

(19) **DANMARK**

(10)

DK 181900 B1



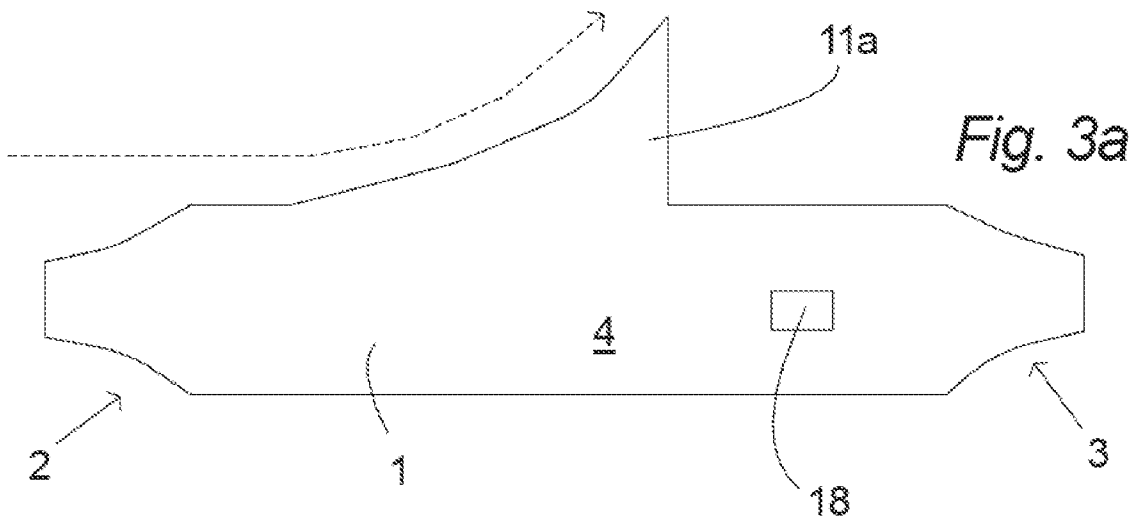
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PATENTSKRIFT

Patent- og
Varemærkestyrelsen

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- (51) Int.Cl.: ***H01R 9/11 (2006.01)*** ***H01B 7/42 (2006.01)*** ***H05K 7/20 (2006.01)***
- (21) Ansøgningsnummer: **PA 2023 70260**
- (22) Indleveringsdato: **2023-05-26**
- (24) Løbedag: **2023-05-26**
- (41) Alm. tilgængelig: **2024-09-29**
- (45) Patentets meddelelse bkg. og publiceret den: **2025-03-11**
- (30) Prioritet:
PA 2023 70156 2023-03-28 DK
PA 2023 70206 2023-04-27 DK
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- (54) Titel: **AN ELECTRICAL CONDUCTOR WITH INTEGRATED AIR GUIDES**
- (56) Fremdragne publikationer:
US 2021/0241965 A1
CN 107732611 A
CN 209625887 U
US 2022/0029329 A1
- (57) Sammendrag:
The invention relates to an electrical conductor comprising at least one first terminal and at least one second terminal spaced apart by a middle segment configured to support conductance of an electric current between said at least one first terminal and said at least second terminal, characterized in that it said middle segment comprises at least one air guide.

Fortsættes...



AN ELECTRICAL CONDUCTOR WITH INTEGRATED AIR GUIDES**Field of the invention**

[0001] The invention relates an electrical conductor with an air guide, a method of manufacturing such electrical conductor, a high-voltage electrical system comprising
5 such electrical conductor and use of such electrical conductor for temperature regulation of the high-voltage electric system.

Background of the invention

[0002] In the art it is known e.g. from CN214590136 to equip an electrical cabinet with an air guide plated to ensure distribution of a cooling flow of air in the electrical
10 cabinet. Further, an intelligent cooling device for an electrical cabinet is known from CN215378039. Further, US20210241965 disclose a filter for a multi-phase power apparatus. The filter comprises a flat winding around an inductor core. US20210241965 also relates to cooling of the power apparatus which may be done in various ways e.g. by means of heat sinks that can be attached to the electrical
15 components. Alternatively, cooling tubes are positioned in casting gaps of a non-planar surface of the winding body for removing heat from the inductor. Further, US2021041965 disclose to guide a flow of air from a fan to the inductor which e.g. is enclosed by a shroud for focusing the air flow to the inductor.

[0003] The air guide plates of the cited prior art for distribution of cooling air inside
20 an electrical cabinet are leading to increase of cost, time of assembling the electrical cabinet and are sources of errors. These problems are solved by the present invention as described below.

Summary of the invention

[0005] The inventors have identified the above-mentioned problems and challenges related to air distribution in an electrical cabinet and solved these problems by the present invention as described below.

