Oct. 1, 1968 R. V. WOODWARD 3,404,360

TRANSFORMER CORE CONSTRUCTION

Filed Oct. 22, 1965

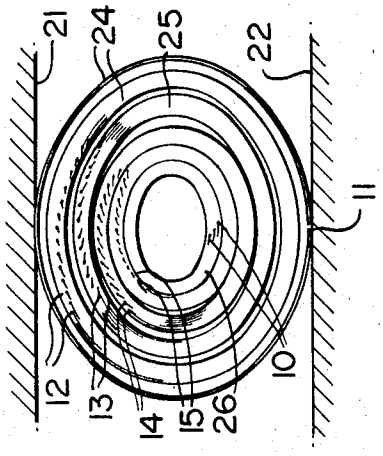


FIG. 2

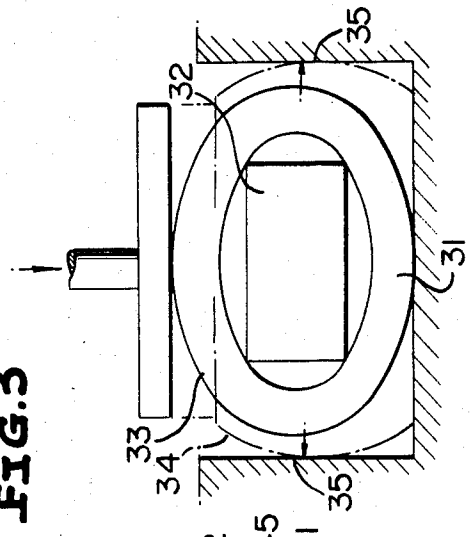


FIG. 3

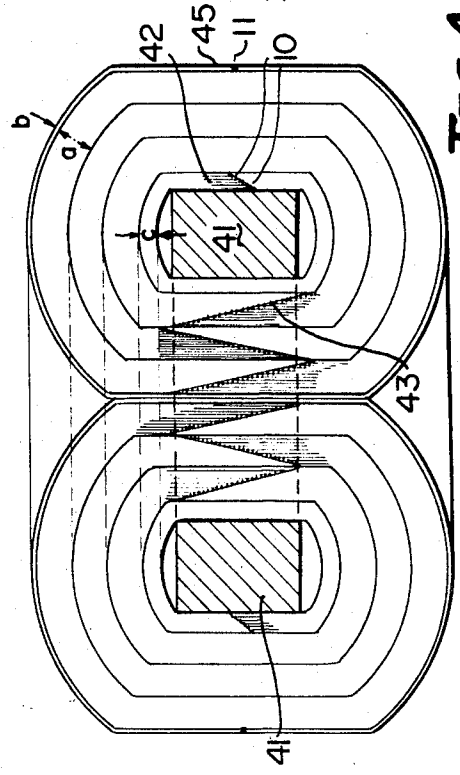
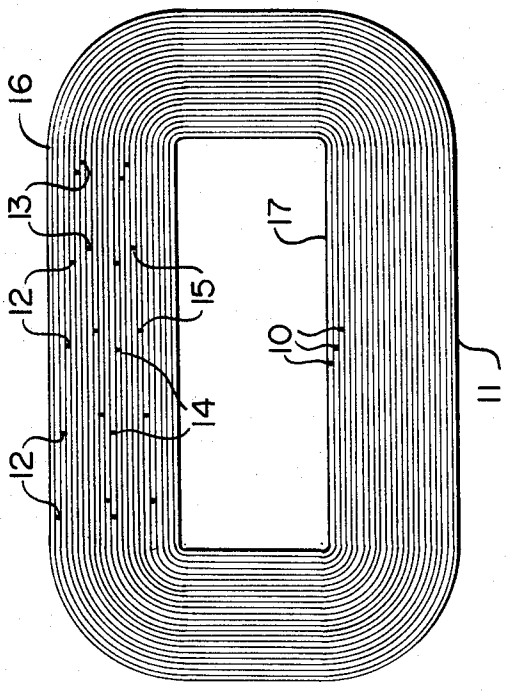


