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

(11) **EP 2 814 045 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
17.12.2014 Bulletin 2014/51

(51) Int Cl.:
H01F 27/00 *(2006.01)*

(21) Application number: **13172024.5**

(22) Date of filing: **14.06.2013**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(71) Applicant: **ABB Technology AG**
8050 Zürich (CH)

(72) Inventors:
- **Wallumrod, John**
  3090 Hof (NO)
- **Stryken, Egil**
  3026 Drammen (NO)
- **Klys, Pawel**
  93-008 Lodz (PL)
- **Fabijanowski, Wojciech**
  92-518 Lodz (PL)
- **Nowak, Roman**
  91-162 Lodz (PL)
- **Nowak, Tomasz**
  30-389 Krakow (PL)
- **Platek, Robert**
  30-719 Krakow (PL)
- **Shoory, Abdolhamid**
  5033 Buchs (CH)

(74) Representative: **ABB Patent Attorneys**
c/o ABB Schweiz AG
Intellectual Property CH-IP
Brown Boveri Strasse 6
5400 Baden (CH)

(54) **Compact low-loss triangular transformer and method for producing the same**

(57) A triangular transformer is provided. It comprises a core including at least three distinct elongated frame sections, each having two end portions, the frame sections being composed of layered sheets of a ferromagnetic material, wherein the frame sections are mounted together to form the triangular core, and wherein each end portion of a first frame section abuts at least one end portion of a second frame section at a joint region, and wherein in at least one joint region comprising a first end portion of a first frame section and an abutting first end portion of a second frame section, the normal vectors of the abutting end portions of abutting sheets have the same direction, and wherein the at least two normal vectors are substantially parallel to a longitudinal axis of the transformer, and/or a cross-sectional plane through the at least one joint region and perpendicular to the abutting sheets of that at least one joint region is substantially parallel to the longitudinal axis. Further, methods for producing such transformers are provided.

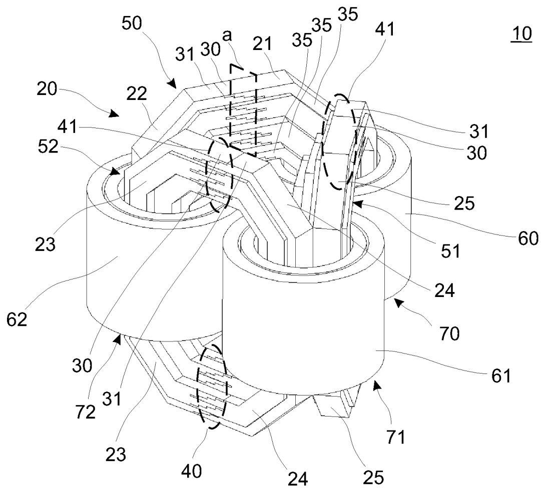

Fig.1

EP 2 814 045 A1

Description

TECHNICAL FIELD

[0001] The present disclosure generally relates to electrical transformers. In particular, it relates to power distribution transformers, and more particularly, to triangular core transformers manufactured in split core configuration.

BACKGROUND OF THE INVENTION

[0002] Triangular core transformers are known to generally have lower material usage compared to traditional planar cores in order to reach the same performance, namely with respect to the criteria no-load loss, in particular core loss, and load loss, i.e., in particular winding loss. The amount of material usage for given losses depends on the way in which the core is realized. It is known that wound cores have lower losses in comparison to stacked cores, the losses of hybrid wound-stacked cores falling in-between the two. A reduction of the material usage can be achieved if both the low voltage (LV) and the high voltage (HV) windings/coils are wound directly on the core, and if one uses special cross-sections of the core legs (namely, the so called pizza or diamond shapes) allowing for more compact transformers.

[0003] The performance of a transformer core is a function of different parameters. To name a few, factors are the peak magnetic flux density in the core, the applied frequency, and the irregularities in the magnetic flux path. For the latter, joints are an important factor. At joints, physically distinct portions, i.e. segments, of the ferromagnetic core abut each other, so that the flux has to pass a physical gap. Though the gap is usually minimized by design, and also frequently by exerting a force to minimize the gap, gaps typically significantly influence transformer losses. Thus, regarding the aspect of the gap influence, an ideal core would have a closed loop characteristics without any gaps. However, using conventional winding equipment, this is typically designed to wind the coil on a transformer leg which has an end, so that a rotational member of the winding machine can perform a continuous rotational motion of the leg, and wherein only after the winding is completed, the yoke is put in place in order to complete the core. This rotational core leg motion is however not possible to perform with an initially closed core. Instead, in that case the conductor would have to be perpetually transferred from one rotational member to another.

[0004] CN 2007/10037948 discloses a wound triangular core. Wound triangular cores are made of three separate and identical core loops. Each core loop is a magnetically closed loop without any joints in the magnetic flux path. The difficulty with such a core is to wind high voltage (HV) and low voltage (LV) windings on the already completed core, which - as described above - cannot be done using traditional tools and requires special techniques. Nevertheless, as stated earlier, the main advantage of this core is the lower no-load loss. In order to solve the problem of cumbersome LV and HV winding on the complete core, one can create openings in one of the top or bottom yokes of each core loop. When the core loops are put together to form the triangular footprint or configuration, the windings, which are wound separately, can be put on the core legs, and the core can then be closed and clamped.

[0005] Further, there are stacked triangular cores, using a similar concept as traditional planar cores. WO 2005/027155 A1 discloses a transformer with stacked triangular core. Therein, legs and yokes are stacked separately and assembled finally to form the complete transformer. The coils in such a core can be wound directly on the core leg, allowing for further optimization of material usage. The yokes in such a core can be straight, bent, or folded.

[0006] US 2689396 A and US 2952068 A disclose transformers with hybrid triangular cores. Thereby, the legs are made of stacked laminations, and the top and bottom yokes each form a single body made of wound laminations.

[0007] However, known configurations suffer from either a cumbersome winding process in the case of a closed core, or from an improvable loss characteristics due to the presence of gaps for the magnetic flux, particularly when the magnetic flux lines have to significantly change direction in the vicinity of the gaps.

[0008] In view of the above, there is a need for a transformer design which further improves the loss characteristics of the known solutions, and further reduces the weight-per-loss ratio.

SUMMARY OF THE INVENTION

[0009] The problems mentioned above are at least partly solved by a transformer according to claim 1 and a method according to claim 9.

[0010] In a first aspect, a triangular transformer is provided. It comprises at least three coils; a core composed of three core frames, wherein each core frame is composed of at least two distinct elongated frame sections comprising layered sheets of a ferromagnetic material, each frame section having two end portions, wherein each end portion of a first frame section abuts at least one end portion of a second frame section at a joint region, and wherein at least two normal vectors on abutting sheets of the abutting end portions have the same direction; and wherein the at least two normal vectors are substantially parallel to a lontigudinal axis (A) of the transformer, and/or a cross-sectional plane (a) through the at least one joint region and perpendicular to the abutting sheets of that at least one joint region is substantially parallel to the longitudinal axis of the transformer.

[0011] A method of producing a triangular transformer with a split core is provided. It comprises producing C-shaped frame sections by laminating sheets of a ferromagnetic material; winding transformer coils onto legs of the core, each leg composed by at least one C-shaped frame section; mounting the C-shaped frame sections together to form the transformer; wherein in at least one joint region comprising a first end portion of a first frame section and an abutting second end portion of a second frame section, the normal vectors of abutting end portions of abutting sheets have the same direction, and wherein the at least two normal vectors are substantially parallel to a longitudinal axis (A) of the transformer, and/or a cross-sectional plane (a) through the at least one joint region and perpendicular to the abutting sheets of that at least one joint region is substantially parallel to a longitudinal axis of the transformer.

[0012] In conventional transformer cores as described further above, a grain orientation of the metal of the sheets is typically perpendicular across the joints between different parts of the core, for example across the joints between legs and the yoke. Consequently, when the magnetic flux lines close their path across the joints, they effectively need to bend by about 90°. For the delta-configuration split-core triangular transformers according to embodiments, the laminated metal sheets of one C-shaped frame section are parallel to the corresponding sheets of the second, abutting C-shaped frame section at the joint between the sections. As a result, the grain orientation remains aligned across the joint. This means, that when the magnetic flux lines close their path across the joint, they don't need to bend or change direction/orientation. For the star-configuration split-core triangular transformer according to embodiments, for example with 30° miter joints, grain orientation across the joints changes by 60°. As a result, when the magnetic flux lines close their path across the joints, they need to bend by 60°, which provides for lesser losses than in conventional cores. See also the comparison results shown in table 1, which are discussed further below.

[0013] The disclosed core configurations according to embodiments can result in better usage of space and hence optimally reduced usage of material, especially when combined with direct-on-the-core winding technology. One can further reduce the material usage by making use of special core leg cross-sections, typically the "pizza" and "diamond" shape.