- 5 [0006] In an aspect, the invention relates to an electrical conductor comprising at least one first terminal and at least one second terminal spaced apart by a middle segment configured to support conductance of an electric current between said at least one first terminal and said at least second terminal, characterized in that it said middle segment comprises at least one air guide, or said first end terminal or said second end terminal comprises at least one air guide, wherein said at least one air guide: is an
10 integrated part of said electrical conductor in the form of a protrusion, and is configured to guide a flow of air in a desired direction, wherein said desired direction is guiding said flow of air to pass a hot spot of a component or of said conductor, wherein said hot spot is defined as a spot of said component or of said conductor
15 having a higher temperature than other parts of said component or of said conductor.

- [0007] An electrical conductor comprising an air guide is advantageous in that it has the effect, that it facilitates both guiding a cooling fluid, such as air, to and possible also around an electrical component to which it is connected or passing by in an electrical cabinet. Such catching and guiding of air flow is achieved while, at the same
20 time, improving the cooling of the electrical conductor itself and supplying the electrical component with power without the need for additional air guiding components.

[0008] In an exemplary embodiment of the invention, said at least one air guide is removably attached to said electrical conductor.

- 25 [0009] This is advantageous in that it has the effect, that it is possible to adjust the position of the air guide on the electrical conductor. Thus, it is possible to adjust airflow directly to a hot spot e.g. of an electrical component or an area which need cooling by airflow.

[0010] In fact, it may be possible during operation of an electrical system to establish a thermography of the electrical system and based on an evaluation of the resulting picture adjust or position one or more the air guides to guide flow of air to relevant areas.

- 5 [0011] Air guides may be attached to the conductor bay clamping, screwing or the like.

[0012] Air guides may be made of a resin, polymer or other suitable materials, preferably materials that is possible to use to manufacture the air guides in an adaptive manufacturing process.

- 10 [0013] In an exemplary embodiment of the invention, said electrical conductor comprising air guide fasteners configured to fix said at least one air guide.

[0014] Having guide fasteners formed in / as part of the surface of the conductor is advantageous in that it has the effect, that external air guides are easy to mount on the conductor at the correct position and with a correct angle for guiding an air flow e.g.

- 15 to a heat generating component.

[0015] Such integrated guide fasteners are advantageous in that they can be manufactured simultaneously with the manufacturing of the conductor.

[0016] In an exemplary embodiment of the invention, said at least one air guide is an integrated part of said electrical conductor.

- 20 [0017] An integrated air guide is advantageous in that it has the effect, that no additional components is needed to distribute an air flow around or along the electrical conductor.

[0018] In an exemplary embodiment of the invention, said middle segment with said at least one integrated air guide is one monolithic geometry.

- 25 [0019] A middle segment and an integrated air guide monolithically formed is advantageous in that it eliminates the need for mounting the air guide on said the

surface of said middle segment. This is because the middle segment and the air guide is one and the same structure.

[0020] An air guide in the form of a protrusion is advantageous in that by the design of the protrusion, the flow of air can be directed to a predetermined area or location in the vicinity of the electrical conductor.

[0021] In an exemplary embodiment of the invention, a plurality of individual air guides is outgrowing from the surface of said middle segment in different directions.

[0022] Hence in an embodiment, one air guide may outgrow from one side of a rectangular middle segment towards. Another air guide may outgrow from the second yet another air guide may outgrow from one of the third and fourth sides, etc.

[0023] Such varying outgrowing air guides may lead to a desired or controlled flow of cooling fluid which may increase or decrease flow speed, create a swirling effect, etc. and thereby increase the overall cooling of the electrical cabinet or increase the area inside the electrical cabinet cooled by the flow of cooling fluid.

[0024] Protrusions or outgrowths are advantageous in that in addition to guiding air they may also act as heat sink and thereby be used to cool the conductor and / or the component to which the conductor is connected.

[0025] In an exemplary embodiment of the invention, said at least one air guide is integrated as part of said electrical conductor as a recess at the surface of said middle segment.

[0026] An air guide in the form of a recess is advantageous in that by the design of the recess, the flow of air can be directed to a predetermined area or location in the vicinity of the electrical conductor.

[0027] In an exemplary embodiment of the invention, the surface of said middle segment is dimpled.

[0028] This is advantageous in that it has the effect, that a dimpled surface creates a turbulent flow of air over the surface of the middle segment and thereby an increased cooling of this surface.

[0029] In an exemplary embodiment of the invention, said at least one air guide
5 branches off in at least two additional air guides.

[0030] This is advantageous in that it has the effect, that if the electrical conductor branches off in two or more conductor branches, each these conductor branches may be cooled by the flow of cooling and thereby each be cooled / temperature regulated.

[0031] In an exemplary embodiment of the invention, said at least one air guide is
10 configured to separate said flow of said cooling flow in at least two flow parts.

[0032] By designing the air guide e.g. in a triangular geometry, the flow of cooling fluid may be split in at two separate air flows. It should be mentioned that other geometries of the air guide may separate air flows in more than two separated air flows.