FIG. 4

FIG. 1



INVENTOR

REX V. WOODWARD

BY Hurwitz & Rose

ATTORNEYS

United States Patent Office 3,404,360
Patented Oct. 1, 1968

3,404,360

TRANSFORMER CORE CONSTRUCTION

Rex V. Woodward, Mount Vernon, Ill., assignor to Power Cores, Inc., Mount Vernon, Ill., a corporation of Illinois

Filed Oct. 22, 1965, Ser. No. 501,058
9 Claims. (Cl. 336—211)

ABSTRACT OF THE DISCLOSURE

A laminated transformer core in which the butt-joints of all laminations in one of the core legs are staggered relative to each other and distributed over the entire length of the leg exclusive of the stressed regions immediately adjacent the corners of the core.

The present invention relates to transformer cores and the assembly and fabrication thereof. In particular, the present invention relates to a formed, or wound, transformer core having improved magnetic characteristics.

One type of transformer construction, well known in the art, provides a preformed coil element having a center portion which forms a window therein. A magnetic core passes through the coil window and encloses a portion of the coil, forming a magnetic circuit thereabout. Such cores are usually formed by the juxtapositioning of a plurality of laminations into a plurality of separate groups. Each group of laminations is generally of rectangular or square shape which consequently defines the geometric configuration of the core.

In the manufacture of such cores, each lamination is cut to the appropriate length, which decreases for each lamination, from the outer one to the inner one, corresponding to the respective decreases in the required perimeter. The laminae are then formed into annular groups, by methods known in the art, and each group is concentrically nested, one within another. Each lamination is butt jointed, the particular location of each butt joint being of material significance with respect to the present invention, the details of which are discussed further on in the specification.

The concentric structure is then shaped and heat treated to relieve stresses in the core material produced by the forming operation.

Each group of laminations is separated from the structure and then individually spread and inserted about a portion of the preformed coil, through the window thereof. The group having the smallest perimeter is inserted, first, the next larger superposed over the first, and so on until the outer group is spread and inserted about all of the others. Each group is closed with a butt joint at various locations on the core. It is known to locate such joints in various positions on the core with respect to the coil window, for example, such as that shown by Hurt, Patent No. 2,702,936; Ellis, Patent No. 2,973,494 and Patent No. 3,154,758. However, it has been found that a particular arrangement in accordance with the present invention, yields improvements not heretofore achieved.

The nature of the formed core construction has presented numerous problems in connection therewith, as for example, the magnetic efficiency of such cores may suffer because perfect abutment of the laminations is not generally possible, and, the resulting air gaps produce a higher core reluctance than if perfect abutment were achievable. In addition, the spreading and bending of the various laminations in fitting them to the coil creates internal stresses in the core material which tend to increase the magnetic core losses further.

In the fabrication of such cores it has been common practice to provide all of the butt-joints in the leg of the core which is disposed within the coil window. In so

doing, the positioning of each joint and the retention of the various laminations in the proper position during assembly is somewhat difficult. The group of laminations last formed within the concentric core structure is separated therefrom and used as the first core group to be fitted to the coil. Thus, this group functions as a core form about which the remainder of the laminations are assembled. The proper alignment of the butt joints of this first group is thus critical because of its effect on the alignment of the remainder of the groups. Since it is very difficult, if not impossible, to view the positioning of the joints within the coil window, the aforementioned problem is created.

In accordance with the present invention, the first group of laminations is fitted to the coil in such a manner that the butt joints thereof are positioned on a core leg disposed outside of the coil window. Hence, the joints may be easily located and positioned properly. Thereafter, the remainder of the groups can be superposed over this first group such that the joints associated therewith will be positioned on the core leg which is disposed within the coil window. The final and outer lamination is then reversed in the manner of the first group to provide an exposed butt joint for easy bonding.

