

HOLDING DEVICE FOR HOLDING A SOFT-MAGNETIC STACKED CORE OF A TRANSFORMER AND TRANSFORMER

Technical field

The invention relates to a holding device for holding a soft-magnetic stacked transformer core comprising layers having an amorphous and/or nanocrystalline structure made of a ferrous alloy, particularly of an FeSiB alloy, wherein the stacked transformer core comprises at least two coil legs running parallel to each other and two yokes connected with opposite ends of the coil legs, and wherein the holding device has at least two holding units that are arrangeable at one of the yokes such that the holding units are arranged at opposite end regions of the stacked transformer core, and at least one mechanical fixing means acting on both holding units, the holding units being non-destructively detachably connected with each other via the fixing means.

Furthermore, the invention relates to a transformer, in particular a three-phase transformer, comprising at least one soft-magnetic stacked transformer core comprising layers having an amorphous and/or nanocrystalline structure made of a ferrous alloy, particularly of an FeSiB alloy, wherein the stacked transformer core comprises at least two coil legs running parallel to each other and two yokes connected with opposite ends of the coil legs, and at least one holding device for holding the stacked transformer core.

Prior Art

Transformers convert an AC input voltage into an AC output voltage that differs from the AC input voltage. Transformers are used, for example, for voltage conversion in power supply systems and in electrical devices.

For each phase of the AC input voltage to be converted, a transformer has a primary coil and a secondary coil, which are arranged on a common transformer core, which is made of ferromagnetic materials or ferrites. In conjunction with the coils, the transformer core bundles the magnetic flux and increases the inductance and the magnetic flux density of the transformer. The transformer core can be formed from a laminated core made of a plurality of mutually electrically insulated transformer laminations. As a result, eddy current losses of the transformer during voltage conversion can be reduced.

A three-phase transformer has a soft-magnetic transformer core which has three coil legs running parallel to each other and two yokes connected at its ends with the coil legs. A primary coil and a secondary coil of the same current phase are arranged on each coil leg. One of the yokes can be monolithically connected to the three coil legs, whereby an E-shaped section of the transformer core is formed. After the coils have been arranged on the coil legs, the second yoke can be connected to the free ends of

the coil legs.

DE 10 2009 048 658 A1 discloses a conventional stacked transformer core, comprising soft-magnetic layers of an electrically conductive core material with an amorphous and/or nanocrystalline structure, which are separated from one another by separating layers of an electrically insulating material. A plurality of the soft-magnetic layers forms a monolithic compound, at least with the separating layers between them. The stacked transformer core thus consists of a laminated core, the transformer laminations each consisting entirely of a monolithic compound of soft-magnetic layers and separating layers. To produce the stacked transformer core, a soft-magnetic layer made of an electrically conductive core material is electrochemically deposited on a base body. An electrically insulating separating layer is produced on the soft-magnetic layer. These processes are repeated until the stacked transformer core has reached the intended shape. At least one soft-magnetic element, in particular one or a plurality of the elements iron (Fe), nickel (Ni) or cobalt (Co), and at least one glass-forming element, in particular phosphorus (P) and/or boron (B), are deposited together as the soft-magnetic layer.

The formation of a stacked transformer core using soft-magnetic amorphous layers is accompanied by a reduction in the losses on the stacked transformer core during its use in a transformer. This is due to the lower magnetic coercive force, so that hysteresis losses when magnetising the stacked transformer core can be kept small.

DE 10 2011 083 521 A1 relates to a conventional press frame structure for a transformer having a plurality of tension elements, with a plurality of struts which are at least partially protruding obliquely from a core of the transformer, and with a plurality of tensioning press plates which are arranged on or near the core of the transformer. The tension elements are arranged outside the windings of the transformer. The tension elements are connected to the tensioning press plates using the struts. The tension elements connect the upper press frame of the transformer with the lower press frame of the transformer. The tension elements cause the core to be clamped between the two press frames.

Summary of the Invention

An object of the invention is to provide a more energy-efficient transformer, in particular a three-phase transformer, of the type mentioned at the beginning.

The object is achieved by the independent patent claims. Advantageous embodiments are given in the dependent claims, the description below and the figures, wherein these embodiments, taken on their own or in a different combination of at least two of these

embodiments, can represent an advantageous and/or further aspect of the invention. Advantageous embodiments of the holding device can correspond to advantageous embodiments of the transformer, and vice versa, even if this is not explicitly referred to below.

A holding device according to the invention serves to hold a soft-magnetic stacked transformer core comprising layers having an amorphous and/or nanocrystalline structure made of a ferrous alloy, particularly of an FeSiB alloy, wherein the stacked transformer core comprises at least two coil legs running parallel to each other and two yokes connected with opposite ends of the coil legs. The holding device has at least two holding units that are arrangeable at one of the yokes such that the holding units are arranged at opposite end regions of the stacked transformer core, and at least one mechanical fixing means acting on both holding units, the holding units being non-destructively detachably connected with each other via the fixing means. Furthermore, the holding device has at least one spacer clamped between the holding units and at least one spring element which is arrangeable between at least one holding unit and the stacked transformer core, wherein the holding device is constructed such that the spring element is elastically deformed by at least indirect contact with the stacked transformer core caused when the stacked transformer core is arranged at the holding device.

The holding device according to the invention is designed as an inherently stable holding device, which means that the holding device can be brought into its holding state and held therein without other components, such as the stacked transformer core, being required to give the holding device stability. The holding device according to the invention is therefore in particular not designed in accordance with a conventional press frame, as is disclosed, for example, in DE 10 2011 083 521 A1. With such a conventional press frame, it is generally necessary to bring the press frame into a holding state and to hold it with the aid of the transformer core. Here, the transformer core is clamped between two frame elements, which means that relatively high tensioning forces, for example in the amount of a few 10,000 N, act on the transformer core, in particular in order to be able to ensure a sufficient non-positive connection or frictional connection between the layers of a conventional electrical sheet stack.

