



(11)

EP 4 407 641 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
31.07.2024 Bulletin 2024/31

(21) Application number: **23153521.2**

(22) Date of filing: **26.01.2023**

(51) International Patent Classification (IPC):
H01F 27/30 (2006.01) **H01F 27/28** (2006.01)
H01F 17/06 (2006.01) **H01F 41/02** (2006.01)
H01F 41/04 (2006.01)

(52) Cooperative Patent Classification (CPC):
H01F 17/062; H01F 27/2804; H01F 27/303;
H01F 27/306; H01F 41/0246; H01F 41/04;
H01F 2027/2814

(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 ME MK MT NL
 NO PL PT RO RS SE SI SK SM TR**
 Designated Extension States:
BA
 Designated Validation States:
KH MA MD TN

(71) Applicant: **ABB E-mobility B.V.**
2629 JG Delft (NL)

(72) Inventors:
• **BAHMANI, Amin**
5018 Erlinsbach (CH)

- **GARCIA-FERRE, Francisco**
5400 Baden (CH)
- **JACIMOVIC, Jacim**
5430 Wettingen (CH)
- **PARK, Ki-Bum**
5442 Fislisbach (CH)
- **BURKART, Ralph Mario**
8037 Zurich (CH)
- **ORTIZ, Gabriel**
8005 Zurich (CH)

(74) Representative: **Zimmermann & Partner
Patentanwälte mbB
Postfach 330 920
80069 München (DE)**

(54) INDUCTOR AND METHOD OF PRODUCING AN INDUCTOR

(57) An inductor (100) is described. The inductor (100) includes a winding (110) and a magnetic core (120). The winding (110) has an axis (112), and a first planar surface (114) essentially orthogonal to the axis (112). The winding (110) defines an inner volume. The magnetic core (120) is form-fit into the inner volume. The core (120) includes a powdered magnetic material.

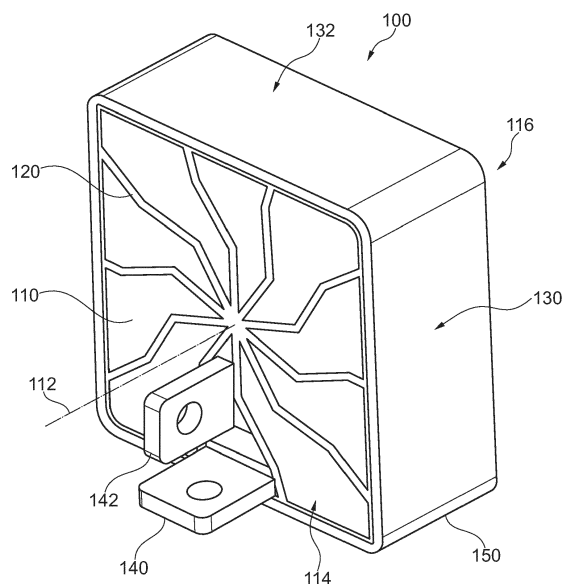


Fig. 1

Description

[0001] Aspects of the invention relate to inductors and methods for production thereof. Aspects of the invention particularly relate to electrical inductors having an improved magnetic core design, and in particular an inductor having improved thermal characteristics.

Technical background:

[0002] An inductor is a passive electrical component that stores energy in a magnetic field when an electric current flows through the component. Some inductors include a magnetic core to increase the inductance of the inductor.

[0003] Inductors may be utilized e.g. as chokes, filters, components of oscillator circuits, or for impedance matching. Inductors are commonly used in electric or electronic circuits, such as converter circuits, particularly for power applications. Power inductors often include a toroidal magnetic core and a conductive wire wound around the toroidal core to form a coil and/or winding.

[0004] During operation, an inductor may be subjected to electric currents, such as high-frequency and/or high amperage currents, causing the inductor to heat up due to electrical resistance within the wire and/or core losses. Insufficient cooling of the inductor may cause overheating and damage to the inductor and/or other components of the electric circuit. Thermal management solutions to prevent overheating of the inductor may be inadequate or undesirable for some applications.

[0005] Thus, there is a need for an inductor having improved thermal characteristics.

Summary of the invention

[0006] In view of the above, the invention as set out in the appended set of claims is provided.

[0007] According to an aspect, an inductor is described. The inductor includes a winding and a magnetic core. The winding has an axis, and a first planar surface essentially orthogonal to the axis. The winding defines an inner volume. The magnetic core is form-fit into the inner volume. The core includes a powdered magnetic material.

[0008] According to an aspect, a method of producing an inductor is described. The method includes forming a winding, the forming the winding including an additive manufacturing process. The winding has an axis, and a first planar surface essentially orthogonal to the axis. The winding defines an inner volume. The method includes molding a magnetic core into the inner volume.

[0009] According to an aspect, the inductor may be an inductor suitable for power applications, such as, but not limited to, power converters, buck converters, boost converters, high-power, high-current and/or high-voltage DC-DC and AC-DC power supplies, industrial automation and control systems, home automation, appliances,

and/or automotive, including electric vehicles (EVs).

[0010] According to an aspect, the inductor may be suitable for applications utilizing and/or requiring conventional toroidal inductors. For example, the inductor may be useable as a substitute or replacement in a circuit designed for a toroidal inductor, or any other type of inductor resembling, at least in part, the shape of a toroidal inductor. In particular, the inductor may have similar, comparable, or even better electrical characteristics than a conventional (toroidal) inductor, particularly while the shape and/or size of the inductor may be comparable to that of a toroidal inductor.

[0011] According to an aspect, a winding is described. A winding, in the context of this disclosure, may be understood as a conductive part of an inductor. Accordingly, any conductor having the geometrical and/or electrical characteristics to be utilized as a winding of an inductor is considered a winding. In particular, a winding should not be strictly understood as a conductor, such as a wire, that has been wound or otherwise deformed to obtain the shape of a winding.

[0012] Further advantages, features, aspects and details that can be combined with embodiments described herein are evident from the dependent claims, the description and the drawings.

Brief description of the Figures:

[0013] The details will be described in the following with reference to the figures, wherein

Fig. 1 is an isometric view of an inductor according to an embodiment;

Fig. 2 is an isometric view of an inductor according to an embodiment;

Fig. 3 is an isometric view of a PCB mounted inductor;

Fig. 4A is a plan view of a PCB for press-fit mounting an inductor according to embodiments;

Fig. 4B is a plan view of a PCB for surface mounting an inductor according to embodiments; and

Fig. 5 is a perspective view of a winding segment according to an embodiment.

Detailed description of the Figures and of embodiments:

[0014] Reference will now be made in detail to the 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 any other embodiment to yield yet a further embodiment. It

is intended that the present disclosure includes such modifications and variations.

[0015] Within the following description of the drawings, the same reference numbers refer to the same or to similar components. Generally, only the differences with respect to the individual embodiments are described. Unless specified otherwise, the description of a part or aspect in one embodiment applies to a corresponding part or aspect in another embodiment as well.

[0016] Fig. 1 shows an inductor 100 according to an embodiment. The inductor 100 has a winding 110, having an axis 112. The winding 110 may act as a coil of the inductor 100. In particular, the winding, when subjected to an electric current, may generate a magnetic field. The magnetic field may be essentially toroidal. A surface normal vector of the essentially toroidal magnetic field may be parallel to the axis 112.

