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(54) **METHOD AND CONDUCTOR STRUCTURE FOR MANUFACTURING AN ELECTRIC WINDING OF AN ELECTROMAGNETIC INDUCTION APPARATUS**

VERFAHREN UND LEITERSTRUKTUR ZUR HERSTELLUNG EINER ELEKTRISCHEN WICKLUNG EINER ELEKTROMAGNETISCHEN INDUKTIONSVORRICHTUNG

PROCÉDÉ ET STRUCTURE DE CONDUCTEUR POUR FABRIQUER UN ENROULEMENT ÉLECTRIQUE D'UN APPAREIL À INDUCTION ÉLECTROMAGNÉTIQUE

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Description

[0001] The present invention relates to the field of electromagnetic induction apparatuses for electric power transmission and distribution grids, for example power transformers.

[0002] More particularly, the present invention relates to a method and a conductor structure for manufacturing an electric winding of an electromagnetic induction apparatus.

[0003] Electric windings of electromagnetic induction apparatuses may be manufactured at industrial level according to various methods.

[0004] A widely used method consists in winding a conductor around a winding direction, so that the electric winding has a plurality of adjacent turns arranged around said winding direction.

[0005] As it is known, generally, electric windings for electromagnetic induction apparatuses have axial and radial channels to ensure the passage of an electrically insulating medium (e.g. insulating oil) among the turns.

[0006] Traditionally, axial channels of an electric winding are obtained by arranging insulating blocks oriented in parallel to the winding direction.

[0007] Electrically insulating spacers interposed between adjacent turns of the electric winding and oriented radially with respect to the winding direction instead define the radial channels.

[0008] According to most traditional solutions of the state of the art, the above-mentioned insulating spacers are inserted manually between each pair of adjacent turns, during the winding process. According to most recent manufacturing methods, the insulating spacers are fixed along a suitable lateral surface of a conductor intended to form the turns of the electric winding. The conductor structure so obtained is then wound around a winding direction. In this way, insulating spacers take position between each pair of adjacent turns of said electric winding. State-of-the-art electric windings for electromagnetic induction apparatuses generally perform their functions in a satisfying way. However, there are still some critical aspects.

[0009] Electric windings, in fact, often show deformed turns, particularly at the regions where radial channels are formed. Basically, this phenomenon is due to the fact that, in operation, an electric winding is subject to huge compressive forces along directions substantially parallel to its winding direction.

[0010] The above-illustrated technical issue may lead to a dangerous unbalancing condition of the overall winding structure, which may cause its collapse in certain operating conditions, e.g. when short-circuit currents flow along the electric winding and this latter is subject to huge mechanical stresses.

[0011] Document JP 2002 110434 A relates to a transposed conductor, wherein a plurality of wire conductors covered with insulating coating films of thermally fused bondability is laminated upon one another by dislocating

the conductors from each other, so that the laminated positions of the conductors may successively change in the lengthwise direction and insulating plates are put on the side faces of the conductors which are parallel in the direction of lamination.

[0012] The main aim of the present invention is to provide a method and a conductor structure for manufacturing an electric winding of an electromagnetic induction apparatus, which allows the above-mentioned critical aspects to be overcome or mitigated.

[0013] Within this aim, another object of the present invention is providing a method and a conductor structure for manufacturing an electric winding, which allow obtaining an electric winding with a high structural balancing and a high resistance to mechanical stresses.

[0014] Another object of the present invention is providing a method and a conductor structure for manufacturing an electric winding, which are relatively easy and inexpensive to implement at industrial level.

[0015] This aim and these objects, together with other objects that will be more apparent from the subsequent description and from the accompanying drawings, are achieved, according to the invention, by a method for manufacturing an electric winding of an electromagnetic induction apparatus, according to claim 1 and to the related dependent claims.

[0016] In a general definition, the method according to the invention comprises the following steps:

- providing a conductor structure including a conductor element extending longitudinally along a main extension direction and a plurality of spacer elements made of electrically insulating material. Said spacer elements are fixed to at least a lateral surface of said conductor element and are arranged spaced one from another along said a lateral surface;
- forming an electric winding by means of said conductor structure, said conductor structure extending axially along a winding direction and having a plurality of turns arranged around said winding direction.

[0017] According to the invention, each turn of said electric winding is formed by a corresponding longitudinal portion of said conductor element.

[0018] According to the invention, said spacer elements are interposed between adjacent turns of said electric winding at opposite sides of said turns.

[0019] According to the invention, each spacer element, which is positioned at one side of a turn, is partially overlapped with two other spacer elements, which are positioned at the opposite side of said turn, the overlapping direction being parallel to the winding direction.

[0020] Conveniently, for at least a turn of the electric winding:

- a spacer element at a first side of said turn is overlapped with at least two spacer elements at a second side of said turn, which is opposite to said first side;

and

- a spacer element at a second side of said turn is overlapped with at least two spacer elements at a first side of said turn.

[0021] Conveniently, each first spacer element at the first side of a turn has at least two overlapping portions, each overlapped, according to suitable overlapping directions, with a corresponding overlapping portion of a different second spacer element at the second side of said turn. Conveniently, each second spacer element at the second side of a turn has at least two overlapping portions, each overlapped, according to suitable overlapping directions, with a corresponding overlapping portion of a different first spacer element at the second side of said turn.

[0022] Conveniently, said overlapping directions are parallel to the winding direction of the electric winding.

[0023] According to an embodiment of the invention, said conductor structure comprises first and second spacer elements with an elongated shape fixed to lateral surfaces of said conductor element along first and second fixing directions transversal to the main extension direction of said conductor element.

[0024] According to a possible variant of the invention, said first fixing directions or said second fixing directions are perpendicular to the main extension direction of said conductor element. According to another possible variant of the invention, both said first fixing directions and said second fixing directions are not perpendicular to the main extension direction of said conductor element.

[0025] According to some embodiments of the invention, said conductor structure comprises first and second spacer elements fixed to said conductor element on opposite lateral surfaces of said conductor element, along the main extension direction said conductor element.

[0026] According to other embodiments of the invention, said conductor structure comprises first and second spacer elements fixed to said conductor element on a same lateral surface of said conductor element.

[0027] According to some embodiments of the invention, said conductor structure comprises first spacer elements or second spacer elements made of a single piece of electrically insulating material.

[0028] According to other embodiments of the invention, said conductor structure comprises first spacer elements or second spacer elements made of multiple pieces of electrically insulating material aligned along first fixing directions or second fixing directions, respectively. According to an embodiment of the invention, said spacer elements are fixed to said conductor element by gluing or by means of an electrically insulating tape or by means of an electrically insulating mesh wound around said conductor element.

[0029] According to some embodiments of the invention, said conductor element is a continuously transposed conductor.

[0030] In a further aspect, the present invention relates

to a conductor structure for an electromagnetic induction apparatus according to the following claim 13.

[0031] The conductor structure, according to the invention, comprises:

- a conductor element extending longitudinally along a main extension direction;
- a plurality of spacer elements made of electrically insulating material, said spacer elements being fixed to at least a lateral surface of said conductor element and being arranged spaced one from another along said lateral surface.

[0032] The conductor structure, according to the invention, forms an electric winding extending axially along said winding direction and having a plurality of adjacent turns arranged around said electric winding direction.

[0033] According to the invention, each turn of said electric winding is formed by a corresponding longitudinal portion of said conductor element.

[0034] According to the invention, said spacer elements are interposed between adjacent turns of said electric winding at opposite sides of said turns.

[0035] According to the invention, for at least a turn of said electric winding, each spacer element, which is positioned at a side of said turn, is partially overlapped with two other spacer elements, which are positioned at the opposite side of said turn, the overlapping direction being parallel to the winding direction.

[0036] In yet a further embodiment, the present invention relates to an electric winding for an electromagnetic induction apparatus, according to the following claim 14.

[0037] In yet a further embodiment, the present invention relates to an electromagnetic induction apparatus for electric power transmission and distribution grids according to the following claim 15.

[0038] Preferably, said electromagnetic induction apparatus is an electric transformer for electric power transmission and distribution grids.

[0039] Further characteristics and advantages of the present invention will be more apparent with reference to the description given below and to the accompanying figures, provided purely for explanatory and non-limiting purposes, wherein:

- Fig. 1 schematically shows a conductor element used in the manufacturing method and conductor structure, according to the present invention;
- Fig. 2 schematically shows an electric winding for an electromagnetic induction apparatus obtained by means of the manufacturing method, according to the present invention;
- Figs. 2A, 2B schematically show opposite views of a turn portion of the electric winding of Fig. 2 manufactured according to an embodiment of the method of the invention;
- Fig. 3 schematically shows opposite views of a turn portion of the electric winding of Fig. 2 manufactured

according to an embodiment of the method of the invention;

- Fig. 4 schematically shows opposite views of a turn portion of the electric winding of Fig. 2 manufactured according to another embodiment of the method of the invention;
- Figs 5-8 schematically illustrate some embodiments or parts of a conductor structure, according to the present invention.