An additional and equally, if not more, important feature of the present invention, is that when the core is structurally arranged as indicated above, the performance of the core is measurably improved over the prior construction. This is contrary to that which would ordinarily be expected by those skilled in the art, hence, the aforementioned convention of positioning all of such joints within the coil window in the path of the greatest flux density even though such a structure complicates the assembly and increases cost of the device.

In accordance with another feature of the present invention, it has been found that the most optimum core performance is achieved by positioning those joints located on the leg within the coil window such that they are arranged in a zigzag distribution and widely and randomly spread across the full length of the leg. Each group has a random number of laminations varying between general limits and no specific number is required.

Accordingly, it is an object of the present invention to provide a formed-type induction core and a method of fabrication therefor wherein said core has improved magnetic characteristics as compared with cores heretofore known.

It is another object of the present invention to provide a formed-type, butt-jointed, multigroup induction core having the butt joints of the innermost groups disposed external to the coil window to provide improved magnetic characteristics as well as easy alignment of the laminations.

It is still another object of the present invention to provide a formed-type core with improved magnetic characteristics by positioning the butt-joints of the laminations on the leg within the coil window such that the joints form a zigzag distribution which is randomly spread across the entire length of the leg.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 illustrates the arrangement of the laminae in accordance with one embodiment of the invention.

FIGURE 2 illustrates, in an expanded view, one manner of arranging the various lamination groups in accordance with the invention and a fixture therefor.

FIGURE 3 is a diagrammatic illustration of one method of forming the core.

FIGURE 4 is a cross-sectional view of a magnetic structure during the final stage of assembly.

Referring now to FIGURE 1, there is shown one specific embodiment of the formed core in accordance with the present invention. Leg **16** of the core is intended to be disposed within the window of a preformed coil, while leg **17** is to be disposed external to the coil. The various laminae of leg **16** are shown to be arranged in a zigzag fashion, having the butt joints **12**, **13**, **14** and **15** spread throughout the entire permissible length of the leg. The butt joints which form each of the diagonals, represent the ends of the laminae of each group, respectively. The number of laminae per group may be any random number, but preferably is a number between **12** and **18**. No particular overlap is essential, the amount of overlap would thus depend on the specific design criteria desired. However, it is essential that the joints of each group be spread across substantially the entire permissible length of the leg **16**.

The expression "entire permissible length of the leg" excludes those portions of each leg which are stressed due to the bends at the corners. These stress regions must be avoided. The length of the regions determined by the thickness of the laminations which often are a function of core size. As an example, in a core of about 7.4" x 4.7", weighing approximately twenty-two pounds, the exclusion region extends for about 5/8" to 3/4" from the corner. Other than for observance of this restriction, the joints may be spread generally stepwise in each group along the entire length of the leg.

The first group of laminations which contains a relatively small number of laminae, preferably three, is shown having the stepped butt-joints **10**. These joints are positioned on the leg **17** external to the coil and preferably are substantially centered, although this is not essential.

The last, or outer lamination is likewise arranged such that the butt joint **11** thereof is also positioned on leg **17** and preferably centrally disposed.

The method of assembling the core, in accordance with the invention, is illustrated in FIGURES 2 and 3. In particular, referring to FIGURE 2, lamination **23** is formed into a generally circular or oval shape and placed between supporting surfaces **21** and **22**. Surfaces **21** and **22** form a supporting jig for merely retaining the laminae in the required shape and relationship during this part of the assembly procedure and such function might be performed by other means known to the art. The lamination **23** is positioned such that the butt joint **11** is located adjacent the surface **22**. Next, the group of laminae **24** is nested within the lamination **23** such that the natural resilient tendency to uncoil retains it in position adjacent thereto, and not as shown in FIGURE 2, which is in expanded view only for the purpose of illustration. The butt-joints **12** of group **24** may be stepped in any manner known to the art and are arranged generally diametrically opposite to joint **11**. The remainder of the groups, such as **25**, are then nested concentrically within one another, the last group to be inserted being group **26**.