[0017] The winding 110 has a first planar surface 114 which is essentially orthogonal to the axis 112. As shown in Fig. 1, the winding may have further essentially planar surfaces, such as the essentially planar second surface 116 opposite the first surface 114. For example, the first surface 114 may be a front surface and the second surface 116 may be a back surface, or vice versa. As shown in Fig. 1, the winding may have one or more side surfaces 130, 132. The one or more side surfaces may be essentially planar, however, other shapes of the one or more side surfaces, such as a lateral surface of a cylinder, may be possible. It should be noted that the first surface 114, the second surface 116, and any of the side surfaces, such as the side surfaces 130, 132, may be non-continuous surfaces, e.g. separated into smaller sub-surfaces as defined by turns of the windings and/or the gaps therebetween. According to embodiments, as shown in Fig. 1, the one or more side surfaces 130, 132 may have a shared edge with the first surface 114, the second surface 116, and/or one or more adjacent outer surfaces. According to embodiments, as shown in Fig. 1, the one or more side surfaces 130, 132 may extend orthogonally to the first surface.

[0018] Fig. 1 shows the first surface 114 of the winding 110. Additional descriptions helping in understanding the structure of the winding 110 are given with reference to Figures 2-5. In the embodiment shown in Fig. 1, the winding 110 includes ten turns. For each turn, a portion of the winding 110 extends along the first surface 114 and the second surface 116 and, while extending along one of the surfaces 114, 116, introduces a rotational offset with respect to the first axis, e.g. either a clockwise, or a counter-clockwise offset. At a point adjacent the center of the winding, the winding extends, for each turn, straight along the axis 112 from the first surface 114 to the second surface 116. Likewise, for each turn, the winding extends at a point adjacent the one or more outer surfaces straight along the axis 112 from the first surface 114 to the second surface 116. By extending straight along the direction of axis 112 and introducing an offset when extending along the first surface 114 and the second surface 116, the

winding 110 forms a coil.

[0019] As shown in Fig. 1, the winding 110 may include ten turns. The number of turns of the winding may be adjusted according to the desired electrical characteristics of the inductor 100, and may include, for example, between 2 and 100 turns, such as between 2 and 50 turns, such as between 5 and 25 turns.

[0020] Beneficially, a winding according to embodiments has at least one planar surface, such as the first surface 114, the second surface 116, or one or more of the side surfaces 130, 132. This may improve cooling of the inductor 100. In particular, the inductor 100 may have improved thermal characteristics when compared to a conventional toroidal inductor. Furthermore, the one or more essentially planar surfaces may allow the easy attachment of cooling components, such as heatsinks.

[0021] The winding 110 defines an inner volume. The inner volume may be a volume as defined by the outer surfaces of the winding, such as the first surface 114, the second surface 116, and any of the side surfaces such as the side surfaces 130, 132, and not occupied by the body of the winding 110. In particular, the inner volume may have an essentially ring-shaped and/or toroidal shape, and/or a shape suitable for confining an essentially toroidal magnetic field. It should be noted that the inductor 100 shown in Fig. 1 has a first surface 114 with an essentially rectangular footprint. Accordingly, the essentially toroidal inner volume of the inductor 100 shown in Fig. 1 may, at least in part, further be defined by the essentially rectangular footprint, e.g. include portions shaped according to the essentially rectangular footprint.

[0022] As shown in Fig. 1, the inductor includes a magnetic core 120. The core 120 is form-fit into the inner volume. In particular, the magnetic core 120 may fully occupy portions of the inner volume, or even completely occupy the inner volume. In particular, the magnetic core 120 may fully occupy the spaces within the inner volume, and even spaces in-between turns of the winding 110, such as gaps between the turns of the winding. In particular, the core 120 may be flush with the winding 110. In particular, the inductor 100 may be devoid of an air-gap between the magnetic core 120 and the winding 110.

[0023] The core 120 includes a powdered magnetic material. For example, the powdered magnetic material may include a ferrite powder or a silicon steel. For example, the powdered magnetic material may include one or more alloys including Fe, FeSiAl, FeSi, FeNi, and/or FeNiMo. For example, the powdered magnetic material may include powdered iron, carbonyl iron, hydrogen-reduced iron, molypermalloy, High-flux (Ni-Fe), Sendust, KoolMU and/or a commercially available alloy such as Nanoperm, Vitroperm, Hitperm and Finemet available at the time of filing of this disclosure. For example, the powdered magnetic material may include a ferrite ceramic.

[0024] According to embodiments, the core 120 may include a binder. The binder may be a curable and/or cured substance, such as a polymer. For example, the binder may be a resin, such as an Epoxy-based resin

and/or a phenolic resin.

[0025] According to embodiments, the magnetic core may include a powdered magnetic material and a binder. The powdered magnetic material may be provided at a volume density of at least 5%, such as at least 10%, at least 15%, at least 20% or even at least 25%. The volume density of the powdered magnetic material may be adjusted according to the desired magnetic properties of the core 120 and/or the desired electric properties of the inductor 100.

[0026] According to embodiments, the winding 110 may be conductive. In particular, the winding may include and/or be comprised of one or more conductive metals or alloys. For example, the winding may include Cu, Fe, Al and/or alloys thereof. For example, the winding may be copper-based, brass-based and/or bronze-based. For example, the winding may be aluminum based.

[0027] According to embodiments, the winding 110 may be manufactured in an additive manufacturing process, such as, but not limited to, 3D printing, particularly metal 3D printing, such as selective laser melting, direct metal laser sintering and/or other known additive manufacturing technologies. Beneficially, additive manufacturing may allow a joint-less construction of the winding 110, however, the winding 110 may likewise be formed of joined winding segments. In particular, the winding may be a single part. In particular, additive manufacturing may allow the winding to have a spatially well-defined interior volume, while allowing the outer surfaces of the winding 110 to be large, e.g. by allowing the winding to be manufactured with small gaps between the turns of the winding 110. Large outer surfaces of the winding 110 may increase the thermal and/or electrical conductivity of the winding. Beneficially, due to the magnetic core 120 being form-fit into the inner volume, no space is lost to air or other non-reactive fillers. This may beneficially improve the power density of the inductor 100. Furthermore, since the magnetic core 120 is form-fit to the winding, i.e. essentially in direct contact with the winding 110 or even one or more of the outside surfaces of the inductor 100, heat may be efficiently transferred away from the core, which may improve cooling and/or increase the power density of the inductor 100.

[0028] As shown in Fig. 1, the inductor 100 may include terminals 140, 142. The terminals 140, 142 may provide an electrical connection to the inductor 100 to electrically connect the inductor 100 to an electric circuit. In the example shown in Fig. 1, the terminals 140, 142 are provided on the first surface 114 and extend along the axis 112. This may allow the inductor to be mounted within a circuit, e.g. on a printed circuit board (PCB), so that the second surface 116 is parallel to the PCB.

[0029] According to embodiments, the terminals 140, 142 may be provided on any other outer surface of the inductor 100, such as one or more of the side surfaces 130, 132. This may allow the inductor 100 to be mounted in different configurations within the circuit.

[0030] As shown in Fig. 1, the inductor 100 may include

a housing 150. The housing 150 may provide electrical insulation to one or more of the outer surfaces 114, 116, 130, 132 of the winding. The housing may include polymers, such as (polymer) sheets applied to the winding, or preformed (polymer) parts provided during or after manufacture of the inductor. According to embodiments, the housing 150 may be provided during manufacture of the inductor 100, e.g. to form a barrier for molding the core 120 and/or infiltrating core materials into the winding 110. According to embodiments, the housing 150 may be applied as a coating, e.g. after the manufacture of the winding 110 and/or the inductor 100.

[0031] Referring now to Fig. 2, an inductor 100 according to embodiments is described. Only the differences to the inductor 100 shown in Fig. 1 will be described. As can be seen in Fig. 2, the inductor 100 is devoid of a housing 150, and the terminals 140, 142 are not shown. As can be seen in Fig. 2, for each turn, the winding 110 extends at a point adjacent the one or more outer surfaces straight along the axis 112 from the first surface 114 to the second surface 116.

