March 14, 1967 C. E. BURKHARDT ETAL 3,309,641

MAGNETIC CORE STRUCTURES FOR ELECTRICAL INDUCTIVE APPARATUS

Filed June 28, 1966

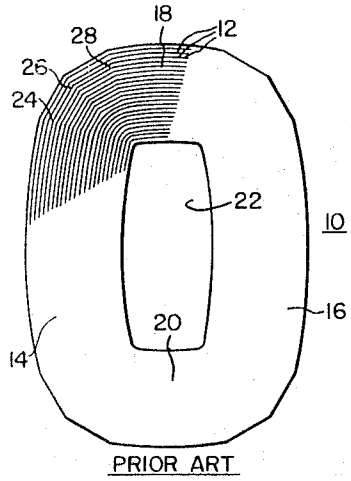


FIG.1.

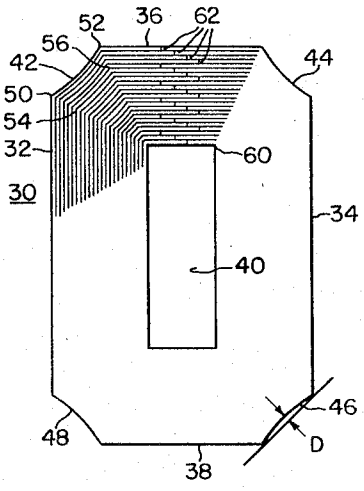


FIG.2.

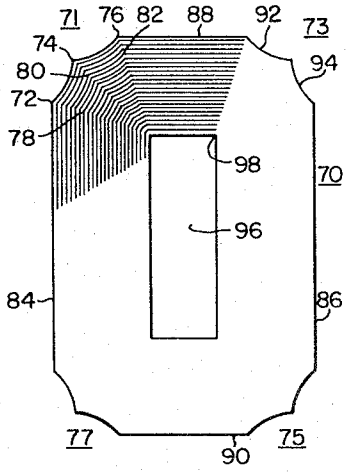


FIG.3.

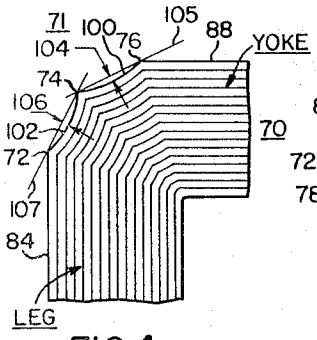


FIG.4.

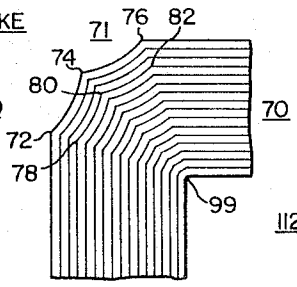


FIG.5.

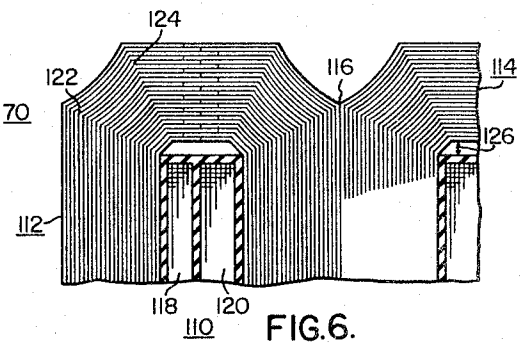


FIG.6.

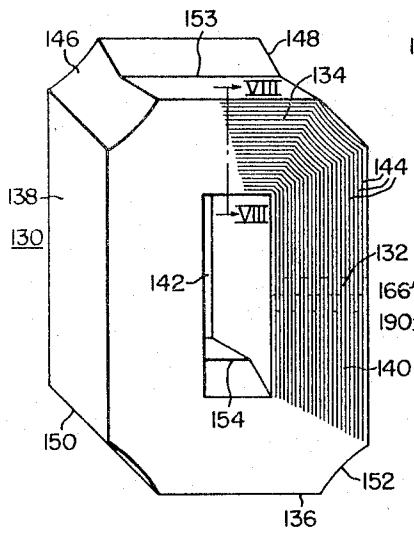


FIG.7.