[0033] In an exemplary embodiment of the invention, said at least one air guide has
15 a geometry selected from the list comprising: circular, oval, triangular, rectangular, square, pentagon and multi sided.

[0034] The design of the geometry of the air guide may be determined by the desired way to split or guide the flow of cooling fluid inside e.g. an electrical cabinet.

[0035] In an exemplary embodiment of the invention, said at least one air guide is
20 formed by electrically conductive material of said middle segment.

[0036] Forming the air guide in an electrically conductive material is advantageous in that it then may be formed in the same material as the electrical conductor. Thus, the electrical conductor and the air guide may be formed simultaneously i.e. as the surface of the middle segment is formed or manufactured, the integrated air guide may
25 also be formed or manufactured.

[0037] In an exemplary embodiment of the invention, said at least one air guide is formed as a concave geometry in the surface of said middle segment or in one of said first end and second end.

5 [0038] This is advantageous in that such concave geometry may form a funnel like geometry guiding a flow of air caught by said funnel to an inlet opening of an internal cooling channel of said electrical conductor.

[0039] Additional air guides provided in the surface of said electrical conductor may assist in guiding a flow of air into said funnel or through the electrical conductor if the design thereof allows so.

10 [0040] It should be noted that the air guides described in this document may also be applied to or made in the surface of the ends of the electrical conductor.

[0041] In an exemplary embodiment of the invention, said first terminal is comprised by a first end and second terminal is comprised by a second end, wherein said at least one air guide is integrated in said first end or in said second end.

15 [0042] Having air guides at the surface of the ends of the electrical conductor is advantageous in that heat generated at the connection between the terminals of the electrical conductor and an electrical component to which it is connected can be removed. In this and similar situations, an air guide is advantageous over known ways of controlling a flow of air inside an electric cabinet to remove heat. According to the
20 present invention, this may be obtained simply by extending the ends of the electrical conductor to establish more area of the conductor that can be used as air guides. By air guides of the present invention, the same areas or even a larger area can be provided with less material and at the same time without compromising the free space needed for mounting the electrical conductor to the electrical component.

25 [0043] In an exemplary embodiment of the invention, said at least part of said middle segment and said air guide is manufactured at least partly, simultaneously, by an additive manufacturing process.

[0044] Manufacturing an electrical conductor according to the present invention by an additive manufacturing process is advantageous in that the ends and middle segment including air guides may be monolithically formed in one piece. This is advantageous in that it has the effect, that the air guides are perfectly secured to the middle segment
5 and thus the risk of them falling off is reduced significantly.

[0045] In an exemplary embodiment of the invention, said middle segment comprising a plurality of conductor branches.

[0046] One conductor branch may be designed and subsequently produced in a harmonica-like shape, spiral-like shape, etc. leading to a plurality of airgaps between
10 parts of the same or neighbouring conductor branch.

[0047] It should be mentioned that a high-power electrical conductor may be built from a mix of conductor branches of different geometries.

[0048] In an exemplary embodiment of the invention, said middle segment is monolithically formed in an electrically conductive material.

15 [0049] Thus, independent of geometry, the middle segment is one piece which is advantageous in that it has the effect, that no need to manually connect middle segment parts. Thereby is mounting speed of the electrical system in which the electric conductor is mounted increased and at the same time risk of human errors are reduced if not eliminated with respect to assembling of the electrical conductor.

20 [0050] A one-piece middle segment may be manufactured by an additive manufacturing process, a moulding process, extrusion process or similar.

[0051] In an exemplary embodiment of the invention, said middle segment is monolithically formed in a first end with said first end of said electrical conductor and monolithically formed in a second end with said second end of said electrical
25 conductor.

[0052] In an exemplary embodiment of the invention, said electrical conductor has a resonance vibration frequency of at least 5 Hz, for example at least 20 Hz, for example

at least 30 Hz, for example at least 70 Hz, for example at least 150 Hz for example at least 300 Hz, for example at least 500 Hz.

[0053] The electrical conductor is advantageously designed and subsequent manufactured so that it has a resonance vibration frequency associated with relative
5 motion between the first end segment and the second end segment that is does not coincide with a natural frequency of the system in which it is included. This is to avoid vibrations initiated by natural frequencies from such electric system or mechanical system. An example of a mechanical system is a wind turbine which may have a natural frequency of 5Hz.

10 [0054] An electrical conductor according to any of the proceeding paragraphs manufactured according to the method of below paragraphs.

[0055] In an aspect, the invention relates to a method of cooling a component, said method comprising the step of:

- providing a flow of a cooling fluid,
- 15 - guiding a part of said flow of said cooling fluid towards said components,

wherein said part of said flow of said cooling fluid is guided towards said component by at least one air guide comprised by a middle segment of an electrical conductor.

[0056] Using air guides comprised by electrical conductors is advantageous in that it has the effect, that the cooling is optimized of a component that is not positioned in
20 the direction of flow of cooling fluid between the air inlet and air outlet.

[0057] The flow of cooling fluid may be established by different temperatures, draught, etc.