[0032] According to embodiments, the surface structure of the winding 110 at the first surface 114 and the second surface 116 may be essentially identical. For example, when rotating the inductor 100 shown in Fig. 1 or Fig. 2 by 180° along an axis perpendicular to the axis 112, the features forming the turns of the winding 110 of the first surface 114 may be congruent with the features of the second surface 116 in the figure.

[0033] As shown in Fig. 1 and 2, the inductor 100 may have an essentially rectangular footprint. In particular, the first surface 114 has an essentially rectangular footprint, or even an essentially quadratic footprint.

[0034] According to embodiments, the inductor 100 may have a circular, elliptical or polygonal base surface. For example, the base surface may be the first surface 114, any other outer surface, such as the second surface 116, and/or one of the side surfaces 130, 132. The inductor 100 may extend in a direction orthogonally to the base surface. The inductor 100 may have a shape such as, but not limited to, a cuboid, a rectangular cuboid, a rhombus, a pyramid or a cylinder. The shape of the inductor 100 may be essentially defined by the shape of the winding 110. In particular, the winding 110 may essentially define outer surfaces of the inductor 100.

[0035] Referring now to Fig. 3, an inductor 300 according to embodiments is described. The inductor 300 includes a winding including ten winding segments 310, five of which are drawn as semitransparent in Fig. 3. A more detailed description of a winding segment 310 is given with reference to Fig. 5. The number of winding segments 310 may be adjusted according to the desired electrical characteristics of the inductor 300, and may include, for example, between 2 and 100 winding segments 310, such as between 2 and 50 winding segments 310, such as between 5 and 25 winding segments 310.

[0036] The inductor 300 further includes a printed circuit board (PCB) portion included in the PCB 330. The

winding segments 310 are individually mounted to the PCB 330 and electrically connected to conductors included in the PCB 330. A more detailed description of a PCB 330 according to embodiments is given with reference to Fig. 4A and Fig. 4B. Electrical conductors included in the PCB 330 form a portion of the winding. In particular, the electrical conductors of the PCB 330 may form a PCB portion of the winding. Accordingly, the winding may include a winding segment portion and a PCB portion.

[0037] As shown in Fig. 3, the shape and/or geometry of the inductor 300 is essentially defined by the plurality of winding segments 310. In the given example, the inductor 300 has an essentially circular first surface 114 and a side surface extending orthogonally from the first surface. The inductor comprises a side surface adjacent the first surface, the side surface forming essentially a lateral surface of a cylinder. According to embodiments, e.g. by modifying the shape of the winding segments 310 and/or the shape of the conductors of the PCB 330, different shapes of the inductor 300, such as the shapes described with reference to the inductor 100 shown in Fig. 1 or Fig. 2 may be obtained.

[0038] According to embodiments, the PCB 330, particularly the PCB portion including the conductors forming the PCB portion of the winding, may define a second planar surface of the inductor 300.

[0039] According to embodiments, the winding segments 310 may be connected between neighboring winding segments in series to each other into the winding, particularly to form the winding, with the conductors included in the PCB portion. In particular, the winding segments 310 and the conductors of the PCB 330 may form a coil.

[0040] According to embodiments, a winding segment 310 may be electrically connected at its first end to the second end of a first neighboring winding segment 310, and the winding segment may be electrically connected at its second end to the first end of a second neighboring winding segment 310 opposite the first neighboring winding segment 310.

[0041] According to embodiments, the conductors comprised in the PCB portion may pairwise connect respective neighboring ones of the winding segments 310 to form the winding. The conductors may specifically connect a radially inner end of a first one of the neighboring winding segments 310 with a radially outer end of a second one of the neighboring winding segments 310.

[0042] As shown in Fig. 3, the winding segments 310 and the PCB 330 define an inner volume 320. In the example shown in Fig. 3, the inner volume 320 is essentially toroidal, however, different shapes of the inner volume 320 may be obtainable depending on the shape of the winding segments 310 and/or the PCB portion.

[0043] In the example shown in Fig. 3, a toroidal magnetic core 340 is provided within the inner volume 320. The toroidal magnetic core 340 may be a prefabricated magnetic core, such as a prefabricated powder core. Manufacturing the inductor 300 having a prefabricated

magnetic core may include providing the PCB 330 and the magnetic core 340, and mounting the winding segments 310 to the PCB 330, e.g. via soldering and/or press-fitting.

[0044] According to embodiments, instead of a prefabricated magnetic core 340, a magnetic core such as the magnetic core 120 described with reference to Fig. 1 and Fig. 2 may be form-fit into the inner volume, e.g. according to embodiments described herein. The magnetic core may be form-fit to the winding portion comprised of the winding segments 310, or even the winding comprising the winding segments 310 and the PCB portion of the winding. According to embodiments, a magnetic core form-fit to the winding segments 310, e.g. before mounting the winding segments 310 to the PCB 330, is considered form-fit into the inner volume. Likewise, a magnetic core form-fit to both the winding segments 310 and the PCB portion of the winding, is considered form-fit to the inner volume.

[0045] Referring now to Fig. 4A and Fig. 4B, two PCBs 330A and 330B suitable for forming a PCB portion of a winding of the inductor 300 are described.

[0046] As shown in Fig. 4A, the PCB 330A includes ten conductors 420 corresponding to the ten winding segments shown in Fig. 3. Each of the conductors 420 may electrically connect two adjacent winding segments 310. The conductors 420 may be double-sided, thick-layered and/or multi-layered, e.g. as required according to the desired electrical properties of the inductor. For example, a winding segment may be electrically connected, at its first end, to the outer connectors 410 of a first conductor 420 of the PCB, and form an electrical connection to the inner connectors 410 of a neighboring second conductor 420 of the PCB.

[0047] The PCB layout of a PCB 330A is configured for press-fit mounting the winding segments. Accordingly, a plurality of through-holes may be provided within the connectors 410. The plurality of through-holes may include a plurality of female press-fit contacts for receiving a corresponding male feature, such as a pin or blade provided on the winding segment. Beneficially, press-fitting the winding segments to the PCB may result in a reliable and/or solderless electrical connection.

[0048] As shown in the left portion of Fig. 4A, the PCB 330A includes two pads for electrically connecting external components to the PCB 330A and/or an inductor provided on the PCB 330A. Additionally, or alternatively, the features of PCB 330A, particularly the conductors 420 having the connectors 410, may be incorporated into to any PCB design, and an inductor according to embodiments described herein may be included into any circuit having the design of PCB 330A.

[0049] According to embodiments, the PCB 330A shown in Fig. 4A may be modified for solder mounting the winding segments. For example, instead of providing through-holes including female press-fit contacts, a conventional through-hole suitable for through-hole soldering may be provided.

[0050] According to embodiments, as shown in Fig. 4B, the PCB 300B may be configured for surface-mounting the winding segments 310. Soldering pads 430 are provided for each of the conductors 420. As shown in Fig. 4B, through-holes may be provided, e.g. within the soldering pads 430, to form an electrical connection between different conductive layers of the PCB 330B. Additionally, or alternatively, through holes may be provided for engaging one or more pin-shaped portions of a winding segment, such as latching pins, to align the winding segment to the PCB 330B for soldering. An electric connection may be formed between the winding segments and the PCB 330B by applying a soldering paste to the soldering pads 430, placing and/or aligning the winding segments to the PCB, and heat-treating the assembled PCB to solder the winding segments to the PCB.