[0040] With reference to the aforesaid figures, the present invention relates to method for manufacturing an electric winding 100 of an electromagnetic induction apparatus (not shown) for electric power transmission and distribution grids.

[0041] Such an electromagnetic induction apparatus may be an electric transformer for electric power transmission and distribution grids, for example a power transformer or a distribution transformer.

[0042] The manufacturing method, according to the invention, comprises a step of providing a conductor structure 1 intended to form the electric winding 100 (figures 5-8).

[0043] The conductor structure 1 comprises a conductor element 2 extending longitudinally along a main extension direction L (figure 1).

[0044] Preferably, the conductor element 2 is shaped as an elongated parallelepiped including conductive material.

[0045] Preferably, the conductor element 2 has a shaped section (e.g. a rectangular or square cross section) opposite first and second lateral surfaces 2A, 2B and opposite third and fourth lateral surfaces 2C, 2D.

[0046] According to some embodiments of the invention, the conductor element 2 is a continuously transposed conductor.

[0047] In this case, the conductor element 2 may be manufactured according to the construction shown in figure 1.

[0048] As an example, the conductor element 2 may comprise two or more stacks 21, 22 of conductors, which are placed side by side along the extension direction L of said conductor element. Stacked conductors 20 have portions alternating between the above-mentioned stacks 21, 22. In this way, portions of stacked conductors 20 alternately occupy every possible cross section position along the whole longitudinal extension of the conductor element 2. Stacked conductors 20 may be at least partially covered by electrically insulating material.

[0049] The conductor element 2 may include an insulating separator 23 arranged between the stacks 21, 22 of conductors along the extension direction L of said conductor.

[0050] The conductor element 2 may include an insulating tape or mesh (not shown) wound around the stacked conductors 20 to maintain these latter in position during the winding operations.

[0051] According to other embodiments of the inven-

tion, however, the conductor element 2 may have different constructions (which may be of known type).

[0052] For example, it may include a single conductor, a plurality of conductors arranged side by side or a bundle of twisted conductors.

[0053] As a further example, the conductor element 2 may be formed by one or more conductive bars or by one or more conductive foils or disks.

[0054] According to some embodiments of the invention (not shown), the conductor structure 1 include one or more layers of electrically insulating material arranged in such a way to externally cover the conductors of said conductor element.

[0055] Such an electrically insulating material may be arranged according to solutions of known type. For example, it may be selected in a group of materials comprising: paper, polyester materials, aramid or stabilized-PE materials, fiberglass materials, and the like.

[0056] The conductor structure 1 comprises a plurality of spacer elements 3A, 3B (or spacers 3A, 3B) made of electrically insulating material (figures 5-8).

[0057] Preferably, such an electrically insulating material is selected in a group of materials comprising: pressed paperboard, plastic materials, fiberglass materials, nylon-based materials.

[0058] Preferably, the spacer elements 3A, 3B have an elongated shape, e.g. with a rectangular or parallelogram shape.

[0059] The spacer elements 3A, 3B are fixed to one or more lateral surfaces 2A, 2B of the conductor element 2 transversally with respect to the main extension direction L of said conductor element.

[0060] The spacer elements 3A, 3B are arranged spaced one from another to delimit suitable empty regions 3C along the one or more lateral surfaces 2A, 2B of the conductor element 2.

[0061] According to some embodiments of the invention, the spacer elements 3A, 3B are fixed to the conductor element 2 by gluing.

[0062] The spacers 3A, 3B may be directly fixed to the conductors of the conductor element 2, or on an insulating layer of said conductor element or on an insulating tape or mesh surrounding said conductor element.

[0063] The spacers 3A, 3B may have one surface or two opposite surfaces at least partially covered by glue.

[0064] The glue may be applied as a uniform layer, as a diamond-dot patterned layer, as a circle-dot patterned layer, as a line-patterned layer, as a matrix-patterned layer, and the like.

[0065] Glue may be applied to the spacers 3A, 3B and/or to the corresponding fixing surfaces 2A, 2B of the conductor element 2 in a known manner, for example by spraying, brushing, dusting, by immersion or by applying a prepreg film activatable by UV radiation or heat.

[0066] Special glues designed to withstand high temperatures (e.g. up to 250 °C) may be used. This solution is particularly advantageous when the insulating medium of the electromagnetic induction apparatus is made of

epoxy resin or similar materials.

[0067] The above-describe solutions are quite advantageous. Gluing the spacer elements allows preventing or reducing possible undesired dislocations of said spacer elements. Such dislocations of the spacers 3A, 3B may occur due tangential forces exerted on the winding turns during the operation of the electromagnetic induction apparatus (this phenomenon is also referred to as "spiraling" of the electric winding) or during manufacturing.

[0068] According to other embodiments of the invention, the spacer elements 3A, 3B are fixed to the conductor element 2 by means of an electrically insulating tape or an electrically insulating mesh wound around the conductor itself, e.g. made of a glass-fiber material or polyester.

[0069] Also in this case, the spacers 3A, 3B may be directly fixed on the conductors 20 of the electrical conductor element 2, or on an insulating layer of said conductor or on an insulating tape or mesh surrounding said conductor.

[0070] According to other embodiments of the invention (not shown), the conductor structure of the invention may comprise one or more strips of electrically insulating material (e.g. paper) fixed to corresponding one or more lateral surfaces of the conductor element along the main extension direction L of said conductor. In general, said strips of insulating material may be fixed to the conductor element in a known manner, e.g. by gluing. Conveniently, the above-mentioned spacer elements are fixed to the said strips of electrically insulating material. The assembly so obtained may be wrapped by an insulating conductor or mesh to form the conductor structure.

[0071] According to the method of the invention, once the conductor structure 1 is obtained, it is carried out a step of forming the electric winding 100 by means of the conductor structure 1 described above.

[0072] The electric winding 100 extends axially along the winding direction DW (figure 2).

[0073] Preferably, e.g. when the conductor structure can be suitably bent by means of a suitable bending apparatus, the step of forming the electric winding 100 include winding the conductor structure 1 around the winding direction DW.

[0074] According to alternative embodiments, e.g. when the conductor structure cannot be bent, the step of forming the electric winding 100 may include the step of mechanically connecting separated portions of the conductor structure 1 to form the electric winding 100.

[0075] The electric winding 100 has a plurality of adjacent turns 101 arranged around the winding direction DW (figure 2).

[0076] Each turn 101 is formed by a corresponding longitudinal portion of the conductor element 2 included in the winding structure 1.

[0077] In the electric winding 100, the first and second lateral surfaces 2A, 2B of the conductor element 2 are positioned perpendicular to the winding direction DW and

form first and second sides 101A, 100B of each turn 101, which extend radially with respect to said winding direction, while the third and fourth lateral surfaces 2C, 2D of the conductor element 2 are positioned parallel to the winding direction DW and form third and fourth sides 101A, 100B of each turn 101, which extend parallel and coaxially to said winding direction (figures 2A, 2B).

[0078] In the electric winding 1, the spacer elements 3A, 3B are interposed between adjacent turns 101 at the first and second sides 101A, 100B of these latter. In this way, the spacer elements 3A, 3B extend along radial planes perpendicular to said the winding direction DW (figure 2). The empty regions 3C delimited by the spacer elements 3A, 3B form radial channels 104 of the electric winding 100, which ensure the passage of an electrically insulating medium (e.g. insulating oil) among adjacent turns 101.

[0079] An important aspect of the invention consists in that, in the electric winding 100, each spacer element 3A, 3B at one side 101A, 100B of a turn 101 of the electric winding is partially overlapped with at least two spacer elements 3B, 3A at the opposite side 101B, 100A of said turn (figures 2, 2A, 2B, 3, 4).

[0080] In other words, in the electric winding 100, each spacer element 3A, 3B at a side 101A, 100B of a turn 101 has at least two overlapping portions 30A, 30B, each overlapping with a corresponding overlapping portion 30B, 30A of a spacer element 3B, 3A at the opposite side 101B, 100A of said turn.

[0081] Figures 2A, 2B show opposite views (i.e. related to the opposite sides 101A, 101B) of a portion of a turn 101 of an electric winding 100, manufactured according to an embodiment of the method of the invention.

[0082] The turn 101 is formed by the conductor element 2, which may be manufactured as described above.

[0083] At the first side 101A and at the second side 101B of the turn 101, first spacer elements 3A and second spacer element 3B are respectively positioned spaced one from another to define intermediate empty spaces 3C intended to form the radial channels 104 of the electric winding 100.

[0084] Figure 3 shows opposite views (i.e. related to the opposite sides 100A, 101B) of a portion of a turn 101 of an electric winding 100, manufactured according to an embodiment of the method of the invention.

