tests have proved the correctness of these theoretical conclusions. The greater area of engagement between leg and yoke laminations permits lowered clamping pressure in comparison to conventional corner construction and has proved beneficial in the reduction of noise caused by higher harmonic laminar vibration.

The substantially uniform distribution of magnetic flux throughout a cross section through the core of the invention is partly attributable to the fact that the overlapping which tapers in a direction crosswise of the laminations compensates for the greater reluctance of the iron portion of the magnetic circuit along the longer perimeter, thus equalizing the total reluctance along each perimeter and thereby equalizing the distribution of flux. The reluctance of a joint which tapers in width decreases directly in proportion to the extent of the overlap, and it is apparent that the reluctance of the joints of the invention decreases in a radially outward direction. This equalization of the reluctance along each perimeter of the core is at least partially attributable to the voids provided at the inner corners of the core. It is apparent that the elimination of the iron increases the reluctance along these short perimeter paths and forces the flux radially outward. The voids also force the flux to cross over to adjoining laminations before reaching the joint, thereby reducing the forces and the vibration at the ends of the laminar members caused by excessive flux density present at the actual edge of the laminar joints.

One feature of construction in applicant's core is that greater mechanical engagement of the laminations is obtained than with conventional cores and yet the voids 21 and 22 at the inner corners of the core are constant in dimension regardless of the size of the core. In conventional overlap mitred joint cores the width of the overlap is constant throughout the length of the joint, and the dimensions of the triangular voids are determined by the

width of the overlap. As the size of the conventional core increases, the width of overlap must increase proportionally to provide adequate mechanical support for the laminations, and the size of the voids in the inner corners of the core increases in direct proportion. In the core of the invention the mechanical support of the laminations is provided by an overlap which increases in width radially outward of the core, and the size of the voids is kept constant and to a minimum, being dependent upon the amount r that the yoke is wider than the core and the dimension s which is determined by the angle of the abutting edges.

Fig. 4 illustrates that unequal flux distribution is present in a conventional interleaved mitred joint core regardless of the operating flux density, whereas the flux distribution in the core of the invention is substantially uniform throughout the cross section regardless of operating flux density. Percentage of total flux is plotted as ordinates against flux density as abscissae, and individual curves are plotted for the average flux density in the inner one third i , the center one third c , and the outer one third o for the core of the invention and a conventional interleaved, mitred joint core. Curves X, Y, and Z are for the core of Fig. 1 and show that approximately 33% of the total flux passes through each one third regardless of the operating flux density. Curve F shows that the flux in the shortest perimeter one third i of a conventional 45 degree cut core remains approximately 36% regardless of the operating flux density, whereas the percentage of the total flux flowing in the outer one third o varies from below 30% to approximately 32% with a change in operating flux density from 13 to 16 kilogauss.

Fig. 8 shows that the uniform flux distribution throughout the cross section of the core of Fig. 1 is not dependent upon operating flux density. The curves are similar to those of Fig. 3 which were plotted at a single operating density. It will be noted that the curves for three operating densities in the core of the invention are substantially coincident, showing that the percentage of total flux is approximately the same in all equal fractions of a cross sectional width of the core of the invention regardless of the operating flux density. It will also be apparent that the curves for the three operating densities in a conventional interleaved, mitred joint core are substantially in agreement, showing that the greatest concentration of flux is in the shortest perimeter one third of such a conventional core regardless of operating flux density.

It is to be understood that the invention may be embodied in a core having any suitable number of laminations per layer, and in Figs. 5 and 6 a three legged, three phase core embodying the invention is illustrated. The laminated magnetic core includes a plurality of layers each having five assembled laminations which are closely fitted at their ends forming butt joints between leg laminations and yoke laminations which are generally mitred. In the arrangement illustrated it will be seen that the various layers are made up of similar laminations except that the laminations are stacked in reversed order in adjoining laminations to provide overlapping of the joints. The layer 50 includes outer leg laminations 51 and 52 which are identical to the laminations 11 and 12 in layer 10 of the embodiment of Fig. 1. The outer leg lamination 51 has an edge 53 making an angle of less than 45 degrees with the longitudinal axis of the assembled laminations, which in the illustrated embodiment of the invention is substantially 41 degrees, and an opposite edge 54 which makes an angle of greater than 45 degrees or substantially 49 degrees with the longitudinal axis of the core. The length of the inner edge of leg lamination 51 outlining the window is greater than the length L of the window by the dimension r . The outer leg lamination 52 is identical to the lamination 51 but reversed end for end therefrom. Cooperating with the leg laminations 51 and 52 is a yoke lamination 55 having an edge 57 making an angle of more than 45 degrees, or substantially