Correspondingly high tensioning forces lead to mechanical tensions within the transformer core. In the case of a stacked transformer core, that is to say a transformer core composed of a plurality of stacked layers which are electrically insulated from one another and are produced from a ferrous alloy, in particular an FeSiB alloy, with an amorphous and/or nanocrystalline structure, such mechanical stresses lead to a

deterioration in energy efficiency and thus to higher losses of the transformer. This is particularly so since mechanical stresses in soft-magnetic ferrous alloys reduce the magnetic permeability of the ferrous alloys. Magnetic permeability is a major factor influencing the material-specific magnetising loss (hysteresis loss). In particular, the very high magnetic permeability of ferrous alloys with an amorphous and/or nanocrystalline structure is disproportionately affected by mechanical stresses. This reduces the energy efficiency of the stacked transformer core and the efficiency of the transformer. This is avoided with the present invention since, with the holding device according to the invention, only the reset force generated by the elastic deformation of the at least one spring element acts on the stacked transformer core, which is significantly reduced compared to the conventional mechanical tensioning forces described. In addition, according to the invention, given the inherent stability of the holding device, there is no need for a conventional frictional connection between the press bars lying on the yoke and at the connection points of the coil legs and the individual layers of the core layered from grain-oriented electrical sheets. In addition, by means of the at least one spring element, only specified preset forces for fixing or holding stacked transformer cores or coil windings are introduced into the inherently stable frame, which have a minimal influence on the stacked transformer core. The introduction of force for holding the stacked transformer core is very low (can be, for example, about 0.5 N/mm^2) and is preset via the at least one spring element. Therefore, the energy efficiency of one with a stacked transformer core with layers which are electrically insulated from one another and are produced from a ferrous alloy, in particular an FeSiB alloy, with an amorphous and/or nanocrystalline structure, is not affected by the holding device according to the invention.

This advantage is achieved according to the invention in particular in that the two holding units for producing the holding state of the holding device are braced against one another via the at least one rigid spacer by means of the at least one mechanical fixing means acting on the two holding units so that the mechanical tensioning forces are absorbed by the spacer and not transferred to the stacked transformer core. The two holding units can also be correspondingly braced against one another via two or more, for example four, mechanical fixing means. Two or more, for example four, spacers can also be correspondingly clamped between the two holding units. For this purpose, the spacer can be made, for example, of a metal, a metal alloy or another rigid or dimensionally stable material. The spacer can extend in the immediate vicinity of a coil leg or be in contact with a coil leg, or can be arranged spaced from the coil leg such

that there is an installation space between the spacer and the coil leg for the coils to be arranged on the coil leg.

The only forces that act on the stacked transformer core held by the holding device according to the invention are the reset forces generated by the elastic deformation of the at least one spring element. Such reset forces are significantly lower than the mechanical tensioning forces conventionally applied with a press frame. The forces acting on the stacked transformer core can thus be determined according to the present invention by the choice of the type and embodiment of the spring element, the spring constant or elastic modulus of which causes the desired holding forces. The spring element can in particular have a linear or non-linear force-path curve. The stacked transformer core can be acted upon by means of corresponding spring elements, for example in the x direction, y direction and z direction. For example, a spring element can be arranged in the region of a butt joint between a coil leg and a yoke.

The holding device can also have two or more corresponding spring elements which can be arranged at different locations between the respective holding unit or the holding units and the stacked transformer core. The spring element can be, for example, a body formed from an elastomer, which is arranged on a single side of the stacked transformer body or on two or more sides of the stacked transformer body or is adapted to its shape. The elastomer body can, for example, be designed as a cuboid, plate shape or the like. Alternatively, the spring element can be designed as a compression spring, for example a coil spring, spiral spring, or plate spring.

The holding device according to the invention is designed in its holding state such that the stacked transformer core is arranged on the holding device with a certain play without the at least one spring element. Only through the arrangement of the at least one spring element on the holding device and a direct or indirect contact of the stacked transformer core with the spring element and the associated elastic deformation of the spring element, realised by at least one further component, is a positive connection between the stacked transformer core and the holding device produced.

The at least one mechanical fixing means can be designed, for example, as a screw connection. A threaded shaft of such a screw connection can extend through the spacer, for example a sleeve-shaped spacer, or can be arranged outside of and spaced apart from the spacer. The sleeve-shaped spacer can be elongated and can have a polygonal, for example square or rectangular, or a round, for example circular, elliptical, or oval, cross-sectional area.

The holding device according to the invention also has the advantage that an assembly

of coils on a stacked transformer core arranged on the holding device can be carried out relatively simply by first loosening the mechanical fixing means, so that a holding unit can then be removed, after which this yoke previously held by said holding device can be removed from the rest of the stacked transformer core. The coils can then be applied to the coil legs of the stacked transformer core, after which the previously removed yoke can be arranged on the remaining stacked transformer core and then the previously removed holding unit can be arranged again on the remaining holding device. Finally, the mechanical fixing means are tightened again in order to bring the holding device into the holding state.

The two holding units can each have a substantially U-shaped cross section and can be arranged on the respective yoke such that they are not arranged exclusively on a side of the respective yoke facing away from the other yoke, but additionally encompass a section of the respective yoke on both sides, but without a positive connection between the respective holding unit and the respective yoke. As a result, the respective yoke can be supported laterally both on its side facing away from the respective other yoke and on its two longitudinal sides, in particular via at least one spring element arranged between the respective holding unit and the respective yoke, said spring element being elastically deformed in the event of a stacked transformer core arranged on the holding device by at least indirect contact with the stacked transformer core, in particular with its respective yoke. Alternatively, two or more spring elements can also be provided to support the yoke.

The spring element(s) additionally compensate for manufacturing tolerances, as a result of which the required manufacturing accuracy of all components of the holding device and the stacked transformer core can be reduced in a cost-reducing manner.

According to an advantageous embodiment, at least one holding unit has at least two holding elements which are arrangeable on opposite yoke end regions of the respective yoke, at least one mechanical fixing means acting on the two holding elements, by means of which the two holding elements are non-destructively detachably connected with each other, at least one spacer clamped between the holding elements and at least one spring element which can be arranged between at least one holding element and the respective yoke, wherein the holding unit is constructed such that the spring element is elastically deformed by at least indirect contact with the stacked transformer core caused when the stacked transformer core is arranged at the holding device. As a result, the respective yoke can also be fixed in the transverse direction by the yoke being clamped on the respective holding unit with elastic deformation of the spring

element. The at least one spring element between the at least one holding element and the respective yoke additionally compensates for manufacturing tolerances, as a result of which the required manufacturing accuracy of all components of the holding device and the stacked transformer core can be reduced in a cost-reducing manner.

