(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 279 177 B1

(12) # EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
26.07.2006 Bulletin 2006/30

(21) Application number: **00921014.7**

(22) Date of filing: **27.04.2000**

(51) Int Cl.:
H01F 27/25 *(2006.01)* ***H01F 41/02*** *(2006.01)*

(86) International application number:
PCT/IL2000/000243

(87) International publication number:
WO 2001/082316 (01.11.2001 Gazette 2001/44)

(54) **A WOUND TRANSFORMER CORE AND A METHOD AND APPARATUS FOR MANUFACTURING THEREOF**

GEWICKELTER TRANSFORMATORKERN, VERFAHREN UND VORRICHTUNG ZUR DESSEN HERSTELLUNG

NOYAU DE TRANSFORMATEUR ENROULE, PROCEDE ET APPAREIL POUR SA FABRICATION

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE

(43) Date of publication of application:
29.01.2003 Bulletin 2003/05

(73) Proprietor: **A.T.T. Advanced Transformer Technologies (1998) Ltd.**
40500 Even Yehuda (IL)

(72) Inventor: **ADAR, Eliezer**
Sde Varburg 44935 (IL)

(74) Representative: **Modiano, Micaela Nadia**
Modiano, Josif, Pisanty & Staub Ltd.,
Baaderstrasse 3
80469 München (DE)

(56) References cited:
WO-A-91/12960
FR-A- 1 311 248
US-A- 2 909 742
US-A- 3 399 365
US-A- 4 413 406

EP 1 279 177 B1

Description

FIELD OF THE INVENTION

[0001] This invention relates to strip wound transformer cores and method of their manufacturing.

BACKGROUND OF THE INVENTION

[0002] A transformer is a known electrical device widely used for transferring the energy of an alternating current in the primary winding to that in one or more secondary windings through electromagnetic induction. It typically contains two or more electrical circuits comprising primary and secondary windings, each made of a multi-turn coil of electrical conductors with one or more magnetic cores coupling the coils by transferring a magnetic flux therebetween.

[0003] Electrical transformer cores are typically formed of high grain oriented silicon steel laminations. The most common procedure for manufacturing such a transformer is to wind the core independently of a preformed coil or coils with which it will ultimately be linked. To this end, the core is formed with a joint at which the core laminations can be separated to open the core and thus accommodate insertion of the core into the coil window(s). The wound core joints are typically of the so-called step-butt joint or step-lap joint types.

[0004] US Patent No. 1,164,288 discloses a technique of fabricating a cylindrical magnetic core for a power transformer. The magnetic core is made from coiled strips, wherein the core is of greater axial dimension than the width of the strip. To manufacture the core, a plurality of layers of the magnetic steel strips is simultaneously coiled to form the cylindrical core. The sum of the width of the strips in each layer is equal to the axial dimension of the core, and at least one longitudinal edge of each strip is staggered is relation to those in adjacent turns of the resultant coil.

[0005] It is known from the disclosure in US Patent No. 2,909,742 that in order to obtain a desired height of the transformer core, a number of toroids can be stacked on top of each other. This technique, however, suffers from energy losses caused by unavoidable introduction of unwanted air gaps between each two adjacent toroids.

[0006] Great advances have been made in amorphous magnetic alloys for use as the core material for transformers because they are lower loss materials as compared to grain steel. However, annealed amorphous metals become extremely brittle, and thus break under mechanical stress, for example, during the stage of closing the core joints. Various techniques have been developed aimed at facilitating the manufacture of a wound transformer core (10) from amorphous strips, wherein the core has joints in a localized region thereof that allow the core to be opened to permit insertion into the window of preformed coil structure. These techniques are disclosed for example in the following patents: US 4,789,849; US 4,790,064; US 4,893,400; US 5,398,402; US 5,398,403; US 5,329,270; US 5,347,746, US 5,548,887.

[0007] U.S. patent No. 4,413,406 discloses a method for forming cores for an electrical transformer, and also discloses the cores made from such a method. In one embodiment an amorphous metal core has relatively thick superimposed laminations comprised of relatively thin amorphous metal sheets. The amorphous metal sheets are heated and bonded together by a metallic bonding agent to form relatively thick amorphous metal packets for the superimposed laminations of the core. The heating and bonding of the amorphous metal sheets reduce the mechanical stresses normally induced into the amorphous metal during the fabrication process. In another embodiment a hybrid core has superimposed laminations certain of which comprise sheets of non-crystalline amorphous metal and one or more sheets of crystalline silicon steel metal.

[0008] WO 91/12960 discloses a laminated amorphous metal strip that has a first layer with at least two side-by-side strips of amorphous metal of unequal widths, and a second layer with at least two side-by-side strips of amorphous metal of unequal widths, the layers being in reverse order with respect to the widths of the strips such that the wider strips overlap and form a brickwork cross-section pattern. A flexible polymeric bonding material is disposed between the layers. A method for fabricating the laminated strip of amorphous metal includes providing rolls of metal, positioning the rolls in strips having differing widths, applying the bonding material, applying pressure while advancing the laminate, and cutting the laminate.

SUMMARY OF THE INVENTION

[0009] There is a need in the art to provide a novel method and apparatus for manufacturing a transformer core of a desired height from a plurality of thin strips made of a magnetic material having predetermined magnetic properties, wherein the available width of such strip is less than the desired height of the core.

[0010] The main idea of the present invention consists in the use of a desired number of layers of magnetic strips to be simultaneously wound so as to form a substantially cylindrical, toroid-like transformer core of a desired height for carrying a coil block mounted thereon. The construction is such that each layer is formed of a desired number of strips arranged along the longitudinal axis of the core, and the layers of a desired number are specifically arranged with respect to each other. This construction is aimed at providing the optimal distribution of magnetic flux inside the strips in the layers. The number of strips in the layer is dictated by the height of the transformer core and by the available widths of the magnetic strips. The number of layers is dictated by the magnetic properties of the magnetic material of which the strips are made. As for the thickness of the resultant winding, it is dictated by the electrical and mechanical parameters of the transfonner, such as the height and cross section of the core, and frequency and rate power of the transformer.

[0011] There is thus provided according to one aspect of the present invention a transformer core to be used in a power distribution transformer, the transformer core having a desired height and being of a substantially cylindrical toroidal shape, wherein:

- the transformer core is in the form of a multi-layer structure wound about a central axis of the toroid;
- each layer in the structure is composed of a predetermined number of magnetic strips arranged along said central axis with air gaps naturally existing between each two adjacent strips of the layer, the predetermined number of the strips being such that the sum of the widths of said strips is substantially equal to said desired height of the core;
- a required number ***n*** of layers in said structure is defined by the magnetic properties of the strips, and the layers are shifted with respect to each other a predetermined distance along said central axis such that each of the air gaps in one layer is overlapped by **(n-1)** strips of the other layers of the structure.

[0012] It is known that the commercially available strips made of amorphous metals are characterized by a working value of magnetic induction, B_w, about 1.35T, and the saturation value of magnetic induction, B_{sat}, about 1.55T. Thus, the number ***n*** of the layers should be such that a magnetic flux created in the first (uppermost) layer and flowing along the longitudinal axis of the layer, while reaching an air gap on its way and passing through all other layers in a transverse direction so as to return into the first layer, will not cause the saturation of the magnetic induction in other layers.