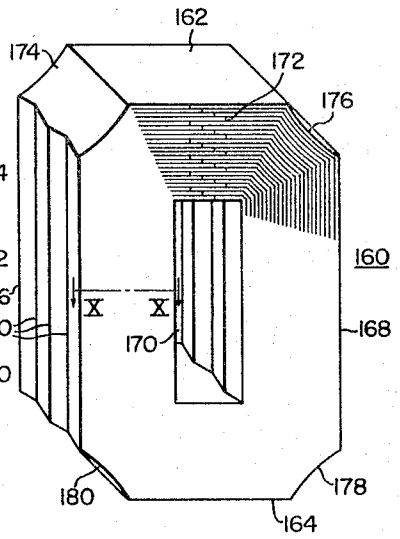


FIG.9.

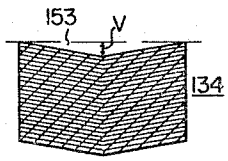


FIG.8.

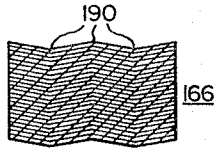


FIG.10.

United States Patent Office 3,309,641 Patented Mar. 14, 1967

1

3,309,641

MAGNETIC CORE STRUCTURES FOR ELECTRICAL INDUCTIVE APPARATUS

Charles E. Burkhardt, Sharon, and Belvin B. Ellis, Pulaski, Pa., assignors to Westinghouse Electric Corporation, Pittsburgh, Pa., a corporation of Pennsylvania

Filed June 28, 1966, Ser. No. 561,206
10 Claims. (Cl. 336—211)

This invention relates in general to electrical inductive apparatus, such as transformers, and more particularly to magnetic core structures for electrical inductive apparatus.

Copending application Ser. No. 559,668, filed May 13, 1966, and assigned to the same assignee as the present application, which is a continuation of application Ser. No. 315,300, filed Oct. 10, 1963, now abandoned, discloses die formed magnetic core structures of the wound type which have at least two discrete bends per outer corner of the core structure. The die formed bends at the outer corners are transmitted through the core "build," and impart dimensional stability to the core by reducing the tendency of the core to "spring back" or return to its "as wound" ring shape. This die formed structure was a significant advance in the art, as external holding fixtures, such as caps and plates, are not required, even during and after stress annealing of the core, to maintain the desired core shape. The "desired" core shape has straight leg and yoke portions separated by substantially round outer corners to utilize the minimum amount of magnetic material, and has an accurate, well defined "window" for receiving its associated electrical coils or windings. Further, the dimensions of the core should be accurately repeatable from core to core in production, in order to insure a close accurate fit between the core and its associated coils, and also to prevent any pressure on the core from the end frames. The discrete bends also insure that the laminations of the magnetic core will be in the same position after the core is opened and reassembled about its associated coils, as it was during the stress anneal. Any slippage or change in the position of the laminations from their positions during stress anneal will increase the losses of the core, as will any pressure on the core from the end frames. Thus, the die formed magnetic core disclosed in the hereinbefore mentioned copending application is less costly to manufacture, and has lower losses than conventional magnetic core structures of the prior art.

In order to maintain the die formed dimensions, including straight leg and yoke portions and an accurately defined window, of the magnetic core structure disclosed in the hereinbefore mentioned copending patent application, the discrete bends at the outer corners must be imparted to all of the laminations of the core, which appear as "bend lines" starting at each bend at the outer corners and traversing the build dimension of the core, to the window or core opening. One of the critical factors in determining whether or not the bend lines will be well defined, completely through the core "build," is the looseness of the wound core. It is not possible to obtain a 100% space factor as the magnetic metallic strip material of which the core is wound is not absolutely flat, nor is a 100% space factor desirable. A certain amount of looseness is essential in order to open the magnetic core at its joint, and reclose the core about its associated electrical coils. Further, core looseness is essential to the

2

process of die forming a plurality of discrete bends at each of the outer corners. Without core looseness, die forming the core would buckle the legs and/or yokes of the core structure. When a wound magnetic core structure is die formed to create the discrete bends at the outer corners, the looseness in the core is forced to the corners, which is desirable from the standpoint of opening and closing the core. However, if the core is too loose, the bends will be only partially transmitted through the "build" dimension of the core. The bends will be sharp and discrete in the outer laminations, and will become less sharp as they proceed through the build toward the core window, until reaching a point where they will be completely rounded. A completely rounded corner has an infinite number of bends, and the greatest tendency to spring-back. Therefore, in the production of these cores, the looseness factor or the space factor must be carefully controlled to a close tolerance, in order to insure that the bends will be transmitted completely through the build, which will then insure substantially straight leg and yoke portions. Close tolerances, however, increase manufacturing cost. Therefore, it would be desirable to be able to obtain sharp discrete bends in each lamination throughout the core build, without restorting to excessively close tolerances on the core space factor.