Group **26**, containing relatively few laminae, as compared with the other groups, is nested therein having the butt-joints **10** reversed in similar orientation to butt-joint **11** of lamination **23**. The structure may be taped or held together in any conventional manner. This ultimately reduces the air gaps between the ends of the butt jointed laminae of each group. The arrangement of the various laminae in the same relative positions as intended in the final device structure, reduces the final space factor and thus, the resulting magnetic losses. The friction between each lamination and the ones adjacent thereto, and the friction between the lamination **23** and the surfaces **21** and **22**, retain all the laminae in the given configuration.

The number of groups of laminae used in the core construction depends on the ultimate design of the inductive device and is not limited by construction in accordance with the invention.

Each core group of FIGURE 2 has its joints offset in a direction opposite to that of its adjacent groups whereby they form zigzag diagonals extending over a sufficient length of the circumference thereof to ultimately provide the disposition of the stepped joints over substantially the entire length of the leg **16** as shown in FIGURE 1. Thus, the vertex formed by each adjacent pair of diagonals would be approximately in line in a direction transverse to the generally parallel perimeters of each group.

The core is then formed to the desired shape by appropriate apparatus, as for example, by such as is diagrammatically illustrated in FIGURE 3. Specifically, there is shown a mandrel **32** which will determine the internal shape of the core. The unfinished core structure **33** is placed on mandrel **32** and a force is applied to the ultimate leg portions by a ram **36** and forming plate **31**. The relative distances of the forming plates **35** serve to determine the final shape of the core. As the ram **36** moves downward, the core portion directly therebeneath and the portion opposite thereto, between the mandrel **32** and the forming plate **31**, straightens into a linear geometry, while the yoke portions of the core structure abut against the forming plates **35** to result in a generally rectangular core configuration. It should be noted that the plates **35** must not be spaced too close together as to decrease the space factor in the leg portions. Although such apparatus as is shown in FIGURE 3 may be utilized to produce the final shape of the core, other apparatus and fixtures might be used, the particular one of which forms no part of the present invention.

Once the core is formed, it is then subjected to a heating operation, for example, by means of an oven, in order to relieve the internal stresses locked in the core material. Thus, the core "sets" with the prescribed configuration and has substantially lower magnetic losses after such treatment. The core is then disassembled into individual core groups after removing any ties or other binding or retaining means which, of course, may have burned off during the heating operation. The individual core groups are now assembled about a preformed coil.

As shown in the cross-section of FIGURE 4, a coil is provided with two leg portions **41** defining the coil window therebetween. The innermost core group **26**, of FIGURE 2, is individually separated from the structure and expanded to fit about the coil leg **41** in such a manner that the ends of the laminations abut one another externally of the coil window and are easily viewable by the assembler. This first, or innermost core group (illustrated as **42** in FIGURE 4) then serves as a form for assembling the remainder of the groups about it. The group **42**, which preferably contains only three laminations, is easily arranged into the proper alignment and the joints are centered with respect to the coil. The shape of the group **42** now permits the remainder of the groups to be readily aligned as group **43** is fitted onto group **42**, and group **44** is fitted onto group **43**, etc. A single lamination **45** is then fitted onto the outermost group and arranged such that the butt-joint **11** is disposed opposite to the joint **10** of group **42**. The joint **11** may then be spot-welded, for example, to permanently secure the core groups into a unitary structure. Likewise, the same procedure is used to form the core structure on the opposite leg of the coil.

Thus, it has been found that by positioning the butt-joints along the entire length of the core leg within the coil window, in the path of highest flux density, improved performance in both lower watts and volt amperes per pound of core material is obtained as compared with prior art formed cores having the stepped butt-joints concentrated in a given region. Furthermore, by positioning the

joints of the innermost three laminations external to coil window, a further increase in performance is obtained. The comparison of performance is illustrated by the data of the table below.