[0051] Referring now to Fig. 5, a winding segment 310 suitable for being surface mounted to a PCB such as the PCB 330B described with reference to Fig. 4B is described. According to embodiments, the winding segment 310 is a solid part formed of a conductive material, such as a metal, such as a metal or alloy described with reference to Fig. 1. According to embodiments, a winding segment 310 may be manufactured by an additive manufacturing process, such as an additive manufacturing process described with reference to Fig. 1. Utilizing an additive manufacturing process may allow manufacturing winding segments with specific shapes and/or dimensions, which may beneficially allow the cost- and time-effective generation of inductors having non-standard shapes, sizes and/or specific electric properties.

[0052] Likewise, according to embodiments, a winding segment 310 may be manufactured by conventional manufacturing methods, such as casting, pressing, machining, or the like.

[0053] As can be seen in Fig. 5, the winding segment 310 includes two latching pins 510, 512. The latching pins 510, 512 may engage with a feature, such as holes, provided in the PCB portion. By engaging with the latching pins, the winding segment may be aligned to the PCB portion, e.g. before soldering the winding segment 310 to the PCB portion. Additional pins may be provided, e.g. to engage with the female press-fit connectors described with reference to Fig. 4A. Accordingly, the winding segment 310 may likewise be mounted onto the PCB 330A.

[0054] The winding segment 310 includes two soldering surfaces 520, 522. The soldering surfaces 520, 522 are flat surfaces for contacting the PCB portion, particularly soldering pads provided on the PCB portion. An electrical connection between the winding segment 310 and a conductor of the PCB portion may be obtained by soldering the soldering surfaces 520, 522 to the soldering pads. Accordingly, the winding segment 310 may be surface mounted to the PCB portion.

[0055] As shown in Fig. 5, the winding segment 310 essentially forms a segment of a cylinder, particularly a segment of a cylinder segmented along the axis of a cylinder, such as a cylindrical sector. Additionally, with re-

spect to the outer soldering surface 520, the inner soldering surface 522 has a rotational offset. The rotational offset enables a plurality of winding segments 310 to form, in conjunction with the conductors of the PCB portion, a winding, particularly an essentially coil-like winding.

[0056] As shown in Fig. 5, the winding segment 310 has a conductive portion extending parallel to the soldering surfaces 520, 522 essentially in a radial direction of a cylinder. The conductive portion may define, at least in part, the first planar surface 114 of the inductor 300 described with reference to Fig. 3. Due to the rotational offset between the outer soldering surface 520 and the inner soldering surface 522, the conductive portion may be shaped according to the rotational offset, e.g. when compared to a cylindrical and/or circular sector.

[0057] As shown in Fig. 5, the winding segment 310 has two conductive portions extending, along the axis of the cylinder, from the soldering surfaces 520, 522 to the first planar surface 114. The axis of the cylinder may be an axis 112 of the inductor as described with reference to Fig. 1 or Fig. 2.

[0058] As shown in Fig. 5, the winding segment 310 defines an unfilled portion in-between the conductive portions. The unfilled portion may define, in a plurality of winding segments 310 arranged to form a portion of an inductor, such as the inductor 300 described with reference to Fig. 3, an inner volume, such as the inner volume 320 described with reference to Fig. 3.

[0059] It should be noted that some or all of the features, particularly geometrical features, of the winding segment 310 described with reference to Fig. 5 may apply to the winding 110 of the inductor 100 described with reference to Fig. 1 or Fig. 2. For example, and not limited thereto, a turn of a winding 110 may be obtained by providing two winding segments 310 and congruently connecting two opposing soldering surfaces 522 of the two winding segments 310. Likewise, particularly when utilizing an additive manufacturing process, the turn of the winding 110, or even the complete winding 110, may be manufactured as a single part.

[0060] According to embodiments, an inductor according to embodiment may be obtained by mounting a plurality of winding segments 310, as shown in Fig. 5, to a PCB, such as the PCB 330B shown in Fig. 4, and by providing a magnetic core.

[0061] According to embodiments, a method of producing an inductor is described. The inductor produced by the method may be an inductor according to embodiments described herein. In particular, some features of the inductor, particularly features relating to the shape, thermal efficiency, magnetic core structure and/or improved compactness of the inductor may be a result of the production method described herein.

[0062] The method includes forming a winding. Forming the winding includes an additive manufacturing process, such as, but not limited to, 3D printing, particularly metal 3D printing, such as selective laser melting, direct

metal laser sintering and/or other known additive manufacturing technologies. In particular, the winding may be directly formed of a single part and simultaneously include features, such as an inner volume, which would otherwise not be manufacturable by reductive manufacturing. Likewise, the winding may be manufactured by combining prefabricated parts, such as winding segments and/or a PCB.

[0063] According to embodiments, the winding has an axis and a first planar surface essentially orthogonal to the axis, such as described with reference to Fig. 1, Fig. 2 or Fig. 3. The winding defines an inner volume, such as the inner volume 320 described with reference to Fig. 3 or Fig. 5.

[0064] According to embodiments, forming the winding includes forming winding segments and arranging the winding segments to define the inner volume.

[0065] According to embodiments, forming the winding may include mounting the winding segments to a PCB portion to form the winding. Mounting the winding segments may include electrically connecting the winding segments to conductors of the PCB portion. For example, mounting the winding segments may include press-fitting the winding segments to the PCB, surface-mount soldering the winding segments to the PCB, or even through-hole soldering the winding segments to the PCB.

[0066] According to embodiments, the winding may be electrically insulated, e.g. by applying a dielectric coating to portions of the winding.

[0067] The method includes molding a magnetic core into the inner volume. Molding the magnetic core may result in the magnetic core being form-fit into the inner volume. In particular, the magnetic core may be in direct contact with the winding, or portions of the winding, such as winding segments of the winding. The molded magnetic core may provide structural stability to the winding, e.g. by bonding, affixing and/or adhering to winding turns or winding segments.

[0068] According to embodiments, molding the magnetic core includes combining a powdered magnetic material and a binder to form a composite. The composite may be moldable, i.e. have liquid or liquid-like properties. For example, and not limited thereto, a powdered magnetic material may be combined with an epoxy resin. For example, the composite may include magnetic particles, such as Fe/Si alloy particles, at a volume density of at least 5%, at least 10%, at least 15%, at least 20% or even at least 25%. Other combinations of magnetic particles and binders may be used, e.g. to arrive at a magnetic core having a composition as described herein with reference to Fig. 1.

[0069] According to embodiments, molding the magnetic core may include infusing the composite into the inner volume of the winding. Infusing the composite may include injecting the composite. Infusing the composite may include pouring the composite into the inner volume, and/or allowing the composite to infiltrate the inner volume of the winding through one or more openings, such

as the gaps between turns of the winding.

[0070] According to embodiments, e.g. to prevent the composite from leaking from the inner volume before hardening, one or more outer surfaces of the winding may be covered. The one or more outer surfaces may be covered e.g. by providing a barrier, such as the housing 150 shown in Fig. 1. The one or more outer surfaces may be covered by applying temporary, i.e. removable, or even permanent barriers, such as sheets, to the one or more outer surface. The one or more outer surfaces may be covered by providing the winding in a carrier and/or a mold, and removing winding from the mold after hardening. Depending on the viscosity and/or rheometric properties of the composite, covering the one or more outer surfaces may be optional.

[0071] According to embodiments, molding the magnetic core includes hardening the composite. Hardening the composite may include incorporating a curing agent, such as a hardener, into the composite, such as a hardening component of a two-component resin. A thermoset binder may be hardened by curing the composite at elevated temperatures, and/or curing of a two-component resin may be accelerated at elevated temperatures. A photoactivatable binder may be cured by exposing the composite to light of a specific wavelength.