Also according to this embodiment, only the reset force generated by the elastic deformation of the at least one spring element between at least one holding element and the respective yoke acts on the stacked transformer core, which is significantly reduced in comparison to the conventional mechanical tensioning forces described above. The two holding elements for producing the holding state of the holding device are braced against one another via the at least one rigid spacer by means of the at least one mechanical fixing means acting on the two holding elements so that the mechanical tensioning forces are absorbed by the spacer and not transferred to the stacked transformer core.

The two holding elements can also be correspondingly braced against one another via two or more, for example four, mechanical fixing means. Two or more, for example four, spacers can also be correspondingly clamped between the two holding elements. For this purpose, the spacer between the holding elements can be made, for example, of a metal, a metal alloy, or another rigid or dimensionally stable material.

The forces acting on the stacked transformer core can be determined by the choice of the type and embodiment of the spring element between the respective holding element and the yoke, the spring constant or elastic modulus of which causes the desired forces. The holding device can also have two or more corresponding spring elements which can be arranged at different locations between the holding elements and the stacked transformer core. The spring element can be, for example, a body formed from an elastomer, which is arranged on a single side of the stacked transformer body or on two or more sides of the stacked transformer body or is adapted to its shape. Alternatively, the spring element can be designed as a compression spring, for example a coil spring, spiral spring, or plate spring.

The at least one mechanical fixing means acting on the holding elements can be designed, for example, as a screw connection. A threaded shaft of such a screw connection can extend through the spacer between the holding units, for example a sleeve-shaped spacer, or can be arranged outside of and spaced apart from this spacer.

The two holding elements can each, for example, have a substantially S-shaped cross section and can be arranged on the respective yoke such that they are not arranged

exclusively on a side of the respective yoke facing away from the other yoke, but additionally encompass a section of the respective yoke on one sides. As a result, the respective yoke can be supported laterally both on its side facing away from the respective other yoke and on its respective longitudinal side, in particular via at least one spring element arranged between the respective holding element and the respective yoke, said spring element being elastically deformed in the event of a stacked transformer core arranged on the holding device by at least indirect contact with the stacked transformer core, in particular with its respective yoke.

According to a further advantageous embodiment, a spring element is U-shaped such that it positively encompasses the stacked transformer core along at least one section of the respective yoke such that a connection region arranged between at least one coil leg and the respective yoke is located between parallel legs of the spring element. As a result, the number of spring elements required can be reduced, which simplifies the assembly of an appropriately equipped transformer. The U-shaped spring element can encompass the respective yoke, for example, on the side facing away from the other yoke and on sections of the longitudinal sides laterally adjoining thereon. Since the connection region between the coil leg and the yoke is located between parallel legs of the spring element, this connection area is secured by the spring element in the course of a positive fit, which is particularly advantageous when the coil leg is connected to the yoke by means of a butt joint.

According to a further advantageous embodiment, the holding device has at least one spring element which is arrangeable at least partially between the spacer and the stacked transformer core, wherein the holding device is constructed such that the spring element is elastically deformed by at least indirect contact with the stacked transformer core caused when the stacked transformer core is arranged at the holding device. In this way, for example, a coil leg connected to equilateral end sections of the yokes can be supported laterally. In addition, the end section can be supported on the end face by one of these yokes, the spring element extending over a connection region between the yoke and the coil leg. The spring element can be supported directly or indirectly on the spacer and/or the stacked transformer core and can in this case form a positive connection with the spacer and/or the stacked transformer core.

According to a further advantageous embodiment, the holding device has at least one spacer arrangeable between adjacent coil legs, at which the coil legs are laterally supported against each other. As a result, the coil legs can be supported indirectly against one another, which is particularly advantageous in the event of a butt joint

between the respective coil leg and the respective yoke since then the, in particular positive, connection between the coil leg and the yoke does not offer any lateral support. The spacer is preferably made of a non-conductive material. The spacer can be made of a rigid or resilient, in particular elastic, material.

According to a further advantageous embodiment, the holding device has at least two support elements that are arrangeable on opposite sides of a coil leg, each of which is connected to the two holding units at the end, in particular in a form-fitting manner. The support elements support the coil leg laterally via a positive connection and transfer the support forces to the holding units. Each support element can, for example, be plate-shaped or rod-shaped. Recesses are formed on the holding units, into which the end sections of the support elements engage in order to be supported laterally on sides facing away from one another.

According to a further advantageous embodiment, the holding device has at least four coil support elements for axially supporting coils that are arranged on a coil leg, wherein two coil support elements are arranged at one holding unit and the two further coil support elements are arranged at the other holding unit, wherein the coil support elements are arrangeable in pairs on opposite sides of the coil leg. Furthermore, the holding device according to this embodiment has at least one spring element per coil support element arranged or arrangeable either between the respective holding unit and the respective coil support element or between the respective coil support element and the respective coil, wherein the holding device is constructed such that the spring element is elastically deformed by at least indirect contact with the coils caused when the stacked transformer core with the coils arranged thereon is arranged at the holding device. As a result, the coils are supported separately from the stacked transformer core on the holding device. This is advantageous since the coils, especially if they are coils with non-glued or loose windings, have to be fixed on the holding device with significantly higher mechanical tensioning forces than the stacked transformer core. Correspondingly high mechanical tensioning forces do not act on the stacked transformer core due to the decoupling of the mechanical fixings of the stacked transformer core on the one hand and coils on the other hand on the holding device. The spring elements according to this embodiment can each be formed, for example, from bodies made of an elastomer or as a compression spring. Alternatively, the coil support elements, which are arranged in the vicinity of the respective holding unit, can be interconnected in order to form a monolithic coil support body, on which a separate opening is formed for each coil leg.