[0014] Further aspects, advantages and features of the present invention are apparent from the dependent claims, the description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] A full and enabling disclosure, including the best mode thereof, to one of ordinary skill in the art is set forth more particularly in the remainder of the specification, including reference to the accompanying figures wherein:

[0016] Fig. 1 schematically shows a perspective view of a transformer according to embodiments;

[0017] Fig. 2 schematically shows a top view of the transformer of Fig. 1;

[0018] Fig. 3 schematically shows part of a method for producing a transformer according to Fig. 1;

[0019] Fig. 4 schematically shows a perspective view of a part of the transformer of Fig. 1, which is an intermediate product during the production of the transformer;

[0020] Fig. 5 schematically shows a perspective view of a further part of the transformer of Fig. 1, which is an intermediate product during the production of the transformer;

[0021] Fig. 6 schematically shows a perspective view of a transformer according to further embodiments;

[0022] Fig. 7 schematically shows a top view of the transformer of Fig. 6;

[0023] Fig. 8 schematically shows part of a method for producing a transformer according to Fig. 6;

[0024] Fig. 9 schematically shows a perspective view of a part of the transformer of Fig. 6, which is an intermediate product during the production of the transformer;

[0025] Fig. 10 schematically shows a perspective view of a further part of the transformer of Fig. 6, which is an intermediate product during the production of the transformer;

[0026] Fig. 11 schematically shows a perspective view of a transformer according to further embodiments;

[0027] Fig. 12 schematically shows a top view of the transformer of Fig. 11;

[0028] Fig. 13 schematically shows part of a method for producing a transformer according to Fig. 11;

[0029] Fig. 14 schematically shows a perspective view of a part of the transformer of Fig. 11, which is an intermediate product during the production of the transformer;

[0030] Fig. 14 schematically shows a perspective view of a further part of the transformer of Fig. 11, which is an intermediate product during the production of the transformer;

[0031] Fig. 16 schematically shows sheets of transformers according to the transformer of Fig. 11;

[0032] Fig. 17 schematically shows a magnetic flux in abutting core sections of a prior art transformer;

[0033] Fig. 18 schematically shows a magnetic flux in abutting core sections transformers according to embodiments;

[0034] Fig. 19 shows a method of clamping a transformer according to the transformer of Fig. 11;

[0035] Fig. 20 to Fig. 22 show cross sectional views of transformers according to embodiments shown in Fig. 1 and Fig. 2;

[0036] Fig. 23 to Fig. 25 show cross sectional views of transformers according to embodiments shown in Fig. 5 and Fig. 6, and in Fig. 11 and Fig. 12.

DETAILED DESCRIPTION OF THE INVENTION

[0037] Reference will now be made in detail to various embodiments, one or more examples of which are illustrated in each figure. Each example is provided by way of explanation and is not meant as a limitation. For example, features illustrated or described as part of one embodiment can be used on or in conjunction with other embodiments to yield yet further embodiments. It is intended that the present disclosure includes such modifications and variations.

[0038] Within the following description of the drawings, the same reference numbers refer to the same components. Generally, only the differences with respect to the individual embodiments are described. When several identical items or parts appear in a figure, not all of the parts have reference numerals in order to simplify the appearance.

[0039] The systems and methods described herein are not limited to the specific embodiments described, but rather, components of the systems and/or steps of the methods may be utilized independently and separately from other components and/or steps described herein. Rather, the exemplary embodiment can be implemented and used in connection with many other applications.

[0040] Although specific features of various embodiments of the invention may be shown in some drawings and not in others, this is for convenience only. In accordance with the principles of the invention, any feature of a drawing may be referenced and/or claimed in combination with any feature of any other drawing. As used herein, the terms C-shaped and U-shaped are used interchangeably, and are intended to describe a structure which has basically the shape of the respective letter C or U. Thereby, the shape is intended to be descriptive for any bent elongated body which substantially resembles that shape - for example, also a half circle, a half ellipsoid, or a structure with curves of different radii and also straight portions is regarded to be C-shaped in this regard. In particular, the C-shaped structure may have features which deviate from a perfect rounded structure, for example edges and corners. Further, various geometrical expressions as used herein are typically related to a transformer having a longitudinal axis. For the definition of terms like "top" and "bottom", it is assumed that this axis is oriented vertically with respect to the surface of the earth, which is in compliance with the geometry and configuration of most delta transformers.

[0041] Fig. 1 shows a triangular transformer according to embodiments, Fig. 2 shows a different viewing angle. As shown in Fig. 1 and Fig. 2, the transformer 10 has a delta-footprint, in the following also called delta configuration. The core 10 comprises three core frames 50, 51, 52, which may also be regarded as core loops, as they provide closed, basically ring-shaped structures for the magnetic flux during operation of the transformer 10. Each core frame is composed of two distinct elongated frame sections 21, 22, 23, 24, 25, 26, which are substantially symmetrical to each other, wherein the end portions 30, 31 may not be exactly symmetrical, but be shaped to fit to each other like key and slot or groove and tongue. The frame sections comprise layered sheets 35 of a ferromagnetic material, i.e., oriented, non-oriented, cold-rolled, hot-rolled, amorphous, domain refined, or laser scribed steel, or ferrites. At joint regions 40, 41, the two frame sections 21, 22, 23, 24, 25, 26 of a core frame 50, 51, 52 are in contact with each other. More precisely, two end portions 30, 31 of the frame sections abut in a joint region 40 at the bottom of the transformer with respect to a longitudinal axis A, see Fig. 2, and at a further joint region 41 at the top of the transformer 10 with respect to axis A. Thereby, in the embodiment shown, the stacked layered sheets 35 of the frame sections 21, 22, 23, 24, 25, 26 have different lengths with respect to each other. Thereby, both end portions 30, 31 of the two frame sections 21, 22, 23, 24, 25, 26, together forming a core frame 50, 51, 52, are adapted such that the abutting end portions 30, 31 are like key and slot, resulting in a tight match that would not be achievable with, e.g., plane end portions 30, 31.

[0042] The abutting end portions 30, 31 of two frame sections comprise end portions of the individual sheets 35. A sheet 35 of a first end portion 30, 31 typically abuts a sheet of the other frame section, refer to joint region 41 in Fig. 1. Thus, the orientation and direction in space of abutting sheets 35 of two connected, abutting frame sections 21, 22, 23, 24, 25, 26 are typically the same. Differently expressed, the orientation of the at least two normal vectors on abutting sheets 35 of the abutting end portions 30, 31 have the same direction. Further, at least two normal vectors of the abutting sheets are substantially parallel to a longitudinal axis A of the transformer 10. Also, a cross-sectional plane a through the at least one joint region 40, 41, which is perpendicular to the abutting sheets 35 of that at least one joint region is substantiallyparallel to a longitudinal axis of the transformer. This can be seen as a consequence from the split-core, with the joint regions 40, 41 being in the top and bottom regions of the transformer. In Fig. 1, plane a is only depicted once for illustrational purposes only. Due to the rotational symmetry of the transformer 10 about axis A, a similar plane a also exists for all of the three core frames.

[0043] The core frames 50, 51, 52, or split-core loops, are comprised by two C-shaped frame sections. Thereby, each of the three legs 70, 71, 72 of the core 20 is a side-by-side arrangement of two C-shaped frame sections. This becomes apparent when regarding Fig. 2. For example, frame sections 21 and 26 belong to the different core frames 50, and 51, respectively. Together, they side-by-side form leg 70, around which coil 60 is wound. The two core frames 50 and 51 thus together form one leg 70 of the core 20. In Fig. 2, the top view on transformer 10 having a delta configuration with a longitudinal axis A also shows, that when two C-shaped frame sections join each other at joint region 41 at their top end (bottom end not visible in Fig. 2), they form a top yoke, and the bottom yokes.

[0044] Fig. 3 shows how a frame section 21, 22, 23, 24, 25, 26 is produced according to embodiments. The sheet shown in Fig. 3I is produced by cutting the raw ferromagnetic material to obtain a rectangular sheet. The sheet is then folded four times by 45° at different folding edges, in order to obtain the shape shown in Fig. 3 II. In order to obtain the end portions 30, 31 shaped as already described above, the folding edges of the various sheets are located asymmetrically with respect to the middle of the longer side of the sheets. With each stacked sheet, respectively with each laminated further sheet 35, the position of the folding edges is shifted during the process, so that the end portion 30, 31 is shaped in the manner already described, see Fig. 3 VI. A plurality of the intermediate product of Fig. 3 VI is then assembled to yield a frame section 22, 23, see Fig. 4. In embodiments, the sheets may also be cut and bent, so that a plain end section 30, 31 results. In this case, other measures should be additionally taken in order to ensure stability of the core 20, respectively the transformer 10.

[0045] Fig. 4 shows a side-by-side arrangement of two frame sections 22, 23, together forming leg 72. On leg 72, a coil 60, 61, 62 is subsequently wound, typically comprising a high voltage (HV) coil and a low voltage (LV) coil. The resulting arrangement is shown in Fig. 5 and herein called phase 66, 67, 68, and forms one part of the transformer 10 according to embodiments representing the side-by-side split core transformer. Three of these phases 66, 67, 68 are subsequently mounted together in order to form the completed transformer as shown in Fig. 1 and Fig. 2. Typically, the assembled transformer 10 is also equipped with a clamping device exerting a force on the core, i.e., the core frames and frame sections, from an outside direction. This serves for the purpose of stabilizing the core and transformer during operation. This is not shown in the present embodiment. It is referred to Fig. 23, where the clamping is described with respect to further embodiments.

[0046] Fig. 6 shows a triangular transformer 10 according to further embodiments, and Fig. 7 shows a respective top view. Differing from the transformer 10 described with respect to Fig. 1 and Fig. 2, in Fig. 6 a so called back-to-back configuration is shown. Therein, the sheets of which the core frames 50, 51, 52 are composed, are produced differently, resulting in a different shape of the resulting core frames 50, 51, 52 and frame sections 21, 22, 23, 24, 25, 26. In Fig. 6, it is shown that the plane between two frame sections is vertical. This is further illustrated in and explained with respect to Fig. 8. An important characteristics is to have a constant width along the length of the individual laminations or sheets 35, which significantly simplifies the cutting and stacking procedure.

[0047] Thereby, the angle between the normal vectors of the laminations of the legs and the yokes, sharing one frame section, is about 138,6°. This means that the sum of the two fold angles should typically be 138,6°. The individual values of the two folding angles can be arbitrarily chosen, for example according to the requirement of cost efficient and practical production. The total number of folds in both the side-by-side production process (transformer shown in Fig. 1 and Fig. 2) and back-to-back configuration (transformer shown in Fig. 6 and Fig. 7) concepts are typically the same for the same number of laminated sheets.