Further, the fewer the bends per corner, the less tendency there is for the core to spring-back after die forming. As hereinbefore stated, a round or curved corner, which is the most desirable since it uses less core material, has an infinite number of bends, and the greatest tendency to spring-back. A square corner, having one bend per corner, would have the least tendency to spring-back, but is unacceptable as it requires 6 to 7% more magnetic core material than rounded corners. Two or more discrete bends per corner are thus essential, in order to make the core competitive cost-wise with prior art cores. Two discrete bends per outer corner are easier to form than three bends per corner, and will have less tendency to spring-back. However, on large cores and/or high production cores, it is more desirable to utilize at least three bends per outer corner, in order to realize still greater savings in magnetic core material. For example, a 1.5% savings in core material may be realized by using three bends per outer corner, as opposed to two. However, this advantage is offset by the increased difficulty in transmitting all three bend lines throughout the magnetic core build, without resorting to almost laboratory type control over the core looseness or space factor. Therefore, it would be desirable to be able to form three or more bends per outer corner of the core, in order to save material on large magnetic cores and/or high production magnetic cores, if all of the bends at the outer corners could be sharply transmitted to each of the core laminations which make up the core build, without excessively stringent tolerances on the space factor of the core.

Still further, certain magnetic core dimensions, or relationships between dimensions, are more difficult to die form without spring-back than others. For example, if the magnetic core has a relatively small opening or window compared to the core build and/or the strip width of the magnetic material of which the core is formed is wide relative to the other dimensions of the core, the core legs and yokes have a greater tendency to bow out, even after die forming. Also, the same difficulty is experienced at the other extreme wherein the leg portions

and yoke portions are excessively long and/or the strip width is very narrow compared to the other dimensions of the core, which results in an inherently flexible design. Therefore, it would be desirable to be able to die form two or more discrete bends into each of the outer corners of wound type cores, including those which have relatively small windows or openings, and/or those wound of metallic strip materials having a relatively wide strip width compared to the other dimensions of the core, and those having inherently flexible designs in which the bend lines may be easily formed but which have long leg and yoke portions and/or very thin strip widths, which will still cause the core to have a tendency to bow even with well defined bend lines. Thus, at the one extreme of core dimensions, the bend lines are difficult to form and transmit throughout the build, which results in a tendency of the core leg and yoke portions to bow. At the other extreme, the bend lines are relatively easy to form and transmit throughout the build, but the core dimensions are such that the leg and yoke portions are extremely flexible, which still causes the core to have a tendency to bow. Thus, it would be desirable to be able to die form wound type magnetic cores of any practical dimension, in which the bend lines are transmitted completely throughout the build, and in which the magnetic core has substantially straight yoke and leg portions.

Accordingly, it is an object of this invention to provide a new and improved magnetic core structure for electrical inductive apparatus.

Another object of the invention is to provide a new and improved magnetic core structure of the wound type having at least two discrete bends per outer corner.

A further object of the invention is to provide a new and improved die formed, wound type magnetic core structure having a plurality of discrete bends at each outer corner, which facilitate the transmitting of the bend lines through the core build, with a practical production tolerance on core space factor.

Another object of the invention is to provide a new and improved die formed, wound type magnetic core structure which facilitates the transmitting of the bend lines completely through the build of the magnetic core structure, without a substantial impairment of the sharpness of the bends as the number of bends per outer corner of the structure is increased from at least two bends per outer corner to three.

Still another object of the invention is to provide a new and improved die formed, wound type magnetic core structure which has at least two discrete bends per outer corner, and in which the sharpness of the bends across the core build is not substantially affected by the relative dimensions of the core.

A still further object of the invention is to provide a new and improved die formed, wound type magnetic core structure which has at least two discrete bends per outer corner, in which the leg and yoke portions will be maintained in a predetermined substantially straight relationship, even on magnetic core structures whose dimensions provide an inherently flexible structure.

Briefly, the present invention accomplishes the above cited objects by providing a magnetic core structure which has a plurality of major sides, each separated by at least one minor side provided by at least two discrete bends per outer corner of the core structure. Instead of forming these minor sides in a flat plane, each of the minor sides, i.e., those sides formed between the discrete bends, are given a "reverse" bend. By "reverse" bend is meant a bend whose curvature is in a direction opposite to the natural substantial ring shape of the core. In other words, the radius of curvature of the bend lies outside the periphery of the magnetic core structure itself. By bending these minor sides inwardly toward the winding axis of the core, the bends at the outer corners are very sharp, and the bends are effectively transmitted to each of the laminations which make up the build or radial dimension of the core.