According to a further advantageous embodiment, a reset force that can be applied with the respective spring element can be set separately. As a result, the reset force can be changed afterwards, for example, adjusted or increased, or optimised. For this purpose, the spring element can be supported on a component of the holding device, the position of which can be varied relative to the remaining holding device. This component can be, for example, a screw body screwed into a screw hole on a holding unit or on a holding element. Two or more, in particular all, reset forces that can be applied with the spring elements can also be correspondingly separately adjustable.

A transformer according to the invention, in particular a three-phase transformer, has at least one soft-magnetic stacked transformer core comprising layers having an amorphous and/or nanocrystalline structure made of a ferrous alloy, particularly of an FeSiB alloy, wherein the stacked transformer core comprises at least two coil legs running parallel to each other and two yokes connected with opposite ends of the coil legs. Furthermore, the transformer has at least one holding device for holding the stacked transformer core, the holding device being designed according to any one of the above-mentioned embodiments or any combination of at least two of these embodiments.

The advantages mentioned above with reference to the holding device are correspondingly connected to the transformer. The ferrous alloy preferably contains at least one soft-magnetic element, in particular one or more of the elements Fe, silicon (Si), Ni or Co, and at least one glass-forming element, in particular P and/or B. The glass-forming element serves to form the amorphous and/or nanocrystalline structure of the respective amorphous layer. The amorphous layers are preferably electrically separated from one another.

At least one coil leg can be firmly bonded and/or positively connected to at least one yoke. To produce the stacked transformer core, for example, an E-shaped component can be produced, which has a section designed as a yoke and three sections designed as a coil leg. After the coils have been arranged on the coil legs, a separate yoke can be connected to the free ends of the coil legs. The yokes can be cuboid, while the coil legs can each have a stepped cross-sectional area. The cuboid design of the yokes means that they can be produced using less material, which reduces the costs for producing the transformer.

At least one coil leg can be connected to the respective yoke by a butt joint, that is to say at a cutting angle of 90°. However, at least one coil leg can also be connected to the respective yoke using a different cutting angle, for example a cutting angle of 45°.

Alternatively, the connecting sections of the respective coil leg and the respective yoke can be formed such that sections of the coil leg and yoke overlap one another. The overlapping sections can be firmly bonded to one another. Alternatively, a connecting section of a coil leg can have so-called step-lap layering. The individual coil legs of a stacked transformer core can be designed in various ways and connected to the respective yoke. In addition, at least one coil leg can be connected to at least one yoke in at least two different ways.

At least one abutment surface of abutment surfaces of a coil leg and a yoke to be connected to one another can be treated at least partially physically and/or chemically. As a result, the abutment surface can be provided with a desired surface roughness, for example. In addition, the treatment of the abutment surface can serve to produce a plane parallelism between abutment surfaces to be connected to one another. Both abutment surfaces to be connected can also be treated accordingly. The physical treatment can, for example, be mechanical, in particular machining, and/or thermal and/or chemical, for example etching.

In the transformer according to the invention, it is possible, for the assembly of coils on the coil legs, first to loosen the mechanical fixing means via which the two holding units are interconnected, and then, after removing the respective holding unit, to release the yoke thus held from the remaining stacked transformer core. Then the coils can be arranged on the coil legs. This process is much easier and quicker to carry out than a conventional assembly process, in which thousands of windings of a transformer core have to be laboriously manually stratified in order to arrange coils on the coil legs, and laboriously manually layered again after the coils have been arranged on the coil legs. The throughput of a plant for manufacturing corresponding transformers can be significantly increased by the significantly faster possible manufacture of the transformer according to the invention.

According to an advantageous embodiment, the coil legs and the yokes each are constituted by a stack of compound bodies firmly bonded to each other, wherein each compound body is constituted by cut-to-length compound segments of a ribbon-like multi-compound, the compound segments being firmly bonded to each other, wherein the multi-compound comprises at least two compound layers firmly bonded to each other, wherein each compound layer is constituted of a foil compound, wherein each foil compound comprises at least two ribbon-like soft-magnetic foils having an amorphous and/or nanocrystalline structure made of a ferrous alloy, particularly of an FeSiB alloy, wherein the foils are firmly bonded to each other. Each amorphous foil forms an

amorphous layer of the stacked transformer core. As a result, the transformer can be produced more cheaply and faster than, for example, the transformer disclosed in DE 10 2009 048 658 A1, in particular since the individual layers of a stacked transformer core are not successively deposited in accordance with DE 10 2009 048 658 A1, which is very time-consuming.

The respective ribbon-like, soft-magnetic foil with an amorphous and/or nanocrystalline structure made of a ferrous alloy, in particular an FeSiB alloy, can be continuously produced using a casting process, which is significantly faster than conventional successive deposition of individual layers of a particular shape and size. For the continuous production of the amorphous foil, a melt can first be produced from the ferrous alloy, for example using an induction melting furnace. The melt can then be poured onto a rotating roller, where the melt is progressively cooled to form the amorphous foil or solidifies to form the amorphous and/or nanocrystalline structure. The thus formed amorphous foil can be pulled off the roller and, after any further processing and/or processing steps, can be wound up to form a foil roll. The amorphous foil can then be unwound again for further process steps.

The fact that the amorphous foil is produced continuously means that the amorphous foil is not formed in a specific size and shape, i.e., adapted to a size and shape of a soft-magnetic component to be produced, but instead is formed as an elongated ribbon that can have a length of, for example, several 10,000 m. The thickness of the amorphous foil can range, for example, from approximately 20 μm to approximately 60 μm . The maximum width of the amorphous foil can be, for example, in a range from approximately 180 mm to approximately 300 mm, in particular up to approximately 400 mm. With a thickness of approximately 25 μm , the length of the amorphous foil can be, for example, 35,000 m.

Furthermore, the ribbon-like foil compound can be continuously produced by continuous, in particular flat or local, bonding of the amorphous foil with at least one correspondingly produced further amorphous foil, which can also be carried out significantly faster than the conventional production of a special foil compound by depositing individual layers, such as is disclosed, for example, in DE 10 2009 048 658 A1. The two amorphous foils can be unwound from different foil rolls simultaneously, for example, for the continuous production of the ribbon-like foil compound.