[0013] Generally speaking, the number of layers should satisfy the following relation: $n \geq B_w/(B_{sat}-B_w)$, ***n*** being integer. Considering the above parameters of the commercially available amorphous strips, the minimal value of ***n*** is 7.

[0014] The predetermined distance defining the shift between each two adjacent layers is such that each of the air gaps in one layer is overlapped by **(n-1)** strips of the other layers of the structure.

[0015] As indicated above, the number of strips in the layer is defined by the desired height of the transformer core, namely, the sum of the width of the strips in the layer is substantially equal to the height of the core. It should be understood that, in order to planarize the top and bottom surfaces of the core, the number of strips in the extreme layers of the entire structure (1^{st} and 7^{th} layers) differs from that of the intermediate layers. The two opposite extreme strips in each of the intermediate layers are of a smaller width than that of the other strips in the layer.

[0016] In a resultant winding, wherein each winding turn is formed by the above-described multi-layer structure, each air gap of the intermediate layer in turn is overlapped by the ***(n-1)*** strips of other layers. Here, some of the overlapping strips are of the structure in the same turn and the others are of the structure of an adjacent turn.

[0017] The strip layers are wound simultaneously being fed from a corresponding number of bobbins (e.g., 7 bobbins). Namely, the bobbins are aligned in an array, each bobbin feeding a corresponding one of the seven strip layers. The strips are fed from the bobbin with the predetermined shift between the layers. To this end, the bobbins may be prepared such that the strips layer wound on each of the bobbins is arranged with respect to the strip layer wound on the other bobbins in a manner corresponding to the arrangement of layers in the resultant core. Alternatively, the bobbins may be identically wound with the strip layers, but mounted with the desired shift with respect to each other.

[0018] Thus, according to another aspect of the present invention, there is provided a method of manufacturing a transformer core according to claim 4

[0019] According to yet another aspect of the present invention, there is provided in apparatus for manufacturing a transformer core according to claim 9

[0020] The present invention may be used for manufacturing a three-phase transformer. A magnetic circuit of such transformer is composed of three transformer cores, each constructed as described above (for carrying three coil blocks, respectively) and two spaced-apart, parallel, plate-like elements attached to the top and bottom surfaces of the transformer cores, respectively. In other words, the transformer cores with the coil blocks mounted thereon are enclosed between the upper and lower plates of the magnetic circuit. The transformer cores are spaced at intervals of 120 degrees about a central vertical axis of the entire transformer structure. The cores are spaced from each other and from the plate-like elements by insulating spacers. All the spacers may be formed of plastic with filler of a magnetic powder with the concentration of 20-50%.

[0021] The plates and the cores may be formed of amorphous strips. The plate may be of a substantially triangular shape with rounded edges, or of a circular shape that simplifies the technological process of its manufacture. The plate-like element may be a toroid manufactured similar to that of the transformer core, as described above.

[0022] The advantages of the above construction of a three-phase transformer consist of the following. The provision of the plate-like elements of a triangular shape with rounded corners allows for effectively transferring the magnetic flux between the three column-like elementary circuits enclosed between the plates. The provision of the column-like elementary circuits formed by one or more toroids produced by wounding the amorphous strips, enables to obtain a desired height of the column irrespectively of the limited width of the strip. By appropriately selecting the dimensions of the elements of the magnetic circuit (i.e., the diameter of each transformer core and each of the plate-like elements), the desired properties of the transformer can be achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

> **Fig. 1A** schematically illustrates a transformer core according to the invention;
> **Fig. 1B** partly illustrates a cross section of the transformer core of Fig. 1A
> **Fig. 2** more specifically illustrates the principles of arranging layers in the core of Figs. 1A-1B;
> **Fig. 3** schematically illustrates the main components of an apparatus for manufacturing the transformer core of Figs. 1A-1B; and
> **Fig. 4** is a schematic illustration of a three-phase transformer utilizing the transformer core of the present invention.

DETAILED DESCRIPTION OF EXAMPLES OF THE INVENTION

[0024] Referring to Fig. 1A, there is illustrated a transformer core **10** to be used in a power distribution transformer (not shown here). The core is in the form of a cylindrically shaped toroid of a desired height **L**. The toroid **10** is formed by coiling a multi-layer structure **12** of magnetic strips about a central axis **14** of a mandrel **16** (constituting a central axis of the toroid).

[0025] As shown in Fig. 1B, the multi-layer structure **12** is composed of a plurality of parallel layers - seven layers L_1-L_7 in the present example, which are arranged along an axis perpendicular to the central axis **14**. Several strips (ribbons) made for example of a soft ferromagnetic amorphous alloy form each of the layers: layer L_1 is formed by strips S_1, layer L_2 is formed by strips S_2, etc. The strips in the layer are arranged in an array extending along the central axis **14**, with the unavoidable existence of an air gap, generally **18**, between each two adjacent strips. The air gaps of each layer are shifted with respect to the air gaps of the adjacent layer, as will be described more specifically further below.

[0026] Turning back to Fig. 1A, it should be understood that the resultant winding of the core **10** is composed of a plurality of turns of regularly repeated multi-layer structure **12**. The number of turns (i.e., the thickness of the resultant winding) is defined by the required power of the transformer.

[0027] Reference is made to Fig 2, more specifically illustrating the principles of the arrangement of layers in the structure **12**, and in the resultant winding. As indicated above, the commercially available amorphous ribbons are typically limited in width (up to 200mm), the width **l** of the strip being typically much smaller than that required for the height of a transformer core. Therefore, each of the layers in the structure **12** is composed of several strips such that the sum of the widths of the strips (together with the gaps between the strips) is substantially equal to the height of the transformer core.

[0028] On the other hand, the amorphous ribbons have certain magnetic properties, such as the working value of a magnetic induction (e.g., B_w= 1.35T), and the saturation value of the magnetic induction (e.g., B_{sat}=1.55T). To optimize the operation of a transformer (i.e., the distribution of a magnetic flux in the structure), the structure **12** is composed of 7 layers. Generally the number ***n*** of layers is determined in accordance with the magnetic properties of the amorphous material, as follows: $n \geq B_w/(B_{sat}-B_w)$, ***n*** being integer.

[0029] As shown in Fig. 2, air gaps exist between each two adjacent strips of the layer. More specifically, strips S_1 of layer L_1 are arranged with air gaps **18a,** strips S_2 of layer L_2 - with gaps **18b,** strips S_3 of layer L_3 - with gaps **18c,** strips S_4 of layer L_4 - with gaps **18d,** strips S_5 of layer L_5 - with gaps **18e,** strips S_6 of layer L_6

- with gaps **18f,** and strips S_7 of layer L_7 - with gaps **18g.** Gaps of each layer are shifted with respect to those of the adjacent layer a predetermined distance along the central axis **14** such that each of the air gaps in one layer is overlapped by six strips of the other layers (generally, **(n-1)** strips). For example, gap **18a** of layer L_1 is overlapped by strips S_2-S_7 of layers L_2-L_7 of the same turn of the resultant winding, gap **18c** of layer L_3 is overlapped by strips S_4-S_7 and further by strips of S_1- S_2 of layers L_1 and L_2 of an adjacent turn of the resultant winding. As exemplified with respect to layer L_1, magnetic flux **F** (produced by the passage of an electric current through the strip S_1) flows across the strip S_1, and while reaching the gap **18a,** flows through the six strips S_2-S_7 of layer L_2-L_7 overlapping this gap **18a**.