[0085] According to the example of Figure 3, the spacer elements 3A are oriented according to first fixing directions F1, which are transversal and perpendicular to the main extension direction L (longitudinal axis) of the conductor element 2.

[0086] The spacer elements 3B are instead oriented according to second fixing directions F2, which are transversal and not perpendicular to the main extension direction L of the conductor element 2.

[0087] Figure 4 shows opposite views (i.e. related to the opposite sides 100A, 101B) of a portion of a turn 101 of an electric winding 100, manufactured according to another embodiment of the method of the invention.

[0088] According to the example of Figure 4, both the first and second fixing directions F1 and F2 of the spacer elements 3A and 3B are transversal and not perpendicular to the main extension direction L of the conductor element 2.

[0089] As it is possible to notice, in all the above-illustrated embodiments of the invention, each spacer element 3A at the first side 100A of the turn 101 is overlapped with two spacer elements 3B at the second side 101B of the turn 101.

[0090] In particular, each spacer element 3A has two overlapping portions 30A overlapped with a corresponding overlapping portion 30B of two different spacer elements 3B along suitable overlapping directions parallel to the winding direction DW.

[0091] Similarly, each spacer element 3B at the second side 100B of the turn 101 is overlapped with at least two spacer elements 3A at the first side 101A of the turn 101.

[0092] In particular, each spacer element 3B has two overlapping portions 30B overlapped with a corresponding overlapping portion 30A of two different spacer elements 3A along suitable overlapping directions parallel to the winding direction DW.

[0093] It has been seen that the solution provided by the claimed invention greatly improves the overall resistance of the electric winding 100 to compressive forces as it ensures an optimal structural balancing.

[0094] It is therefore possible to prevent or remarkably mitigate the onset of deformation phenomena of the turns of the electric winding 100 during the operation of the electromagnetic induction apparatus.

[0095] As it can be understood from the examples of figures 3 and 4, the above-mentioned result is achieved by suitably arranging the spacer elements 3A, 3B of the conductor structure 1.

[0096] Preferably, the spacer elements of the conductor structure 1 include first spacer elements 3A with an elongated shape (e.g. as an elongated plate of rectangular shape) fixed to the conductor element 2 along first fixing directions F1 transversal to the main extension direction L of said conductor element.

[0097] Preferably, the spacer elements of the conductor structure 1 include also second spacer elements 3B with an elongated shape (e.g. as an elongated plate of parallelogram shape) fixed to the conductor element 2 along second fixing directions F2 transversal to the main extension direction L of said conductor element.

[0098] Preferably, the first and second fixing directions F1, F2 are not parallel. In practice, the fixing directions F1, F2 intersect one to another (when they are referred to a same reference plane).

[0099] Both the first and second fixing directions F1 and F2 of the spacer elements 3A and 3B are transversal to the main extension direction L of the conductor element 2.

[0100] According to some embodiments of the invention (Figures 3, 6-8), the first fixing directions F1 or the second fixing directions F2 are perpendicular to the main

extension direction L of the conductor element 2.

[0101] According to other embodiments of the invention (Figure 4), both the first and second fixing directions F1 and F2 are not perpendicular to the main extension direction (L) of said conductor element.

[0102] According to some embodiments of the invention, the first spacer elements 3A or the second spacer elements 3B may be made of a single piece of electrically insulating material.

[0103] Figures 3-4, 6-8 show embodiments of the invention in which both the spacers 3A, 3B are made of a single piece of insulating material.

[0104] According to other embodiments of the invention (figure 5), the first spacer elements 3A or the second spacer elements 3B may be made of multiple pieces of electrically insulating material aligned along the first fixing directions F1 or the second fixing directions F2.

[0105] According to some embodiments of the invention, the first and second spacer elements 3A, 3B are fixed to the conductor element 2 on a same lateral surface 2A of said conductor.

[0106] Figure 6 shows an embodiment of this type, in which the first and second spacer elements 3A, 3B are fixed at subsequent consecutive longitudinal portions 2E, 2F of the conductor element 2, along the main extension direction L of said conductor. Conveniently, each longitudinal portion 2E, 2F has a length (measured along the main extension direction L) equal to the length of a turn 101 of the electric winding 100.

[0107] According to other embodiments of the invention (figures 7-8), the first and second spacer elements 3A, 3B are fixed to the conductor element 2 on opposite lateral surfaces 2A, 2B of said conductor along the main extension direction L of this latter.

[0108] Figure 7 shows an embodiment of this type, in which the first and second spacer elements 3A, 3B are fixed to opposite lateral surfaces 2A, 2B of the conductor element 2 at same longitudinal portions 2G of the conductor element 2, along the main extension direction L. Conveniently, the longitudinal portions 2G of said conductor, on which the spacers elements are fixed, alternate (along the main extension direction L) with longitudinal portions 2H, on which no spacer elements are fixed. Conveniently, each longitudinal portion 2G, 2H has a length (measured along the main extension direction L) equal to the length of a turn of the electric winding 100.

[0109] Figure 8 shows another embodiment of this type, in which the first and second spacer elements 3A, 3B are fixed to opposite lateral surfaces 2A, 2B of the conductor element 2 along the entire length of the conductor element 2. According to this solution, the spacer elements 3A, 3B of adjacent turns 101 may be overlapped and in contact one with another. This improves the overall structural sturdiness of the electric winding 100 even if it may cause an increased spacing between each pair of adjacent turns 101.

[0110] The method and conductor structure, according to the invention, provide relevant advantages. The meth-

od and conductor structure, according to the invention, allow obtaining an electric winding with a high structural balancing and a high resistance to mechanical stresses, in particular to compression stresses.

[0111] This allows preventing or reducing the deformation of the turns of the electric winding in operation with a consequent remarkable increase of the reliability of the electromagnetic induction apparatus in operation, even in presence of fault events or short-circuit events.

[0112] The method and conductor structure, according to the invention, are relatively easy to implement at industrial level at competitive costs with respect to known solutions of the state of the art.

Claims

1. A method for manufacturing an electric winding (100) of an electromagnetic induction apparatus, comprising the following steps:

- providing a conductor structure (1) including a conductor element (2) extending longitudinally along a main extension direction (L) and a plurality of spacer elements (3A, 3B) made of electrically insulating material, said spacer elements being fixed to at least a lateral surface (2A, 2B) of said conductor element and being arranged spaced one from another along said lateral surface (2A, 2B);
- forming an electric winding (100) by means of said conductor structure, said electric winding extending axially along a winding direction (DW) and having a plurality of turns (101) arranged around said winding direction, wherein each turn (101) of said electric winding (100) is formed by a corresponding longitudinal portion (2E, 2F) of said conductor element (2); wherein said spacer elements (3A, 3B) are interposed between adjacent turns of said electric winding (100) at opposite sides (101A, 101B) of said turns (101);

characterised in that, for at least a turn (101) of said electric winding, each spacer element (3A, 3B) at one side (101A) of said turn is partially overlapped with two spacer elements (3A, 3B) at the opposite side (101B) of said turn, the overlapping direction is parallel to the winding direction (DW).

2. Method, according to claim 1, **characterised in that**, for at least a turn (101) of said electric winding:

- a spacer element (3A) at a first side (101A) of said turn is overlapped with at least two spacer elements (3B) at a second side (101B) of said turn, which is opposite to said first side;
- a spacer element (3B) at a second side (101B)

of said turn is overlapped with at least two spacer elements (3A) at a first side (101A) of said turn.

3. Method, according to one or more of the previous claims, **characterised in that** said conductor structure (1) comprises first and second spacer elements (3A, 3B) with an elongated shape fixed to at least a lateral surface (2A, 2B) of said conductor element (2) along first and second fixing directions (F1, F2) transversal to the main extension direction (L) of said conductor element.

4. Method, according to claim 3, **characterised in that** said first fixing directions (F1) or said second fixing directions (F2) are perpendicular to the main extension direction (L) of said conductor element.

5. Method, according to claim 3, **characterised in that** both said first fixing directions (F1) and said second fixing directions (F2) are not perpendicular to the main extension direction (L) of said conductor element.

6. Method, according to one or more of the previous claims, **characterised in that** said conductor structure (1) comprises first and second spacer elements (3A, 3B) fixed to said conductor element (2) on a same lateral surface (2A) of said conductor element.

7. Method, according to one or more of the claims from 1 to 5, **characterised in that** said conductor structure (1) comprises first and second spacer elements (3A, 3B) fixed to said conductor element (2) on opposite lateral surfaces (2A, 2B) of said conductor element.

8. Method, according to one of the previous claims, **characterised in that** said conductor structure (1) comprises first spacer elements (3A) or second spacer elements (3B) made of a single piece of electrically insulating material.