To form the material bond between the amorphous foils, for example, an adhesive can be continuously applied to at least one of the two unwound foil sections during the further unwinding of the amorphous foils, for example by means of an application roller

or by spraying on the adhesive. Alternatively, the adhesive can be applied in a dot-like manner or in lines. The adhesive forms an adhesive layer between two mutually adjacent amorphous foils of the foil compound, which can be electrically insulating in order to electrically separate the amorphous foils from one another. As a result, eddy current losses at the stacked transformer core can be kept as low as possible.

Alternatively, the adhesive layer can provide little or no electrical insulation, the electrical separation of the amorphous foils from one another being able to take place in another way. For example, at least one main side of an amorphous foil can be treated, for example by a diffusion process or the like, such that a section of the amorphous foil adjacent to the main side has a reduced electrical conductivity compared to the other amorphous foil, which is used for electrical insulation between interconnected amorphous foils.

Alternatively, during the further uncoiling of the amorphous foils, another agent, for example an oil, can be continuously applied to at least one of the two unwound foil sections, which creates or strengthens adhesion between the amorphous foils. Alternatively, the agent can be applied in a dot-like manner or in lines. Further alternatively, the material bond between the amorphous foils can be produced in that at least one connection side of at least one amorphous foil is at least partially heated and thereby partially melted before the amorphous foils are brought together, so that the molten material of this amorphous foil on the other amorphous foil solidifies and causes the material bond.

To produce the foil compound, the amorphous foil can also be connected to two or more, for example two to seven, further amorphous foils, the foil compound thereby having a corresponding number of foil layers. The foil compound can then be wound up into a foil compound roll in order to be available for further processing and/or machining steps. A foil compound with five layers of amorphous foils with a respective thickness of approximately 25 μm can be produced, for example, with a length of approximately 7,000 m. The thickness of the foil compound can be, for example, in a range from approximately 40 μm to approximately 400 μm .

Before winding up the foil compound, at least one electrically insulating separating layer can be applied continuously on at least one side to the foil compound or can be formed on the foil compound. This is particularly advantageous if the foil compound is later to be connected to at least one correspondingly produced further foil compound, since the foil compounds are then electrically separated from one another to reduce eddy current losses. Alternatively, an electrically insulating adhesive can also be used to connect the

foil compounds. An electrically insulating separating layer can also be arranged on each side of the foil compound. The foil compound provided with the at least one separating layer can then be wound up to form a foil compound roll in order to be available for further processing and/or machining. The separating layer can, for example, be formed on one side of the foil compound by treating the corresponding main side of the foil compound, for example by a diffusion process or the like, such that a section of the foil compound adjacent to the main side has a reduced electrical conductivity compared to the rest of the foil compound, which is used for electrical insulation between interconnected foil composites.

The continuous application or formation of at least one electrically insulating separating layer on at least one face to or on the foil compound can be carried out significantly faster than, for example, the separation of separating layers in accordance with DE 10 2009 048 658 A1. The electrically insulating separating layer can be applied to the foil compound by a continuous material connection, for example using a sprayed-on adhesive or other adhesive agent, of the foil compound with a foil forming the separating layer. The electrically insulating separating layer can be formed on the foil compound, for example, by continuous application, for example by means of an application roller or by spraying, of an insulation material on the foil compound, which hardens as quickly as possible after its application to form the separating layer. Alternatively, the separating layer can be formed on the foil compound by treating a main side of the foil compound as described above.

Before the foil compound is produced, at least one electrically insulating separating layer can be applied continuously on at least one side to each of the foils or can be formed on each of the foils. The continuous application or formation of at least one electrically insulating separating layer on at least one face to or on the respective amorphous foil can also be carried out significantly faster than, for example, the separation of separating layers in accordance with DE 10 2009 048 658 A1. The electrically insulating separating layer can be applied to the respective amorphous foil by a continuous material connection, for example using a sprayed-on adhesive or another adhesive agent, of the amorphous foil with a foil forming the separating layer. The electrically insulating separating layer can be formed on the respective amorphous foil, for example, by continuous application, for example by means of an application roller or by spraying, of an insulation material on the amorphous foil, which hardens as quickly as possible after its application to form the separating layer. Alternatively, the separating layer can be formed on the respective amorphous foil by treating a main side

of the amorphous foil as described above. An electrically insulating separating layer can also be arranged or formed on each side of the respective amorphous foil. The respective amorphous foil provided with the at least one separating layer can then be wound up to form a foil roll in order to be available for further processing and/or machining.

The continuous integral connection of the foil compounds to one another can take place by means of an adhesive or another adhesive agent which is applied continuously to at least one of the foil compounds by means of an application roller or by spraying. The adhesive or the adhesive agent can be electrically insulating. The width of the multi-compound can be, for example, in a range from approximately 200 mm to approximately 1000 mm. The thickness of the multi-compound can be, for example, in a range from approximately 40 μm to approximately 2000 μm .

The thickness of a compound body can be, for example, in a range from approximately 3 mm to approximately 400 mm. The width of a compound body can be, for example, in a range from approximately 30 mm to 1000 mm. The length of a compound body can be, for example, in a range from approximately 100 mm to 2500 mm. The compound segments can, for example, be selected, stacked and firmly bonded to one another such that the compound body formed therefrom, for example, has a rectangular, trapezoidal or other cut surface. At least one groove or the like can also be formed on at least one side surface of the respectively formed compound body. The compound segments can be of different thicknesses, length and/or width in order to produce a step-like bevel of the compound body formed therefrom. A width and/or length of the compound body is the same over a height of the stack or at least partially decreases in a step-like manner in at least one end region of the stack with respect to the height, towards the free end of the end region.

The respective coil leg or the respective yoke can be produced by firmly bonding compound bodies of the same or different width and/or length, with a cross-sectional area of the coil leg or yoke being formed with a gradation by using compound bodies of different widths or lengths on at least one corner region. As a result, the coil leg can be given, for example, a cross-sectional area that is approximately circular, elliptical, or oval in its cross section, for which purpose each corner region is formed with a corresponding gradation. For example, the yoke can have a rectangular cross-sectional area. The compound bodies can be interconnected by means of an adhesive or another adhesive agent. The adhesive or the adhesive agent can be electrically insulating.