[0058] In an exemplary embodiment of the invention, the method further comprising the step of guiding said flow of said cooling fluid around inside an electrical cabinet
25 by means of said at least one air guide, wherein said at least one air guide is integrated in the surface of said middle section.

[0059] In an exemplary embodiment of the invention, said electrical cabinet comprises a fan, wherein said fan is establishing said flow of said cooling fluid in a direction from an air inlet to an air outlet, and wherein said air guide is positioned in said flow of said cooling fluid so as to guide said part of said flow of said cooling fluid
5 in a direction which is nonparallel with said direction.

[0060] By allowing electrical conductors having middle segments comprising air guides e.g. in the top, middle bottom, left side, middle and / or right side of the electrical panel an optimized distribution of the flow of cooling fluid is obtained. In fact, each corner of the electrical cabinet may be cooled by parts of the flow of cooling
10 fluid and this without the need of additional components mounted to the electrical cabinet.

[0061] In an exemplary embodiment of the invention, a plurality of electrical conductors comprising a plurality of air guides are guiding said flow of said cooling fluid in multiple directions inside said electrical cabinet.

15 [0062] By using a plurality of electrical conductors comprising air guides, it is possible to distribute the flow of cooling fluid inside the electrical cabinet better than what is possible with known systems.

[0063] In an aspect, the invention relates to a high-power electrical system comprising: an electrical cabinet comprising an air inlet and an air outlet, a plurality
20 of electrical conductors comprised by said electrical cabinet, at least one component comprised by said electrical cabinet, and a fan configured to establish a flow of air between an air inlet and an air outlet. Wherein at least part of said plurality of electrical conductors comprises at least one integrated air guide, wherein said air guides are configured to change direction of said flow of air inside said electrical cabinet.

25 [0064] In an aspect, the invention relates to the use of an electrical conductor comprising an air guide according to any of the preceding paragraphs for temperature regulation of the high-power electrical system as described in the above paragraph.

The drawings

[0065] For a more complete understanding of this disclosure, reference is now made to the following brief description, taken in connection with the accompanying drawings and detailed description, wherein like reference numerals represent like parts. The drawings illustrate embodiment of the invention and elements of different drawings can be combined within the scope of the invention:

Fig. 1a-c illustrates various electrical conductor according to the present invention,

Fig. 2 illustrates a flowchart according to a method of a manufacturing an electrical conductor,

10 Fig. 3a-3b and 5 illustrates a conductor having different types of air guides,

Fig 4. illustrates guide fasteners,

Fig 6. illustrates a guide of air when a conductor split into two or more conductor branches, and

Fig 7. illustrates an electrical system comprising conductors with air guides.

Detailed description

[0066] The present invention is described in view of exemplary embodiments only intended to illustrate the principles and implementation of the present invention. The skilled person will be able to provide several embodiments within the scope of the
5 claims.

[0067] Fig. 1a -1c illustrates various embodiments of an electrical conductor 1 according to the present invention. Fig. 1a illustrates an electrical conductor 1 having a twisted geometry / design. The electrical conductor 1 comprises a first end 2 and a second end 3, where the second end 3 being distal to the first end 2 and spaced apart
10 from each other by a middle segment 4.

[0068] The middle section 4 in this particular embodiment comprises a plurality of conductor branches 5. In this particular embodiment the individual conductor branches are spaced apart by air gaps 6 both in the longitudinal and 6a transversal direction 6b of the electrical conductor 1. This twisted design of the conductor branches adds
15 flexibility to the conductor 1 and thus the ability to absorb vibrations. Further, the design is lightweight and easy to mount.

[0069] In this particular embodiment, the first end 2 comprises a first terminal 7 and the second end 3 comprises a second terminal 8. The first and second terminals 7, 8 may comprise one or more terminal holes 10 for connecting the electrical conductor 1
20 to other electrical components. The electrical conductor 1 is configured to support conductance of an electric current between the first and second terminals 7, 8.

[0070] Each of these two terminals 7, 8 may, via terminal holes 10, clamps, plugs or other electrical connection means, for example be galvanically coupled to terminals, busbars, components (such as breakers, contactors, power modules, reactors, etc.) and
25 other electrical conductors according to the present invention, etc. of an electrical installation. Typically, the electrical conductor 1 and thus the terminals, busbars, components, etc. to which it may be connected would be comprised by an electric box i.e. located inside an enclosure such as a panel, cabinet, etc.

[0071] In various embodiments, the electrical conductor 1 may have several first ends 2, several second ends 3, several first terminals 7, and/or several second terminals 8.

[0072] Fig. 1b illustrates an electrical conductor 1 having a web-like or lattice-like geometry / design. As the electrical conductor 1 illustrated in fig. 1a, the electrical conductor illustrated in fig. 1b comprises a first end 2 and a second end 3 separated by a middle section 4. The first end 2 may comprise a first terminal 7 and the second end 3 may comprise a second terminal 8. The first and second terminals 7, 8 may comprise one or more terminal holes 10 for connecting the electrical conductor 1 to other electrical components.