49 degrees, with the lateral axis of the core and abutting against the edge 53 and also having an opposite edge 58 making an angle of less than 45 degrees, or substantially 41 degrees, with the lateral axis of the core and abutting against the edge 59 of the leg lamination 52. Another yoke lamination 56 has an edge 60 making an angle of less than 45 degrees, or substantially 41 degrees, with the lateral axis and abutting against the edge 54 and also has an opposite edge 61 making an angle of greater than 45 degrees, or substantially 49 degrees, with the lateral axis of the assembled laminations and abutting against the edge 62 of the leg lamination 52. As in the embodiment of Fig. 1, the width of the yoke laminations 55 and 56 is slightly greater than that of the outer leg laminations 51 and 52, the latter being indicated by the dimension R and the former by the dimension $R+r$. The length of the inner edge 64 of the yoke lamination 55 outlining the right hand window is less than the width W of the window by the dimension s. The inner edges of the yoke laminations outlining the windows are offset from the inside corner at diagonally opposite outside corners in the same layer. The inner edge 64 is offset from the inside angle of the lower right hand outside corner so that edge 57 extends from a point along the yoke offset from the inner angle, forming a triangular void 81 between the edge 57 and the inner edge of leg lamination 51. In the same manner a triangular void 82 is formed in the diagonally opposite upper left hand outer corner between edge 61 and the inner edge of outer leg lamination 52. As explained for the embodiment of Fig. 1, these voids 81 and 82 are constant in dimension regardless of the size of the core.

A center leg lamination 65 is provided extending between the yoke laminations 55 and 56 intermediate the ends thereof. At each end the center leg lamination 65 has two edges perpendicular to each other. For example, at one end the edge between corner 67 and point 68 is at right angles to the edge between point 68 and corner 69. The outer edges of the lamination 65, like the inner edges of the leg laminations 51 and 52, are longer than the length L of the windows in the core structure by the dimension r, the corner 67 being advanced by the dimension r lengthwise beyond the corner 69 at the opposite side. The slope of the edge from the corner 67 to the point 68 is at an angle to the lateral axis greater than 45 degrees, and the slope of the edge from the corner 69 to the point 68 is at the complementary angle less than 45 degrees to the lateral axis of the core. The edge between corners 70 and point 71 is perpendicular to the edge between corner 72 and point 71; the edge from corner 70 to point 71 is cut at the same angle to the lateral axis of the core as the edge from corner 69 to point 68; and the edge from corner 72 to point 71 is cut at the same angle to the lateral axis of the core as the edge from corner 67 to point 68.

The yoke laminations 55 and 56 are provided with triangular cutout portions to receive the ends of the center leg laminations 65. The edges 75 and 76 cut in the yoke lamination 56 are perpendicular to each other, the edge 75 is cut at an angle to the lateral axis less than 45 degrees and equal to the angle at which the edge between corner 69 and point 68 is cut. The edge 76 is cut at an angle to the lateral axis greater than 45 degrees and equal to the angle at which the edge between corner 67 and point 68 is cut. The yoke lamination 55 is also cut with perpendicular edges 77 and 78 forming a triangular cutout which makes tight butt contact with the edges of center leg lamination 65 between corners 70 and 72 and point 71.

The laminations of layer 80 are identical to those of layer 50 but reversed in position to provide overlap between laminations in adjacent layers. For example, in layer 50 the joint at the corner between edges 53 and 57 extends from a point along the inner edge of the yoke offset from the inner corner to a point along the outer

edge of the yoke offset from the outside corner, whereas the joint at this corner in layer 80 extends from the inner corner to a point along the outer edge of the leg offset from the outside corner. It will be appreciated that these two joints are offset from each other to form an overlap which tapers in a direction across the laminations, the overlap increasing in width in a radially outward direction. The triangular voids 81 and 82 are constant in dimension regardless of core size and have sides of a length r and s in exactly the same manner as the embodiment of Fig. 1. It will also be noted that the triangular voids 81 and 82 formed at the diagonally opposite inner corners between the outer legs and the yokes occur in layer 80 at diagonally opposite inner corners reversed from those in layer 50.