[0072] According to embodiments, the magnetic core of an inductor having a winding 110 such as the inductor 100 described with reference to Fig. 1 and Fig. 2, may be molded into the inner volume of the winding 110 as described above.

[0073] Additionally, or alternatively, according to embodiments, the magnetic core of an inductor having a winding including winding segments, such as the winding segments 310 described with reference to Fig. 3 and Fig. 5, may be molded before forming the winding, e.g. by mounting the winding segments to a PCB portion.

[0074] Accordingly, a method of producing an inductor may include arranging the winding segments on a carrier to form the inner volume. In particular, the winding segments may be arranged to form a winding portion, e.g. as shown in Fig. 3. While the winding segments are arranged to form the winding portion, the inner volume may be defined by the winding segments and the carrier, e.g. be enclosed by the winding segments and the carrier. Alternatively, the inner volume may be an open volume, the open volume being defined by the winding segments.

[0075] According to embodiments, the carrier may be a board having similar features to the PCB shown in Fig. 4A or Fig. 4B. For example, the carrier may have one more through-holes for press-fitting the winding segments, or may have one or more through-holes for aligning the winding segments. In the carrier, the conductors 420 may be optional.

[0076] According to embodiments, after arranging the winding segments on the carrier, a magnetic core may be formed as described above. Additionally, or alternatively, a composite may be introduced into the inner volume through an opening provided in the carrier, or, in

case the inner volume is an open inner volume, directly into the inner open volume.

[0077] According to embodiments, after molding the magnetic core, the winding segments and the magnetic core are separated from the carrier. Beneficially, according to embodiments, the winding segments may be held in place by the hardened magnetic core. After separating the winding segments and the magnetic core from the carrier, the winding segments and the magnetic core may be mounted to a PCB, such as the PCB 330A, 330B shown in Fig. 4A or Fig. 4B.

[0078] According to embodiments, the composite may be formed before being molded into the inner volume, e.g. as described above. According to yet further embodiments, the composite may be formed inside the inner volume. For example, powdered magnetic particles may be introduced into the inner volume, and a binder may be infiltrated into the inner volume and/or the powdered magnetic particles to form the composite and/or the molded core. Additionally, or alternatively, particularly for windings comprising winding segments arranged on a carrier and having an open inner volume, the powdered magnetic particles and/or the composite may be pressed.

[0079] An inductor described herein may be suitable for use in power applications. In particular, the inductor may have an inductance of more than 0.1 micro-Henry (μH), more than 0.2 μH , more than 0.5 μH , more than 1 μH , more than 2 μH , more than 5 μH , more than 10 μH , more than 20 μH , more than 50 μH , more than 100 μH , more than 200 μH , more than 500 μH , or even more than 1000 μH . In particular, the inductor may have a current rating of more than 1 Ampere (A), more than 2 A, more than 5 A, more than 10 A, more than 20 A, more than 50 A, more than 100 A, more than 200 A, more than 500 A, more than 1000 A, or even more than 2000 A.

[0080] An inductor according to embodiments described herein may beneficially allow attaching thermal management components, such as heatsinks, to the first planar surface. A winding as described herein, when compared to e.g. a wire-wound coil, may have a higher effective electrical cross-section, which may beneficially reduce electrical resistance and coil losses. Furthermore, thermal energy may more easily be transferred along and/or through the winding. In particular, heat is more efficiently transported from the magnetic core through the winding, which may improve the thermal characteristics of the inductor.

[0081] An inductor according to embodiments described herein may beneficially be provided in various shapes and sizes, and may easily be integrable into e.g. spatially confined designs or even pre-existing circuit designs. Accordingly, an inductor as described herein may offer a more space-effective solution compared to known designs.

[0082] An inductor according to embodiments described herein may more efficiently utilize an inner volume. In particular, a molded core may be form-fit into the inner volume, which may reduce the volume of spaces

not occupied by non-reactive material. Accordingly, an inductor according to embodiments may be smaller than a conventional inductor having the same electrical characteristics. Furthermore, by being form-fit to the thermally conductive winding, heat may be directly and/or more efficiently transferred from the core to the outside of the inductor.

[0083] While the above refers to an inductor having a molded core, several of the benefits described herein may be, according an example given to help in understanding the invention, obtained by an inductor utilizing winding segments and a prefabricated magnetic core, or even no magnetic core.

[0084] In the example, a prefabricated core 340 as shown in Fig. 3 may be utilized. The prefabricated core may be a toroidal core, such as a toroidal powder core, e.g. as commercially available at the time of filing this disclosure. Accordingly, the magnetic core is not limited to any specific composition, and may be chosen according to the desired electrical characteristics of the inductor.

[0085] According to the example, a method of producing the inductor may include forming a plurality of winding segments, the forming of the plurality of winding segments comprising an additive manufacturing process, and mounting the winding segments to a PCB portion to form a winding. A magnetic core may be provided before mounting the winding segments, such that the magnetic core is comprised in the inner volume after mounting the winding segments to the PCB. The winding segments may be directly mounted to the PCB, particularly without being previously mounted to a carrier.

[0086] To help in understanding the example, the following clauses are provided:

1. An inductor, comprising:

a winding, the winding comprising winding segments and a printed circuit board, PCB, portion, wherein

the winding segments are individually mounted to the PCB portion and electrically connected to conductors comprised in the PCB portion, and wherein

the electrical conductors comprised in the PCB portion form a portion of the winding, wherein

the winding segments are connected in series to each other into the winding with the conductors comprised in the PCB portion between neighboring winding segments.

2. The inductor according to clause 1, further comprising a magnetic core.

3. The inductor according to clause 2, wherein the magnetic core is a toroidal magnetic core, preferably

a prefabricated toroidal magnetic core.

4. The inductor according to any one of the preceding clauses, wherein the winding has an axis, and wherein the winding has a first planar surface essentially orthogonal to the axis.

5. The inductor according to any one of the preceding clauses, wherein the winding segments are press-fitted to the PCB portion.

6. The inductor according to any one of the clauses 1 to 4, wherein the winding segments are surface mounted to the PCB portion.

7. The inductor according to any one of the preceding claims, wherein the winding segments are formed by an additive manufacturing process.

8. The inductor according to any one of the clauses 4 to 7, wherein the inductor comprises one or more side surfaces adjacent the first surface, the side surfaces being essentially planar and extending orthogonally to the first surface.

9. The inductor according to any one of the preceding clauses, wherein the inductor has a circular, elliptical or polygonal base surface and extends in a direction orthogonally to the base surface.

10. The inductor according to any one of the clauses 4 to 9, wherein the inductor comprises a side surface adjacent the first surface, the side surface forming essentially a lateral surface of a cylinder.

11. Method of producing an inductor according to any one of the preceding clauses, comprising:

forming a plurality of winding segments, the forming of the plurality of winding segments comprising an additive manufacturing process, wherein the winding has an axis, and wherein the winding has a first planar surface essentially orthogonal to the axis, and wherein

mounting the winding segments to a PCB portion to form a winding.

12. The method according to clause 11, wherein the mounting comprises placing the pins of the winding segments into holes in a PCB to press-fit the winding segments to the PCB, and soldering the winding segments to the PCB.

13. The method according to clause 11, wherein the mounting comprises providing soldering paste onto soldering pads on a PCB, and soldering the winding

segments to the soldering pads to surface mount the winding segments on the PCB.

14. The method according to any one of the clauses 11 to 13, further comprising: providing a magnetic core in an inner volume defined by the winding.