[0073] Between the two terminals 7, 8 conductor branches 5 in a web-like structure extend (only one is highlighted). These conductor branches meet and branch off in a plurality of intersection points 9. Note that the first and second ends 2, 3 are also partly manufactured as a web-like design as the middle segment 4. Also note, that the first and second terminals 7, 8 comprise more than one terminal hole 10. The terminal holes 10 of the terminals 7, 8 is made in a part of the ends 2, 3 which has non-perforated surface i.e. a surface different from the web-like surface of e.g. the middle segment 4 of the electrical conductor in this particular embodiment. The planar contact surface of the terminals 7, 8 around the terminal holes 10 is preferred to provide a connection surface to another flat surface with as little resistance as possible and sufficiently strong contact surface between bolt / nut and electrical conductor 1.

[0074] Fig 1c illustrate an electrical conductor having a bionic geometry / design. As the electrical conductor 1 illustrated in fig. 1a and 1b, the electrical conductor illustrated in fig. 1c comprises a first end 2 and a second end 3 separated by a middle section 4. The first end 2 may comprise a first terminal 7 and the second end 3 may comprise a second terminal 8. The first and second terminals 7, 8 may comprise one or more terminal holes 10 for connecting the electrical conductor 1 to other electrical components.

[0075] The middle segment 4 in this embodiment is of a so-called bionic design, preferably achieved as a computer generated design. Such computer-generated design is provided based on input to a computer program controlling an additive manufacturing machine / process or able to export data to a controller of an additive manufacturing machine / process such as from a user or another computer. Input may include dimension, maximum current to be conducted, required strength, maximum deflection (elastic or plastic), etc. As the electrical conductor illustrated in fig. 1b, the electrical conductor of this particular embodiment comprises both longitudinal conductor branches 5a and transversal conductor branches 5b. It is noted, that together the conductor branches 5a, 5b forms a transversal conductor branch outgrowth i.e. if seen in a side view, the electrical conductor 1 of fig. 1c would be thicker at the middle section 4 than at the ends 2, 3. The conductor branches 5 are spaced apart in space by air gaps 6 in both X (6a), Y (6b) and Z (6c) directions. Further note, that the terminals 7, 8 are designed with a planar surface to obtain best possible contact with a component having a planar surface, to which the electrical conductor 1 is to be connected to, such as clamped against, via for example bolt and nuts. Also note, that independent from the geometry of the ends 2,3, the terminals 7,8 are aligned / raised so that the contact surface for, e.g., all three terminals 7 are in the same plane.

[0076] The above embodiments of an electrical conductor 1 all feature airy geometries having air gaps 5 between conductor branches 6. The electrical conductor 1 of the present invention may in other embodiments feature other airy geometries such as web-like, gyroid-like, lattice-like, etc., as described in more detail herein, which in various embodiments may provide improved cooling, reduced material consumption, improved flexibility, and/or other advantages described in more detail herein. The term ‘-like’ is used in connection with gyroid-like, lattice-like, etc., to emphasize that it is an airy geometry resembling the named structure, rather than a specific systematic structure, that is relevant in preferred embodiments of the invention.

[0077] It should be noted that the three different designs of electrical conductors of the present invention illustrated in fig. 1a-1c is not limiting for the designs or

geometries or structures that is possible to manufacture according to the present invention. Other designs that are possible to represent digitally and transfer to an additive manufacturing device and thus manufacture by additive manufacturing is considered to fall with the scope of the present invention. This includes designs having
5 plane surfaces with internal ducts, manufactured by different materials, manufactures with protrusions or recesses, manufactured to have auxiliary functions beside conducting current, etc. Particularly, high-power conductors are advantageous to manufacture according to the present invention.

[0078] Note that embodiment of the invention, such as the above-described electrical
10 conductors, may comprise further terminals 7, 8 between the ends 2, 3, which are not illustrated. Also note, that a plurality of the illustrated electrical conductors 1 may be connected to form a complete electrical conductor. In this case the first and second end 2, 3, is referred to as the ends of the complete electrical conductor which may comprise terminals 7,8 and e.g. terminal holes 10 for connecting the complete electrical
15 conductor to other components. Between these first and second ends 2, 3 of the complete electrical conductor, terminals 7, 8 of a plurality of electrical conductors as illustrated may be connected.