[0030] It should be understood that the shift between the layers is appropriately selected. For example, considering the equal width of the intermediate strips of the layer (i.e., strips between two opposite extreme strips), the sum of shift distances of all the layers in the structure should not exceed the width of the intermediate strip.

[0031] Fig. 3 illustrates the main components of an apparatus **20** for manufacturing the transformer core **10.** The apparatus **20** comprises seven bobbins B_1-B_7 (generally, ***n*** bobbins), each for carrying a corresponding strip layer to be fed to the mandrel **16**. The layers are previously wound onto the bobbins in a manner, which will be described further below, and simultaneously fed onto the mandrel **16**, by a suitable driving assembly, which is not specifically shown.

[0032] The driving assembly may be of any known suitable kind, and may be associated with the mandrel **16** for driving the revolution thereof, while the bobbins are rotatably mounted on their shafts (not shown) to rotate against the tension of the feeding layers. In order to provide the desired tension of the layers during the coiling procedure, the driving assembly may also be associated with the shafts of bobbins for driving the revolution thereof. The construction may be such that the bobbins are driven together for rotation about the mandrel, which, in this case, is mounted stationary.

[0033] Further provided in the apparatus **20** is a guiding assembly **22**, comprising one or guiding rollers, generally at **24**, and a pair of width limiting rollers **26** accommodated at opposite ends of the mandrel **16** extending normally to the direction of movement of the layers onto the mandrel.

[0034] As further shown in the figure, the layers are prepared on the bobbins with the corresponding shift between the strips of each two adjacent layers as described above. To this end, either the corresponding arrangements of strips of different layers are previously determined, and the strips are wound on the bobbins accordingly, or identically wound bobbins are prepared and then cut by any suitable cutting tool.

[0035] It should be noted, although not specifically shown, that the layers of sufficient width, appropriately shifted with respect to each other, could be wound on the mandrel, and the so produced core then cut at opposite ends. In this case, the bobbing and/or guiding means may be appropriately shifted.

[0036] Reference is now made to Fig. 4, illustrating a three-phase transformer **30** utilizing the transformer cores designed as described above. The transformer **30** comprises a magnetic circuit formed by an upper plate-like element **32a,** a lower plate-like element **32b,** and three parallel identical cores **10** (only two of them being shown in the drawing). The magnetic circuit is arranged such that the plates **32a** and **32b** are parallel to each other, and the cores **10** serve as supports between the plates, thereby forming a cage-like structure spatially symmetrical about a central axis **CA.** In the present example, each of the plates **32a** and **32b** is a toroid, and is made of amorphous ribbons **34** wound about a central hole **35** to form the planar toroid. Further provided are three coil blocks **36,** each mounted on a corresponding one of the cores **10.** Each of the coil blocks **36** includes a primary winding **36a** and a secondary winding **36b.** Thus, each phase of the transformer **30** is formed by the transformer core **10** with the corresponding coil block **36** mounted thereon.

[0037] The transformer **30** has a modular structure, namely, the plates **32a** and **32b,** and the cores **10** can be easily assembled together and disassembled. When one of the plates **32a** or **32b** is removed, the coil blocks **36** can be removed as well, thereby enabling, for example, to repair the coil.

[0038] In the present example, each of the plates **32a** and **32b** has a generally triangular shape with rounded sides and corners. The amorphous ribbon **34** is made of an alloy having soft ferromagnetic properties. Each of the cores **10** is a toroid manufactured as described above. This construction enables to achieve a desired height of the core **10,** notwithstanding the fact that the width of amorphous ribbon is typically limited.

[0039] The entire structure is held together with three de-mountable bands **38** (only two of them being seen in the figure), each having a screw (or spider) **40** to tighten the band. Structural members **42** are provided, each located between the corresponding one of the bands **38** and each of the plates **32a** and **32b.** A base **44** supports the entire structure. An inner, upper surface of the plate **32b** is brought into contact with lower surfaces of the cores **10** to transfer magnetic fluxes therebetween, as will be described more specifically further below.

[0040] The transformer **30** operates in the following manner. As an electric current passes through each primary winding **36a** of the coil block **36,** a magnetic flux is generated and propagates along the corresponding core **10** between the upper and lower plates **32a** and **32b.** Arrows **46, 48** and **50** show fluxes generated in the three cores **10,** respectively. The magnetic flux flowing through the column **10** generates an induced voltage in the secondary winding **36b** of the corresponding coil block **36.** The device having this structure thus functions as a three-phase transformer.

[0041] Thus, the electric current, for example, with the working frequency of50Hz, is supplied from a power source (not shown) to a terminal of coil of the primary winding **36a,** and, whilst passing through the coil turns, creates the basic magnetic flux **46.** Assuming, for example, that at a given moment the flux **46** flows up. Then, the flux **46** is divided into two identical fluxes **52** and **54** in the plate **32a.** These fluxes **52** and **54** flow along two identical portions of the toroidal plate **32a,** and, then, flow down through the two other cores **10.** The flux **52** changes into flux **48,** and the flux **54** changes into the flux **50** passing down through the cores **10.** Then, the fluxes **48** and **50** flow along two equal paths of the toroidal plate **32b.** Whilst passing along the toroidal plate **32b,** the flux **48** changes into a flux **56,** and the flux **50** changes into a flux **58.** The fluxes **56** and **58** are transferred into the core **10** forming the sum flux **46,** which flows up. Thus, the magnetic flux loop is closed. The fluxes of the other phases of the transformer flow in the similar way summing up the total magnetic flux.

[0042] The plates **32a** and **32b** could have a circular shape. In this case, the flux streams **52, 54, 56** and **58** will flow along circular paths therein. In the example of Fig. 4, each of the plates **32a** and **32b** is shaped like an equilateral triangle with rounded sides and corners. This results in a shorter path for the flux streams in the plates between the cores **10,** i.e., the shape of the flux streams is closer to a straight line. This enables to achieve a lower magnetic reluctance, or better conductance of the magnetic flux.

[0043] Those skilled in the art will readily appreciate that various modifications and changes can be applied to the preferred embodiments of the invention as hereinbefore exemplified without departing from its scope as defined in and by the appended claims.

Claims

1. A transformer core (10) to be used in a power distribution transformer, the transformer core (10) having a desired height (L) and being of a substantially cylindrical toroidal shape in the form of a multi-layer structure (12) wound about a central axis (14) of the toroid, each layer in the structure (12) being composed of a predetermined number of magnetic strips (S) arranged along said central axis (14) with air gaps (18) naturally existing between each two adjacent strips of the layer, the predetermined number of the strips being such that the sum of the widths (1) of said strips is substantially equal to said desired height (L) of the core (10), the transformer core (10) being **characterized in that**
a required number n of layers in said structure is defined by the magnetic properties of the strips to satisfy a relation $n \geq B_w/(B_{sat}-B_w)$, wherein B_w is a working value of a magnetic induction, and B_{sat} is a saturation value of the magnetic induction, and
the layers are shifted with respect to each other a predetermined distance in a direction along said central axis such that each of the air gaps in one layer is overlapped by ***(n-1)*** strips of the other layers of the structure.

2. The transformer core (10) according to Claim 1, wherein said magnetic strips (S) are made of amorphous metals.

3. The transformer core (10) according to Claim 2, wherein the working value of the magnetic induction and the saturation value of the magnetic induction of the amorphous strip are, respectively, about 1.35T and 1.55T, the number of layers being no less than 7.