In magnetic core structures which have an inherently flexible design, such as those having very long leg and/or yoke portions, or very narrow strip width, sharp, well defined bend lines at the outer corners may be insufficient to maintain the magnetic core in the desired configuration, as the flexible leg and yoke portions may still bow out in their center portions. In this instance, the invention accomplishes the cited objects by giving the outer corners a reverse bend, as hereinbefore described, and by additionally selectively die grooving the predetermined portions of the magnetic core which are to be stiffened. Since the outer corners are die formed, the die grooving may be performed in the same operation, if desired, and it is possible to select and groove only the areas which require the stiffening. Areas which do not require additional stiffening, such as very short portions of the magnetic core and the portion of the magnetic core in which the openable joint is disposed, need not be grooved.

Further objects and advantages of the invention will become apparent from the following detailed description, taken in connection with the accompanying drawings, in which:

FIGURE 1 is an elevational view of a magnetic core assembly of the prior art, illustrating incomplete forming of the corner bends through the core build, which may result with certain core space factors,

FIG. 2 is an elevational view of a magnetic core assembly constructed according to the teachings of the invention, having two discrete bends per outer corner,

FIG. 3 is an elevational view of a magnetic core assembly constructed according to the teachings of the invention, having three discrete bends per outer corner,

FIG. 4 is a fragmentary view of a magnetic core which illustrates that the amount of reverse curvature may be different on adjacent minor sides of a die formed magnetic core structure,

FIG. 5 is a fragmentary view of a magnetic core constructed according to the teachings of the invention, wherein the bend lines are spaced apart at the core window to form a radius on the inner corners of the magnetic core structure,

FIG. 6 is a fragmentary, elevational view, in section, of a transformer constructed according to the teachings of the invention,

FIG. 7 is a perspective view of a magnetic core constructed according to the teachings of the invention, illustrating selective grooving of the yoke members of a magnetic core,

FIG. 8 is a cross sectional view of the yoke portion of the magnetic core illustrated in FIG. 7, taken along the line VIII—VIII,

FIG. 9 is a perspective view of a magnetic core constructed according to the teachings of the invention, illustrating selective grooving of the leg members of a magnetic core, and

FIG. 10 is a cross-sectional view of the magnetic core illustrated in FIG. 9, taken along the line X—X.

Referring now to the drawings, and FIGURE 1 in particular, there is shown a magnetic core structure **10** which is typical of those which may result when a wound type magnetic core structure having too great a space factor is die formed according to the teachings of the hereinbefore mentioned, copending patent application. Magnetic core **10** has a plurality of nested turns **12** formed of a metallic strip material, such as singly or multiply oriented silicon steel, leg portions or members **14** and **16**, yoke portions or members **18** and **20**, and an opening or window **22** defined by the various leg and yoke members.

As shown in FIG. 1, the various leg and yoke members of magnetic core **10** are slightly bowed in an outward direction from the core axis, even though the core structure **10** was die formed to provide two additional minor sides at each outer corner by three discrete bends, such as bends **24**, **26** and **28**. The bowing of the leg and yoke members in magnetic core **10** is due to the only partial

transmission of the discrete bends through the lamination turns, which is evidenced by the incomplete bend lines **24**, **26** and **28**. As shown in FIG. 1, these bend lines start at the outer lamination turn and progress inwardly for a portion of the core build-up. The bends at each succeeding lamination turn become less defined as the turns proceed inwardly, until reaching a point at which the lamination turns at the inner corners are substantially round or curved. These unbent lamination turns try to return to their "as wound" condition, which exerts a force on the outer lamination turns which have been bent, resulting in an outward bowing of the leg and yoke members.

The partial transmission of the bends **24**, **26** and **28** at the inner corners of the core, through the radial build, may be due to one, or a combination of many factors, such as too low a space factor, too small an opening **22** compared to the core build, or, too wide a strip width compared to the length of the leg and yoke members. Further, having three bend lines per outer corner makes the core inherently more difficult to form than a core having two bend lines per outer corner. By far the most critical factor, however, is the space factor of the core; with the more bend lines per outer corner, the more critical the space factor.

The bowing of the leg and yoke members is undesirable, as the core end frames exert pressure on the core, producing stresses which strain the core material and increase the true watts loss of the core, as well as causing an increase in the exciting volt amperes of the core. The bowed legs, also allow the unbent laminations to slip out of the position they occupied during stress anneal, during the opening and reclosing of the core when it is assembled with its associated electrical coils or windings. The slippage of these laminations produces stresses therein, and also prevents complete closure of the core joint, both conditions adding to the losses of the magnetic core. If the leg and yoke portions are bowed, which also causes large radius corners on the core window, the coil must necessarily be designed to fit the worst possible bowing conditions or deviations from the desired dimensions, which cause a poor fit between the coils and core, which also adds to the core losses.