[0079] The cross-sectional area of the conductor / conductor branches can be exploited to its full potential in an electrical conductor of the present invention. The
20 conductor is designed and manufacture to have a cross-sectional area that is able to comply with requirements to current to be conducted without have excess of material used. The design of the present conductor may not have surplus material which is not used for conducting current when nominal current is supplied e.g. to a 1400A power module. If extra material is used, this is used for cooling the conductor or a safety
25 margin. The amount of such extra material can be determined relatively precise by the software which is used to design the conductor. As a rule of thumb, the larger surface for cooling, the higher amps is possible to conduct. The design software may be able to put weight on amps, cooling properties (cooling medium, surface, etc.), frequency of the current when designing the geometry of the conductor, etc. when designing the
30 conductor. Accordingly, a conducting cross-sectional area of a conductor as illustrate

in fig 1b may be 80mm² may in certain embodiments be sufficient to conduct a current of 1300A due to the airy design allowing a very advantageous cooling. In fact, tests have shown that the temperature of a conventional massive busbar with a conducting cross-sectional area of 516mm² conducting 1300A increases to a temperature where
5 neighboring components of plastic is in risk of melting.

[0080] Hence, it should be noted that the conductor may be designed and subsequently manufactured so that a percentage of the cross-sectional area of the electrical conductor e.g., above 80% such as between 90% and 100% is used to conduct current during normal operation. This is in contrary to known massive busbars
10 that does not exploit the material in its center to conductor current. This is at least true for most frequencies of currents conducted in high-power systems including renewable systems, vehicles and the like.

[0081] The high percentage of utilization of cross-sectional area for conducting current compared to known massive conductors is possible to obtain in that the conductor of the present invention and thus the individual conductor branches because
15 they are designed with a cross-sectional area that sums up to be able to conduct a current of a given frequency. Further, the material reduction is also made possible because of the possibility of cooling also inside the conductor. In fact, a conductor branch may along most of its length, in some embodiments along all of its length, be
20 cooled from all angles i.e. a 360° cooling of the conductor branches is possible.

[0082] As mentioned, a conductor of the present invention may form an airy geometry which depending on the kind of airiness may not facilitate a secure or robust platform or structure for fastening the conductor e.g. to the electric cabinet. Accordingly, in proximity of through-holes for fastening the conductor or through-
25 holes, e.g. terminal holes, for connecting the conductor to components or other conductors, the geometry of the conductor may not be airy. Preferably, around a through-hole the density of the conductor is higher or more concentrated to form an, e.g., planar surface and thereby provide the best possible preconditions for conducting current between two parts of a joint and to distribute the force required to fastening a
30 conductor in the joint or to a support structure. Hence, a through-hole may be designed

as a cylinder through which a bolt may pass through and with planar upper and lower parts extending from the periphery of the cylinder to facilitate the force and / or current distribution in the joint. Other mounting and/or terminal points may be preferred in some embodiments, such as flanges, protrusions, plugs or sockets, etc., with or without
5 through-holes, but with the same consideration of ensuring sufficient robustness and stability of the electrical conductor for the intended mounting or connection method. The through-holes could be 6mm, 8mm, 10mm or 12mm in diameter.

[0083] It should be mentioned that terminals for electrical connection may be positioned at or between the ends of an electrical conductor. Thus, in principle, a
10 conductor may be manufactured by an additive manufacturing process and when the first end and first part of the middle segment is manufactured these may be rolled onto a conductor holder as the middle segment is continued to be manufactured. Alternative, the conductor is guided out of the printing areas e.g. by a conveyer belt as the conductor is manufactured. This may result in a long conductor with two ends. Either
15 during manufacturing or after, terminals may be made in the conductor and also after manufacturing, the conductor may be cut into desired lengths. In this way, terminals may be manufactured or provided either at the ends or between the ends of the conductor.

[0084] The term monolithic is in this description used to describe the geometry or
20 structure of an electrical conductor according to the present invention. Such conductor is preferably manufactured by an additive manufacturing process and thereby, it is manufactured as a single piece, unit or block from one end to the other or at least one end and a middle segment is manufacture as a single piece. Such conductor may thus be formed from a single material as a single piece, unit or block where its one or more
25 ends are monolithically formed with a middle segment connecting the one or more ends i.e. monolithically formed should be understood as made in one continuous process with no need for additionally adding one part to another I.e. one or more ends are manufactured together with the middle segment as one unit with no connections such as welding, soldering, or by any clamping or fastening means, except for the type
30 of micro binding intrinsic to the particular additive manufacturing technology utilized,

such as, e.g., layer-by-layer melting, sintering, liquid binding, spraying, etc. With this said, it should be mentioned, that it is possible to add additional elements such as terminals, cooling fins, etc in a post manufacturing process e.g., by a cold spray process.

- 5 [0085] Put in another way a conductor of the present invention is the result of a process forming the conductor in one structure, a conductor composed of an electrically conductive material without joints or seams and thus constituting a conductor as a rigid whole exhibiting a rigidly fixed uniformity. To such conductor it is possible to connect additional conductors via terminals and thereby branch off one
10 current path to two or more current paths or vice versa.

- [0086] It should be mentioned that the conductor may be manufactured from more than one type of material. In this situation, the conductor could be said to be polyolithic. The term polyolithic should in this context be understood as a geometry or structure of an electrical conductor that is manufactured in one piece as a monolithic structure, as
15 described above, where the conductor is manufactured from two or more materials. Hence, a polyolithic conductor of the present invention is a conductor resulting from a process forming the conductor in one structure where the process is using two or more different materials. Such two or more materials may be a combination of electrical conductive or non-conductive materials.