TABLE I

B	VA per lb.			Watts per lb.		
	1	2	3	1	2	3
13,194	.468	.448	.412	.387	.375	.346
13,854	.539	.504	.469	.438	.419	.398
14,513	.641	.579	.530	.482	.463	.434
15,173	.723	.667	.601	.541	.514	.493
15,833	.879	.815	.737	.585	.550	.551
16,493	1.097	.988	.925	.651	.623	.610
17,152	1.559	1.381	1.295	.741	.697	.687
17,812	2.401	2.036	2.109	.845	.793	.788
18,208	3.175			.940		
18,340			3.181			.893
18,472		3.075			.918	

The column indicated as B represents various values of flux density in gauss developed in the core during test. The next three columns represent the volt-ampere loss for three different core constructions, types I, II and III, respectively. The type III construction is that shown in FIGURE 1 having the butt-joints of the first three laminations external of the coil window and with the joints spread across the maximum permissible length of the leg as indicated hereinabove. The type II construction provides the butt-joints of the first three laminations internal of the coil window in a manner similar to that of prior art core groups but again with the joints spread across the entire core leg. The type I construction is that of the prior art with all joints within the core windows and the joints grouped together over a short length of the leg. The next adjacent columns list the corresponding values of the power loss in watts per pound of core material.

The cores tested each weighed approximately 22 pounds. The window size was 4¾ x 2", the legs and yokes were 1.34 inches thick and 3⅜ inches wide.

The data presented in Table I is test data and it can be observed that at all values of flux both the types II and III cores provide superior results. Thus a marked improvement is obtained as a result of the spreading of the joints over the entire permissible length of the leg within the core window as opposed to concentrating the joints in a given location.

The comparison between core types II and III also clearly illustrates that the type III core is superior to the type II in the watts per pound category at all values of flux except at 15,833 gausses and the last entry in each column. The deviation at a flux of 15,833 gausses cannot be explained and may be due to faulty reading or achieving a higher flux density than indicated. At the point of highest flux, the same flux reading was not obtained for any of the three cores. However, the performance of types II and III cores at the upper end of their operating range is comparable.

As to the performance of the three cores relative to volt-amperes per pound, types II and III are again clearly superior and type III is superior to type II over all but the very upper end of the range.

The above analysis and data clearly indicates that distribution of the core joints in an extended length of the leg in the coil window produces superior results over concentration of the joints in one area or another. Further, the location of the inner and outer laminations externally of the coil window produces better operation than when all joints are located within the window. Although the increase in performance of type III over type II is not as significant as type II relative to type I, the increased ease of assembly is an important factor in favor of use of the type III core.

While I have described and illustrated one specific embodiment of my invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

I claim:

1. A magnetic core comprising a plurality of generally rectangular-shaped, butt-jointed laminations of high permeability material, each said lamination comprising a closed loop having a single joint therein,

the rectangular shape of said laminations defining laminations having two leg members and two yoke members joined by corners, the formation of said corners creating internal stresses in said high permeability material in regions of the material encompassing said corners and material immediately adjacent said corners whereby the permeability of said material in said regions is reduced relative to the remainder of the material of said laminations,

said laminations being of increasing size and nested one within the other to form a stack of contiguous laminations providing a core having two leg members and two yoke members, and

a majority of said butt joints being located in one of said legs of said core, the butt-joints of all of said laminations being staggered relative to one another and distributed over the entitre length of said leg exclusive of said regions whereby each butt-joint is disposed between continuous lengths of two adjacent laminations in which lengths the permeability of the material has not been reduced due to formation of said corners.

2. The combination according to claim 1 wherein the ratio of the length of the legs of said laminations to the length of said region at one end of said leg lies in a range of approximately 6 to 1 to 7 to 1 and higher as the length of the leg increases.