The reversal of center leg laminations 65 in adjoining layers also provides overlap with the yoke laminations 55 and 56 which increases in width in an outward direction. The overlap with yoke lamination 56 includes two small quadrilateral areas (see Fig. 6) defined by points 69, 91, 71 and 72 and by points 70, 91, 68 and 67 respectively. It will be appreciated that the flux divides in two directions at the junction of the center leg to the yoke, and that this joint compensates for the greater reluctance of the longer perimeter paths through both of the outer legs. It will be noted that the inner edge 66 of yoke lamination 56 outlining the right hand window is offset from the inside corner by the dimension s forming a triangular void 92 having sides of length r and s between edge 76 and the edge of the center leg lamination 65. A similar triangular void 93 of the same size is formed between edge 77 and the edge of the center leg lamination 65. It will also be noted that similar voids 92 and 93 are formed in layer 80 in opposite ones of the diagonally opposite inner corners between the center leg and the yokes.

In Fig. 7 an arrangement of laminations is illustrated for a three legged core for a single phase, shell type transformer. The construction is similar to the embodiment of Fig. 5 with the exception that the center leg is wider than both the yokes and the outer winding legs and that each layer includes two pairs of yoke laminations instead of a single pair of laminations as in the embodiment of Fig. 5. The core illustrated in Fig. 7 thus includes a plurality of layers each having seven assembled laminations. The outer leg laminations are similar to corresponding leg laminations of the embodiments of Figs. 1 and 5 and their description will not be repeated. The shape of the center leg laminations 101 is similar to that of the center leg laminations 65 of the embodiment of Fig. 5 with the exception that the width of the laminations 101 is greater, and this description will not be repeated. Two differently shaped laminations 102 and 103 are required for the yoke pieces, the two members alternating from side to side. The yoke lamination 102 is similar in shape to the yoke laminations 13 and 14 of the embodiment of Fig. 1 with the exception that the one angularly cut edge is not sheared perpendicular to the longitudinal axis of the core.

Cooperating with a center leg lamination 101 and an outer leg lamination 105 in the upper layer of laminations is a yoke lamination 102 having an edge 107 cut at an angle of greater than 45 degrees with the lateral axis of the core and providing a tight butt joint with an edge 106 of the outer leg lamination 105 and also having an edge 108 which makes an angle of less than 45 degrees with the lateral axis of the core and provides a tight butt joint with the edge 109 of center leg lamination 101. The yoke lamination 103 has edge surfaces in six planes, three of which form edges for the butt joints of said laminations. At one end the yoke lamination 103 has an edge 110 at an angle of less than 45 degrees to the lateral axis of the assembled laminations and abutting against an edge 111 of the outer leg lamination 112. At the opposite end the yoke lamination 103 has a first edge 114 cut at an

angle greater than 45 degrees with the lateral axis of the core and abutting against the edge 116 of the center leg lamination 101 and also a second edge 118 abutting against and cut at the same angle to the lateral axis as the edge 109. The yoke laminations 120 and 121 are similar to but oppositely disposed from the yoke laminations 102 and 103 respectively. These yoke laminations 120 and 121 abut against the edges of the center leg lamination 101 and the leg laminations 105 and 112 to form tight butt joints at the corners of the core.

The adjacent layer has laminations similar to those of the top layer 100 with adjoining edges of leg and yoke laminations forming butt joints shown in dotted lines in Fig. 7, but the laminations are oppositely arranged with respect to the layer 100 so that the joints at each of the corners will be offset from each other to provide overlapping of the various laminations of each layer with the laminations of adjoining layers. It will be apparent that the overlap at the corners between yoke and outer leg members will taper in a direction across the laminations and will increase in a radially outward direction as in the other embodiments. For example, the plane of the butt joint between edges 106 and 107 is at an angle of greater than 45 degrees with the lateral axis and the plane of the joint in the adjacent layer defined by edges 124 and 125 is at an angle of more than 45 degrees with the longitudinal axis. It will also be apparent that the overlap at ends of the center winding leg will comprise two quadrilateral areas 126 and 127 which increase in width in an outward direction as in the embodiment of Fig. 5, and that this construction will compensate for the greater reluctance of the longer perimeter paths through both of the outer legs. Triangular voids 132 and 133 of constant dimension regardless of the size of the core are formed in each layer at the inner corners between the center leg and the yokes. For example, in the top layer a triangular void 132 is formed between edge 123 and an edge of center leg lamination 101 and a similar triangular void 133 is formed between edge 114 and the edge of lamination 101.