- 20 [0087] In most embodiments, the electrical conductor 1 is designed to comply with high voltages i.e. voltages above 24V such as 110V, 230V, 400V, 690V, 1000V, 1500V and up to kV systems. just to mention a few voltage levels of an electrical installation in which the electrical conductor 1 of the present invention would be suitable. In terms of current, an electrical conductor 1 according to the present
25 invention may be designed to conduct several hundreds of amps (16, 32, 64, and so on up to 100, 200 and so on up to e.g. 900A) up to a couple of thousand amps (1000A-3000A). Electrical conductors may be designed to conduct higher currents than 3000A e.g. by improving cooling of the conductor in combination with an increased cross-sectional area of the conducting part of the conductor.

[0088] Mentioning these voltages, it should be noted, that in principle there are no lower limits as to the voltage and current. I.e., versions of the electrical conductor may be designed to be used in, e.g., 3.3V, 5V, 9V, 12V, 15V, 20V, 24V or 48V systems, such as USB power delivery PD systems, conducting currents below, e.g., 10A, such as 5A, 3A, 2.4A, or 2A just to mention a few examples.

[0089] Thus, the electrical conductor 1 of the present invention is suitable for use in almost any type of electrical installation. This includes everything from low voltage to high voltage AC and or DC systems where transfer / conducting of current or communication signals is needed.

[0090] The present invention is particularly advantageous for electrical busbars designed for high-power electrical systems, e.g. from 10kW and up, such as 22kW, 50kW, 110kW, 150kW, 225kW, 300kW, 350kW, 500kW, 800kW, 1MW, 2MW, 3MW, or even higher, such as e.g. 5MW or 10MW systems, with voltages of e.g. 110V, 230V, 400V, 690V, 800V, 1000V, 1500V, 6kV or e.g. 10kV, and currents from e.g. 16A, 32A or 64A, to several hundreds, e.g. 100A, 200A or 500A, or even thousands, e.g. 1000A to 4000A. By local connecting busbar is referred to busbars for local connections inside such a high-power electrical system, e.g. contained inside an electrical cabinet housing a power converter, inverter, transformer, generator, electric motor, breaker, high-power battery system, battery charger, or similar power systems, possibly including capacitors, reactors or inductors, power resistors, dump loads, etc. A system, component or conductor may be categorized as a high-power system, component or conductor if it is operating at currents in the range of 800-1000A or higher.

[0091] Non-limiting examples of such electrical installations / systems include energy facilities such as grid components such as substations with grid support, voltage regulation, power to x plants, etc., energy generating systems such as wind turbines, wind farms, solar plants, etc., electric installations in a private homes and industry, industrial machines, household appliances, etc. and means for transportation such as airplanes, heavy duty vehicles, light duty vehicles such as automobiles, trains, ships, etc.

[0092] Accordingly, the electrical conductor may be a high-power electric conductor of a high-power electric system. In a high-power electric system, conductors may be spaced apart and / or isolated from each other with greater distances than what is possible e.g. in an electrical motor. This distance is referred to as a safety clearance and the size of it depends on the voltage differences in the system. Thus, when depending on air as isolator between an otherwise non-isolated busbar / conductor and another conductor or structure of conductive material such as a metal cabinet, the distances must be taken into account in compliance with safety regulations. It should be mentioned that air quality / pollution degree, such as humidity and particle content, may also be relevant for the distance of the safety clearance. In case a conductor is used in a high-voltage system the surface is manufactured to reduce field concentrations.

[0093] Further, the cross-sectional area of a current path through a conductor according to the present invention is larger than the cross-sectional area of e.g. a winding of an electric motor. This may be true both with respect to a cross-sectional area at a given point of the conductor and over a distance of e.g. 20cm or 30cm in the longitudinal direction of the conductor and physical dimensions.

[0094] Current conducting busbars of a high-power installation or system is typically fastened to a structure comprising the system for every 25-35cm. If the current is conducted by cables, the distance between cable fasteners may be even smaller. The fastening may be made by screwing bolts into a support structure such as an electric cabinet or by screwing clamps to the support structure which is then closed and thereby fastening the cable / busbar. The conducting cables / busbars are of course insulated from the support structure.

[0095] In such high-power installations where the primary aim of conductors is to distribute electric energy to components, the magnetic field around a conductor of the present invention is not as important as it is e.g. around a winding of an electrical motor. Thus, since the magnetic field is not the main purpose for manufacturing the electrical conductor for a high-power installation the conductor is typically not designed to have a certain magnetic field when conducting current.