This invention insures that the discrete bends will be completely formed in each lamination turn across the build dimension of the magnetic core, and at the same time allows the core space factor tolerance to be relaxed. Thus, improved, lower loss magnetic cores may be produced, with a dimension and space factor which is practical for normal production procedures.

FIG. 2 illustrates a magnetic core **30** constructed according to an embodiment of the invention. Magnetic core **30** has a plurality of nested, superimposed turns **31** formed of a suitable strip of magnetic metallic material, such as grain oriented silicon steel. Magnetic core **30** is shaped to provide four major outer sides **32**, **34**, **36**, and **38**, which define a window or opening **40** for receiving its associated electrical coils (not shown). Sides **32** and **34** may be the leg portions of the core **30**, and sides **36** and **38** may be the yoke portions.

In this embodiment of the invention, each major side of magnetic core **30** is separated by a minor side, such as minor sides **42**, **44**, **46** and **48**. Thus, magnetic core **30** has an outer periphery which defines an octagonal configuration. Each minor side, such as minor side **42**, is formed by two discrete bends **50** and **52** at an outer corner between two adjacent major sides. The discrete bends **50** and **52** in the outer lamination turn are transmitted completely through the build dimension of the magnetic core, forming sharp discrete bends in each of the lamination turns which make up the radial or build dimension of the core, which form two distinct bend lines **54** and **56** at each outer corner of the core, which proceed from the outer bends **50** and **52** inwardly through the build to the opening **40**. If it is desirable to have square corners on opening **40**, such as corner **60**, the bend lines associated

with each outer corner of the core may be arranged to meet at the associated corner of the window or opening **40**, as shown in FIG. 2. Thus, the two discrete bends in each lamination turn, for all practical purposes, merge to form a single bend in the lamination turns immediately adjacent the core opening. This may be desirable if the coils are cast or encapsulated in a solid resin system, such as an epoxy. Square corners on the window or opening, however, require more core material than slightly rounded inner corners. Thus, as will be described hereinafter, the bend lines may be directed to the window **40** such that there is a small space between them when they reach the inner lamination. This will form a small "radius" at the window corners, which is completely satisfactory when using conventional uncapsulated type coils, as a small space is provided between the coils and the yoke portions of the magnetic core at this point.

The two discrete bends **50** and **52** at each outer corner provide a magnetic core structure which requires only slightly more magnetic material than conventional rounded corners, and the bend lines **54** and **56**, being sharply transmitted through each of the laminations which make up the build dimension of the core, maintain substantially straight leg and yoke portions, and a well defined window **40**, with the dimensions of the core being accurately repeatable in production.

Sharp, well defined bend lines **54** and **56**, are produced when each of the lamination turns are discretely bent, providing straight leg and yoke portions. Sharp, well defined bend lines are assured, according to the teachings of this invention, even with a relatively wide tolerance on the coil space factor, by reverse bending the plurality of minor sides **42**, **44**, **46** and **48**. Thus the minor sides are given a "scalloped" appearance, as the minor sides are bent or curved inwardly toward the winding axis of the core for a predetermined distance or deviation from a flat plane disposed across the outer corners formed by the bends **50** and **52**. Thus, the minor sides are bent or curved in a direction opposite to the normal substantially ring shape of the core. In other words, the center of the radius of the curved minor sides lies outside of the outer periphery of the magnetic core.

By reverse bending the minor sides of the core **30**, the bend lines are sharply transmitted across the complete core build. The reverse curve in the laminations which form the minor sides will have the smallest radius or greatest deflection or deviation D from a flat plane disposed across the bend lines corners at the outer lamination, as shown at minor sides **46**. The deflection D of the laminations may become progressively less from lamination turn to lamination turn, as the core build is traversed from the outer to the inner lamination turn, with the deflection becoming substantially zero at some point between the inner and outer laminations.

Magnetic core **30** may be uncut, if its associated electrical coils are to be wound through the opening **40**, or, as is more common, it may have an openable joint of any suitable design to facilitate its assembly with pre-wound electrical coils, such as the step-lap joint **62** shown in FIG. 2, which is described in detail in U.S. Patents 2,972,804 and 2,973,494, assigned to the same assignee as the present application.