9. Method, according to one of the previous claims, **characterised in that** said conductor structure (1) comprises first spacer elements (3A) or second spacer elements (3B) made of multiple pieces of electrically insulating material aligned along first fixing directions (F1) or second fixing directions (F2), respectively.

10. Method, according to one of the previous claims, **characterised in that** said spacer elements (3A, 3B) are fixed to said conductor element (2) by gluing or by means of an electrically insulating tape or by means of an electrically insulating mesh wound around said conductor element (2).

11. Method, according to one or more of the previous

claims, **characterised in that** said conductor element (2) is a continuously transposed conductor.

12. Method, according to one or more of the previous claims, **characterised in that** said electromagnetic induction apparatus is an electric transformer for electric power transmission and distribution grids. 5
13. A conductor structure (1) for an electromagnetic induction apparatus, comprising: 10
- a conductor element (2) extending longitudinally along a main extension direction (L);
 - a plurality of spacer elements (3A, 3B) made of electrically insulating material, said spacer elements being fixed to at least a lateral surface (2A, 2B) of said conductor element and being arranged spaced one from another along said lateral surface (2A, 2B); 15
- wherein said conductor structure (1) forms an electric winding (100) extending axially along a winding direction and having a plurality of turns (101) arranged around said electric winding direction, 20
- wherein each turn (101) of said electric winding (100) is formed by a corresponding longitudinal portion (2E, 2F) of said conductor element (2); 25
- wherein said spacer elements (3A, 3B) are interposed between adjacent turns of said electric winding (100) at opposite sides (101A, 101B) of said turns (101); 30
- characterised in that**, for at least a turn of said electric winding, each spacer element (3A, 3B) at one side of said turn is partially overlapped with two spacer elements (3A, 3B) at the opposite side of said turn, the overlapping direction is parallel to the winding direction (DW). 35
14. An electric winding (100) for an electromagnetic induction apparatus **characterised in that** it comprises a conductor structure (1), according to claim 13. 40
15. An electromagnetic induction apparatus for electric power transmission and distribution grids **characterised in that** it includes an electric winding (100), according to claim 14. 45

Patentansprüche

1. Verfahren zum Herstellen einer elektrischen Wicklung (100) einer elektromagnetischen Induktionseinrichtung, umfassend die folgenden Schritte: 50
- Bereitstellen einer Leiterstruktur (1) mit einem Leiterelement (2), das sich in Längsrichtung entlang einer Hauptstreckungsrichtung (L) erstreckt, und einer Mehrzahl von Abstandhalter-

elementen (3A, 3B) aus elektrisch isolierendem Material, wobei die Abstandhalterelemente an mindestens einer lateralen Fläche (2A, 2B) des Leiterelements fixiert und entlang der lateralen Fläche (2A, 2B) voneinander beabstandet angeordnet sind;

- Ausbilden einer elektrischen Wicklung (100) mittels der Leiterstruktur, wobei sich die elektrische Wicklung axial entlang einer Wicklungsrichtung (DW) erstreckt und eine Mehrzahl von Windungen (101) aufweist, die um die Wicklungsrichtung angeordnet sind, wobei jede Windung (101) der elektrischen Wicklung (100) durch einen entsprechenden Längsabschnitt (2E, 2F) des Leiterelements (2) ausgebildet wird;

wobei die Abstandhalterelemente (3A, 3B) zwischen angrenzenden Windungen der elektrischen Wicklung (100) auf entgegengesetzten Seiten (101A, 101B) der Windungen (101) angeordnet sind;

dadurch gekennzeichnet, dass bei mindestens einer Windung (101) der elektrischen Wicklung jedes Abstandhalterelement (3A, 3B) auf einer Seite (101A) der Windung teilweise mit zwei Abstandhalterelementen (3A, 3B) auf der entgegengesetzten Seite (101B) der Windung überlagert ist, wobei die Überlagerungsrichtung parallel zu der Wicklungsrichtung (DW) ist.

2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** bei mindestens einer Windung (101) der elektrischen Wicklung:

- ein Abstandhalterelement (3A) auf einer ersten Seite (101A) der Windung mit mindestens zwei Abstandhalterelementen (3B) auf einer zweiten Seite (101B) der Windung überlagert ist, die entgegengesetzt zu der ersten Seite ist;
- ein Abstandhalterelement (3B) auf einer zweiten Seite (101B) der Windung mit mindestens zwei Abstandhalterelementen (3A) auf einer ersten Seite (101A) der Windung überlagert ist.

3. Verfahren nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Leiterstruktur (1) erste und zweite Abstandhalterelemente (3A, 3B) mit einer länglichen Form umfasst, die an mindestens einer lateralen Fläche (2A, 2B) des Leiterelements (2) entlang erster und zweiter Fixierungsrichtungen (F1, F2) transversal zu der Hauptstreckungsrichtung (L) des Leiterelements fixiert sind. 50

4. Verfahren nach Anspruch 3, **dadurch gekennzeichnet, dass** die ersten Fixierungsrichtungen (F1) oder die zweiten Fixierungsrichtungen (F2) senkrecht zu der Hauptstreckungsrichtung (L) des Lei-

terelements sind.

5. Verfahren nach Anspruch 3, **dadurch gekennzeichnet, dass** sowohl die ersten Fixierungsrichtungen (F1) als auch die zweiten Fixierungsrichtungen (F2) nicht senkrecht zu der Haupterstreckungsrichtung (L) des Leiterelements sind. 5
6. Verfahren nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Leiterstruktur (1) erste und zweite Abstandhalterelemente (3A, 3B) umfasst, die an dem Leiterelement (2) auf einer gleichen lateralen Fläche (2A) des Leiterelements fixiert sind. 10
7. Verfahren nach einem oder mehreren der Ansprüche 1 bis 5, **dadurch gekennzeichnet, dass** die Leiterstruktur (1) erste und zweite Abstandhalterelemente (3A, 3B) umfasst, die an dem Leiterelement (2) auf entgegengesetzten lateralen Flächen (2A, 2B) des Leiterelements fixiert sind. 15 20
8. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Leiterstruktur (1) erste Abstandhalterelemente (3A) oder zweite Abstandhalterelemente (3B) aus einem einzelnen Stück aus elektrisch isolierendem Material umfasst. 25
9. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Leiterstruktur (1) erste Abstandhalterelemente (3A) oder zweite Abstandhalterelemente (3B) aus mehreren Stücken aus elektrisch isolierendem Material umfasst, die entlang erster Fixierungsrichtungen (F1) bzw. zweiter Fixierungsrichtungen (F2) ausgerichtet sind. 30 35
10. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Abstandhalterelemente (3A, 3B) an dem Leiterelement (2) durch Kleben oder mittels eines elektrisch isolierenden Bands oder mittels eines elektrisch isolierenden Netzes, das um das Leiterelement (2) gewickelt ist, fixiert sind. 40 45
11. Verfahren nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** das Leiterelement (2) ein durchgehend ausgekreuzter Leiter ist. 50
12. Verfahren nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die elektromagnetische Induktionseinrichtung ein elektrischer Transformator für elektrische Leistungsübertragungs- und -verteilungsnetze ist. 55
13. Leiterstruktur (1) für eine elektromagnetische Induk-

tionseinrichtung, umfassend:

- ein Leiterelement (2), das sich in Längsrichtung entlang einer Haupterstreckungsrichtung (L) erstreckt;
- eine Mehrzahl von Abstandhalterelementen (3A, 3B) aus elektrisch isolierendem Material, wobei die Abstandhalterelemente an mindestens einer lateralen Fläche (2A, 2B) des Leiterelements fixiert und entlang der lateralen Fläche (2A, 2B) voneinander beabstandet angeordnet sind; wobei die Leiterstruktur (1) eine elektrische Wicklung (100) ausbildet, die sich axial entlang einer Wicklungsrichtung erstreckt und eine Mehrzahl von Windungen (101) aufweist, die um die elektrische Wicklungsrichtung angeordnet sind, wobei jede Windung (101) der elektrischen Wicklung (100) durch einen entsprechenden Längsabschnitt (2E, 2F) des Leiterelements (2) ausgebildet wird; wobei die Abstandhalterelemente (3A, 3B) zwischen angrenzenden Windungen der elektrischen Wicklung (100) auf entgegengesetzten Seiten (101A, 101B) der Windungen (101) angeordnet sind; **dadurch gekennzeichnet, dass** bei mindestens einer Windung der elektrischen Wicklung jedes Abstandhalterelement (3A, 3B) auf einer Seite der Windung teilweise mit zwei Abstandhalterelementen (3A, 3B) auf der entgegengesetzten Seite der Windung überlagert ist, wobei die Überlagerungsrichtung parallel zu der Wicklungsrichtung (DW) ist.