According to a further advantageous embodiment, the compound layers each are

formed from a longitudinally separated foil compound, wherein one foil compound is longitudinally separated with respect to a cross section width of the respective multi-compound at a different place than the other foil compound arranged adjacent to said foil compound. A multi-compound of any width can be produced by staggering the arrangement of compound segments produced by the respective longitudinal division of the respective foil compound and firmly bonding the compound segments. The one foil compound can be longitudinally separated, for example, at a single point on its cross-sectional area, while the further foil compound can be longitudinally separated, for example, at two points on its cross-sectional area, which corresponds to the cross-sectional area of the first-mentioned foil compound. The multi-compound can be formed by an alternating arrangement of these two foil compounds, wherein the multi-compound can also be formed from more than two foil compounds. The individual foil compounds can also have a different number of longitudinal separations. For the formation of the multi-compound, it is essential that longitudinal separations of adjacent foil compounds are offset with respect to the longitudinal extent of the multi-compound or are not aligned with one another in the thickness direction of the multi-compound. Alternatively, the foil compounds of the compound layers are not correspondingly longitudinally separated.

In the following, the invention is explained by way of example with reference to the attached figures using preferred embodiments, the features explained below, both individually and in different combinations with one another, representing an advantageous and/or further aspect of the invention.

Brief Description of the Figures

In the figures:

- Figure 1 shows a schematic and perspective view of an exemplary embodiment of a transformer according to the invention;
- Figure 2 shows a schematic and perspective view of the holding device shown in Figure 1;
- Figure 3 shows a schematic and perspective partial sectional view of a portion of the transformer shown in Figure 1;
- Figure 4 shows a schematic and perspective sectional illustration of a further section of the transformer shown in Figure 1 in a first variant;
- Figure 5 shows a schematic and perspective sectional illustration of a further section of the transformer shown in Figure 1 in a further variant;
- Figure 6 shows a schematic sectional view of a further exemplary embodiment of a

transformer according to the invention;

Figure 7 shows a further schematic sectional illustration of the transformer shown in Figure 6; and

Figure 8 shows a schematic sectional view of a further exemplary embodiment of a transformer according to the invention.

Detailed Description of the Figures

In the figures, like or functionally identical components are shown with the same reference numbers. A repeated description of these components may be omitted.

Figure 1 shows a schematic and perspective view of an exemplary embodiment of a transformer 1 according to the invention in the form of a three-phase transformer.

The transformer 1 has a soft-magnetic stacked transformer core 2 comprising layers (not shown) having an amorphous and/or nanocrystalline structure made of a ferrous alloy, particularly of an FeSiB alloy. The stacked transformer core 2 comprises three coil legs 3 running parallel to each other and two yokes 4 connected with opposite ends of the coil legs 3. Two coils 18 and 19 are arranged on each coil leg 3.

The coil legs 3 and the yokes 4 each are constituted by a stack of compound bodies (not shown) firmly bonded to each other, wherein each compound body is constituted by cut-to-length compound segments (not shown) of a ribbon-like multi-compound (not shown). The respective multi-compound comprises at least two compound layers (not shown) firmly bonded to each other, wherein each compound layer is constituted of a foil compound (not shown), wherein each foil compound comprises at least two ribbon-like soft-magnetic foils (not shown) having an amorphous and/or nanocrystalline structure made of a ferrous alloy, particularly of an FeSiB alloy, wherein the foils are firmly bonded to each other.

The compound layers of the multi-compound can each be formed of a longitudinally separated foil compound (not shown), wherein one foil compound is longitudinally separated with respect to a cross section width (not shown) of the respective multi-compound at a different place than the other foil compound arranged adjacent to said foil compound.

The transformer 1 also has a holding device 5 for holding the stacked transformer core 2. The holding device 5 has two holding units 6 and 7 that are arranged at one of the yokes 4 such that the holding units 6 and 7 are arranged at opposite end regions of the stacked transformer core 2.

Furthermore, the holding device 5 has four mechanical fixing means 8 acting on the two holding units 6 and 7 and via which the two holding units 6 and 7 are non-destructively

detachably connected with each other. Each fixing means 8 is designed as a screw connection. The fixing means 8 are each arranged in a corner region of the holding device 5.

In addition, the holding device 5 has four spacers 9 clamped between the holding units 6 and 7, which are sleeve-shaped in the exemplary embodiment, a threaded shaft 39 of the respective fixing means 8 being passed through the respective spacer 9. The threaded shafts 39 of the fixing means 8 can be extended upwards beyond the holding unit 6 such that they are additionally used to hold a cover (not shown) of a transformer tank (not shown).

Furthermore, the holding device 5 has a plurality of spring elements (not shown) arranged between the respective holding unit 6 or 7 and the stacked transformer core 2. The holding device 5 is constructed such that the spring elements are elastically deformed by at least indirect contact with the stacked transformer core 2 caused when the stacked transformer core 2 is arranged at the holding device 5. At least one spring element can be U-shaped such that it positively encompasses the stacked transformer core 2 along at least one section of the respective yoke 4 such that a connection region (not shown) arranged between at least one coil leg 3 and the respective yoke 4 is located between parallel legs (not shown) of the spring element. A reset force that can be applied with the respective spring element can be set separately.

Each holding unit 6 or 7 has two holding elements 10 and 11, which are arranged at opposite yoke end regions of the respective yoke 4. Furthermore, each holding unit 6 or 7 has two mechanical fixing means 12 acting on the two holding elements 10 and 11 and by means of which the two holding elements 11 and 12 are non-destructively detachably connected with each other. In addition, each holding unit 6 or 7 has two spacers 13 clamped between the holding elements 10 and 11, which are sleeve-shaped in the exemplary embodiment, a threaded shaft 40 of the respective fixing means 12 being passed through the respective spacer 13. Each holding unit 6 or 7 furthermore has a plurality of spring elements (not shown) arranged between the respective holding element 11 or 12 and the respective yoke 4. The respective holding unit 6 or 7 is constructed such that the respective spring element is elastically deformed by at least indirect contact with the stacked transformer core 2 caused when the stacked transformer core 2 is arranged at the holding device 5. A reset force that can be applied with the respective spring element can be set separately.

