Feb. 20, 1951 J. G. FORD ET AL 2,542,806

METHOD OF MANUFACTURING WOUND CORE STRUCTURES

Filed May 10, 1946

Fig. 1.

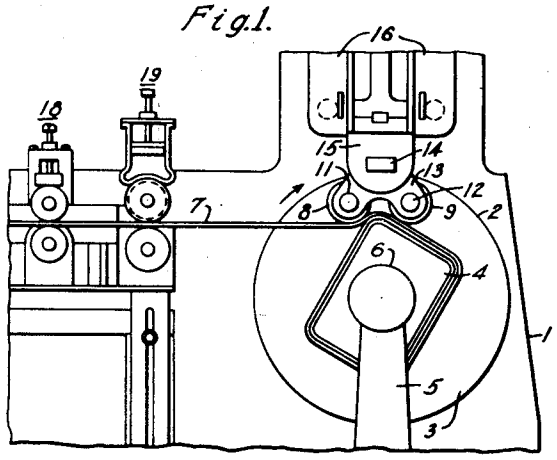


Fig. 2.

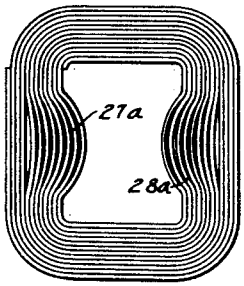


Fig. 3.

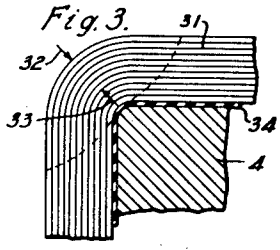


Fig. 4.

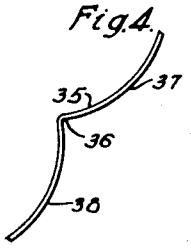


Fig. 6.

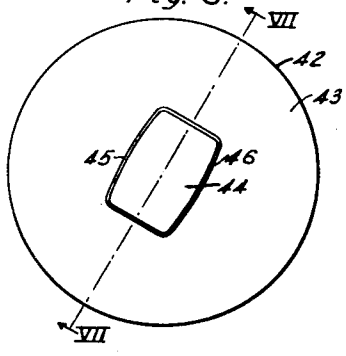


Fig. 5.

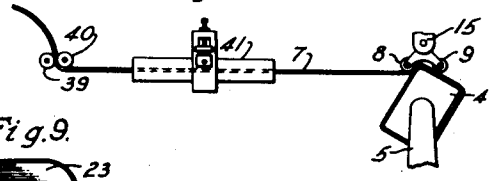


Fig. 9.

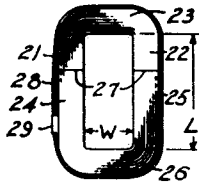


Fig. 7.

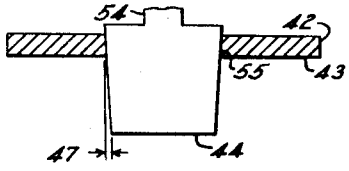


Fig. 8.

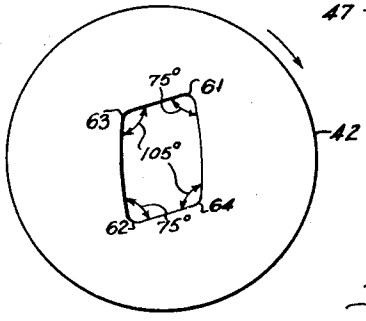
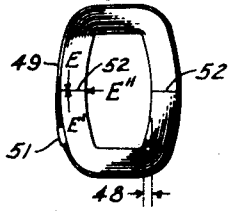


Fig. 10.



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METHOD OF MANUFACTURING WOUND CORE STRUCTURES

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3 Claims. (Cl. 29—155.57)

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This invention relates to electrical apparatus such as transformers, and particularly to a method of manufacturing wound core structures for use in such electrical apparatus.

Magnetic steel has been developed in recent years having preferably good magnetic characteristics in the direction of rolling which are better than in other directions and which are better than the magnetic properties of commercial grades of silicon steel formerly employed. Such improved magnetic steel is characterized by low watts loss per unit weight and high permeability in the direction in which the magnetic material is rolled during its process of manufacture. In order to take full advantage of the higher permeability and lower watts loss characteristic of such newer magnetic steel, it is necessary to so use such steel that the magnetic flux passes through it in the direction of rolling. When so used, the permissible flux density may be much higher than formerly employed. With the advent of more efficient magnetic steels which permit the core structure to be operated at much higher magnetic induction than was formerly the practice, the amount of iron required to form a core structure of a transformer having a given power rating has been greatly reduced.