4. A method of manufacturing a transformer core (10) to be used in a power distribution transformer, wherein the transformer core (10) has a desired height (L) and is formed of a multi-layer structure (12) of magnetic strips (S) wound so as to create a resultant substantially cylindrical toroidal winding of the core, said multi-layer structure (12) including a predetermined number (n) of layers each including a predetermined number of said magnetic strips (S), the method being **characterized in that**:

(a) the number n of said layers in the structure (12) is specified in accordance with magnetic properties of the strips to satisfy a relation $n \geq B_w/(B_{sat}-B_w)$, wherein B_w is a working value of a magnetic induction, and B_{sat} is a saturation value of the magnetic induction;

(b) each of the layers is prepared from said predetermined number of the parallel magnetic strips (S), with air gaps (18) naturally existing between each two adjacent strips in the layer;
(c) said multi-layer structure (12) is wound about a central axis (14) of a mandrel (16) supporting the core during the manufacture, by simultaneously feeding the n layers in a manner that the layers of the core are shifted with respect to each other a predetermined distance along said central axis such that each of the air gaps in one layer is overlapped by **(n-1)** strips of the other layers of the structure.

5. The method according to Claim 4, wherein the preparation of each of the layers comprises winding the strips on a bobbin (B) such that a sum of widths (1) of the strips is substantially equal to the desired height (L) of the core (10), the bobbins being aligned in a spaced-apart parallel relationship, such that the layers on the bobbins are shifted with respect to each other said predetermined distance along the axis of the bobbin.

6. The method according to Claim 4, wherein edges of at least some of the wound layers are cut such that extreme strips on said bobbins are of different widths as compared to that of identical intermediate strips on the bobbins.

7. The method according to Claim 4, wherein the preparation of the layers comprises winding identical layers of the strips on bobbins and accommodating the bobbins in a manner to provide the shifting of the layers with respect to each other.

8. The method according to Claim 7, and also comprising the step of cutting opposite ends of the resultant core so as to planarize its top and bottom surfaces.

9. An apparatus (20) for manufacturing a transformer core (10) to be used in a power distribution transformer, wherein the transformer core (10) has a desired height (L) and is formed of a multi-layer structure (12) of magnetic strips (S) wound so as to create a substantially cylindrical toroidal winding of the core, the apparatus **characterized in that** it comprises:

i. a required number of bobbins (B), each carrying a predetermined number of the magnetic strips (S) for a corresponding one of the layers, the strips being wound on the bobbin and arranged along an axis thereof with small air gaps (18) naturally existing between each two adjacent strips, wherein the required number (n) of the layers is defined by magnetic properties of the strips to satisfy a relation $n \geq B_w/(B_{sur}-B_w)$, wherein B_w is a working value of a magnetic

induction, and B_{sat} is a saturation value of the magnetic induction;
ii. a drive assembly for driving the simultaneous movement of the strips layers from the bobbins onto a mandrel supporting the transformer core (10); and
iii. a guiding assembly (22) for guiding the winding of the fed layers about a central axis (14) of the mandrel (16) with a required density between the layers,

wherein the layers of the core (10) are shifted with respect to each other a predetermined distance along said central axis of the mandrel such that each of the air gaps in one layer is overlapped by **(n-1)** strips of the other layers.

10. The apparatus according to Claim 9, wherein the bobbins are aligned in a spaced-apart parallel relationship along an axis perpendicular to the axis of the bobbin, and the layers on the bobbins are shifted with respect to each other said predetermined distance along the axis of the bobbin.

11. The apparatus according to Claim 9, wherein the strips of different layers are arranged on respective bobbins in a similar manner, and the bobbins are aligned in a spaced-apart parallel relationship along an axis perpendicular to the axis of the bobbin, being shifted with respect to each other said predetermined distance along an axis parallel to the axis of the bobbin.

12. The apparatus according to Claim 9, wherein the driving assembly is associated with a shaft of the mandrel for driving revolution thereof.

13. The apparatus according to Claim 9, wherein the driving assembly is associated with the bobbins for providing rotation thereof about the axis of the mandrel.

14. The apparatus according to Claim 9, wherein the guiding assembly (22) comprises width limiting rollers (26) accommodated at opposite ends of the mandrel (16).

15. A three-phase transformer (30) comprising a magnetic circuit (32a, 32b, 10) and three coil blocks (36), wherein the magnetic circuit comprises two spaced-apart, parallel, plate-like elements (32a, 32b); and three spaced-apart, parallel transformer cores (10), each constructed according to any one of Claims 1 to 3, and carrying the corresponding one of said three coil blocks (36) and serving for the corresponding one of the three phases, wherein the columns (10) are substantially perpendicular to the plate-like elements (32a, 32b) and are enclosed therebetween such as to form a spatial symmetrical structure about a central axis (CA) of the transformer (30).

Patentansprüche

1. Ein Transformatorkern (10), der in einem Energieverteiler-Transformator verwendet werden soll, wobei der Transformatorkern (10) eine gewünschte Höhe (L) und eine im Wesentlichen zylindrische Ringform in Form einer Mehrschicht-Struktur (12) hat, die um eine Mittelachse (14) des Rings gewickelt ist, wobei jede Schicht in der Struktur (12) aus einer vorbestimmten Anzahl von Magnetstreifen (S) besteht, die entlang der Mittelachse (14) angeordnet sind, wobei natürlicherweise Luftspalte (18) zwischen jeden zwei benachbarten Streifen der Schicht vorhanden sind, wobei die vorbestimmte Anzahl der Streifen derart ist, dass die Summe der Breiten (1) der Streifen im Wesentlichen gleich mit der gewünschten Höhe (L) des Kerns (10) ist, wobei der Transformatorkern (10) **dadurch gekennzeichnet ist, dass** eine erforderliche Anzahl ***n*** von Schichten in der Struktur bestimmt wird durch die magnetischen Eigenschaften der Streifen, um einer Beziehung $n \geq B_w / (B_{sat} - B_w)$ zu entsprechen, worin B_w ein Arbeitswert einer magnetischen Induktion ist und B_{sat} ein Sättigungswert der magnetischen Induktion ist, und die Schichten im Verhältnis zueinander über einen vorbestimmten Abstand in eine Richtung entlang der Mittelachse verschoben sind, sodass jeder der Luftspalte in einer Schicht durch ***(n-1)*** Streifen der anderen Schichten der Struktur überlagert ist.

2. Der Transformatorkern (10) gemäß Anspruch 1, worin die Magnetstreifen (S) aus amorphen Metallen hergestellt sind.

3. Der Transformatorkern (10) gemäß Anspruch 2, worin der Arbeitswert der magnetischen Induktion und der Sättigungswert der magnetischen Induktion des amorphen Streifens ungefähr 1,35T beziehungsweise 1,55T beträgt, wobei die Anzahl der Schichten nicht weniger als 7 beträgt.