The holding device 5 can also have at least one spring element (not shown) at least partly arranged between the respective spacer 9 and the stacked transformer core 2,

wherein the holding device 5 can be constructed such that the spring element is elastically deformed by at least indirect contact with the stacked transformer core 2 caused when the stacked transformer core 2 is arranged at the holding device 5.

Furthermore, the holding device 5 can have at least one spacer (not shown) which is arranged between two coil legs 3 arranged adjacent to one another and on which the two coil legs 3 are laterally supported against each other. Corresponding spacers are shown, for example, in Figure 6.

The holding device 5 also has three pairs each of two support elements 14 arranged on opposite sides of the respective coil leg 3, each of which is connected at the end to the two holding units 6 and 7.

In addition, the holding device 5 has four coil support elements 15 per coil leg 3 for axially supporting the coils 18 and 19 arranged on the respective coil leg 3. For each coil leg 3, two coil support elements 15 are arranged on one holding unit 6 and the two other coil support elements 15 are arranged on the other holding unit 7. For each coil leg 3, the coil support elements 15 are arranged in pairs on opposite sides of the respective coil leg 3. As indicated by dash-dotted lines on the holding unit 7, coil support elements 15 extending between adjacent coil legs 3 can be monolithically interconnected.

Furthermore, the holding device 5 per coil support element 15 has two spring elements (not shown) which are arranged between the respective holding unit 6 or 7 and the respective coil support element 15 and each engage in an opening 16 in the respective holding unit 6 or 7. The holding device 5 is constructed such that the spring elements are elastically deformed by an indirect contact via the coil support element 15 with at least one of the coils 18 or 19 caused when the stacked transformer core 2 with coils 18 and 19 indicated by dash-dotted lines and arranged thereon is arranged at the holding device 5.

Figure 2 shows a schematic and perspective view of the holding device 5 shown in Figure 1. In particular, all four spacers 9 are shown.

Figure 3 shows a schematic and perspective partial sectional view of a portion of the transformer 1 shown in Figure 1. The coils are omitted, as a result of which the support elements 14 and their respective arrangement on the respective coil leg 3 can be seen better.

Figure 4 shows a schematic and perspective sectional illustration of a further section of the transformer 1 shown in Figure 1 in the region of the holding element 11 of the holding unit 6 in a first variant. An opening 16 formed on the holding element 11 is

shown, into which a pin 20 of the spring element 21 shown engages. On a support plate 22, which is formed by monolithically connecting coil support elements (not shown) arranged between adjacent coil legs 3, as is shown in Figures 1 and 3, a separate depression 23 is formed for each spring element 21, in which the respective spring element 21 is partially received. A depression 25 is formed on a bottom 24 of the recess 23, into which a further pin 26 of the respective spring element 21 engages. Each spring element 21 is made monolithically from an elastomer.

Figure 5 shows a schematic and perspective sectional illustration of a further section of the transformer 1 shown in Figure 1 in the region of the holding element 11 of the holding unit 6 in a second variant. An opening 16 formed on the holding element 11 is shown, into which a pin 17 of the plate-shaped spring element 27 shown engages. The spring element 27 is supported on one side on a support plate 28 which is formed by monolithically connecting coil support elements (not shown) arranged between adjacent coil legs 3, as is shown in Figures 1 and 3. Each spring element 27 is made monolithically from an elastomer.

Figure 6 shows a schematic sectional view of a further exemplary embodiment of a transformer 29 according to the invention in the form of a three-phase transformer. The transformer 29 substantially differs from that the exemplary embodiment shown in Figures 1 to 5 in that the stacked transformer core 2 is supported on the holding unit 6 and 7 by means of spring elements 30 and 31 of a larger area and on the spacers 33 by two further spring elements 32, which are arranged separately to the fixing means 8. Otherwise, the transformer 29 can be formed corresponding to Figures 1 to 5, which is why reference is made to the above description of Figures 1 to 5 to avoid repetition. The holding device 5 also has four spacers 34 arranged in pairs between two adjacent coil legs 3, on which the respective two coil legs 3 are laterally supported against each other.

Figure 7 shows a further schematic sectional illustration of the transformer 29 shown in Figure 7 according to the cutting plane A-A from Figure 6. It can be seen that the spring elements 30 and 31 are each U-shaped in cross section. In each case, a connection region 35 between the respective yoke 4 and the respective coil leg 3 is arranged between parallel legs 36 of the respective spring element 36. Instead of the respective U-shaped spring element 30 or 31, three separately produced elements (not shown) can be arranged correspondingly in a U-shape, one element forming a leg as a spring element and the other element forming a leg as a sliding body, while this element connecting the two elements can be designed as a spring element.

Figure 8 shows a schematic sectional view of a further exemplary embodiment of a transformer 37 according to the invention in the form of a three-phase transformer. The transformer 35 differs in particular from the exemplary embodiment shown in Figures 6 and 7 in that each holding unit 6 or 7 is U-shaped in cross section and thus has two parallel legs 38, between which the respective spring element 30 or 31 is received. The mechanical fixing means of the holding unit 5 are not shown. Between the free ends of the legs 38 and at least one coil 18 or 19, a spring element 41 is arranged, which is elastically deformed by contact with the respective coil 18 or 19.