[0048] Compared to the transformer 10 of Fig. 1, the orientation and direction in space of abutting sheets 35 of two connected, abutting frame sections 21, 22, 23, 24, 25, 26 are also typically the same. Thus, the orientation of the at least two normal vectors on abutting sheets 35 of the abutting end portions 30, 31 have the same direction. However, the normal vectors of the abutting sheets 35 are not parallel to a longitudinal axis A of the transformer 10. Yet, a cross-sectional plane a through the at least one joint region 40, 41, which is perpendicular to the abutting sheets 35 of that at least one joint region is typically substantially parallel to the longitudinal axis of the transformer. Similar as with the transformer of Fig. 1, this can be seen as a consequence from the split-core concept, with the joint regions 40, 41 being in the top and bottom regions of the transformer.

[0049] The process of manufacturing the side-by-side and back-to-back type transformers according to embodiments can be summarized as follows: Sheets of the ferromagnetic core material are typically cut, or otherwise manufactured, to bring them to adequate dimensions fitting to the intended dimensions of the core. The resulting sheets 35 are folded as described before. The folded sheets are subsequently stacked or laminated in order to produce the C-shaped frame sections 21, 22, 23, 24, 25, 26 as exemplarily shown in Fig. 8, I to VI. Thereby, typically the two variants as described above with respect to Fig. 3 to Fig. 5 on the one hand, or Fig. 8 to Fig. 10 may be employed to make the C-shaped frame sections. Two of the so produced C-shaped frame sections are subsequently arranged in the side-by-side or back-to-back configurations, to form an arrangement which subsequently serves as a transformer leg 70, 71, 72. Thus, the so produced frame section comprises one transformer leg. The portions of the frame sections 21, 22, 23, 24, 25, 26 protruding out of the wound coil 60, 61, 62, typically form the associated top and bottom half-yokes after assembly of the transformer 10.

[0050] Next, the coils 60, 61, 62, typically each having a LV and a HV winding part, are wound on the thus-produced frame section to complete one phase 66 as shown in Fig. 5 for a side-by-side configuration, and in Fig. 10 for a back-to-back configuration. This process is then repeated for the other two phases 67 and 68 (not shown). The thus produced three phases are joined or mounted in order to complete the triangular transformer as shown in Fig. 1 and Fig. 2, or Fig. 6 and Fig. 7, respectively.

[0051] As shown in Fig. 11, a so called star-footprint (or star configuration) split-core triangular transformer 10 according to embodiments is comprised of three C-shaped frame sections 21, 23, 25 joined together at their ends 30, 31 (end-to-end configuration) to form the star footprint of the core of the transformer 10. Thereby, the core frames 50, 51, 52 are comprised by two neighboring frame sections 21, 23, 25 each. This is different from the embodiments described above, where three pairs of two

C-shaped frame sections 21, 22, 23, 24, 25, 26 form a core frame 50, 51, 52 each. In the embodiment of Fig. 11, each C-shaped frame section 21, 23, 25 makes a complete leg 70, 71, 72, and a top and bottom yoke connected to that leg. The yokes are connected together, with respect to an axis A, at the center of the transformer. This is different from the described delta-footprint split core triangular transformer, in which each C-shaped frame section only contains half of the corresponding top and bottom yokes, and each leg is a back-to-back or side-by-side configuration of two C-shaped sections 21, 22, 23, 24, 25, 26. Further, the cross-sectional area of each C-shaped frame section in the star-footprint core is approximately twice that of each C-shaped section in the delta-footprint core, when transformers with the same power ratings are compared.

[0052] The process of making a star-footprint split-core triangular transformer can be summarized as follows. As shown in Fig. 13, the sheets of ferromagnetic material are cut and shaped. Subsequently, they are folded, and the individual laminations are stacked to form one C-shaped frame section comprising one core leg and two (top and bottom) yokes as shown in Fig. 14 and Fig. 15. The shaping process consists of two 30° miter cuts. In order to facilitate the step-lap joining of the three core sections, the miters need to be done with different lengths for different layers, as is shown in Fig. 16 for five different sheets 35, which later form five layers of the core section: From left to right in Fig. 16, the relation between the length of the left end side and the right end side gradually varies. Then, the LV and HV windings 60, 61, 62 are wound directly on the core leg 70, 71, 72 to form one of the three phases 66, 67, 68. The three assembled phases in the star footprint are then joined to form the star configuration transformer 10 of Fig. 11 and Fig. 12.

[0053] In Table 1, various parameters are shown for a of transformers according to embodiments (delta-footprint triangular transformer, as shown in Fig. 1, 2, 6, and 7, and star-footprint triangular as in Fig. 11 and Fig. 12), in comparison to known transformers. It can be seen that in particular to the total cross section of joints respectively gaps, the transformers of embodiments are better (less cross section) than all other variants except the wound, gapless transformer. However, the latter has severe disadvantages due to the winding procedure, as was laid out above. The same competitive situation can be regarded with respect to the bend angles of the magnetic flux, which is lowest in transformers according to embodiments, with the same exception of the wound core. These angles are shown exemplarily for a known transformer in Fig. 17. Typically, the flux line has to bend by 90°. To the contrary, in the lower sketch of Fig. 18, the flux lines (indicated by the arrow) in a transformer according to embodiments such as in Fig. 1 and Fig. 2 are shown, where the flux lines protrude straight, also over joints, as exemplarily shown. The upper sketch in Fig. 18 shows the flux lines (indicated by the arrows) in a star configuration transformer according to embodiments, such as of Fig. 11 and Fig. 12. The flux lines have to bend, but only by 60°, which is better than in the prior art stacked transformers and thus produces less loss.

[0054] Fig. 19 shows an example for a clamping device and schematically a method for reinforcing transformers according to embodiments, starting with a base plate 101 of a clamping device 100. It is noted that most of the transformers described herein need an external clamping to be stable. As this is a concept well known to the skilled person, this was not accounted for in greater detail. Several known clamping techniques can be adapted to the embodiments described herein using standard knowledge. In Fig. 19, a star configuration transformer 10 is shown, which is stabilized by clamping with a clamping device 100.

[0055] Fig. 20 shows a cross-sectional view of a transformer 10 according to embodiments as shown in Fig. 1 and Fig. 2, having a side-by-side configuration. The three legs 70, 71, 72 have an outline resembling a circle, and accordingly the windings 60, 61, 62 have a round cross section. In Fig. 21, a similar transformer 10 to that of Fig. 20 is shown, wherein the cross section resembles a circle segment, or a "pizza slice", hence the type of the cross section is also called pizza type. Fig. 22 shows a further transformer 10 similar to that of Fig. 20, wherein the outline of the legs 70, 71, 72 resembles a diamond. The three shapes described before are advantageous with respect to an efficient material usage per unit of nominal power rating of the transformer. In order to implement them, sheets of varying width are employed during the manufacturing process of the transformer 10.

[0056] Fig. 23 shows a cross-sectional view of a transformer 10 according to embodiments as shown in Fig. 6 and Fig. 7, having a back-to-back configuration, or to embodiments as shown in Fig. 11 and Fig. 12, having a star configuration. The three legs 70, 71, 72 have an outline resembling a circle, and accordingly the windings 60, 61, 62 have a round cross section. In Fig. 24, a similar transformer 10 to that of Fig. 23 is shown, wherein the cross section resembles a circle segment, or a "pizza slice", hence the type of the cross section is also called pizza type. Fig. 25 shows a further transformer 10 similar to that of Fig. 24, wherein the outline of the legs 70, 71, 72 resembles a diamond. The three shapes described before are advantageous with respect to an efficient material usage per unit of nominal power rating of the transformer.

[0057] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. While various specific embodiments have been disclosed in the foregoing, those skilled in the art will recognize that the spirit and scope of the claims allows for equally effective modifications. Especially, mutually non-exclusive features of the embodiments described above may be combined with each other. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

Claims

1. Triangular transformer (10), comprising:

- at least three coils (60, 61, 62);
- a core (20) composed of three core frames (50, 51, 52), wherein each core frame (50, 51, 52) is composed of at least two distinct elongated frame sections (21, 22, 23, 24, 25, 26) comprising layered sheets (35) of a ferromagnetic material, each frame section (21, 22, 23, 24, 25, 26) having two end portions (30, 31), wherein each end portion (30, 31) of a first frame section (21, 23, 25; 21, 23, 25) abuts at least one end portion (30, 31) of a second frame section (22, 24, 26; 23, 25, 21) at a joint region (40, 41), and the end portions (30, 31) of the layered sheets (35) each have a normal vector, and two normal vectors of the abutting end portions (30, 31) have the same direction; and wherein
- the two normal vectors are substantially parallel to a longitudinal axis (A) of the transformer (10), and/or
- a cross-sectional plane (a) through the at least one joint region (40, 41) and perpendicular to the abutting end portions (30, 31) of the layered sheets (35) of that at least one joint region (40, 41) is substantially parallel to the longitudinal axis (A).

2. The triangular transformer of claim 1, with a core (10) having a delta shaped footprint, wherein each frame section (21, 22, 23, 24, 25, 26) is substantially C-shaped, the joint regions (40, 41) between abutting end portions (30, 31) of the frame sections (21, 22, 23, 24, 25, 26) being located at the top and bottom yokes of the transformer (10).

3. The triangular transformer of claims 1 or 2, wherein the core (20) comprises three legs (70, 71, 72), and wherein each leg is formed by two frame sections (21, 22, 23, 24, 25, 26).

4. The triangular transformer of any preceding claim, wherein the legs (70, 71, 72) are each formed by a side-by-side arrangement of two C-shaped frame sections (21, 22, 23, 24, 25, 26), and wherein the narrow sides of the layered sheets (35) of the two C-shaped frame sections (21, 22, 23, 24, 25, 26) abut.

5. The triangular transformer of claims 1 to 3, wherein the legs (70, 71, 72) of the core (20) are each formed by a back-to-back-arrangement of two C-shaped frame sections (21, 22, 23, 24, 25, 26), wherein the two C-shaped frame sections (21, 22, 23, 24, 25, 26) are arranged such that portions of the abutting sheets (35) of the two C-shaped frame sections (21, 22, 23, 24, 25, 26) are parallel to each other.