14. Elektrische Wicklung (100) für eine elektromagnetische Induktionseinrichtung, **dadurch gekennzeichnet, dass** sie eine Leiterstruktur (1) nach Anspruch 13 umfasst.

15. Elektromagnetische Induktionseinrichtung für elektrische Leistungsübertragungs- und -verteilungsnetze, **dadurch gekennzeichnet, dass** sie eine elektrische Wicklung (100) nach Anspruch 14 umfasst.

Revendications

1. Procédé de fabrication d'un enroulement électrique (100) d'un appareil à induction électromagnétique, comportant les étapes suivantes :

- mettre en place une structure (1) de conducteur comprenant un élément conducteur (2) s'étendant longitudinalement suivant une direction principale (L) d'extension et une pluralité d'éléments (3A, 3B) d'espacement constitués de matériau électriquement isolant, lesdits éléments

- d'espacement étant fixés à au moins une surface latérale (2A, 2B) dudit élément conducteur et étant disposés de manière espacée les uns par rapport aux autres le long de ladite surface latérale (2A, 2B) ;
- former un enroulement électrique (100) au moyen de ladite structure de conducteur, ledit enroulement électrique s'étendant axialement suivant une direction (DW) d'enroulement et possédant une pluralité de spires (101) disposées autour de ladite direction d'enroulement, chaque spire (101) dudit enroulement électrique (100) étant formée par une partie longitudinale (2E, 2F) correspondante dudit élément conducteur (2) ;
 - lesdits éléments (3A, 3B) d'espacement étant interposés entre des spires adjacentes dudit enroulement électrique (100) sur des côtés opposés (101A, 101B) desdites spires (101) ;
- caractérisé en ce que**, pour au moins une spire (101) dudit enroulement électrique, chaque élément (3A, 3B) d'espacement d'un côté (101A) de ladite spire est en recouvrement partiel avec deux éléments (3A, 3B) d'espacement du côté opposé (101B) de ladite spire, la direction de recouvrement étant parallèle à la direction (DW) d'enroulement.
2. Procédé selon la revendication 1, **caractérisé en ce que**, pour au moins une spire (101) dudit enroulement électrique :
 - un élément (3A) d'espacement d'un premier côté (101A) de ladite spire est en recouvrement avec au moins deux éléments (3B) d'espacement d'un second côté (101B) de ladite spire, qui est opposé audit premier côté ;
 - un élément (3B) d'espacement d'un second côté (101B) de ladite spire est en recouvrement avec au moins deux éléments (3A) d'espacement d'un premier côté (101A) de ladite spire .
 3. Procédé selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** ladite structure (1) de conducteur comporte des premiers et seconds éléments (3A, 3B) d'espacement de forme allongée fixés à au moins une surface latérale (2A, 2B) dudit élément conducteur (2) suivant des premières et secondes directions (F1, F2) de fixation transversales à la direction principale (L) d'extension dudit élément conducteur.
 4. Procédé selon la revendication 3, **caractérisé en ce que** lesdites premières directions (F1) de fixation ou lesdites secondes directions (F2) de fixation sont perpendiculaires à la direction principale (L) d'extension dudit élément conducteur.
 5. Procédé selon la revendication 3, **caractérisé en ce qu'**à la fois lesdites premières directions (F1) de fixation et lesdites secondes directions (F2) de fixation sont non perpendiculaires à la direction principale (L) d'extension dudit élément conducteur.
 6. Procédé selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** ladite structure (1) de conducteur comporte des premiers et seconds éléments (3A, 3B) d'espacement fixés audit élément conducteur (2) sur une même surface latérale (2A) dudit élément conducteur.
 7. Procédé selon une ou plusieurs des revendications 1 à 5, **caractérisé en ce que** ladite structure (1) de conducteur comporte des premiers et seconds éléments (3A, 3B) d'espacement fixés audit élément conducteur (2) sur des surfaces latérales (2A, 2B) opposées dudit élément conducteur.
 8. Procédé selon une des revendications précédentes, **caractérisé en ce que** ladite structure (1) de conducteur comporte des premiers éléments (3A) d'espacement ou des seconds éléments (3B) d'espacement constitués d'une seule pièce de matériau électriquement isolant.
 9. Procédé selon une des revendications précédentes, **caractérisé en ce que** ladite structure (1) de conducteur comporte des premiers éléments (3A) d'espacement ou des seconds éléments (3B) d'espacement constitués de multiples pièces de matériau électriquement isolant alignées suivant des premières directions (F1) de fixation ou des secondes directions (F2) de fixation, respectivement.
 10. Procédé selon une des revendications précédentes, **caractérisé en ce que** lesdits éléments (3A, 3B) d'espacement sont fixés audit élément conducteur (2) par collage ou au moyen d'un ruban électriquement isolant ou au moyen d'un grillage électriquement isolant enroulé autour dudit élément conducteur (2) .
 11. Procédé selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** ledit élément conducteur (2) est un conducteur continuellement transposé.
 12. Procédé selon une ou plusieurs des revendications précédentes, **caractérisé en ce que** ledit appareil à induction électromagnétique est un transformateur électrique destiné à des réseaux de transport et de distribution d'énergie électrique.
 13. Structure (1) de conducteur pour appareil à induction électromagnétique, comportant :

- un élément conducteur (2) s'étendant longitudinalement suivant une direction principale (L) d'extension ;
 - une pluralité d'éléments (3A, 3B) d'espacement constitués de matériau électriquement isolant, lesdits éléments d'espacement étant fixés à au moins une surface latérale (2A, 2B) dudit élément conducteur et étant disposés de manière espacée les uns par rapport aux autres le long de ladite surface latérale (2A, 2B) ;
 - ladite structure (1) de conducteur formant un enroulement électrique (100) s'étendant axialement suivant une direction d'enroulement et possédant une pluralité de spires (101) disposées autour de ladite direction d'enroulement électrique, chaque spire (101) dudit enroulement électrique (100) étant formée par une partie longitudinale (2E, 2F) correspondante dudit élément conducteur (2) ;
 - lesdits éléments (3A, 3B) d'espacement étant interposés entre des spires adjacentes dudit enroulement électrique (100) sur des côtés opposés (101A, 101B) desdites spires (101) ;
 - caractérisé en ce que**, pour au moins une spire dudit enroulement électrique, chaque élément (3A, 3B) d'espacement d'un côté de ladite spire est en recouvrement partiel avec deux éléments (3A, 3B) d'espacement du côté opposé de ladite spire, la direction de recouvrement étant parallèle à la direction (DW) d'enroulement.
14. Enroulement électrique (100) pour appareil à induction électromagnétique **caractérisé en ce qu'il** comporte une structure (1) de conducteur selon la revendication 13.
15. Appareil à induction électromagnétique destiné à des réseaux de transport et de distribution d'énergie électrique, **caractérisé en ce qu'il** comprend un enroulement électrique (100) selon la revendication 14.

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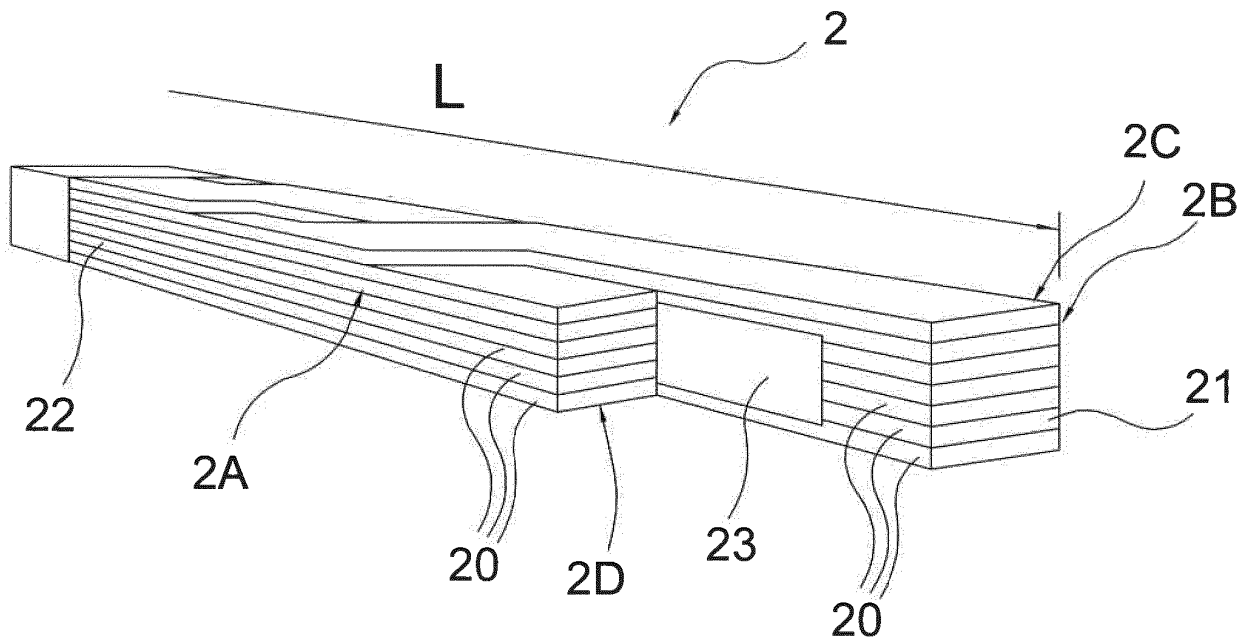