4. Ein Verfahren zur Herstellung eines Transformatorkerns (10), der in einem Energieverteiler-Transformator verwendet werden soll, worin der Transformatorkern (10) eine gewünschte Höhe (L) hat und aus einer Mehrschicht-Struktur (12) von Magnetstreifen (S) gebildet ist, die gewickelt sind, um eine resultierende im Wesentlichen zylindrische ringförmige Wicklung des Kerns zu erzeugen, wobei die Mehrschicht-Struktur (12) eine vorbestimmte Anzahl (n) von Schichten einschließt, von denen jede eine vorbestimmte Anzahl der Magnetstreifen (S) einschließt, wobei das Verfahren **dadurch gekennzeichnet ist, dass**

(a) die Anzahl ***n*** der Schichten in der Struktur (12) in Übereinstimmung mit magnetischen Eigenschaften der Streifen angegeben wird, um einer Beziehung $n \geq B_w / (B_{sat} - B_w)$ zu entsprechen, worin B_w ein Arbeitswert einer magnetischen Induktion ist und B_{sat} ein Sättigungswert der magnetischen Induktion ist;
(b) jede der Schichten aus der vorbestimmten Anzahl der parallelen Magnetstreifen (S) hergestellt ist, wobei natürlicherweise Luftspalte (18) zwischen jeden zwei benachbarten Streifen in der Schicht vorhanden sind;
(c) die Mehrschicht-Struktur (12) um eine Mittelachse (14) eines Dorns (16) gewickelt ist, welcher den Kern während der Herstellung hält, durch gleichzeitiges Einführen der ***n*** Schichten auf eine Art und Weise, dass die Schichten des Kerns zueinander um einen vorbestimmten Abstand entlang der Mittelachse verschoben sind, sodass jeder der Luftspalte in einer Schicht durch **(n-1)** Streifen der anderen Schichten der Struktur überlagert wird.

5. Das Verfahren gemäß Anspruch 4, worin die Herstellung jeder der Schichten das Wickeln der Streifen auf eine Spule (B) umfasst, sodass eine Summe von Breiten (1) der Steifen im Wesentlichen gleich der gewünschten Höhe (L) des Kerns (10) ist, wobei die Spulen in einem beabstandeten parallelen Verhältnis ausgerichtet sind, sodass die Schichten auf den Spulen im Verhältnis zueinander um den vorbestimmten Abstand entlang der Achse der Spule verschoben sind.

6. Das Verfahren gemäß Anspruch 4, worin Kanten mindestens einiger der gewickelten Schichten so geschnitten sind, dass äußere Streifen auf den Spulen verschiedene Breiten haben im Vergleich zu derjenigen von identischen intermediären Streifen auf den Spulen.

7. Das Verfahren gemäß Anspruch 4, worin die Herstellung der Schichten das Wickeln identischer Schichten der Streifen auf Spulen und das Anordnen der Spulen auf eine solche Art und Weise umfasst, dass für die Verschiebung der Schichten im Verhältnis zueinander gesorgt wird.

8. Das Verfahren gemäß Anspruch 7, das auch den Schritt des Schneidens gegenüberliegender Enden des resultierenden Kerns zum Abflachen seiner oberen und unteren Oberflächen umfasst.

9. Eine Vorrichtung (20) zur Herstellung eines Transformatorkerns (10), der in einem Energieverteiler-Transformator verwendet werden soll, worin der Transformatorkern (10) eine gewünschte Höhe (L) hat und aus einer Mehrschicht-Struktur (12) von Magnetstreifen (S) gebildet ist, die so gewickelt sind, dass sie eine im Wesentlichen zylindrische ringförmige Wicklung des Kerns erzeugen, wobei die Vorrichtung **dadurch gekennzeichnet ist, dass** sie Folgendes umfasst:

i) eine erforderliche Anzahl von Spulen (B), von denen jede eine vorbestimmte Anzahl der Magnetstreifen (S) für eine entsprechende der Schichten trägt, wobei die Streifen auf die Spule gewickelt und entlang einer Achse davon angeordnet sind, wobei natürlicherweise kleine Luftspalte (18) zwischen jeden zwei benachbarten Streifen vorhanden sind, worin die erforderliche Anzahl (n) der Schichten durch magnetische Eigenschaften der Streifen bestimmt wird, um einer Beziehung $n \geq B_w / (B_{sat} - B_w)$ zu entsprechen, worin B_w ein Arbeitswert einer magnetischen Induktion ist und B_{sat} ein Sättigungswert der magnetischen Induktion ist;
ii) eine Antriebseinheit zum Antreiben der gleichzeitigen Bewegung der Streifenschichten von den Spulen auf einen Dorn, welcher den Transformatorkern (10) hält; und
iii) eine Führungseinheit (22) zum Führen der Wicklung der eingeführten Schichten um eine Mittelachse (14) des Dorns (16) mit einer erforderlichen Dichte zwischen den Schichten,

worin die Schichten des Kerns (10) im Verhältnis zueinander um einen vorbestimmten Abstand entlang der Mittelachse des Dorns verschoben sind, sodass jeder der Luftspalte in einer Schicht durch **(n-1)** Streifen der anderen Schichten überlagert wird.

10. Die Vorrichtung gemäß Anspruch 9, worin die Spulen in einem beabstandeten parallelen Verhältnis entlang einer Achse ausgerichtet sind, die rechtwinklig zur Achse der Spule ist, und die Schichten auf den Spulen um den vorbestimmten Abstand entlang der Achse der Spule zueinander verschoben sind.

11. Die Vorrichtung gemäß Anspruch 9, worin die Streifen verschiedener Schichten auf ähnliche Art und Weise auf entsprechenden Spulen angeordnet sind und die Spulen in einem beabstandeten parallelen Verhältnis entlang einer Achse ausgerichtet sind, die rechtwinklig zur Achse der Spule ist, wobei sie um den vorbestimmten Abstand entlang einer Achse parallel zur Achse der Spule im Verhältnis zueinander verschoben sind.

12. Die Vorrichtung gemäß Anspruch 9, worin die Antriebseinheit mit einer Welle des Dorns verbunden ist, um seine Rotation anzutreiben.

13. Die Vorrichtung gemäß Anspruch 9, worin die Antriebseinheit mit den Spulen verknüpft ist, um für die Rotation davon um die Achse des Dorns zu sorgen.

14. Die Vorrichtung gemäß Anspruch 9, worin die Führungseinheit (22) Breitenbegrenzungsrollen (26) umfasst, die an gegenüberliegenden Enden des Dorns (16) angebracht sind.

15. Ein Drehstromtransformator (30), der einen Magnetkreis (32a, 32b, 10) und drei Spulenblöcke (36) umfasst, worin der Magnetkreis zwei beabstandete, parallele, plattenähnliche Elemente (32a, 32b) umfasst; und drei beabstandete parallele Transformatorkerne (10), von denen jeder gemäß einem beliebigen der Ansprüche 1 bis 3 konstruiert ist und den entsprechenden der drei Spulenblöcke (36) trägt und für die jeweilige der drei Phasen dient, worin die Säulen (10) im Wesentlichen rechtwinklig zu den plattenähnlichen Elementen (32a, 32b) sind und so dazwischen eingeschlossen sind, dass sie eine räumliche symmetrische Struktur um eine Mittelachse (CA) des Transformators (30) herum bilden.