List of Reference Symbols

- | | |
|----|--------------------------|
| 1 | Transformer |
| 2 | Stacked transformer core |
| 3 | Coil leg |
| 4 | Yoke |
| 5 | Holding device |
| 6 | Holding unit |
| 7 | Holding unit |
| 8 | Fixing means of 5 |
| 9 | Spacer of 5 |
| 10 | Holding element |
| 11 | Holding element |
| 12 | Fixing means of 6, 7 |
| 13 | Spacer of 6, 7 |
| 14 | Support element |
| 15 | Coil support element |
| 16 | Opening at 10, 11 |
| 17 | Pin of 27 |
| 18 | Coil |
| 19 | Coil |
| 20 | Pin of 21 |
| 21 | Spring element |
| 22 | Support plate |
| 23 | Depression at 22 |
| 24 | Base of 23 |
| 25 | Recess at 23 |
| 26 | Pin of 21 |
| 27 | Spring element |
| 28 | Support plate |
| 29 | Transformer |
| 30 | Spring element |
| 31 | Spring element |
| 32 | Spring element |
| 33 | Spacer |
| 34 | Spacer |

- 35 Connection region between 3 and 4
- 36 Leg of 30, 31
- 37 Transformer
- 38 Leg of 6, 7
- 39 Threaded rod of 8
- 40 Threaded rod of 12
- 41 Spring element

Claims

1. A holding device (5) for holding a soft-magnetic stacked transformer core (2) comprising layers having an amorphous and/or nanocrystalline structure made of a ferrous alloy, particularly of a FeSiB alloy, wherein the stacked transformer core (2) comprises at least two coil legs (3) running parallel to each other and two yokes (4) connected with opposite ends of the coil legs (3), comprising
 - at least two holding units (6, 7) that can be arranged at one of the yokes (4) such that the holding units (6, 7) are arranged at opposite end regions of the stacked transformer core (2), and
 - at least one mechanical fixing means (8) acting on both holding units (6, 7), the holding units (6, 7) non-destructively detachably connected with each other via the fixing means (8), **characterised by**
 - at least one spacer (9, 33) clamped between said holding units (6, 7) and at least one spring element (21, 27, 30, 31, 32) arrangeable between at least one holding unit (6, 7) and the stacked transformer core (2),
 - wherein the holding device (5) is constructed such that the spring element (21, 27, 30, 31, 32) is elastically deformed by at least indirect contact with the stacked transformer core (2) caused when the stacked transformer core (2) is arranged at the holding device (5).

2. The holding device (5) according to claim 1, characterised in that at least one holding unit (6, 7) comprises
 - at least two holding elements (10, 11) arrangeable at opposite yoke end regions of the respective yoke (4),
 - at least one mechanical fixing means (12) acting on both holding elements (10, 11), the holding elements (10, 11) being non-destructively detachably connected with each other via the fixing means (12),
 - at least one spacer (13) clamped between the holding elements (10, 11), and at least one spring element (21, 27, 30, 31) arrangeable between at least one holding element (10, 11) and the respective yoke (4),
 - wherein the holding unit (6, 7) is constructed such that the spring element (21, 27, 30, 31) is elastically deformed by at least indirect contact with the stacked transformer core (2) caused when the stacked transformer core (2) is arranged at the holding device (5).

3. The holding device (5) according to claim 1 or 2, characterised in that at least one spring element (30, 31) is U-shaped such that it positively encompasses the stacked transformer core (2) along at least one section of the respective yoke (4) such that a connection region (35) arranged between the coil legs (3) and the respective yoke (4) is located between parallel legs (36) of the spring element (30, 31, 35).
4. The holding device (5) according to any one of the claims 1 to 3, characterised by at least one spring element (32) at least partly arrangeable between the spacer (33) and the stacked transformer core (2), wherein the holding device (5) is constructed such that the spring element (32) is elastically deformed by at least indirect contact with the stacked transformer core (2) caused when the stacked transformer core (2) is arranged at the holding device (5).
5. The holding device (5) according to any one of the claims 1 to 4, characterised by at least one spacer (34) being arrangeable between adjacent coil legs (3), at which the coil legs (3) are laterally supported against each other.
6. The holding device (5) according to any one of the claims 1 to 5, characterised by at least two support elements (14) arrangeable on opposite sides of a coil leg (3) and being connected at its ends with both holding elements (6, 7).
7. The holding device (5) according to any one of the claims 1 to 6, characterised by
 - at least four coil support elements (15) for axially supporting of coils (18, 19) being arranged on a coil leg (3), wherein two coil support elements (15) are arranged at one holding unit (6, 7) and the two further coil support elements (15) are arranged at the other holding unit (6, 7), wherein the coil support elements (15) are arrangeable in pairs on opposite sides of the coil leg (3), and
 - at least one spring element (21, 27, 41) per coil support element (15) arranged or arrangeable either between the respective holding unit (6, 7) and the respective coil support element (15) or between the respective coil support element (15) and the respective coil (18, 19),

- wherein the holding device (5) is constructed such that the spring element (21, 27, 41) is elastically deformed by at least indirect contact with at least one coil (18, 19) caused when the stacked transformer core (2) with the coils (18, 19) thereon is arranged at the holding device (5).
8. The holding device (5) according to any one of the claims 1 to 7, characterised in that a reset force that can be applied by the respective spring element (21, 27, 30, 31, 32, 41) is separately adjustable.
 9. A transformer (1, 29, 37), particularly a three-phase transformer, comprising
 - at least one soft-magnetic stacked transformer core (2) comprising layers having an amorphous and/or nanocrystalline structure made of a ferrous alloy, particularly of a FeSiB alloy, wherein the stacked transformer core (2) comprises at least two coil legs (3) running parallel to each other and two yokes (4) connected with opposite ends of the coil legs (3), and
 - at least one holding device (5) for holding the stacked transformer core (2), **characterised in that** the holding device (5) is constructed according to any one of the claims 1 to 8.
 10. The transformer (1, 29, 37) according to claim 9, characterised in that the coil legs (3) and the yokes (4) each are constituted by a stack of compound bodies firmly bonded to each other, wherein each compound body is constituted by cut-to-length compound segments of a ribbon-like multi-compound, the compound segments being firmly bonded to each other, wherein the multi-compound comprises at least two compound layers firmly bonded to each other, wherein each compound layer is constituted of a foil compound, wherein each foil compound comprises at least two ribbon-like soft-magnetic foils having an amorphous and/or nanocrystalline structure made of a ferrous alloy, particularly of a FeSiB alloy, wherein the foils are firmly bonded to each other.
 11. The transformer (1, 29, 37) according to claim 10, characterised in that the compound layers each are formed from a longitudinally separated foil compound, wherein one foil compound is longitudinally separated with respect to a cross section width of the respective compound body at a different place than the other

foil compound arranged adjacent to said foil compound.