3. A magnetic core comprising a plurality of generally rectangular-shaped, butt-jointed laminations of high permeability material, each said lamination comprising a closed loop having at least one joint therein;

the rectangular shape of said laminations defining laminations having two leg members and two yoke members joined by corners, the formation of said corners creating internal stresses in said high permeability material in regions of the material encompassing said corners and material immediately adjacent said corners whereby the permeability of said material in said regions is reduced relative to the remainder of the material of said laminations,

said laminations being of increasing size and nested one within the other to form a stack of contiguous laminations providing a core having two leg members and two yoke members,

a majority of said butt joints being located in one of said legs of said core, the butt-joints of all of said laminations located in said one of said legs being staggered relative to one another and distributed over the entire length of said leg exclusive of said regions whereby each butt joint is disposed between continuous portions of two adjacent laminations in which portions the permeability of the material is substantially unaffected by internal stresses created during formation of said corners.

4. The combination according to claim 3 wherein the joints of the three innermost laminations are disposed in another of said legs of said core and the remainder of said joints are disposed in said one of said legs of said core.

5. The combination according to claim 4 wherein the joints in said one leg are randomly disposed relative to one another.

6. The combination according to claim 5 wherein the ratio of the length of the legs of said laminations to the length of said region at one end of said leg lies in a range of approximately 6 to 1 to 7 to 1 and higher as the length of the leg increases.

7. The magnetic core according to claim 4 further

comprising an outermost lamination having a butt-joint positioned in said other leg.

8. The method of making a laminated magnetic core comprising the steps of

forming several groups of core members by cutting a plurality of laminations of magnetic strip material of increasing lengths such that the ends of each lamination abut when formed into a closed configuration, said laminations and said groups being of such lengths as to tightly nest one within the other;

arranging the butt-joints of the laminae of each group in an offset manner and extending over a length such that the joints extend over the entire length of a leg of the final configuration exclusive of regions encompassing the corners of the final configuration and the adjacent areas having reduced permeability due to stresses created in the formation of the corners of the core;

forming a single lamination into a generally elliptical configuration having a butt-joint in a given position along the length thereof;

clamping said single lamination so as to retain it in said configuration and position;

assembling the longest of said groups into a similar elliptical configuration and inserting said longest group within said single lamination with said offset butt-joints positioned opposite to the butt-joint of said single lamination;

assembling the successively smaller groups into elliptical configurations and inserting them inside of said longest group such that the butt-joints of said groups form a zigzag pattern over a sufficient length so as to result in said pattern extending over the entire length of a leg in the finished core;

assembling the innermost group into an elliptical configuration and inserting said group inside of the other

groups such that the butt-joints of said innermost group are positioned opposite to the butt-joints of said other groups; pressing the assembly to its final rectangular size and shape whereby corners are formed between the legs and the yokes of the core and heat treating said core to relieve strains and to set the final configuration.

9. The method according to claim 8 further comprising the steps of

removing said innermost group, spreading said group at the butt-joints thereof, inserting said group through the window of a preformed coil such that said butt-joints are positioned external to said coil window to provide easy alignment;

successively removing said other groups from the assembly, going from the innermost outward, and fixing each respective group on said coil such that the butt-joints are positioned internal to said coil window;

removing said single lamination from said clamped position and superposing it over said groups such that the butt-joint is positioned external to said coil window.

References Cited

UNITED STATES PATENTS

3,204,210	8/1965	Duenke	336—217 X
3,223,955	12/1965	Olsen et al.	336—211
3,307,132	2/1967	Ellis	336—211
3,001,163	9/1961	Pfuntner et al.	336—217
3,025,483	3/1962	Treanor	336—217 X
3,341,941	9/1967	Olsen	29—609

LARAMIE E. ASKIN, *Primary Examiner.*

DAVID A. TONE, *Assistant Examiner.*