FIG.1

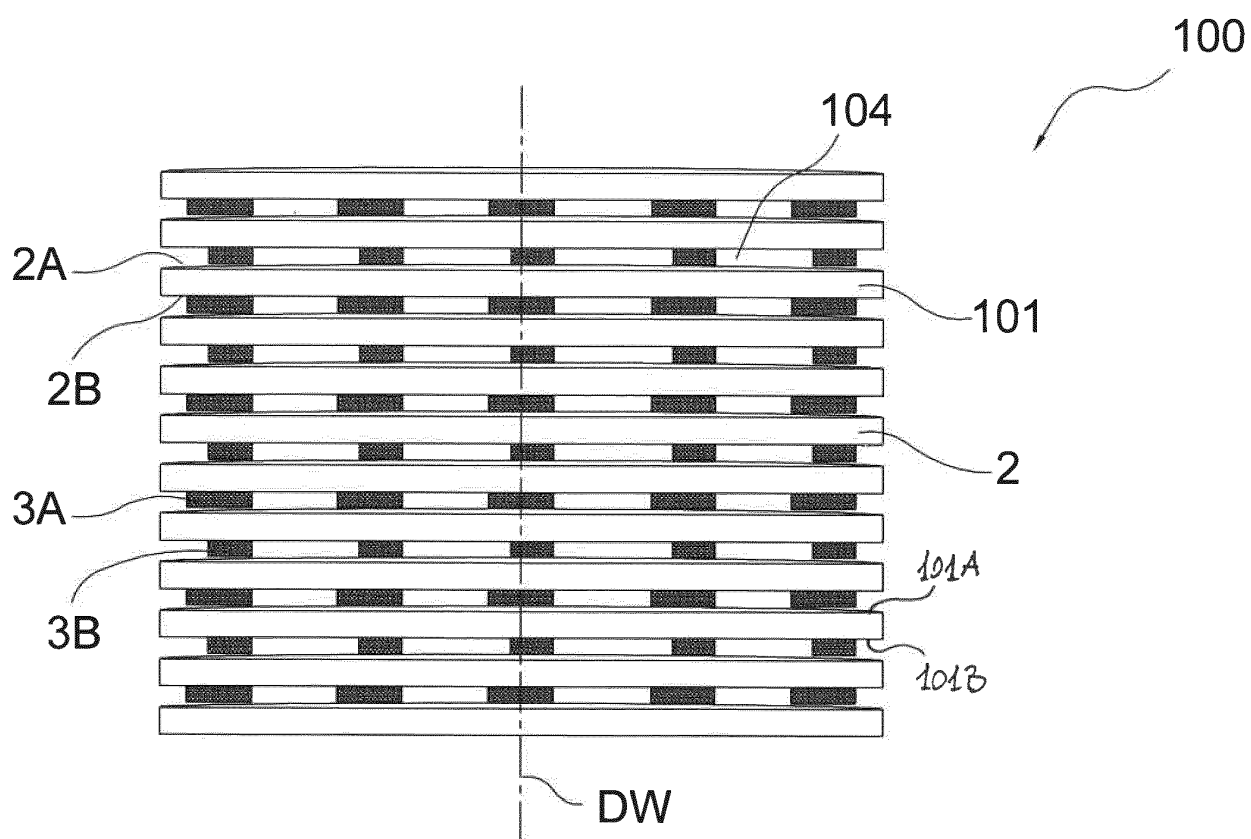


FIG.2

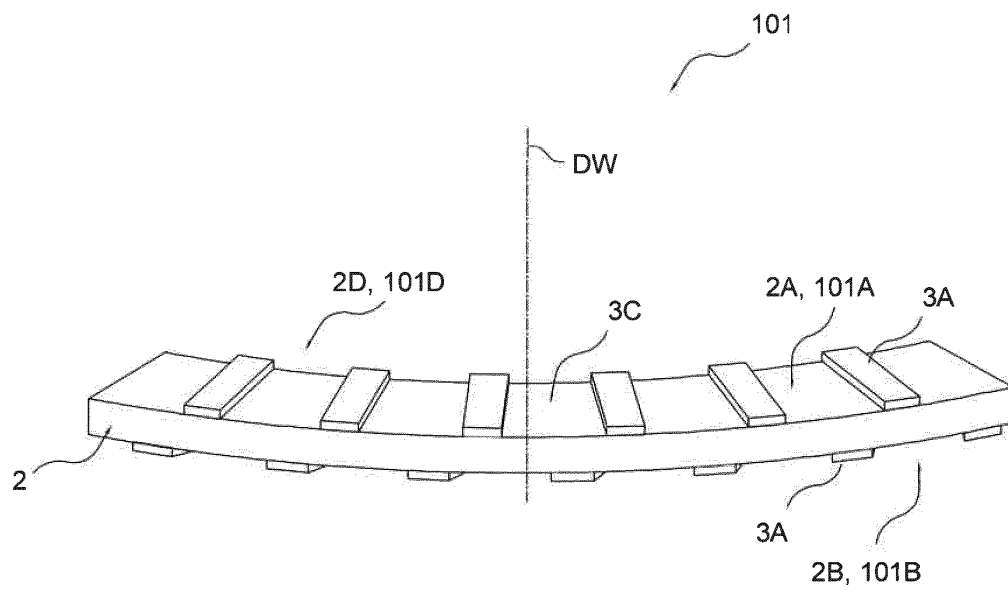


FIG. 2A

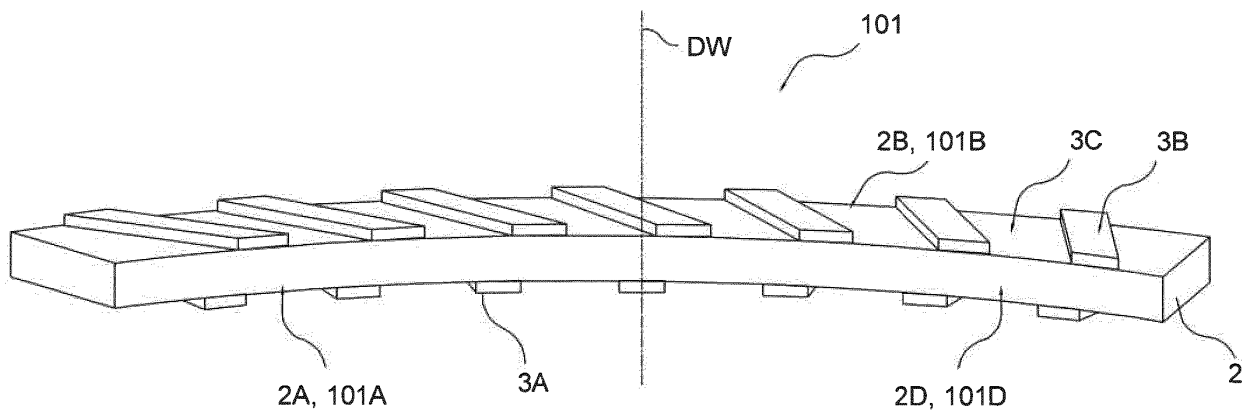


FIG. 2B

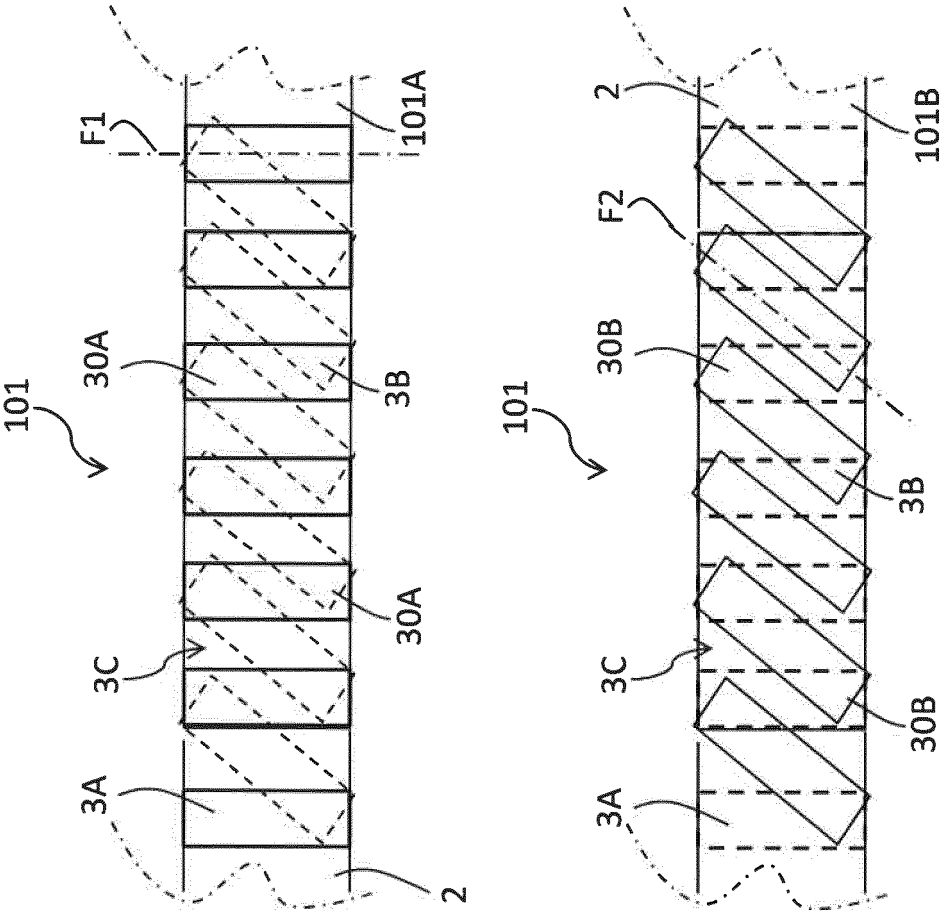