15. The inductor obtained by a method according any one of clauses 11 to 14.

Claims

1. An inductor, comprising:

a winding and a magnetic core, wherein the winding has an axis, and wherein the winding has a first planar surface essentially orthogonal to the axis; the winding defines an inner volume; and the magnetic core is form-fit into the inner volume, wherein the core comprises a powdered magnetic material.

2. The inductor according to claim 1, wherein the inductor comprises one or more side surfaces adjacent the first surface, the side surfaces being essentially planar and extending orthogonally to the first surface.

3. The inductor according to claim 1 or 2, wherein the first surface has an essentially rectangular footprint.

4. The inductor according to any one of the preceding claims, wherein the inductor has a circular, elliptical or polygonal base surface and extends in a direction orthogonally to the base surface.

5. The inductor according to any one of the preceding claims, wherein

the winding comprises winding segments and a printed circuit board, PCB, portion, wherein the winding segments are individually mounted to the PCB portion and electrically connected to conductors comprised in the PCB portion, and wherein the electrical conductors comprised in the PCB portion form a portion of the winding.

6. The inductor according to claim 5, wherein the winding segments are connected in series to each other into the winding with the conductors comprised in the PCB portion between neighboring winding segments.

7. The inductor according to claim 5 or 6, wherein the winding segments are press-fitted to the PCB portion.
8. The inductor according to claim 5 or 6, wherein the winding segments are surface mounted to the PCB portion. 5
9. Method of producing an inductor, comprising: 10
 - forming a winding, the forming the winding comprising an additive manufacturing process, wherein
 - the winding has an axis, and wherein the winding has a first planar surface essentially orthogonal to the axis, and wherein the winding defines an inner volume; and 15
 - molding a magnetic core into the inner volume. 20
10. The method according to claim 9, wherein forming the winding comprises forming winding segments and arranging the winding segments to define the inner volume. 25
11. The method according to claim 10, further comprising:
 - mounting the winding segments to a PCB portion to form the winding. 30
12. The method according to claim 11, comprising
 - arranging the winding segments on a carrier to form the inner volume; 35
 - molding the magnetic core,
 - separating the winding segments and the magnetic core from the carrier; and mounting the winding segments and the magnetic core to the PCB portion. 40
13. The method according to any one of claims 9 to 12, wherein molding the magnetic core comprises:
 - combining a powdered magnetic material and a binder to form a composite; 45
 - infusing the composite into the inner volume; and
 - hardening the composite. 50
14. The method according to any one of claims 9 to 13, wherein the magnetic core comprises Fe/Si alloy particles at a volume density of at least 5%.
15. The inductor obtained by a method according any one of claims 9 to 14. 55