6. The triangular transformer of claim 1, having a star footprint, and having three C-shaped frame sections (21, 22, 23, 24, 25, 26), wherein three end portions (30, 31) are joined together in, with respect to the longitudinal axis (A) of the transformer (10), a first joint region (41) at the top of the transformer, and three end portions (30, 31) are joined at a second joint region (40) at the bottom of the transformer, with respect to the longitudinal axis (A) of the transformer (10).

7. The triangular transformer of any preceding claim, wherein at least one C-shaped frame section (21, 22, 23, 24, 25, 26) has at least two corners, each either having a single turn with a 90° angle $\pm$ 20 %, or each having at least two bend angles, of which the sum equals 90° $\pm$ 20%.

8. The triangular transformer of any preceding claim, wherein a horizontal cross-section through at least one of the coils (60, 61, 62) yields an inner outline of the coil which is one of: a circle, a circle segment, or a diamond.

9. A method of producing a triangular transformer with a split core (20), comprising:

- producing C-shaped frame sections (21, 22, 23, 24, 25, 26) by laminating sheets (35) of a ferromagnetic material;
- winding transformer coils (60, 61, 62) onto legs (70, 71, 72) of the core (20), each leg composed by at least one C-shaped frame section,
- mounting the C-shaped frame sections together to form the transformer (10); wherein in at least one joint region (40, 41) comprising a first end portion (30, 31) of a first frame section and an abutting second end portion of a second frame section, the normal vectors of abutting end portions (30, 31) of layered sheets (35) have the same direction,

and wherein:

- the at least two normal vectors are substantially parallel to a longitudinal axis (A) of the transformer, and/or
- a cross-sectional plane (a) through the at least one joint region (40, 41) and perpendicular to

the abutting end portions (30, 31) of the layered sheets (35) of that at least one joint region (40, 41) is substantially parallel to the longitudinal axis (A).

10. The method of claim 9, the transformer having a star configuration, wherein three frame sections (21, 23, 25) have a 120 degree angle orientation to each other, such that three abutting first end portions (30) of the three frame sections (21, 23, 25) are mounted together in a first joint region (41) at the top of the transformer, and three abutting second end portions (31) of the three frame sections are mounted together in a second joint region (40) at the bottom of the transformer with respect to the longitudinal axis (A) of the transformer.

11. The method of claim 9, with a core having a delta configuration, wherein six C-shaped frame sections are produced by laminating sheets (35), and arranging two frame sections each to form a leg (70, 71, 72) of the transformer,

- winding coils onto the three legs (70, 71, 72),
- mounting the C-shaped frame sections together in a delta configuration, wherein two neighboring C-shaped frame sections are joined together at their end portions to form one core frame each.

12. The method of claim 9, wherein the sheets (35) are rectangular and have an elongated shape, and are folded at least two fold lines prior to the laminating.

13. The method of claim 9, wherein the sheets (35) are rectangular and have an elongated shape, and are folded at two fold lines prior to the laminating.

14. The method of any of claims 9 to 12, wherein at least one C-shaped frame section (21, 22, 23, 24, 25, 26) has at least two corners, each either having a single bend angle with a 90° angle $\pm$ 20 %, or each having at least two bend angles, of which the sum equals 90° $\pm$ 20 %.

15. The method of any of claims 9 to 14, wherein a horizontal cross section through at least one of the coils (60, 61, 62) yields an inner outline of the coil which is one of: a circle, a circle segment, or a diamond.

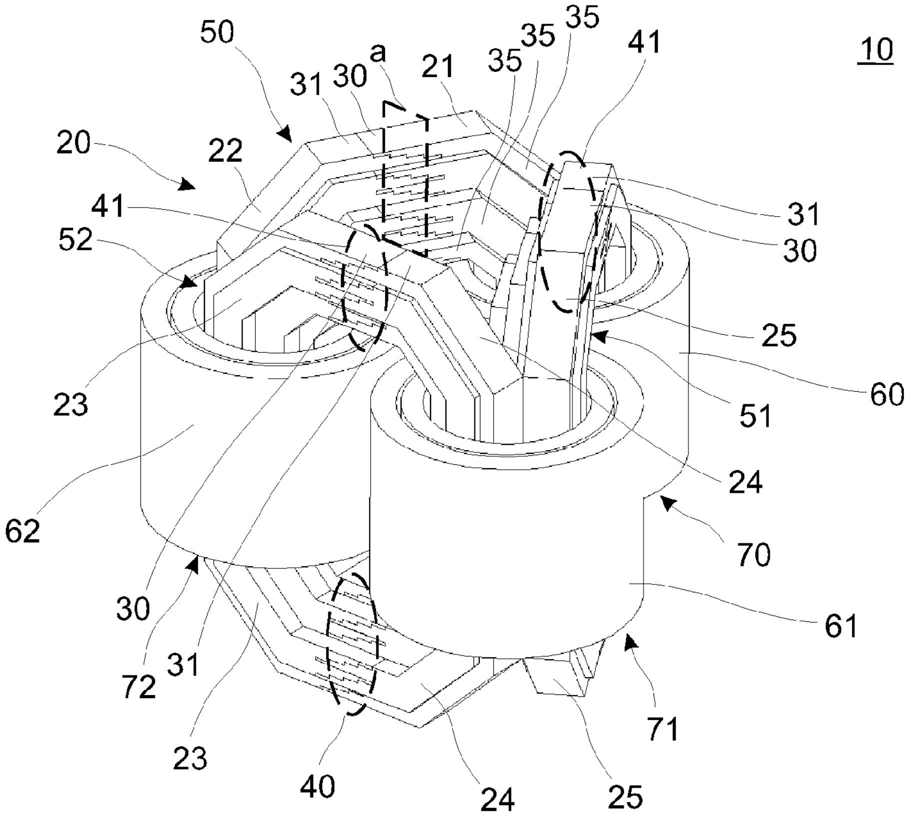
10
50
a
31
30
21
35
35
35
41
20
22
41
52
31
30
25
23
60
51
62
24
70
30
61
72
31
23
71
40
24
25

Fig.1

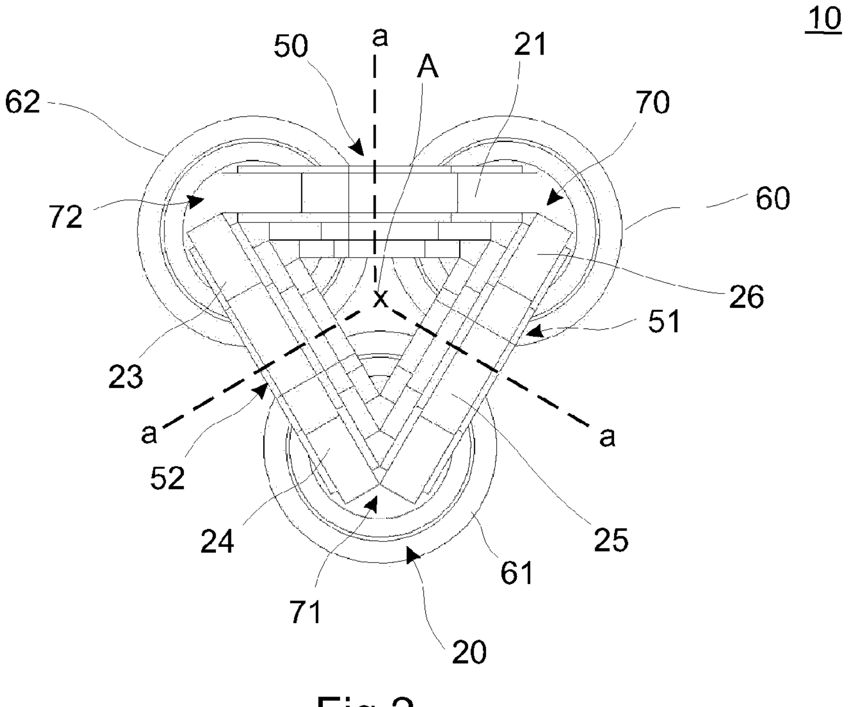
10
a
50
A
21
62
70
72
60
26
51
23
a
a
52
24
25
61
71
20