Revendications

1. Noyau de transformateur (10) destiné à être utilisé dans un transformateur de distribution de puissance, le noyau de transformateur (10) ayant une hauteur (L) souhaitée et ayant une forme toroïdale sensiblement cylindrique se présentant sous la forme d'une structure multi-couche (12) enroulée autour d'un axe central (14) du tore, chaque couche dans la structure (12) étant composée d'un nombre prédéterminé de bandes magnétiques (S) agencées le long dudit axe central (14) avec des entrefers (18) existant naturellement entre chaque deux bandes adjacentes de la couche, le nombre prédéterminé des bandes étant tel que la somme des largeurs (1) desdites bandes est sensiblement égale à ladite hauteur (L) souhaitée du noyau (10), le noyau de transformateur (10) étant **caractérisé en ce que** :
un nombre requis n de couches dans ladite structure est défini par les propriétés magnétiques des bandes pour satisfaire une relation $n \geq B_w / (B_{sat} - B_w)$, dans laquelle B_w est une valeur de travail d'une induction magnétique et B_{sat} est une valeur de saturation de l'induction magnétique, et
les couches sont décalées l'une par rapport à l'autre sur une distance prédéterminée dans une direction le long dudit axe central, de sorte que chacun desdits entrefers dans une couche est chevauché par (n - 1) bandes des autres couches de la structure.

2. Noyau de transformateur (10) selon la revendication 1, dans lequel lesdites bandes magnétiques (S) sont fabriquées à partir de métaux amorphes.

3. Noyau de transformateur (10) selon la revendication 2, dans lequel la valeur de travail de l'induction magnétique et la valeur de saturation de l'induction magnétique de la bande amorphe sont respectivement environ 1,35 T et 1,55 T, le nombre des couches étant non inférieur à 7.

4. Procédé de fabrication d'un noyau de transformateur (10) destiné à être utilisé dans un transformateur de distribution de puissance, dans lequel le noyau de transformateur (10) a une hauteur (L) souhaitée, et est formé avec une structure multi-couche (12) de bandes magnétiques (S) enroulées de façon à créer un enroulement toroïdal sensiblement cylindrique résultant du noyau, ladite structure multi-couche (12) comprenant un nombre prédéterminé (n) de couches, comprenant chacune un nombre prédéterminé desdites bandes magnétiques (S), le procédé étant **caractérisé en ce que** :

(a) le nombre n desdites couches dans la structure (12) est spécifié selon les propriétés magnétiques des bandes pour satisfaire une relation $n \geq B_w / (B_{sat} - B_w)$, dans laquelle B_w est une valeur de travail d'une induction magnétique et B_{sat} est une valeur de saturation de l'induction magnétique ;
(b) chacune des couches est préparée à partir d'un nombre prédéterminé de bandes magnétiques (S) parallèles, avec des entrefers (18) qui existent naturellement entre chaque deux bandes adjacentes dans la couche ;
(c) ladite structure (12) à plusieurs couches est enroulée autour d'un axe central (14) d'un mandrin (16) supportant le noyau pendant la fabrication, en alimentant simultanément les n couches, de sorte que les couches du noyau sont décalées les unes par rapport aux autres sur une distance prédéterminée le long dudit axe central, de sorte que chacun des entrefers dans une couche est chevauché par (n - 1) bandes des autres couches de la structure.

5. Procédé selon la revendication 4, dans lequel la préparation de chacune des couches comprend l'enroulement des bandes sur une bobine (B), de sorte qu'une somme des largeurs (1) des bandes est sensiblement égale à la hauteur (L) souhaitée du noyau (10), les bobines étant alignées selon une relation parallèle espacée, de sorte que les couches sur les bobines sont décalées les unes par rapport aux autres sur ladite distance prédéterminée le long de l'axe de la bobine.

6. Procédé selon la revendication 4, dans lequel les bords d'au moins certaines des couches enroulées sont coupés, de sorte que les bandes extrêmes sur lesdites bobines sont de largeurs différentes par rapport à celles des bandes intermédiaires identiques sur les bobines.

7. Procédé selon la revendication 4, dans lequel la préparation des couches comprend l'enroulement des couches identiques des bandes sur les bobines, et la réception des bobines, afin de réaliser le décalage des couches les unes par rapport aux autres.

8. Procédé selon la revendication 7, comprenant également l'étape consistant à couper les extrémités opposées du noyau résultant, afin d'aplatir ses surfaces supérieure et inférieure.

9. Dispositif (20) pour fabriquer un noyau de transformateur (10) destiné à être utilisé dans un transformateur de distribution de puissance, dans lequel le noyau de transformateur (10) a une hauteur (L) souhaitée, et est formé avec une structure multi-couche (12) de bandes magnétiques (S) enroulées de façon à créer un enroulement toroïdal sensiblement cylindrique du noyau, le dispositif étant **caractérisé en ce qu'**il comprend :

i. un nombre requis de bobines (B), chacune supportant un nombre prédéterminé de bandes magnétiques (S) pour une couche correspondante des couches, les bandes étant enroulées sur la bobine et agencées le long de son axe avec de petits entrefers (18) qui existent naturellement entre chaque deux bandes adjacentes, dans lequel le nombre requis (n) de couches est défini par les propriétés magnétiques des bandes pour satisfaire une relation $n \geq B_w / (B_{sat} - B_w)$, dans laquelle B_w est une valeur de travail d'une induction magnétique et B_{sat} est une valeur de saturation de l'induction magnétique ;
ii. un ensemble d'entraînement pour entraîner le mouvement simultané des couches de bandes à partir des bobines sur un mandrin supportant le noyau de transformateur (10) ; et
iii. un ensemble de guidage (22) pour guider l'enroulement des couches alimentées autour d'un axe central (14) du mandrin (16) avec une densité requise entre les couches,

dans lequel les couches du noyau (10) sont décalées les unes par rapport aux autres sur une distance prédéterminée le long dudit axe central du mandrin, de sorte que chacun des entrefers dans une couche est chevauché par (n - 1) bandes des autres couches.

10. Dispositif selon la revendication 9, dans lequel les bobines sont alignées selon une relation espacée parallèle le long d'un axe perpendiculaire à l'axe de la bobine, et les couches sur les bobines sont décalées les unes par rapport aux autres sur ladite distance prédéterminée le long de l'axe de la bobine.

11. Dispositif selon la revendication 9, dans lequel les bandes des différentes couches sont agencées sur des bobines respectives d'une manière similaire, et les bobines sont alignées selon une relation parallèle espacée le long d'un axe perpendiculaire à l'axe de la bobine, en étant décalées les unes par rapport aux autres sur ladite distance prédéterminée le long d'un axe parallèle à l'axe de la bobine.

12. Dispositif selon la revendication 9, dans lequel l'ensemble d'entraînement est associé à un arbre du mandrin pour sa révolution d'entraînement.

13. Dispositif selon la revendication 9, dans lequel l'ensemble d'entraînement est associé avec les bobines pour proposer leur rotation autour de l'axe du mandrin.

14. Dispositif selon la revendication 9, dans lequel l'ensemble de guidage (22) comprend des rouleaux de limitation de largeur (26) logés au niveau des extrémités opposées du mandrin (16).

15. Transformateur triphasé (30), comprenant un circuit magnétique (32a, 32b, 10) et trois blocs hélicoïdaux (36), dans lequel le circuit magnétique comprend deux éléments en forme de plaque parallèles espacés (32a, 32b) ; et trois noyaux de transformateur (10) parallèles espacés, chacun construit selon l'une quelconque des revendications 1 à 3, et supportant l'un desdits trois blocs hélicoïdaux (36) et servant pour la phase correspondante des trois phases, dans lequel les colonnes (10) sont sensiblement parallèles aux éléments en forme de plaque (32a, 32b), et sont enfermées entre eux pour former une structure symétrique spatiale autour d'un axe central (CA) du transformateur (30).