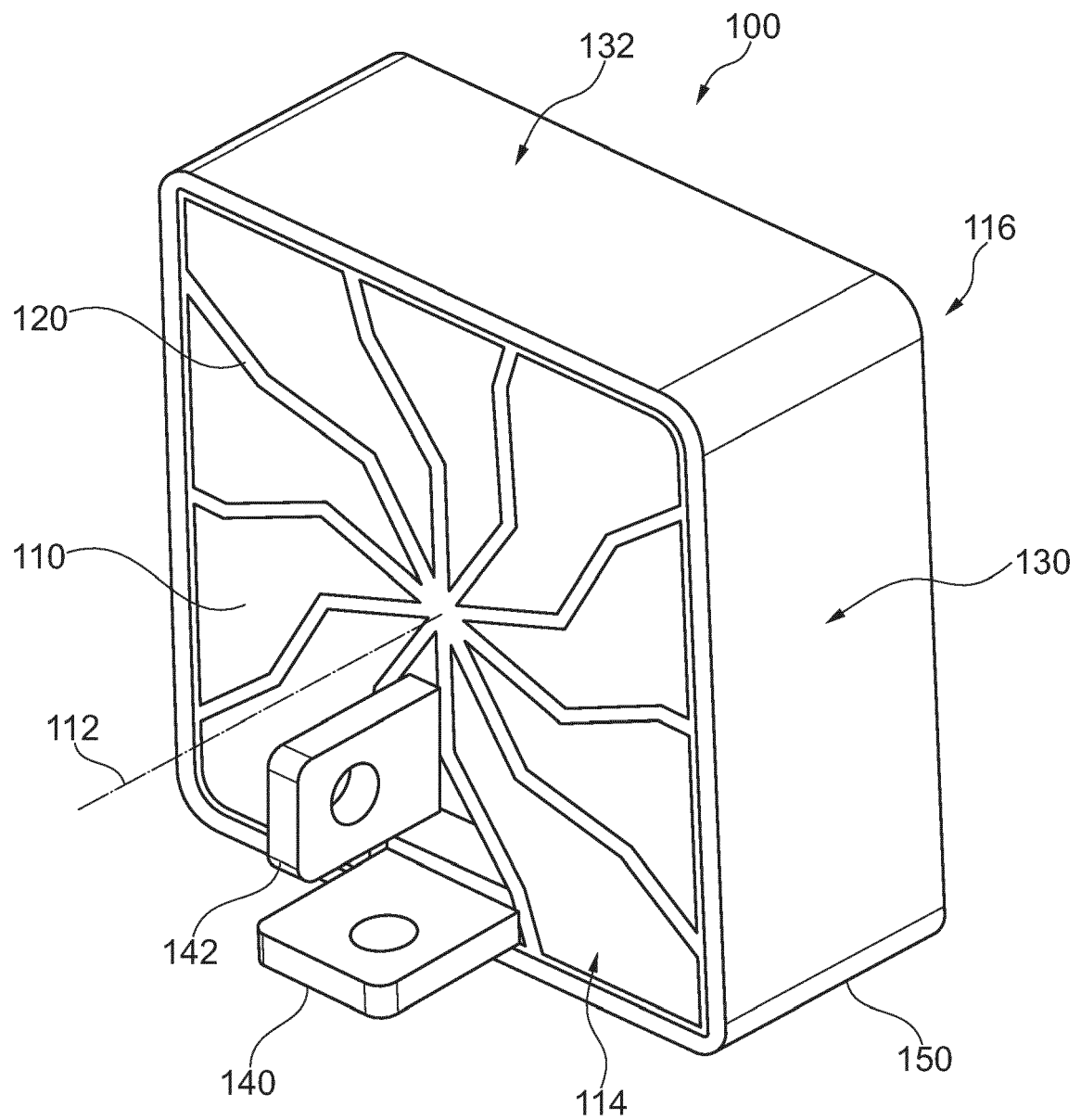


Fig. 1

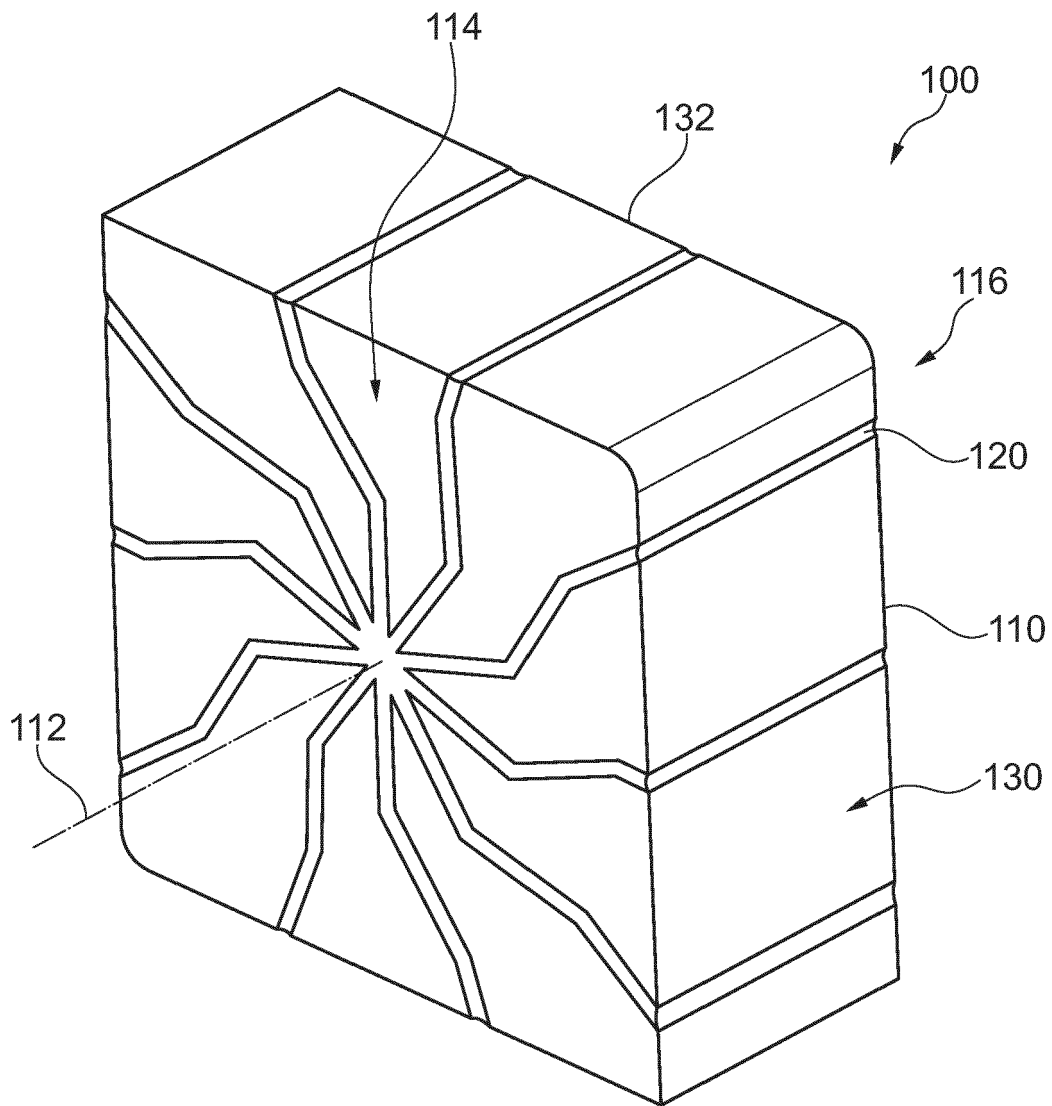


Fig. 2

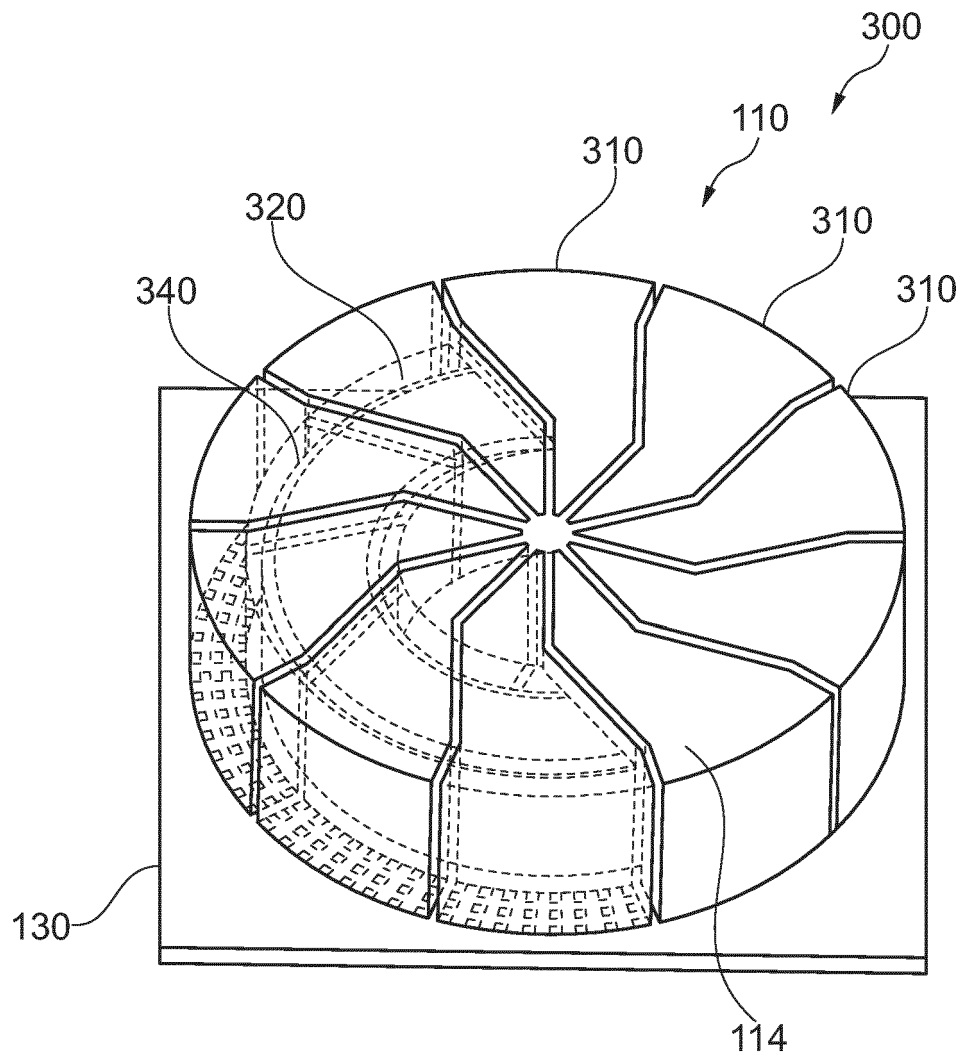
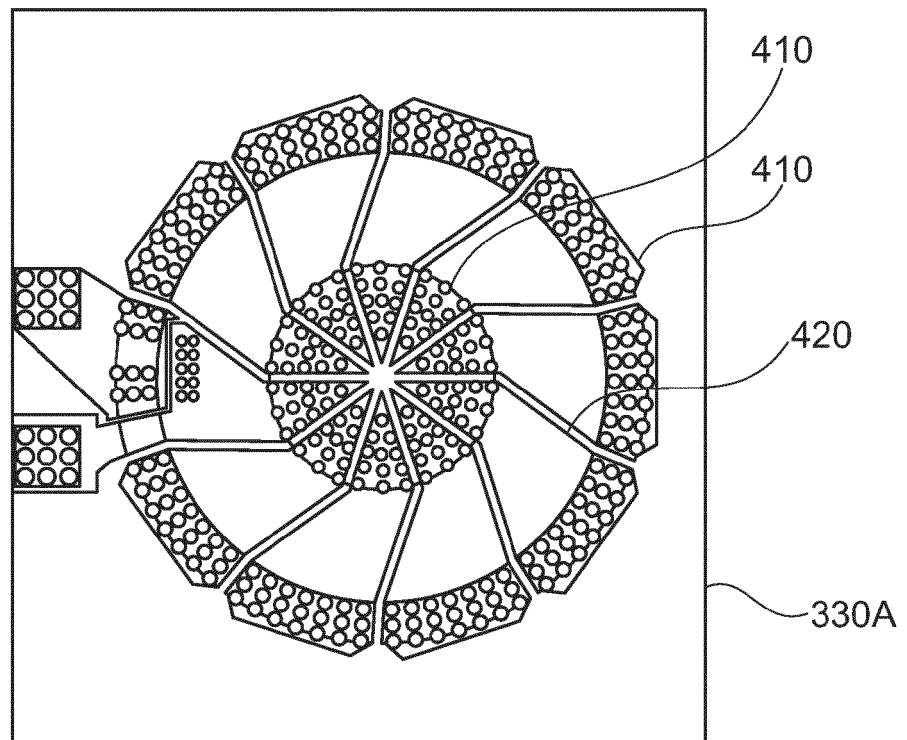