Fig.2

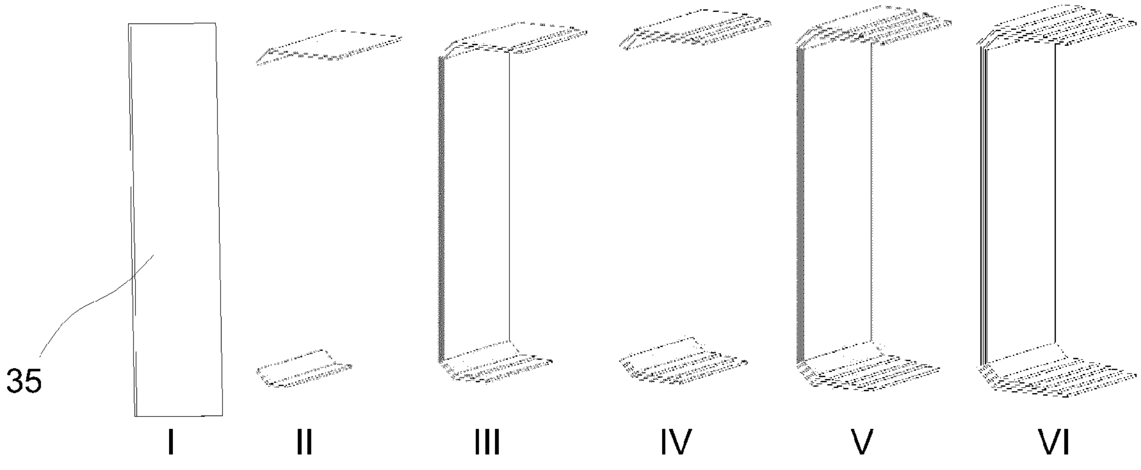

Fig.3

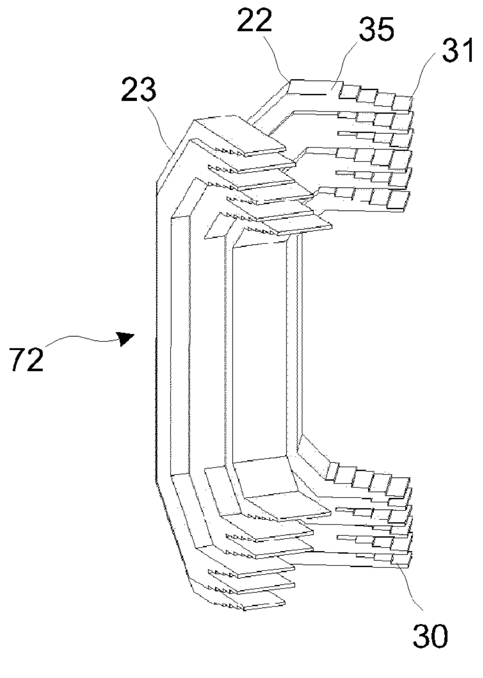

Fig.4

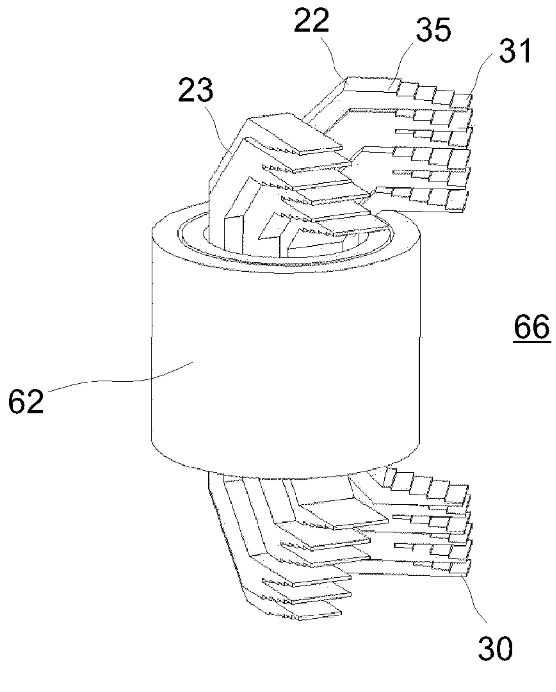

Fig. 5

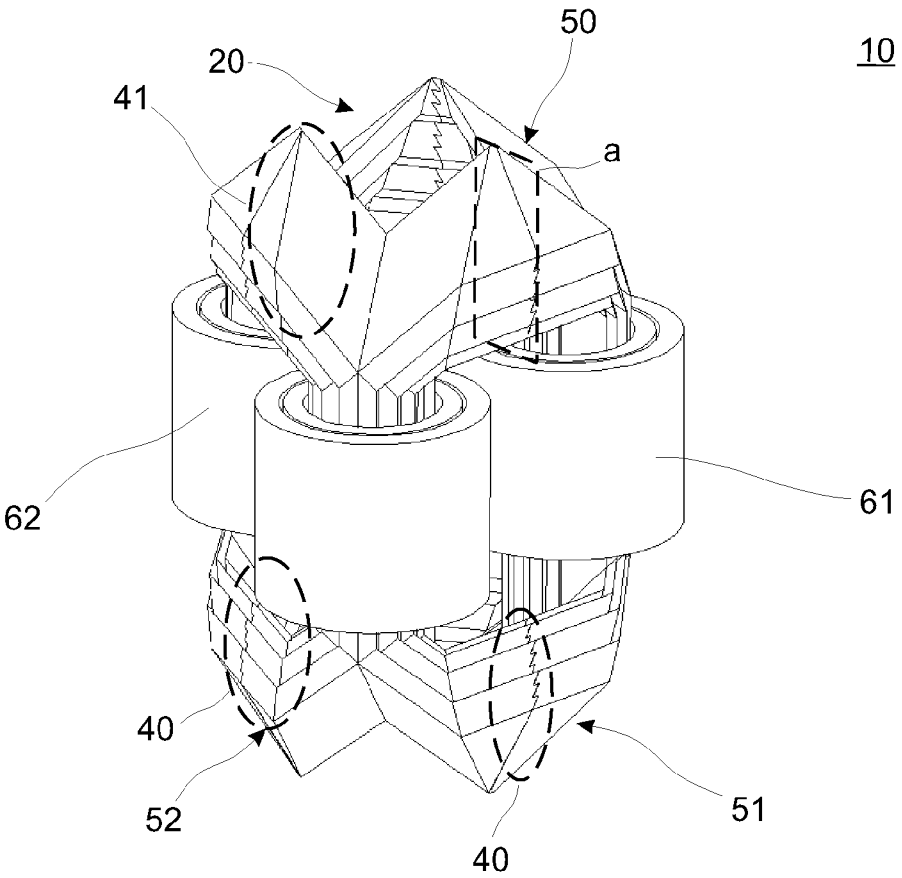

Fig.6

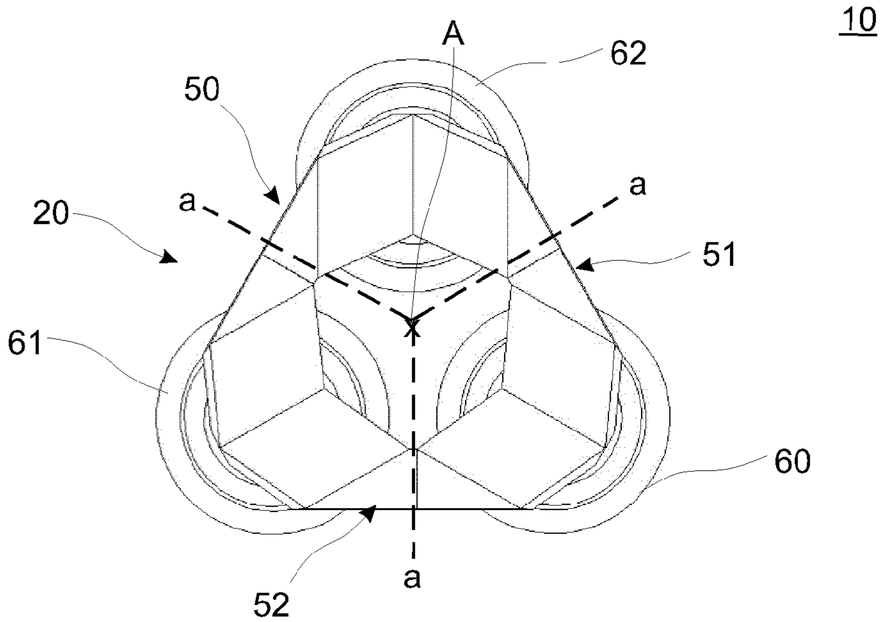

Fig.7

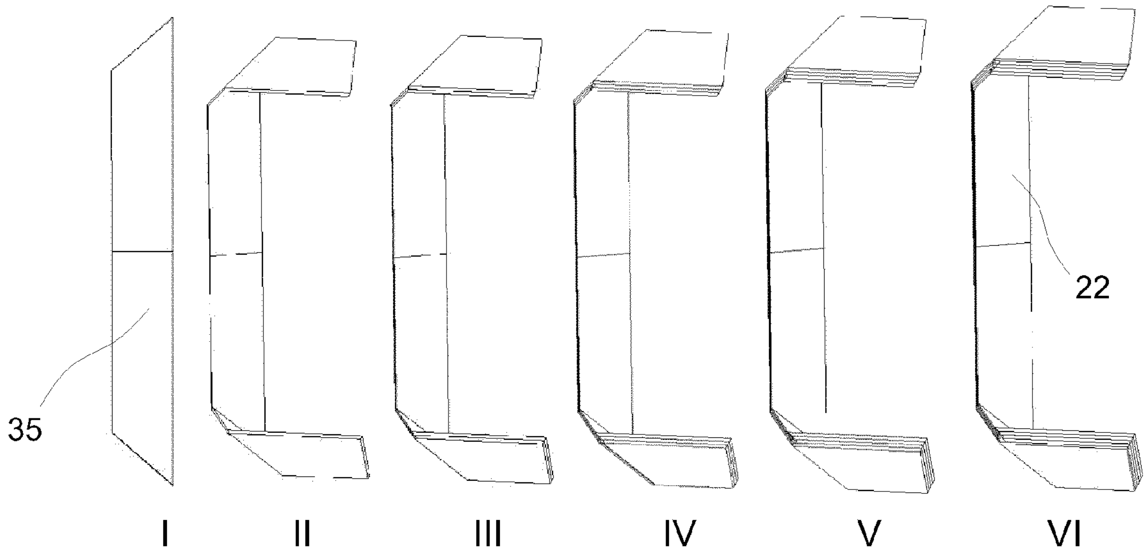

Fig. 8

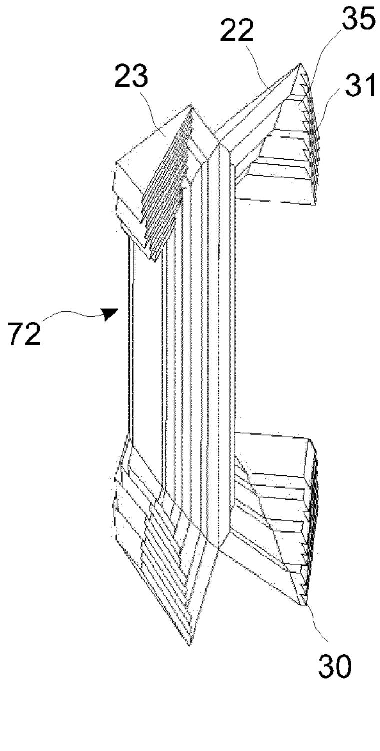

Fig. 9

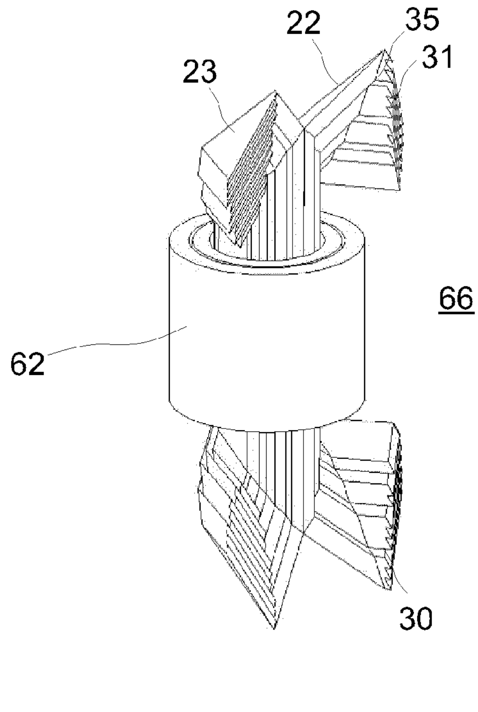

Fig. 10

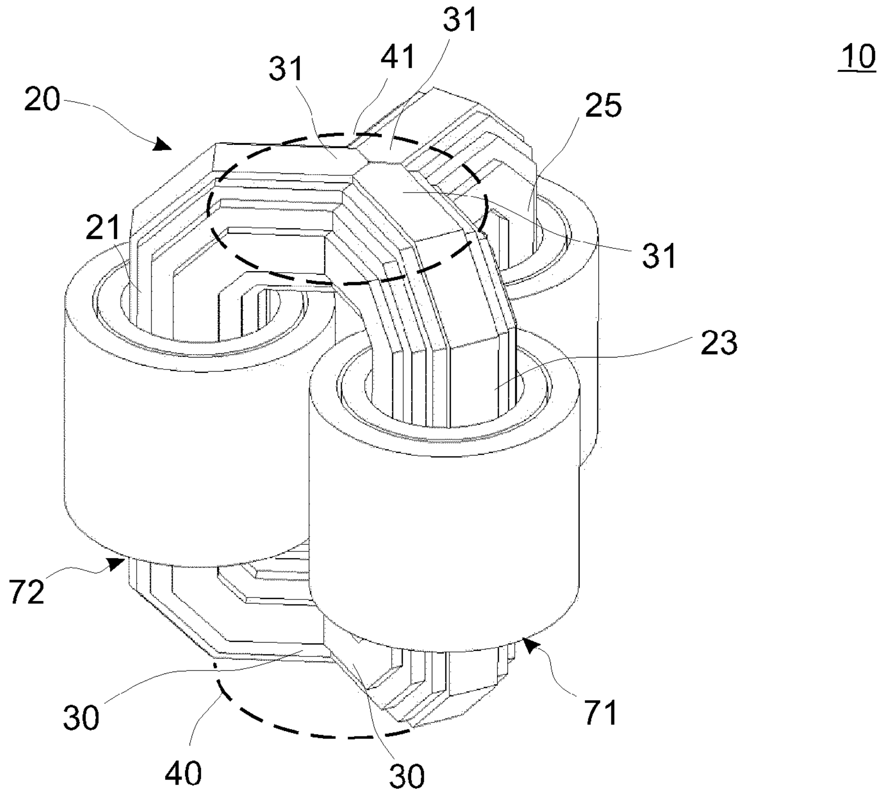
31
41
31
10
20
25
21
31
23
72
30
71
40
30