In order to take advantage of this characteristic of the newer higher grade magnetic steels, a form of magnetic circuit structure has been developed comprising one or more core loops made of magnetic sheet steel ribbon wound layer upon layer on a shaping form, such as a steel mandrel, having the desired dimensions. The core loops so formed are usually provided with substantially rectangular windows or openings therethrough. The mandrels are designed to correspond substantially in size and shape to the desired size and shape of the window in the finished core loop, the window in the core loop being bounded by the flat side of the inner turn of the ribbon of steel forming the core loop. The core loops so formed, while remaining on the mandrels on which they were wound, are then annealed to relieve strains in the sheet stel ribbon caused by the winding operation. The loops are placed on their sides in rows and are then loaded by applying weights so as to preserve the form of the rectangular core loop during the annealing process. The wound and annealed core loops are then vacuum impregnated with a plastic adhesive bonding material which flows into the spaces between the successive turns or layers of magnetic sheet steel, after which the core loop structures are baked so that the bonding material adheres to the

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layers of the sheet steel forming a solid structure. The bonding material may be a thermoplastic material such as a vinylite-alvar resin with slight additions of phenolic type or hydrolyzed vinyl type resins.

These core loop structures are further processed by cutting the loop to form two U-shaped parts adapted to be reassembled about the circuit conducting coils, grinding and etching the surfaces formed by the cutting operation to provide smooth butt joints when the U-shaped core parts are reassembled.

The above described method of manufacturing spirally wound magnetic circuit structures employs several relatively expensive operations and tools which make it difficult to compete with core structures formed of punchings. These operations include the practice of winding each core loop on a mandrel and retaining it on the mandrel for a considerable part of its processing, such as during the annealing operation, and during the operation of impregnating the wound core loop with bonding material and baking it to form solid core loops. These expensive operations include the removal of the core loop from the mandrel, placing spreaders to prevent collapsing of the core loop after it is removed from the mandrel, and loading the wound core loops with a heavy weight to prevent bulging of the layers during the annealing and baking operations. The manufacture of core loop structures by the above described method requires the use of a great many mandrels because each mandrel must follow the processing of the core loop for a considerable time after the winding operation, so that it is not free for use for winding another loop for a considerable time after one loop has been wound thereon, thus requiring that many mandrels of the various shapes and sizes employed must be available for use in manufacturing cores where a considerable production is desired. All of these steps have been regarded as necessary in the manufacture of a core of the above described character.

It is an object of the invention to form core loop structures of the above indicated character withou tthe necessity of employing all of the steps previously regarded as essential to the formation of such core loop structures.

It is a further object of the invention to so modify the mandrel or shaping form about which the core loops are wound from the conventional mandrel previously used, and the manner of winding the steel ribbon on the mandrel, that when the core loop is wound to the desired form

it may then be removed from the mandrel and remain in its desired form without the support of the mandrel during further processing. The same mandrel, therefore, may be repeatedly used for winding one core loop after another at short time intervals so that the mandrel may remain a permanent part of the winding machine structure.

A conventional mandrel used in accordance with conventional practice will produce a core which, when it is removed from the mandrel, collapses into an undesirable and unusable form, unless the annealing and bonding steps which give the wound core its rigidity are first performed before removing the mandrel from the wound core loop.

In accordance with one feature of the invention, the special shape of the mandrel places extra stresses in the core material during winding, so that these forces balance the normal forces that tend to cause the wound core to collapse and to deform the wound core form its desired shape, upon removal of the core from the mandrel.

Other objects and advantages of the invention will be apparent from the following description of a preferred manner of practicing the invention, reference being had to the accompanying drawing, in which:

Figure 1 is a side elevational view of a portion of a conventional machine employed for winding wound magnetic core loops of the character described,

Fig. 2 is a side elevational view of a wound core loop illustrating the manner in which the turns of a core loop wound on a conventional mandrel in a conventional manner tend to collapse if removed from the mandrel before the annealing and bonding operations have been performed,

Figs. 3 and 4 are details,

Fig. 5 is a diagrammatic view of apparatus employed in a winding operation illustrating one feature of the invention,

Fig. 6 is a side elevational view of a face plate and mandrel for use in practicing the invention,

Fig. 7 is a sectional view through the face plate along the broken line VII—VII on Fig. 6.

Fig. 8 is a side elevational view of a face plate and mandrel modified for use in accordance with one aspect of the invention,

Fig. 9 is an elevational view of a conventional prior art core loop structure, and

Fig. 10 is an elevational view outlining a core loop formed in accordance with the invention.