FIG. 3

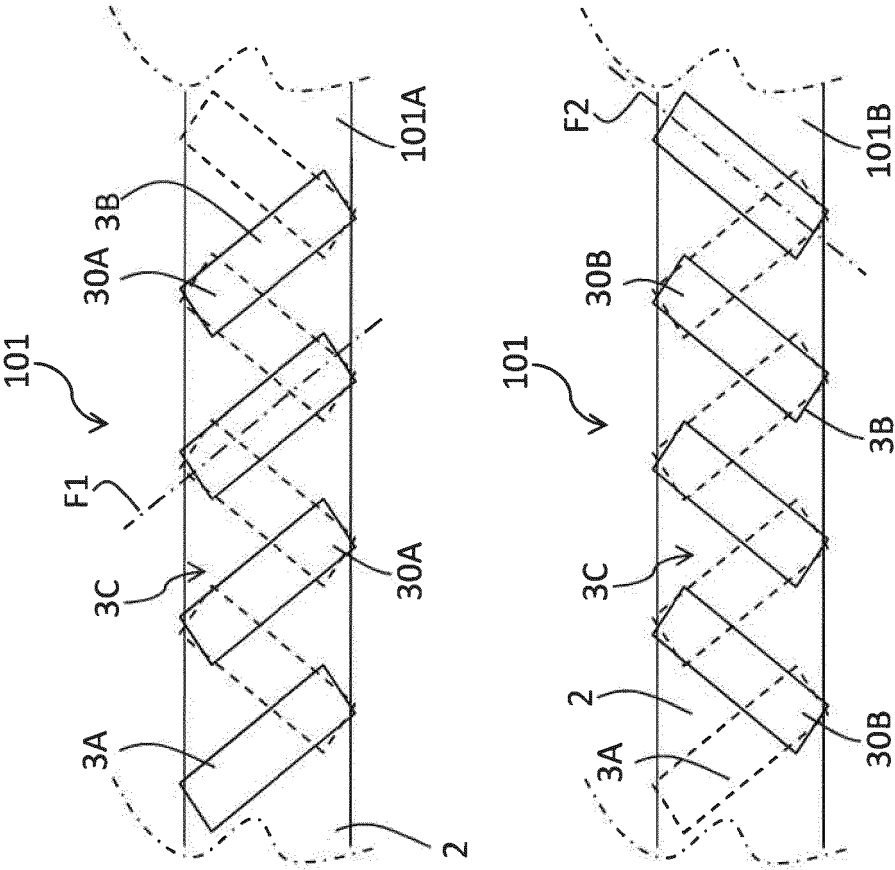


FIG. 4

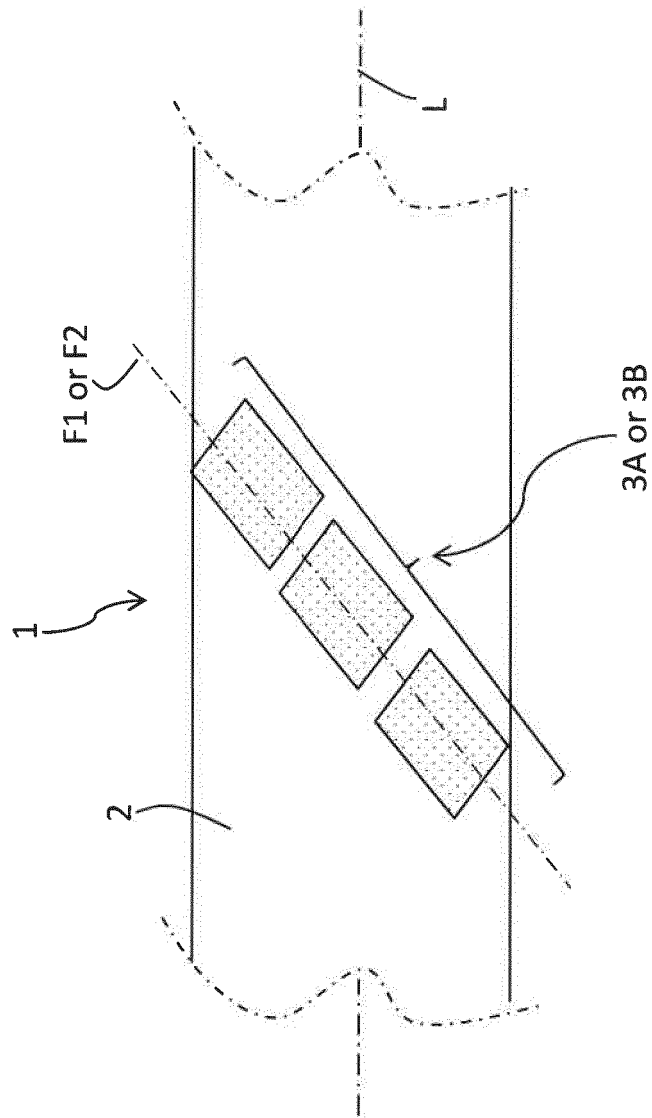


FIG. 5

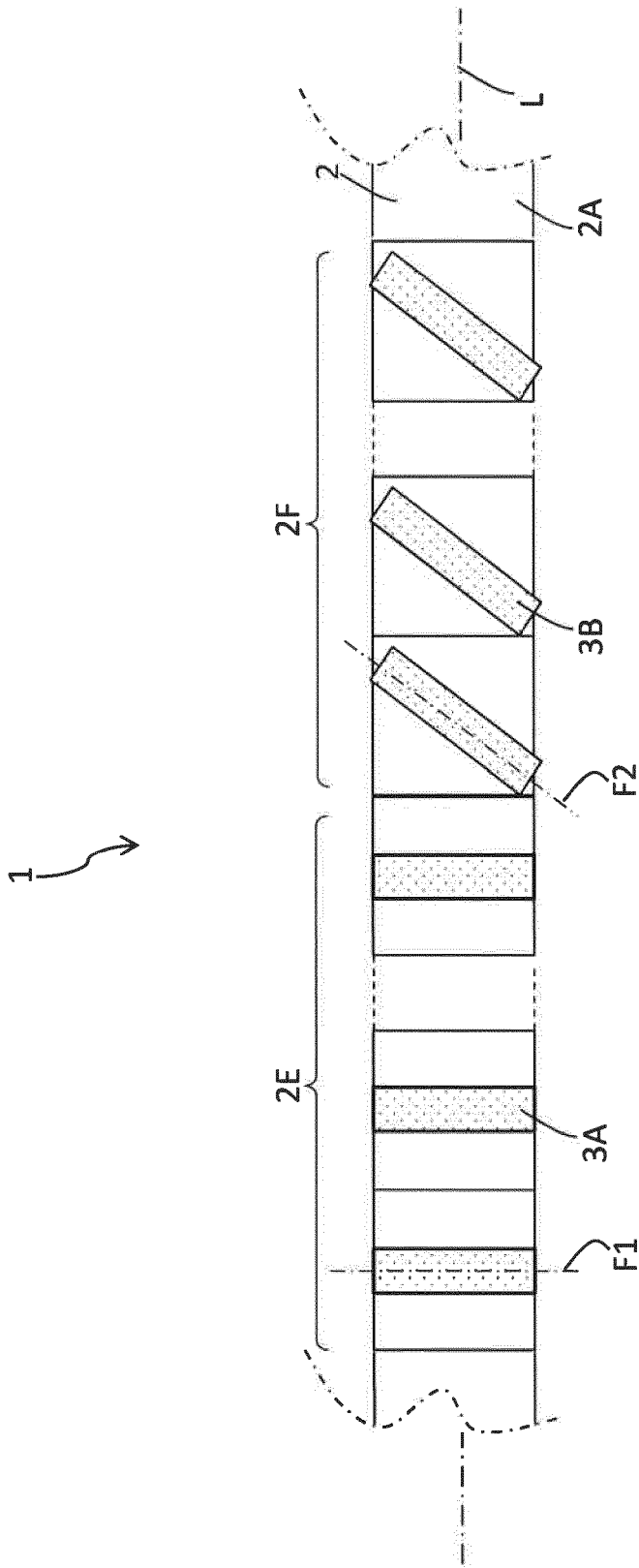