Fig. 11

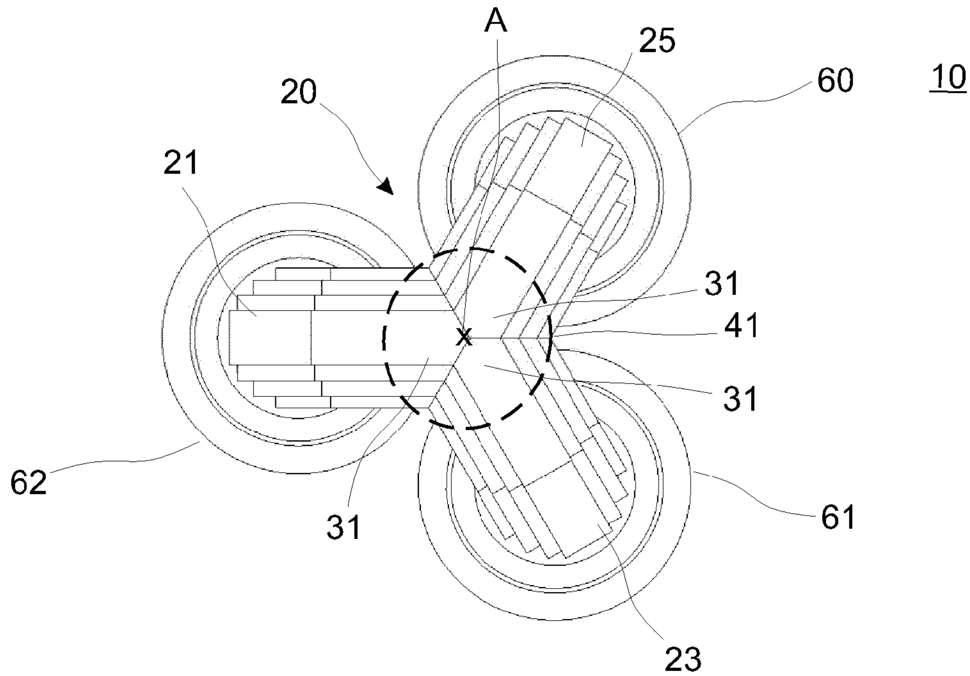
A
25
20
60
10
21
31
41
x
31
62
31
61
23

Fig. 12

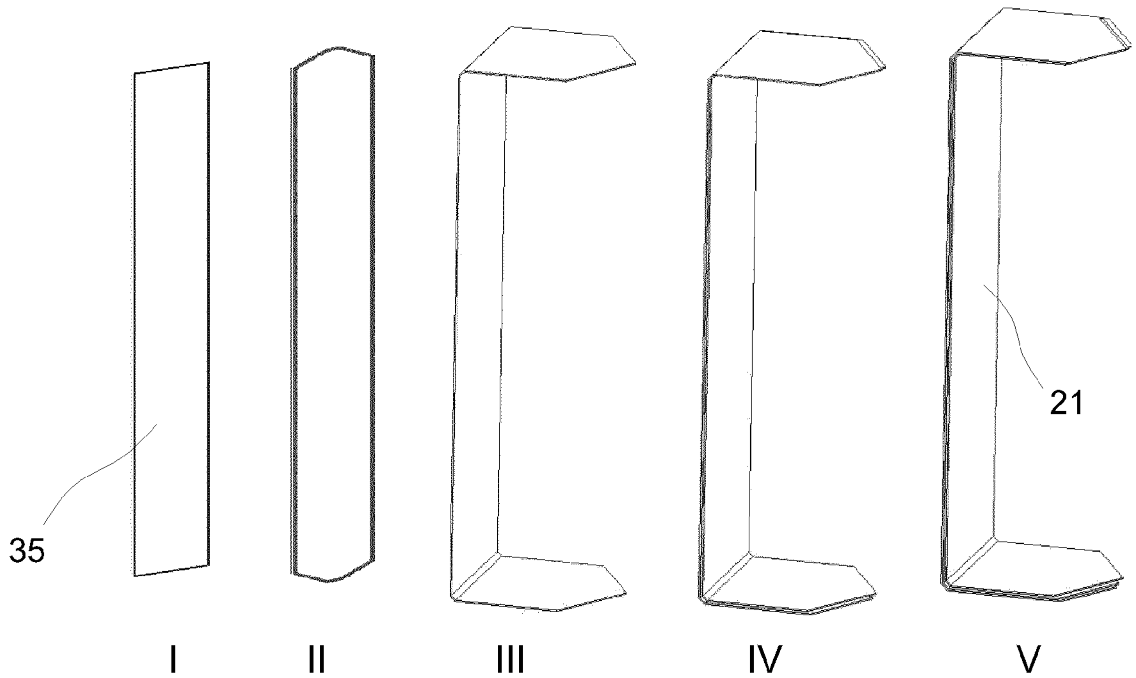

Fig. 13

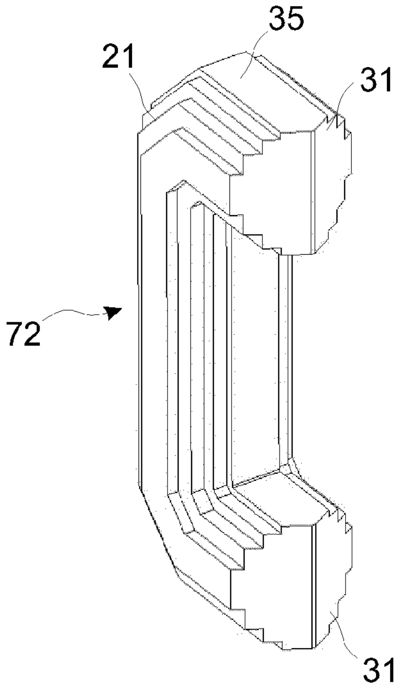

Fig. 14

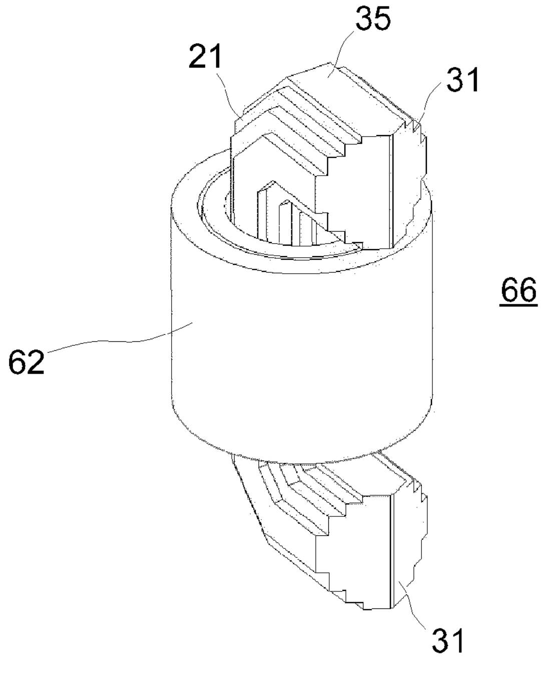

Fig. 15

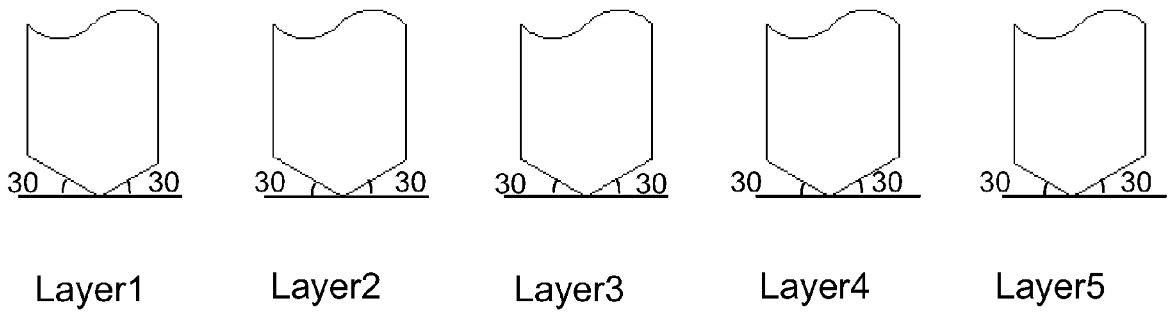

Fig. 16

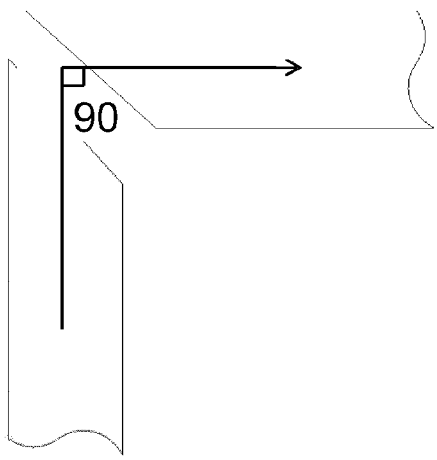

Fig. 17

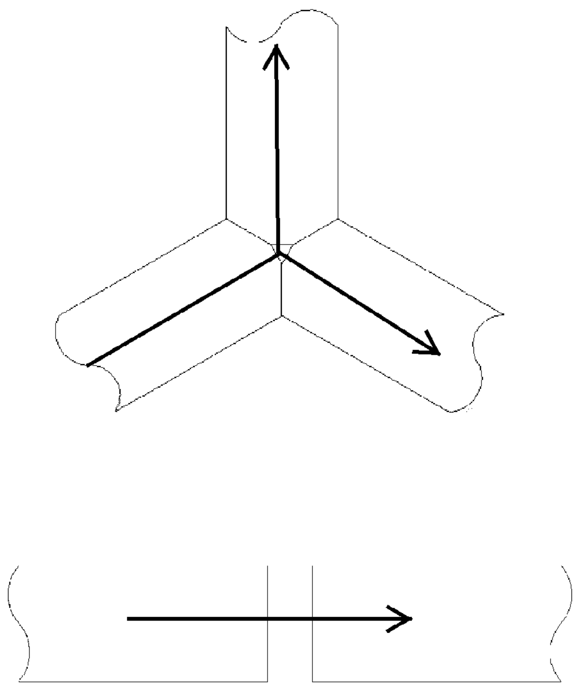

Fig. 18

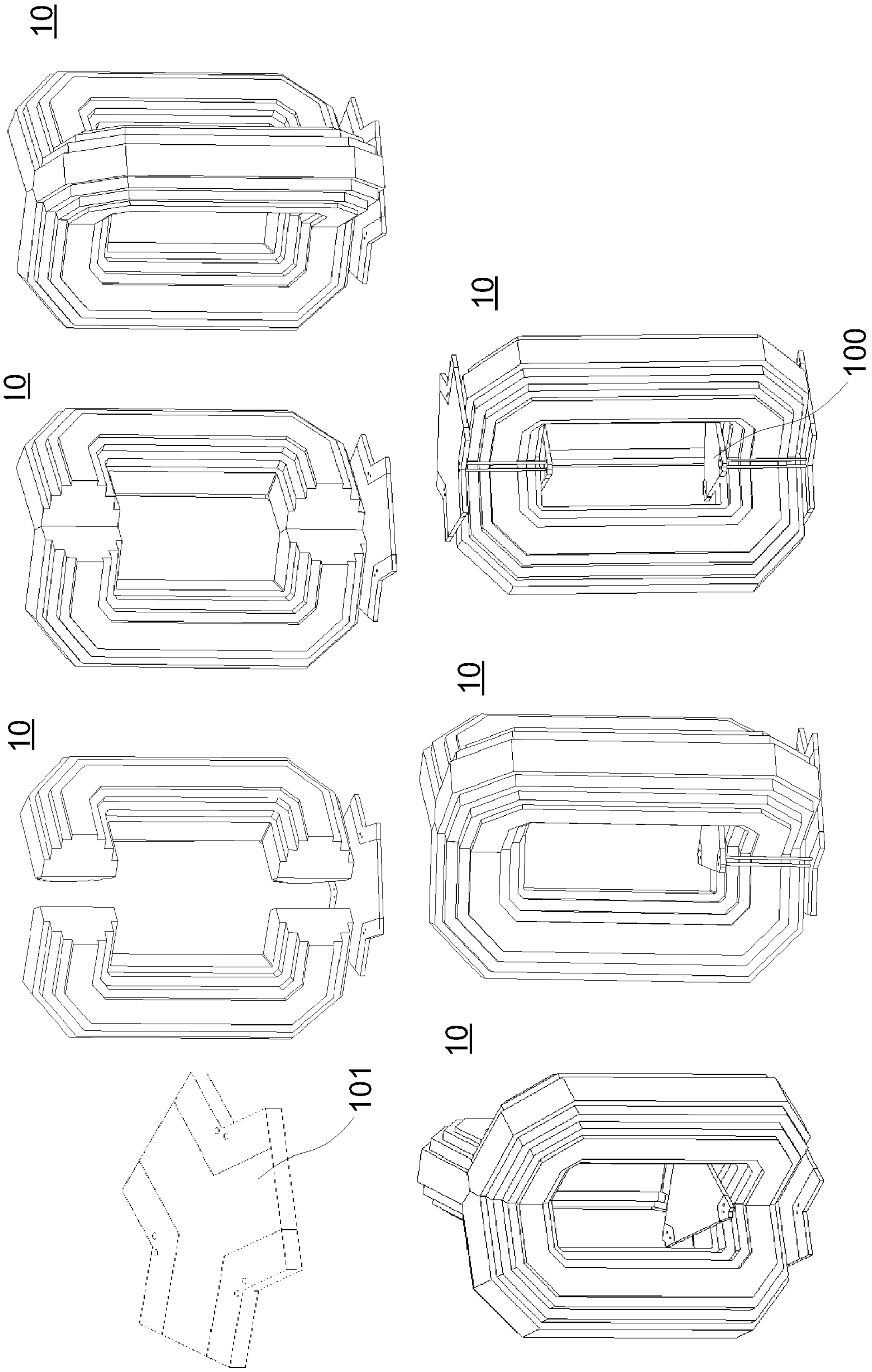

Fig. 19

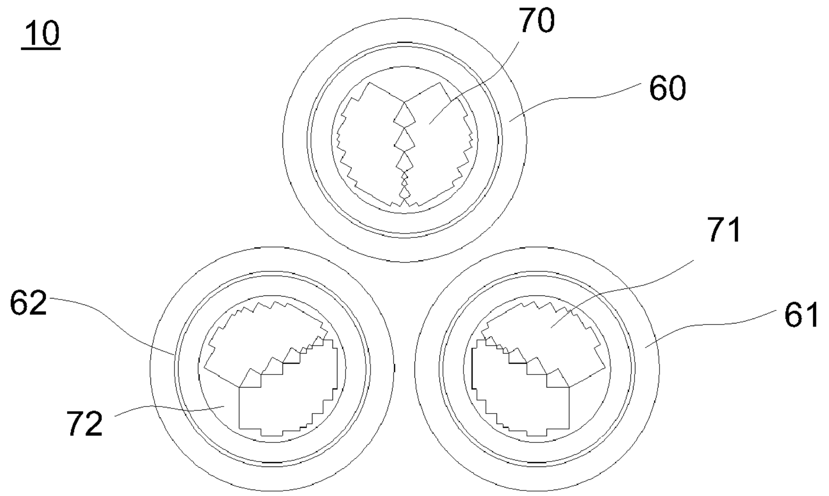

Fig. 20

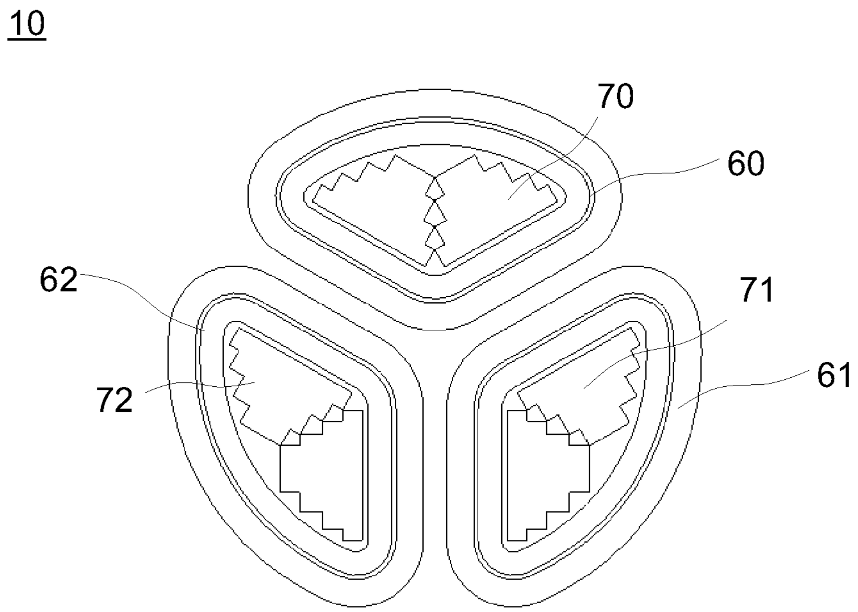

Fig. 21

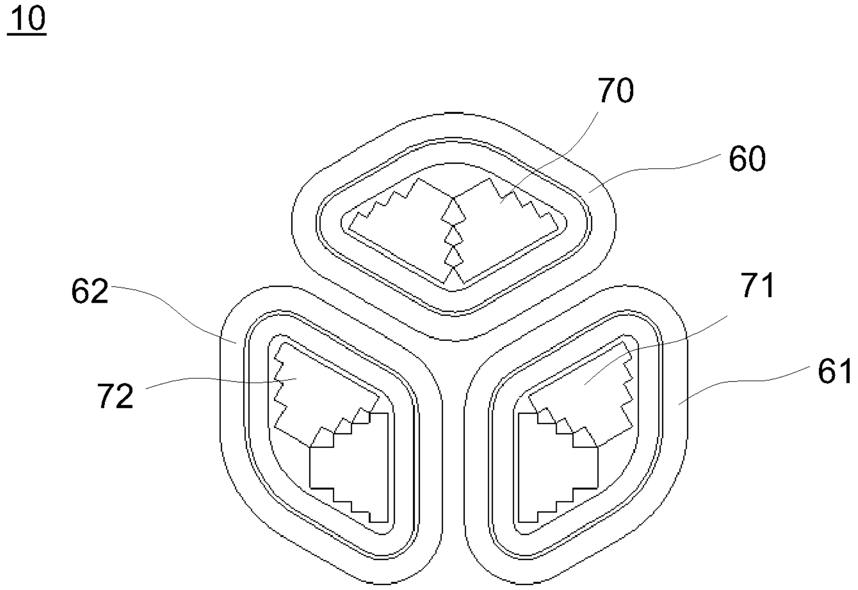

Fig. 22

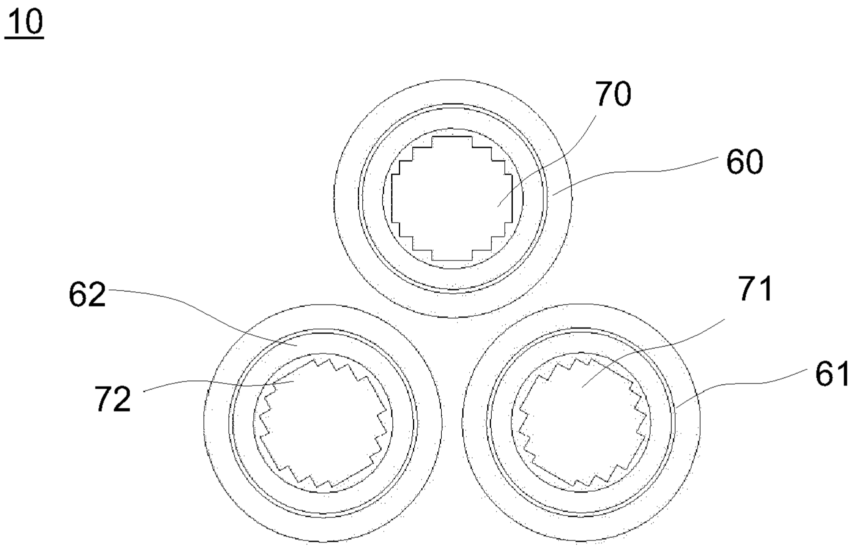

Fig. 23

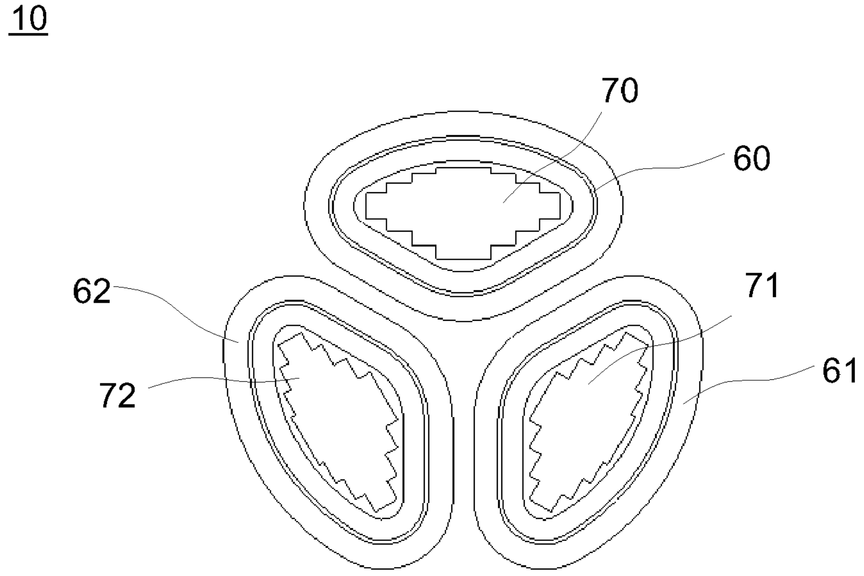

Fig. 24

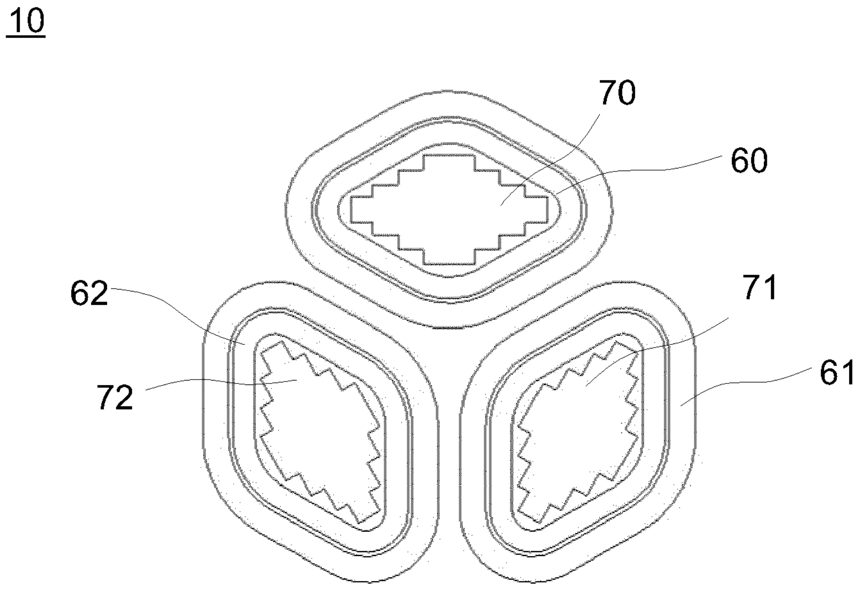

Fig. 25

	Best-case material usage (%)	Total joint cross-section (%)	Magnetic flux bend angle across the joints (°)	Actual to apparent flux density ratio (%)
Stacked planar	100	100	90	100