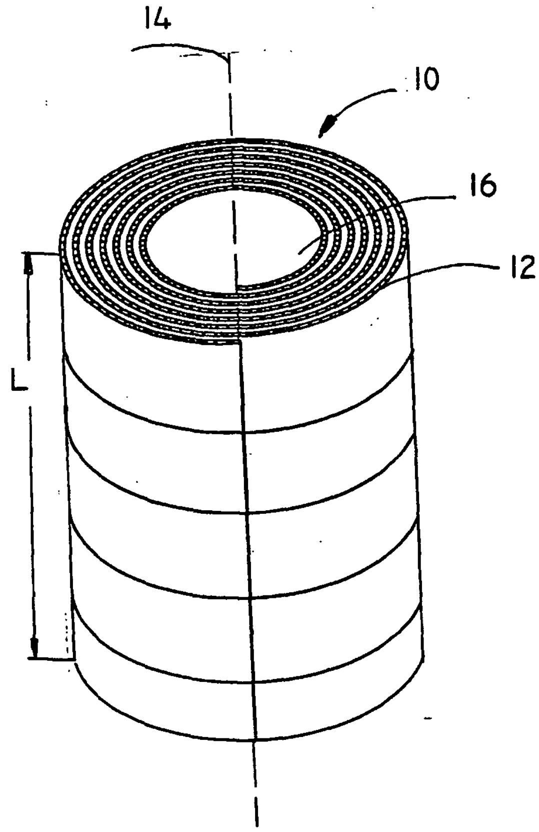
14
10
16
12
L

FIG. 1A

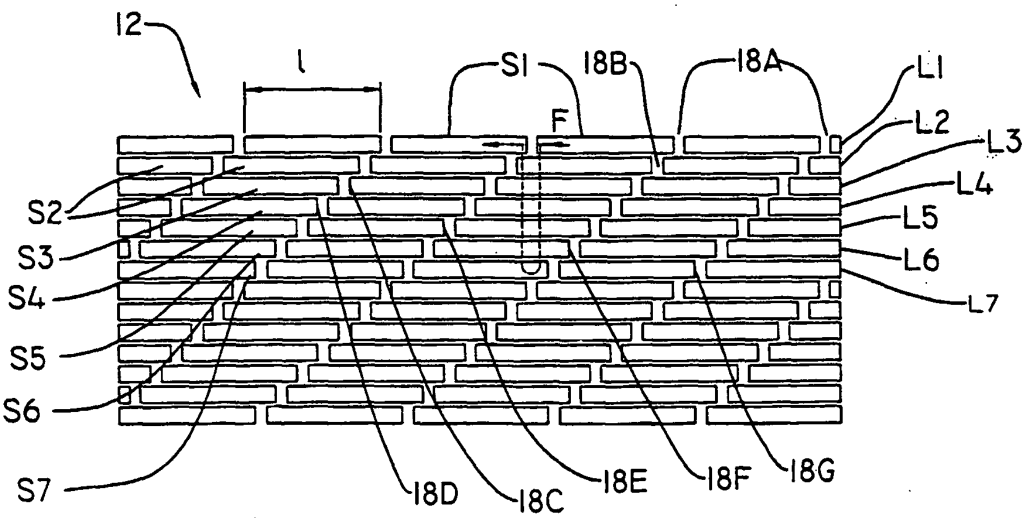
12
l
S1
18B
18A
L1
L2
L3
L4
L5
L6
L7
F
S2
S3
S4
S5
S6
S7
18D
18C
18E
18F
18G