Referring to the drawing and particularly to Fig. 1 thereof, a portion of a conventional machine for forming magnetic core loops from a continuous strip of magnetic sheet steel ribbon is illustrated. This machine may correspond to that disclosed and claimed in United States Patent 2,264,800, issued December 2, 1941, to C. C. Hortsman et. al. and assigned to the same assignee at this application. The winding machine includes a supporting base 1 that supports a shaft (not shown) carrying a winding head 2 on one end thereof. The winding head is provided with a circular face plate 3 upon which a mandrel 4 corresponds in shape to the outline of the window of the core loop to be wound. In accordance with their conventional practice, the mandrels are held in position upon the face plate of the machine during the winding operation and removed therefrom together with the wound core loop after

winding. A steel ribbon 7 is wound about the mandrel 4 as the mandrel and winding head are revolved in a clockwise direction as viewed in Fig. 1. A pair of follower rolls 8 and 9 bring constant pressure downwardly on the winding strip during the operation of winding it upon the mandrel. The follower rolls 8 and 9 are mounted upon pins 11 and 12 through a supporting member 13 that is pivotally mounted upon a pin held by the chuck 14 mounted on a carriage 15. The carriage 15 is mounted within a bracket frame structure 16 so as to move vertically under a constant downward pressure for the purpose of bringing the follower rolls constantly against the steel ribbon 7 as it is being wound upon the mandrel. The supporting member 13 is free to move about its pivotal support 14 so that the rolls follow the rectangular shape of the wound core loop during the winding operation. The steel strip 7 passes through two sets of braked rolls indicated generally at 18 and 19 which maintain a drag on the steel ribbon so as to keep it taut or under a slight tension while being wound on the mandrel. The force or drag occasioned by the braked rolls together with the force of the follower rolls 8 and 9 applies a certain pressure on the steel strip in the direction of the mandrel during the winding operation. A friction type of guide can also be used successfully.

When a conventional core loop is wound, annealed, bonded and baked, cut and worked as described above, it will appear as illustrated in Fig. 9. The window in the core loop shown in Fig. 9 has a length L and a width W and the leg portions 21 and 22 of the upper U-shaped core portion 23 are in alignment, respectively, with the leg portions 24 and 25 of the lower U-shaped core portion. These two portions unite to form butt joint surfaces at 27, the two core portions being forced together by the metal band 28 that is applied and maintained under tension, the opposite ends being held by the coupling sleeve 29. Since the U-shaped core parts 23 and 26, including the leg portions thereof, are solid as a result of the bonding process applied while the core loop was on the mandrel and since the leg portions are vertical, the forces between them are directly along the axis of these leg portions.

If, on the other hand, the wound loop is removed from the mandrel as soon as wound, that is, before the annealing and bonding operations are performed it will collapse into the shape shown in Fig. 2, the several laminations in the area shown at 27*a* and 28*a* on the inner side of the loop being forced into the area of the window. This is caused by the forces introduced into the steel ribbon comprising the core loop during the winding operation.

Referring to Fig. 3 as the several layers of ribbon steel 31 are wound about the mandrel 4 under the tension caused by the braked rolls 18 and 19, and the pressure caused by the follower rolls 8 and 9, a certain force is applied to the ribbon 7 or 31 of sheet steel, which is required in order to bend the steel ribbon about the corners of the mandrel and to hold the layers closely adjacent one another. This applied force inwardly may be indicated by the arrow 32 and is opposed by a corresponding resistance which is the force applied by the mandrel 4 through the lining 34 against the force 32 which is necessary to hold the layers of steel in their desired position. Fig. 4 illustrates a portion 35 of a single turn of one of the layers 31 as it would appear if unwound after being wound to form a core loop. Fig. 4

shows a portion 36 which has been given a permanent bend about a corner of the mandrel, while the portions 37 and 38 on either side are bent in the other direction, that is, in a direction to unwind the layer from the group of layers 31.

When the wound core loop is processed as above described forming a solid body in accordance with prior art practice before being removed from the mandrel, the bonding operation solidly holds the laminations in their desired position with respect to each other. If, on the other hand, the core loop is removed from the mandrel prior to the bonding operation, the inner forces 32 applied during the winding operation are not opposed by corresponding resisting force 33 from the mandrel and the result is that the forces 32 acting inwardly cause a certain contracting or inward movement of the layers of sheet steel causing the loop to collapse into a form characterized by the illustration in Fig. 2. For the reasons given above, it has formerly been thought necessary to anneal, bond and bake the wound core loops to form solid core loop structures before removing the loop from the mandrel.