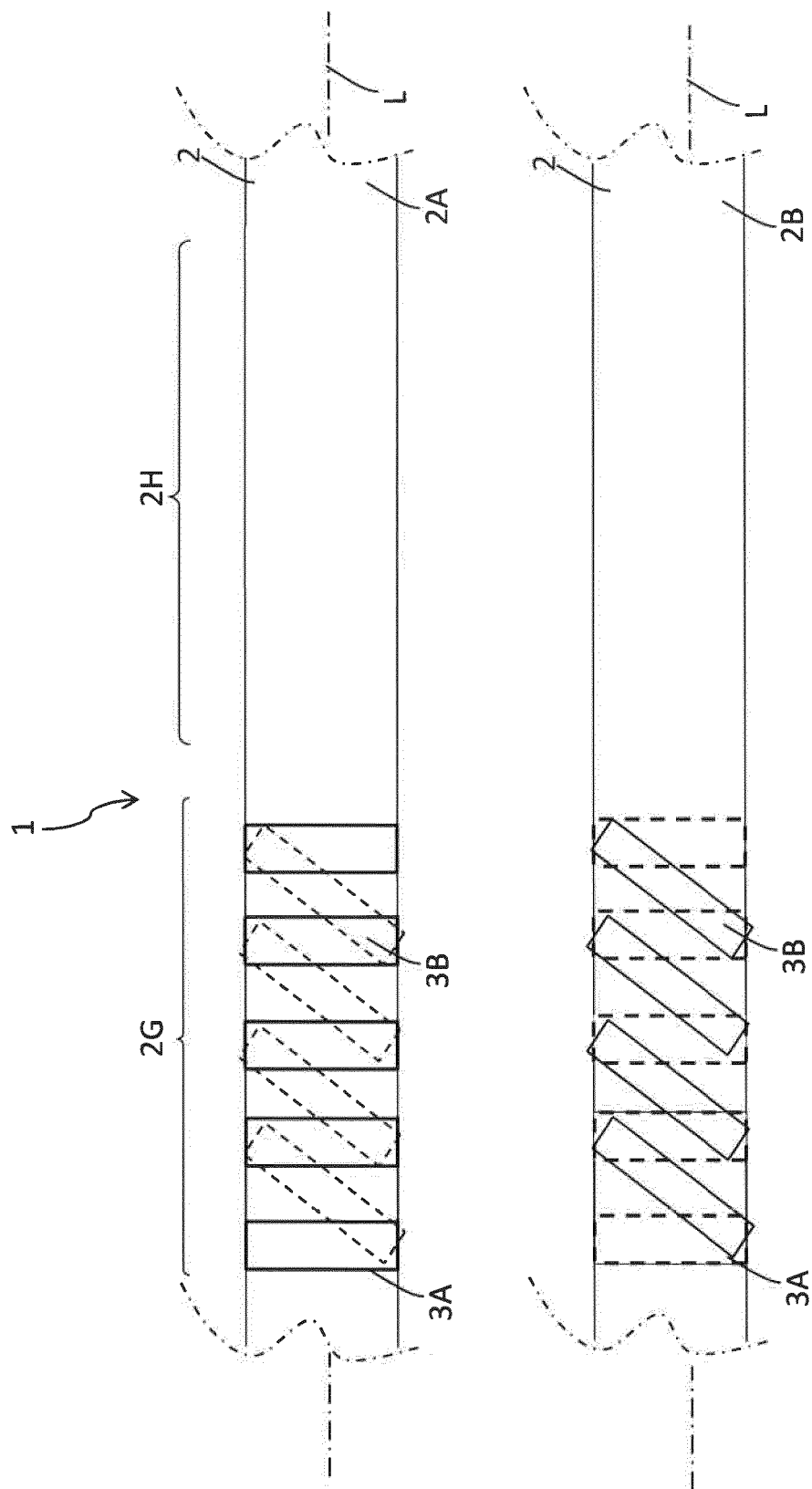


FIG. 6



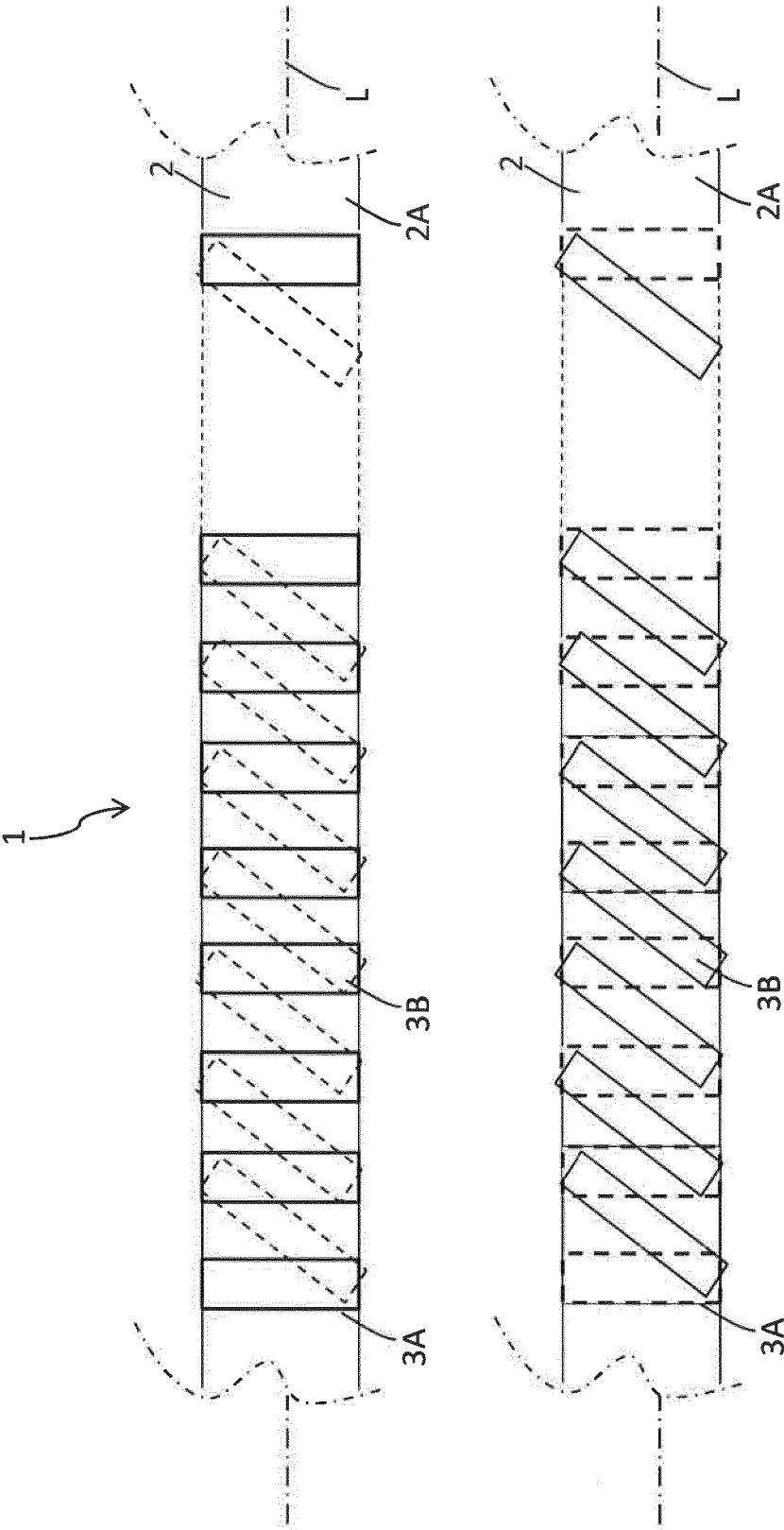


FIG. 8

REFERENCES CITED IN THE DESCRIPTION

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