Magnetic core **30** may be formed by any suitable method, which includes the step of die forming. For example, magnetic core **30** may be formed by the steps of winding a strip of metallic magnetic material, such as grain oriented silicon steel, on a mandrel of predetermined diameter, to a predetermined build or radial thickness dimension, backwinding to provide a predetermined looseness or space factor in the core, cutting the core, if an openable joint is required, arranging the lamination turns to form a predetermined joint pattern, die forming the core to form the plurality of major and minor sides, as well as reverse bending the minor sides, and stress anneal-

ing the shaped core to remove the winding and forming stresses. The leg portions **32** and **34** may also be given a slight reverse bend, which causes them to bow inward slightly after forming. Thus, during the stress anneal operation, the only holding fixture required will be an internal spreader type fixture which is inserted into the window **40** to return the leg portions to a straight position. The stress annealing relieves the stresses which tend to bow the legs inwardly, and maintains the legs, as well as the yokes, in a straight relationship.

The shaping step of the magnetic core **30**, which is accomplished by die forming, may be performed in a single step, or in multiple steps, depending upon the design of the dies and the type of press utilized. For example, with a four-way die, i.e., one which closes inwardly in the direction of all four major sides, the die may be designed to form the minor sides and reverse bend the minor sides in one operation. The die would be shaped to form the major sides and minor sides, along with the reverse bends, and include an inner die which is inserted into the opening **40** at an appropriate time during the forming cycle.

If a two-way die is used, it may be necessary to reverse bend the minor sides in a separate die, after the minor sides have been formed flat, or a die having movable inserts or changeable contours may be used, which will start to form the minor sides in a flat plane, and then towards the end of the forming cycle, change its contour to reverse bend the minor sides. While the reverse bend is shown as a smooth curve, the insert means for forming the reverse bend may be rectangular in shape, instead of curved, which will reverse bend the minor sides and cause the outer laminations to have a small inward step therein.

The amount of the deflection D of the minor sides on the magnetic core **30** from a flat plane will be largely determined by the configuration of the magnetic core, i.e., the relationship between the build, strip width, leg and yoke dimensions, and space factor of the core. However, the amount of deflection is not critical. It should be large enough to transmit the bends through each of the lamination turns of the core, but should not be large enough to use up all of the core looseness, which would cause the legs and/or yoke members to buckle. A deviation D of .040 inch has been found to be excellent on magnetic cores rated 10 kva. and having four minor sides, as shown in FIG. 2.

A magnetic core having four major sides and four minor sides, as shown in FIG. 2, is excellent for magnetic cores having a relatively small rating, and/or cores which have a relatively low production. With larger rated cores, and high production cores, it may be advantageous to use more than two bend lines per corner, in order to save magnetic core material. The more bend lines per corner, the closer the core configuration will approximate round corners. For example, in going from two bends per corner to three, a savings in core material of 1½% may be realized. Although the invention is not to be limited to three bends per corner, more than three bends per outer corner would, in general, not be used, as any additional savings in core material would be minor compared with the difficulty in forming more than three discrete bends, in which the bend lines would be sharply defined across the core build.

FIG. 3 illustrates a magnetic core **70** constructed according to the teachings of the invention, which utilizes three bends per outer corner, such as bends **72**, **74** and **76**, which form bend lines **78**, **80** and **82**, respectively, across the build dimension of outer corner **71**. This arrangement, in addition to four major sides **84**, **86**, **88** and **90**, separated by corners **71**, **73**, **75** and **77**, form two additional minor sides between each two adjacent major sides, such as minor sides **92** and **94** at corner **73** between major sides **86** and **88**. Thus, the outer periphery of magnetic core **70** has twelve sides, forming a dodecagon. According to the teachings of this invention, each of the minor sides at each of the outer corners is given a reverse bend, which causes the minor sides to deflect inwardly from a flat plane disposed across the corners formed by the discrete bends. If a rectangular opening **96** having square corners, such as corner **98**, is desired, the bend lines would be arranged to meet at the corner of the opening. Thus, even though the outer periphery of the core is dodecagonal, the window or opening **96** may be rectangular, if desired. If it is desirable to produce a small "radius" on opening **96**, bend lines **78**, **80** and **82** may be arranged to strike the inner lamination turn in spaced relation, such as shown in FIG. 5. FIG. 5 is a fragmentary view of corner **71** of magnetic core **70** shown in FIG. 3, with like reference numerals indicating like components. It will be noted that corner **99** has a slight radius, due to the spaced bend lines **78**, **80** and **82** at the inner lamination turn. Although in theory the inner lamination turn will also have a dodecagonal configuration, the bends may be so close together that for all practical purposes they form a curve or radius on the inner corners of the core opening.