In accordance with the invention, the steel ribbon 7 is passed through a set of forming rolls 39 and 40 (shown in Fig. 5) giving the ribbon a bend in a direction contrary to the direction in which the ribbon is bent when it is formed about the shaping form or mandrel 4 shaping the core loop. The steel ribbon 7 then passes through a drag brake 41 to maintain it under tension as it is wound onto the mandrel 4. This operation causes the successive layers of ribbon in the core loop, as it is wound, to lay close to each other and to conform to the shape of the next adjacent layer with a minimum of follower roll pressure so that a large part of the force causing the layers to remain close together is inherent in the forces within the steel ribbon itself that are introduced during the passing of the ribbon of steel between the forming rolls 39 and 40. Thus a lesser force 32 is required.

Referring to Figs. 6 and 7, in the practice of the invention, a winding head 42 is employed having a face plate 43 through which extends a mandrel or shaping form 44 having the outline shown in Fig. 6 corresponding to the desired shape of the window of the loop to be wound, and having a slight taper from the face plate outwardly to the outer end of the mandrel as shown in Fig. 7. This taper is very slight, say .005'' per inch along all four faces of the mandrel, so that after the core loop is wound, it will pass easily from the mandrel without binding. Also, the long sides 45 and 46 of the mandrel 44 are slightly convex by an amount, say .005'' per inch approximately. The degree of the taper and the degree of the convexity of the mandrel surfaces are so slight that it is impossible to show them to scale. They are therefore exaggerated so as to show clearly in Fig. 6.

It will be appreciated, therefore, that the dimension shown at 47 in Fig. 7, corresponding to the amount of taper of the mandrel 44, is exaggerated in order to be sufficiently large to be illustrated. Likewise, the dimension 48 shown in Fig. 10, corresponding to the offset from the perpendicular resulting from the convex surface of the mandrel 44 is likewise exaggerated for the same reason. With the long sides of the mandrel formed slightly convex (say by .005'' per inch approximately) when the band of steel 49 is positioned about the two U-shaped core parts and held tightly in place by the clamp 51, the forces between the U-shaped members will not be directly opposing each other at the butt joint surfaces 52 but will vary slightly as shown by the two arrows E and E' resulting in lateral component E'' which tends to force the two adjoining legs of the U-shaped member outwardly from the window against the force of the band 49 rather than toward the window.

It will be noted that the mandrel 44, as used in the practice of our invention, may be affixed to rotate with the driving shaft 54 of the winding machine driving the mandrel with the smaller end of the tapered mandrel extending outwardly away from the face plate 43. After the core has been wound to size and the end of the strip of steel ribbon comprising the core structure is cut and fastened to the wound core loop either by spot welding, or by a clip, or other suitable means, the core loop is removed from the mandrel by a power driven mechanism which may either move the face plate 43 outwardly over the mandrel 44 or may retract the mandrel 44 through the opening 55 in the revolving head of the winding machine through which the mandrel extends.

After the wound core loop has been removed from the mandrel, it is then placed upon a suitable support lying on its side, that is with the surface comprising the edges of the wound ribbon supporting the loop and in this position is annealed and impregnated with a suitable bonding material and baked while remaining on its side. These operations eliminate considerable handling which is required when the coil loop is annealed while still on the mandrel upon which it is wound. Cores can thus be produced much less expensively than by the prior art process described above, in which a considerable number of mandrels are necessary in order to provide for an appreciable rate of production of such wound cores. It will be appreciated that all four sides of the core loop may be formed with convex sides and, in certain core loops the four sides may be of equal length.

Relatively smaller sizes of cores may be made in the manner described above. With larger size cores, having leg portions longer than the yoke portions, it is desirable to employ an additional feature of the invention, reference being had to Fig. 8 of the drawing. When core loops are wound in the manner illustrated in Fig. 1, it has been found that the bending action resulting from the follower rolls is not the same over all four corners of the mandrel. If each of the four surfaces of the mandrel about which the steel ribbon is wound, as shown in Figs. 1 and 6, are 90° with respect to the adjacent surfaces, the bend of the ribbon of steel resulting from the follower rolls passing from the long side of the mandrel to the short side is considerably less than the bend when the roll is passed from the short side to the long side. Thus when the cores are removed from the mandrels, the core tends to take the shape of a rhomboid, that is, a parallelogram in which two opposite corners are greater than 90° while the remaining two opposite corners are less than 90°. This is caused because the forces applied at 32, as shown in Fig. 3, are greater for two opposite corners than for the remaining two opposite corners of the rectangular loop as wound. In accordance with one aspect of the invention, this tendency of the core loop to take a shape in which the four corners have different angles may be overcome by shaping the mandrel in such a form that, as the ribbon of steel is wound, two of the four corners 61 and 62,