Fig. 3

A)



B)

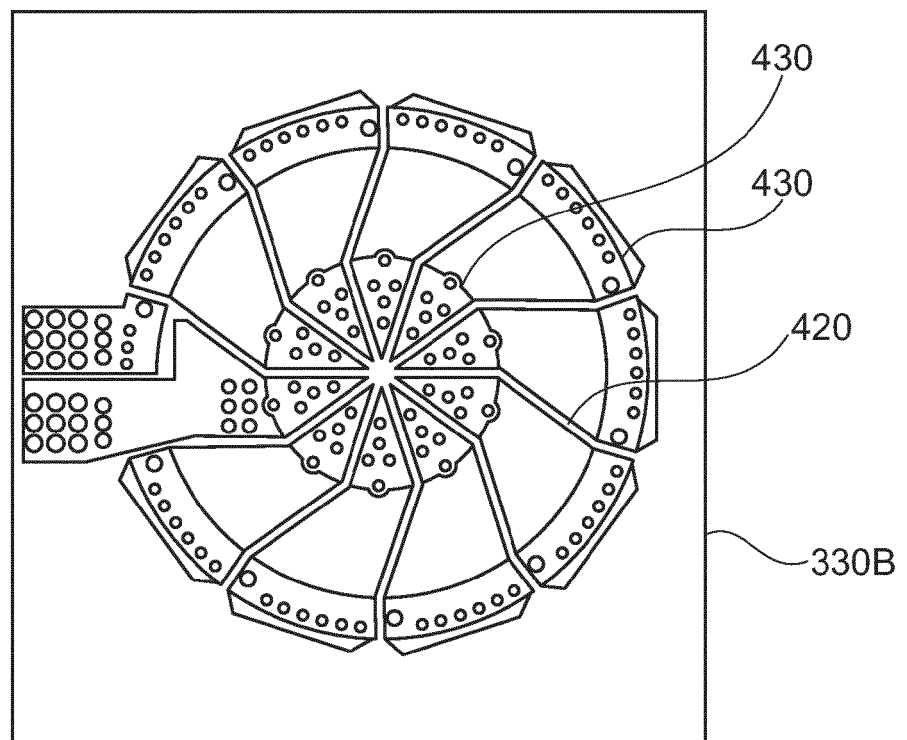


Fig. 4

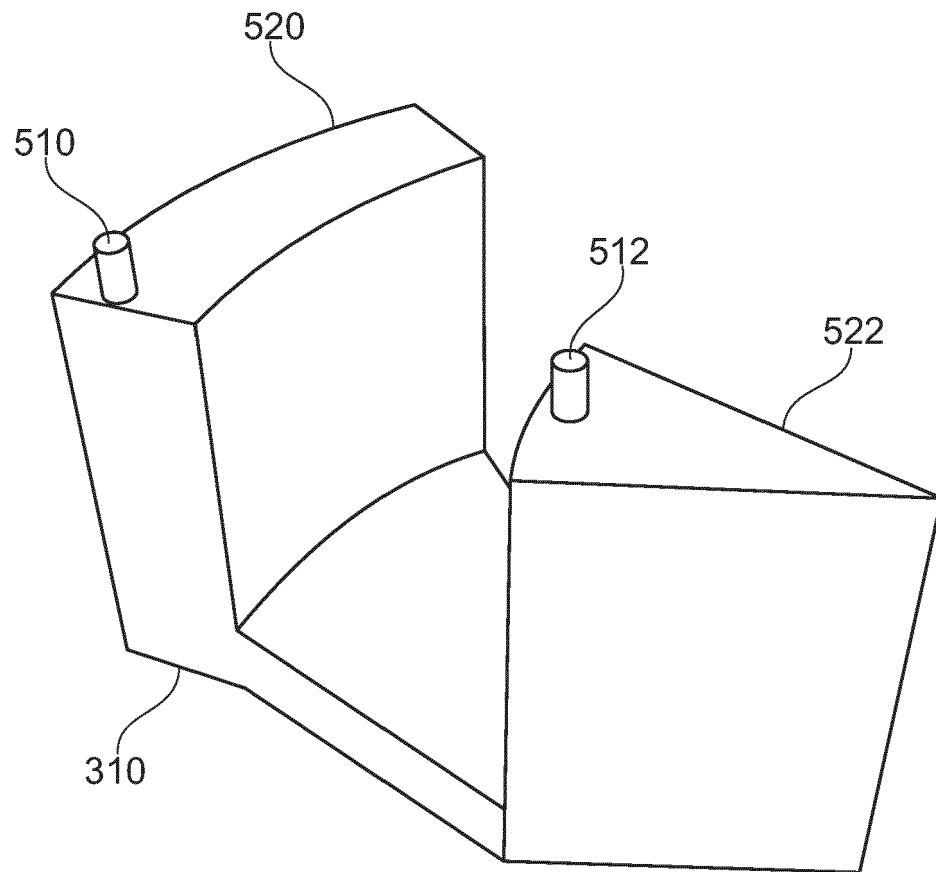


Fig. 5



EUROPEAN SEARCH REPORT

Application Number

EP 23 15 3521

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2014/132386 A1 (KOSTELNIK ET AL) 15 May 2014 (2014-05-15)	1-11, 13-15	INV. H01F27/30
A	* paragraphs [0019], [0020], [0068] * * figures 5-15 *	12	H01F27/28 H01F17/06 H01F41/02 H01F41/04
X	US 2008/186124 A1 (SCHAFER ET AL) 7 August 2008 (2008-08-07)	1-11, 13-15	
A	* paragraph [0083] * * figure 1 *	12	
A	ZHANG ET AL: "Applications and Future of Automated and Additive Manufacturing for Power Electronics Components and Converters", IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS, vol. 10, no. 4, 13 December 2021 (2021-12-13), pages 4509-4525, XP011916610, ISSN: 2168-6777, DOI: 10.1109/JESTPE.2021.3135285 [retrieved on 2021-12-13] * figures 10, 19 *	1-15	
E	EP 4 191 621 A1 (ROLLS ROYCE) 7 June 2023 (2023-06-07) * figures 1, 2 *	1, 2, 4	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC) H01F

1

EPO FORM 1503 03:82 (P04C01)

Place of search Munich	Date of completion of the search 27 June 2023	Examiner Subke, Kai-Olaf
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		

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 23 15 3521

5

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.

27-06-2023

10

15

20

25

30

35

40

45

50

55

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 2014132386 A1	15-05-2014	DE 102012220022 A1	08-05-2014	
		EP 2728979 A1	07-05-2014	
		EP 3700308 A1	26-08-2020	
		US 2014132386 A1	15-05-2014	
		US 2015310982 A1	29-10-2015	

US 2008186124 A1	07-08-2008	CN 101553890 A	07-10-2009	
		EP 2095379 A2	02-09-2009	
		TW 200841572 A	16-10-2008	
		US 2008186124 A1	07-08-2008	
		WO 2008060551 A2	22-05-2008	

EP 4191621 A1	07-06-2023	EP 4191621 A1	07-06-2023	
		US 2023170125 A1	01-06-2023	