When die forming two additional minor sides per corner, using a two-way die which, for purposes of example, will be assumed to move inwardly perpendicular to the leg portions of the core, the bend lines disposed nearer the yoke portion will form first, and are thus easier to form than the remaining bend lines. In other words, the bends associated with the bends at the outer corners which are further from the dies than the other bends, form first. For this reason, the magnitude of the reverse bend on the minor side nearer the yoke portion, need not be at great as the magnitude of the reverse band on the minor side nearer the leg portion. This arrangement is shown in FIG. 4, which is a fragmentary view of corner **71** of magnetic core **70** shown in FIG. 3. Minor side **100** has an inward deflection or deviation **104** from a flat plane **105** disposed across bends **74** and **76**, and minor side **102** has an inward deflection **106** from a flat plane **107** disposed across bend lines **72** and **74**, with deflection **106** being greater than deflection **104**. For example, on a 10 kva. core constructed according to the configuration of the magnetic core **70**, deflections of .020" and .040" were found to be excellent for deflections **104** and **106**, respectively.

As hereinbefore mentioned, with some types of electrical windings or coils, a clearance is provided between the yoke portions of the magnetic cores and the ends of the coils or windings. Advantage may be taken of this fact to save core material by arranging the bend lines to strike the inner lamination turn in spaced relation at the various corners of the core opening. For example, FIG. 6 illustrates a fragmentary view, in section, of a transformer **110**, which includes two similar magnetic core structures **112** and **114** disposed in side by side relation to form a winding leg **116** for receiving high and low voltage coils **118** and **120**, respectively. The internal and external dies are formed to cause the bend lines **122** and **124** to strike the inner corners in spaced relation, which automatically provides an accurate and repeatable space **126** between the coils and yoke portions of the core.

Reverse bending the minor sides of a magnetic core, according to the teachings of the invention will form well defined bend lines and straight leg and yoke portions over a wide tolerance of core space factor, and also for core configurations in which the opening is small compared to the build dimension and/or the strip width or core depth is large compared to the yoke and leg dimensions. If a core configuration were to be required, however, in which reverse bending the minor sides is not sufficient to prevent bowing, die forming of the core allows selective stiffening of the leg and/or yoke members to be incorporated with little or no extra cost. Examples of when additional stiffening may be necessary includes those magnetic cores which have relatively long yoke and/or leg members,

and/or those magnetic cores which utilize very thin strip widths compared to the other dimensions of the core. U.S. Patent 2,584,564, assigned to the same assignee as the present application, teaches grooving the entire periphery of a magnetic core which is formed of two C type cores, by grooving the strip material before winding. This procedure would not be suitable for magnetic cores having step-lap type joints, as it is not desirable to groove and thus stiffen the portion of the core having the openable joint. It would complicate the opening and reclosure of the core to accommodate the electrical windings. Forming the groove in the strip before winding would also not be suitable for a dye formed core, as the dies would then have to be designed so that they would not remove the groove. The dies, however, may be designed to impart a groove, or sharp peripheral or circumferential bend into the core, and it could be selectively applied only to the portion or portions of the core which require the extra stiffening. Since the stiffness factor may be approximated by the formula $(V/d)^2$ where V is the depth of the deformation and d is the thickness of the material, only a slight deformation or groove would be required to substantially increase the stiffness of a leg or yoke member. For example, using 12 mil thick magnetic material, a .048" groove or deformation would increase the stiffness of the flat strip 16 times.

FIG. 7 illustrates a wound magnetic core **130**, in perspective, which utilizes the reverse bends on the minor sides of a polygonal core, as hereinbefore described, and also selective grooving of the yoke portions of the core. In this instance, the yoke portions were selected to be grooved as the core **130** has an openable joint **132** in one of the leg portions. If the openable joint is confined to one leg portion, the other leg portion may be grooved, if necessary.

Magnetic core **130** includes yoke portions **134** and **136**, and leg portions **138** and **140**, which define an opening **142** in the core. The core **130** is formed of a plurality of superimposed, nested turns **144** of metallic magnetic material, and in addition to the yoke and leg portions, has a plurality of minor sides **146**, **148**, **150** and **152**, which have reverse bends therein to provide well defined bends in each of the laminations throughout the radial build of the core and aid in maintaining straight leg and yoke portions. If the core still tends to bow, a linear deformation or groove may be imparted to the core which runs parallel to the edges of the strip which make up each lamination turn, and which is transmitted through the complete core build. Thus, unlike the discrete bends at the core corners, which cross the strip perpendicular to the sides of the strip, these bend lines or grooves are disposed parallel to the edges of the strip. While it would be most advantageous to form the groove while die forming the core to form the additional minor sides, the die grooving could be performed in a separate die forming operation, preferably after forming the core into its polygonal shape.