Although it is not illustrated in the drawing, it will be apparent that the overlap which increases in width in an outward direction permits the use of a through bolt for mechanical support near the outside corner and passing through the overlapped portions of the laminations.

Only three embodiments of the invention have been described and illustrated, but it will be apparent that the invention is not so limited and covers any laminated core having yoke members and leg members substantially perpendicular to each other. Three phase shell type cores embodying the invention and arrangement of parts disclosed herein have been constructed, tested, and successfully operated under actual service conditions. Although a preferred configuration of butt joints has been illustrated and described, it will be appreciated that the invention is not so limited but covers other arrangements providing uniform flux distribution wherein the joints originate and terminate at points different from those of the described embodiments. Consequently, we do not desire to be limited to the particular embodiments described and intend in the appended claims to cover all modifications within the true spirit and scope of the invention.

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

1. A closed magnetic core having leg portions and yoke portions meeting at right angles and forming corners and including a plurality of layers of laminations, each layer including yoke laminations and leg laminations forming generally mitred straight line butt joints at said corners, the width of said yoke laminations being greater than that of said leg laminations, in each corner the joint in one layer extending from the vicinity of the inner corner at an angle greater than 45 degrees to the longitudinal axis of said leg portion, the joint in

an adjacent layer at the same corner running at an angle of greater than 45 degrees to the longitudinal axis of said yoke portion from a point along the inner edge of said yoke offset from said inner corner, whereby a void is provided in said adjacent layer at said inner corner, the lamination of one layer overlapping the joint of an adjacent layer and the overlap between said joints so increasing in width in a radially outward direction and the reluctance of the inner perimeter flux paths being so increased by said voids that the magnetic flux density is substantially uniform throughout said core and hot spots caused by undue concentration of magnetic flux at the inner corners of the core are avoided.

2. A closed magnetic core having leg portions and yoke portions meeting at right angles and forming corners and including a plurality of superimposed layers of laminations, each layer including a yoke lamination and a leg lamination having preferred grain orientation lengthwise thereof and forming a generally mitred straight line butt joint, the width of said yoke lamination being greater than that of said leg lamination, the joint in one layer extending from the vicinity of the inner corner at an angle of approximately 49 degrees to the longitudinal axis of the leg portion, the joint in an adjacent layer extending at an angle of approximately 49 degrees to the longitudinal axis of the yoke portion from a point along the inner edge of said yoke offset from said inner corner, whereby a void is provided in said adjacent layer at said inner corner, the lamination in one layer overlapping the joint of an adjacent layer and the overlap between said joints so increasing in width in a radially outward direction and the reluctance of the inner perimeter flux paths at said inner corner so increasing that the magnetic flux density is substantially uniform throughout the closed core and crowding of magnetic flux to the inner corners of the core is avoided.

3. A magnetic core having three parallel leg members and yoke members connecting the ends of the leg members to form a substantially rectangular core having two substantially rectangular windows, said core including a plurality of superimposed layers of laminations having a preferred grain orientation and being positioned in said core so that the direction of magnetization is substantially coincident with said orientation, the laminations of said yoke members being wider than the laminations of the outer leg members, adjoining edges between yoke and leg laminations forming generally mitred butt joints at the corners between said leg and yoke members, the joint in one layer extending from the vicinity of the inner corner at an angle of greater than 45 degrees to the longitudinal axis of the leg member and the joint in an adjacent layer extending at an angle of greater than 45 degrees to the longitudinal axis of the yoke member from a point along the inner edge of said yoke member offset from said inner corner, whereby a void is provided in said adjacent layer at said inner corner, the lamination in one layer overlapping the joint of an adjacent layer and the overlap so increasing in width in a radially outer direction and the reluctance of the inner perimeter flux paths being so increased by said voids that the magnetic flux density is substantially uniform throughout said core and crowding of magnetic flux to the inner corners of the core is avoided.

References Cited in the file of this patent

UNITED STATES PATENTS

2,300,964	Putman	Nov. 3, 1942
2,407,626	Welch	Sept. 17, 1946
2,407,688	Sclater	Sept. 17, 1946
2,628,273	Somerville	Feb. 10, 1953

FOREIGN PATENTS

592,020	Great Britain	Sept. 4, 1947
---------	---------------	---------------