FIG. 2

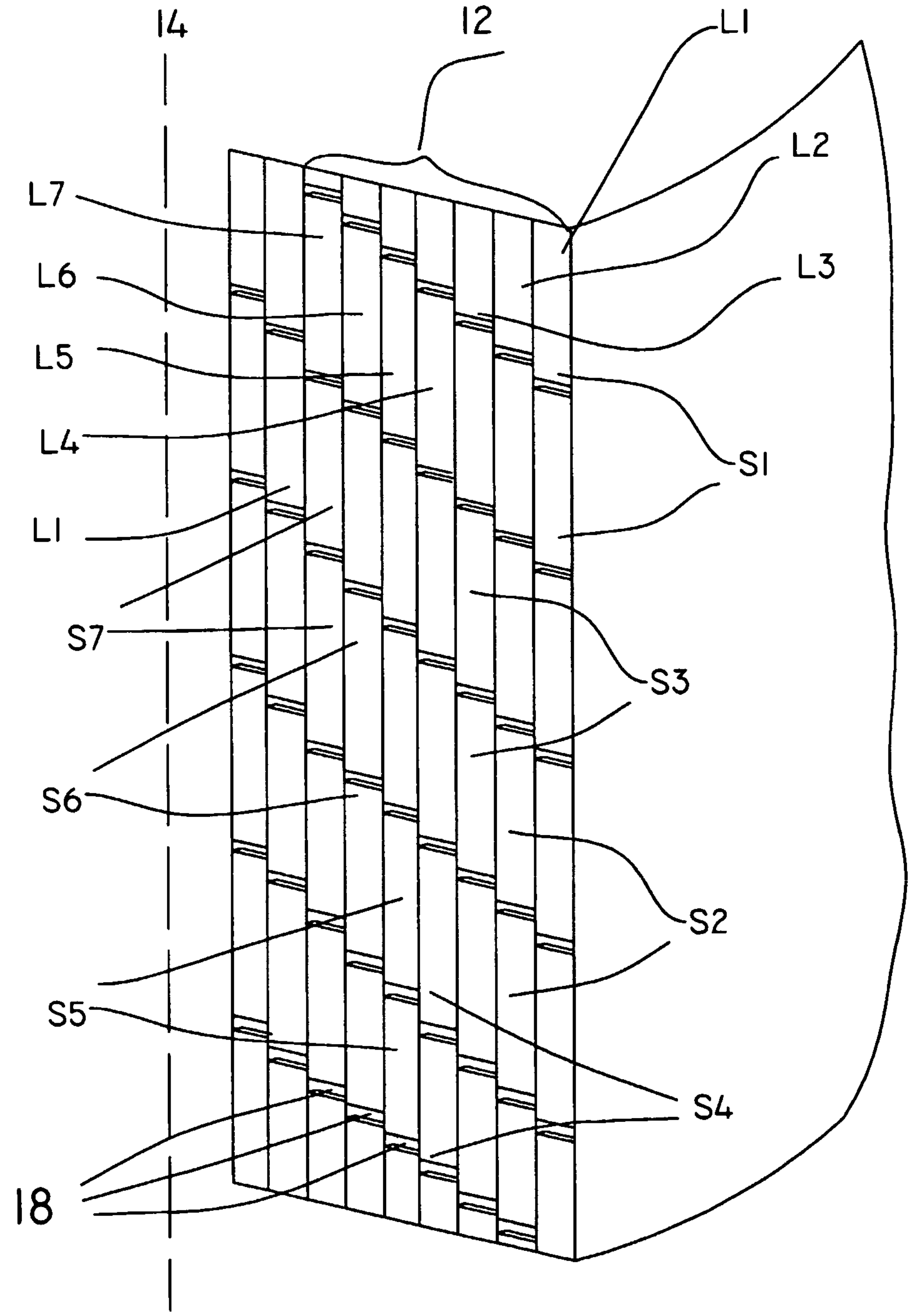

FIG. 1B

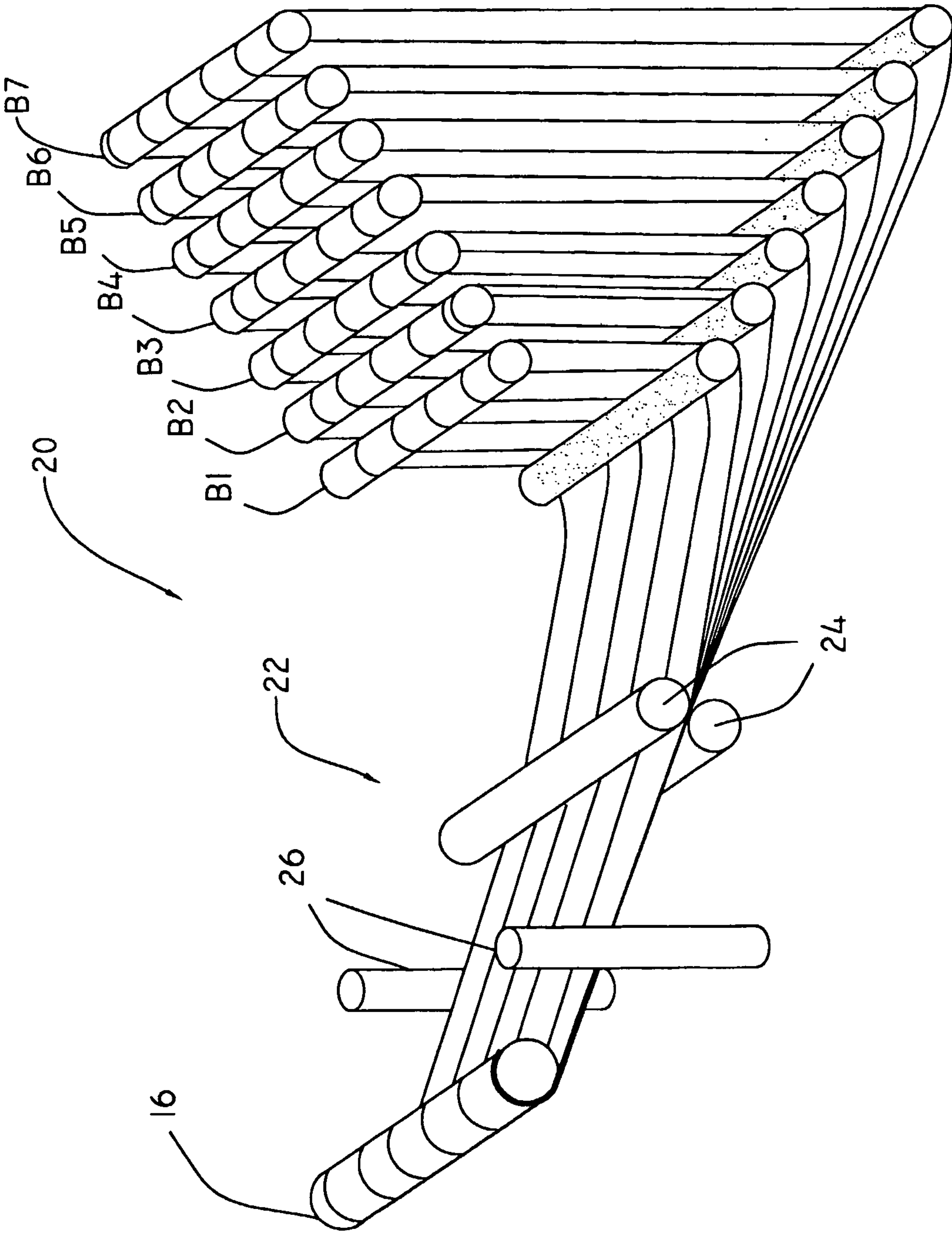

FIG. 3

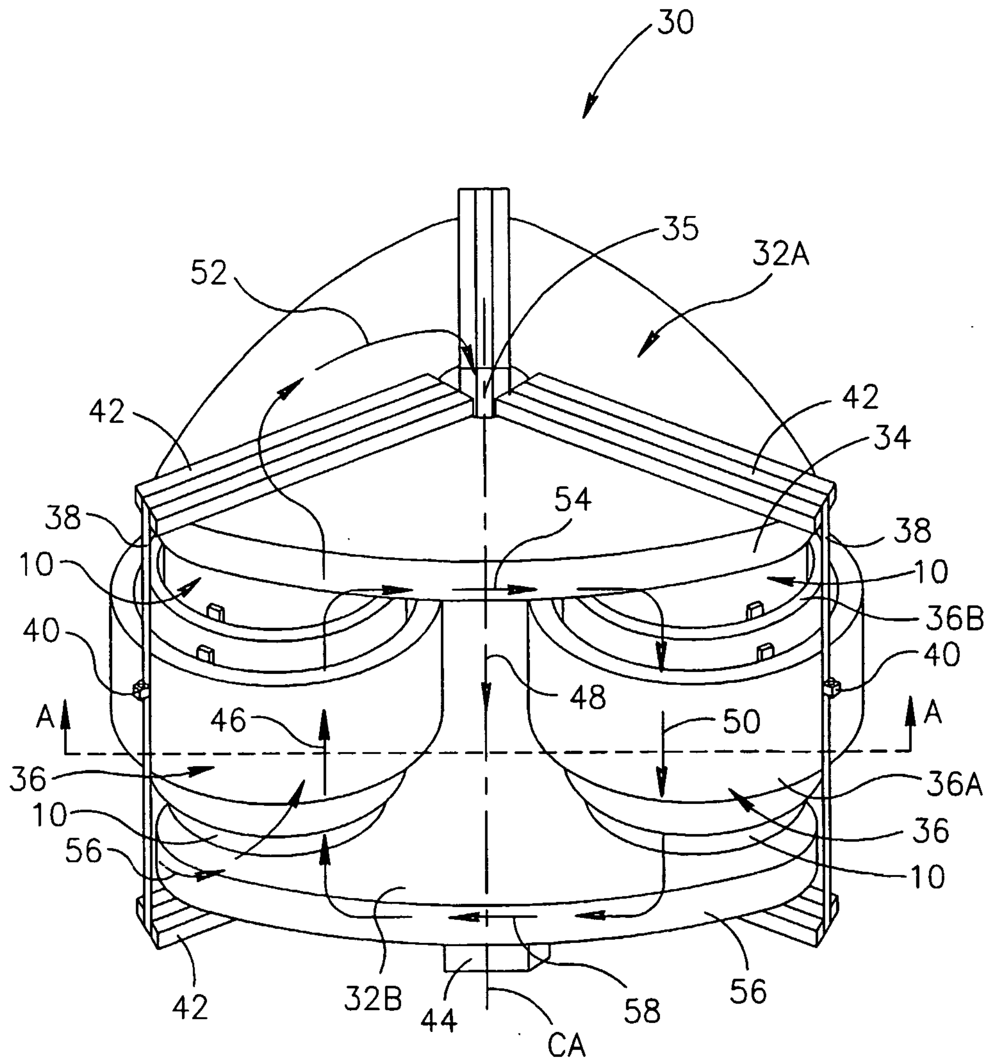
30
35
32A
52
42
42
34
54
38
38
10
10
36B
40
40
48
A
46
50
A
36
36A
10
36
56
10
42
32B
44
58
56
CA

FIG.4