The deformation or groove **153** in yoke portion **134** and the deformation or groove **154** in yoke portion **136**, may be as selective as required, running the complete length of the yoke, or any portion of it. The exact configuration of the groove is not critical, with a suitable configuration being shown in FIG. 8, which is a cross sectional view of yoke member **134** of magnetic core **130** shown in FIG. 7. As illustrated in FIG. 8, the groove **153** may be a simple V shape or triangular shape, having a deformation dimension V.

FIG. 9 illustrates a wound magnetic core **160**, in perspective, constructed according to the teachings of the invention, having yoke portions **162** and **164**, and leg portions **166** and **168**, which define an opening **170**, as well as minor sides **174**, **176**, **178** and **180**. Magnetic core **160** has an openable joint **172** in the yoke portion **162**. Therefore, if extra stiffening is required, beyond that provided by reverse bending the minor sides **174**, **176**, **178** and **180**, the core legs may be grooved as shown at **190** on leg **166**. FIG. 10 is a cross sectional view of leg **190** of magnetic core **160**, taken along the line X—X, which illustrates another suitable configuration for the groove. In this instance, two V shaped grooves are disposed in spaced parallel relation. The grooves may be rectangular, rounded, triangular or of any other suitable configuration. It will be noted that the grooves are transmitted completely through the nested or superimposed laminations which make up the radial build of the core.

Thus, in summary, there has been disclosed a new and improved magnetic core structure for electrical inductive apparatus which lends itself to production techniques, does not have critical tolerances on the space factor of the core, and which is applicable to the cores constructed of narrow or wide magnetic strip, cores having small or large windows, and cores having short or long leg and yoke members relative to the other dimensions of the core.

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 descriptionn or shown in the accompanying drawings, shall be interpreted as illustrative, and not in a limiting sense.

We claim as our invention:

1. A magnetic core comprising a plurality of superimposed turns of metallic laminations, said superimposed turns of metallic laminations providing a laminated core structure in which the outer turn defines a plurality of major outer sides separated by outer corners and the inner turn defines an opening in the structure, at least the outer corners of said core structure each having a plurality of discrete bends which provide a plurality of additional outer sides, said discrete bends at each of said outer corners extending through all of the superimposed turns of the metallic laminations, from the outer lamination turn to the inner lamination turn, each of said additional outer sides being bent inwardly a predetermined amount to insure that the discrete bends are sharply defined in each of the lamination turns.

2. The magnetic core of claim **1** in which each of the outer corners has two discrete bends, forming one additional minor side at each outer corner.

3. The magnetic core of claim **1** in which each of the outer corners has three discrete bends, forming two additional minor sides at each outer corner.

4. The magnetic core of claim **1** in which the plurality of discrete bends which start at each outer corner form bend lines which proceed through the superimposed turns of metallic laminations and intersect the inner lamination at a common point.

5. The magnetic core of claim **1** in which the plurality of discrete bends which start at each outer corner form bend lines which proceed through the superimposed turns of metallic laminations and intersect the inner lamination in predetermined spaced relation.

6. The magnetic core of claim **1** in which each of the turns of metallic laminations are cut to provide single turn laminations having two ends, and at least one openable joint in said structure.

7. The magnetic core of claim **6** in which the two ends of each lamination turn are substantially aligned.

8. The magnetic core of claim **1** in which at least certain of said major outer sides has at least one substantially linear deformation which is disposed substantially parallel to the outer edges of the lamination turns, said at least one deformation extending completely through the plurality of superimposed turns of metallic laminations, from the outer lamination turn to the inner lamination turn.

9. The magnetic core of claim **1** including an openable joint in one of said major outer sides, certain of the remaining major outer sides having at least one substan-

tially linear deformation which is disposed substantially parallel to the outer edges of the lamination turns, said at least one linear deformation extending completely through the plurality of superimposed turns of metallic laminations, from the outer lamination turn to the inner lamination turn.

10. The magnetic core of claim **1** in which the outer corners have three discrete bends, forming first and second additional minor sides at each outer corner, said first minor sides at each outer corner being bent inwardly a greater distance than said second minor side.

No references cited.

LEWIS H. MYERS, *Primary Examiner.*

T. J. KOZMA, *Assistant Examiner.*