Stacked triangular	76	100	90	115
Wound triangular	76	0	NA	115
Hybrid wound-stacked triangular	76	100	90	100
Delta-footprint split-core triangular	76	50	0	115
Star-footprint split-core triangular	76	41	60	100

Table 1

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 13 17 2024

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	KR 101 026 357 B1 (KP ELECTRIC CO LTD [KR]) 5 April 2011 (2011-04-05) * figures 1 - 4 * -----	1-15	INV. H01F27/00
Y	WO 99/09567 A1 (ALLIED SIGNAL INC [US]) 25 February 1999 (1999-02-25) * page 1, lines 7, 8 * * page 2, line 26 - page 3, line 16 * * page 8, line 8 - line 21 * * page 9, lines 3, 4 * * figures 5 - 11 * -----	1-15	
A	GB 616 536 A (BRITISH THOMSON HOUSTON CO LTD) 24 January 1949 (1949-01-24) * page 1, lines 10 - 40 * * figures 10 - 13 * -----	1,9	
A	EP 0 962 949 A1 (LAGOR S R L [IT]) 8 December 1999 (1999-12-08) * paragraphs [0001], [0002], [0053]; figures 4a - 4c * -----	1,9	

TECHNICAL FIELDS SEARCHED (IPC)

H01F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	29 November 2013	Van den Berg, G

4

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 13 17 2024

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

29-11-2013

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
KR 101026357	B1	05-04-2011	NONE			
WO 9909567	A1	25-02-1999	AT	317153	T	15-02-2006
			AU	9112398	A	08-03-1999
			CA	2300900	A1	25-02-1999
			CN	1276910	A	13-12-2000
			DE	69833380	T2	28-09-2006
			EP	1005698	A1	07-06-2000
			ES	2257815	T3	01-08-2006
			JP	4350890	B2	21-10-2009
			JP	2001516143	A	25-09-2001
			US	2002067239	A1	06-06-2002
			WO	9909567	A1	25-02-1999
GB 616536	A	24-01-1949	NONE			
EP 0962949	A1	08-12-1999	NONE			

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- CN 200710037948 **[0004]**
- WO 2005027155 A1 **[0005]**
- US 2689396 A **[0006]**
- US 2952068 A **[0006]**