as shown in Fig. 8, are made less than 90°, but the remaining two, 63 and 64, are made greater than 90°. The particular angular relationship between the surfaces joined at these four corners will be different for different sizes of cores. As here illustrated, the mandrel is shown with the corners 61 and 62 having an acute angle of approximately 75° while the remaining two corners 63 and 64 have an obtuse angle of approximately 105°. With a rectangular shaped mandrel too little bending occurs at the corners 61 and 62 and too much bending occurs at the corners 63 and 64. By forming the mandrel as a rhomboid, as shown in Fig. 8, the bending that will occur at the corners 61 and 62 is increased above that which would occur if a rectangular mandrel were used and the bending at the corners 63 and 64 is less than what would occur if a rectangular mandrel were used. By properly designing the particular mandrel in accordance with the particular core loop to be wound, the core loop may be so formed that when removed from the mandrel, the resulting change in shape from its wound shape will cause it to form a core loop in which the adjacent sides are perpendicular to each other.

It will be apparent from the above description of our invention that the practice of the invention will result in the manufacture of core loop structures that may be easily removed from the mandrel and in which stresses are developed in the layers of the core structure during the process of manufacture so that they balance the normal forces that tend to cause the core loop to collapse or deform from its desired shape upon removal of the core loop from the mandrel. A core manufactured in accordance with the herein disclosed invention may easily be removed from the mandrel. Such a core contains stresses that prevent the loop from collapsing or deforming upon removal of the mandrel.

Modifications in the details of the practice of the invention from that described will occur to those skilled in the art and we do not wish to be limited otherwise than by the scope of the appended claims.

We claim as our invention:

1. The method of making a magnetic structure comprising forming a closed core loop of the desired dimensions by passing a ribbon of magnetic sheet steel through a set of forming rolls to give the steel ribbon a bend in one direction and in then winding the ribbon of magnetic sheet steel to give the ribbon a bend in the opposite direction, the ribbon being wound layer upon layer around a shaping form that is slightly tapered toward one end so that the wound core loop is more easily removed from the shaping form, the shaping form outlining a rhomboidal shaped window about which the layers of steel ribbon are wound forming a closed core loop having two relatively long and two relatively short sides, the corners of the loop where the ribbon passes from a long side to a short side having an acute angle and the corners of the loop where the ribbon passes from a short side to a long side having an obtuse angle, fastening the outer end of the last turn of the ribbon to the wound core loop, and then applying pressure to one side of the wound core loop to force it from the shaping form over its tapered end, and then positioning the core loop on edge and annealing the core loop after removal from the shaping form to remove stresses in the steel that are introduced during the loop forming operation.

2. The method of making a magnetic structure comprising forming a closed core loop of the desired dimensions by passing a ribbon of magnetic sheet steel through a set of forming rolls to give the steel ribbon a bend in one direction, then winding the ribbon of magnetic sheet steel to give the ribbon a bend in the opposite direction, the ribbon being wound layer upon layer around a shaping form that is slightly tapered toward one end so that the wound core loop is more easily removed from the shaping form, the shaping form outlining a rhomboidal shaped window about which the layers of steel ribbon are wound forming a closed core loop having two relatively long and two relatively short sides, the corners of the loop where the ribbon passes from a long side to a short side having an acute angle and the corners of the loop where the ribbon passes from a short side to a long side having an obtuse angle, and then positioning the core loop on edge and annealing the core loop after removal from the shaping form to remove stresses in the steel that are introduced during the loop forming operation.

3. The method of making a magnetic structure comprising forming a closed core loop of the desired dimensions by passing a ribbon of magnetic sheet steel through a set of forming rolls to give the steel ribbon a bend in one direction, then winding the ribbon of magnetic sheet steel to give the ribbon a bend in the opposite direction, the ribbon being wound layer upon layer around a substantially rectangular shaping form having the two longer sides only thereof slightly convex to form a closed core loop having two relatively long and two relatively short sides, the longer sides being slightly convex providing a central window that is slightly wider through the middle portion thereof than at the ends and outlined by slightly bowed core leg portions, fastening the outer end of the last turn of the ribbon to the wound core loop, then removing the core loop from the supporting shaping form, and then positioning the core loop on edge and annealing the otherwise unsupported core loop after removal from the shaping form to remove stresses in the steel that are introduced during the loop forming operation while retaining the slightly convex shape of the longer sides of the loop to prevent collapse of the inner layers thereof.

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JOHN H. BRAMBLE.

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