[0096] Further, again comparing to e.g. a winding of an electrical motor, a conductor of the present invention would as a general rule be designed with a surface area that is as large as possible to optimize the possible advantages of the invention as described herein. Depending on the purpose of the conductor, the surface may for example be
5 designed for conducting current, conducting current and heat dissipation or heat dissipation. Thus, even though all portions of a conductor of the invention may comprise an electric conductive material, not all portions are necessarily used for conducting current through the conductor. In general, the available area around a conductor is exploited to expand the surface of the conductor for one of, for example,
10 the heat dissipation or current conducting purposes, or other described purposes such as improved flexibility, reduced material consumption, air guidance, etc. The available area is limited by safety clearances to other conductors of different phases having different voltage levels, grounded structures such as elements of an electric cabinet, etc.

[0097] An example of a portion of a conductor that is primarily used for non-conducting purposes such as heat dissipation or air guidance, is an outgrowth from the surface of the conductor which is not connected at the distal end of where it is growing from the surface of the conductor. Such outgrowth or protrusion may for heat dissipation purposes preferably comprise some kind of bionic design with airgaps
20 between branches, possibly with a continuous surface towards a direction of air flow for air guidance purposes. Such portions would be referred to as conductor branches if these were part of the middle segment conducting current from one end to the other. Such outgrowth may in principle take any form or geometry exploiting the free space around the area as long as safety clearance distances are maintained. In such examples,
25 the fraction of current conducted by the surface area of the outgrowing conductor portion is very small if not zero.

[0098] An example of a portion of a conductor that is only used for conducting a current may in principle not be possible in that heat dissipates even from a solid block and a planar surface. What should be understood by a portion of a conductor primarily
30 used for conducting current, is a varying structure or geometry for a middle segment

of the conductor between the first and second terminals. When space is narrowed between components in an electrical system, if other conductors are to be passed, if the conductor has to pass through a current sensor or bushing, etc., the surface area of that particular portion of a conductor middle segment may be reduced to comply with
5 available space, thereby typically increasing the conductor density to achieve a narrower outer dimension. In this example, at this particular portion of the conductor, the current conducting portion of the surface area of the conductor becomes high; possibly so high that a hot spot is created where additional cooling is required to continue to maintain a certain current conduction capacity. Hence, this is an example
10 which may benefit from a combination of the conducting portion with an outgrowth portion, as described above, e.g. on each side of the narrowed part of the conductor. In this way, heat generated at the narrow space can be dissipated via the nearby outgrowths, e.g. further in combination with internal cooling channels.

[0099] An example of a portion of a conductor that is used for both heat dissipation
15 and current conduction is a middle part between the terminals, with an airy design or geometry. In such example, the surface areas having the main purpose of dissipating heat and conducting current, respectively, may be the same or close to be the same. This is due to a geometry comprising conductor branches spaced apart from each other so that a flow of cooling air may pass freely by each conductor branch, i.e., through
20 air gaps defined by the conductor branches. In this example the current conducting surface area is large compared to traditional conductors / busbars and windings e.g. of an electric motor. Another difference between a motor winding and a conductor of the present may be found in the circumference of the conductor. The limited space inside a motor obviously limits the circumference of the winding. This is not the case to the
25 same extent e.g. in an electrical cabinet comprising a conductor of the present invention. More space is available and thus the circumference can be made larger leading to an airy design with airgaps for increased cooling. Further, the cross-sectional area of the individual conductor branches of a conductor according to the present invention is often lower than the cross-sectional area of a motor winding.

- [0100] As mentioned, the electrical conductor 1 may comprise first and second ends 2, 3 spaced apart by a middle segment 4. One complete or final electrical conductor may comprise a plurality of interconnected electrical conductors 1 of the types illustrated / described above. In such embodiment the illustrated electrical conductors may be used as sections of the final or complete electrical conductor. Thus, a final or complete electrical conductor may comprise first and second ends 2, 3, with a plurality of first and second terminals 7, 8 at the ends or between them, e.g. with terminal holes 10 for connecting a plurality of the illustrated / described electrical conductors to form the final or complete electrical conductor.
- 5
- [0101] The terminals 7, 8 may comprise one or more terminal holes 10 or other structures for connecting the electrical conductor 1 to other electrical conductors such as busbars, cables or the above-described electrical conductors, electrical components such as breakers, power modules, batteries, etc.
- 10
- [0102] Alternatively, in an embodiment, one or both of the terminals 7, 8 of the electrical conductor 1 form part of an electrical component as an alternative to being provided as freely connectable locations at the conductor 1.
- 15
- [0103] A terminal 7, 8 may in a simple embodiment comprise a terminal hole 10 through the terminal 7, 8. Via such hole, a bolt can go through and continue through a component with which the electrical conductor 1 is to be connected. The electrical conductor and the component are then clamped together via a nut and the bolt.
- 20
- [0104] Alternatively, a terminal 7, 8 may be a click terminal that is either designed to receive a click part from a component to which the electrical conductor is to be connected or designed with a click part that is to be inserted into such other components.
- 25
- [0105] Alternatively, a terminal 7, 8 at an end 2, 3 of the electrical conductor may be manufactured with a thread which when engaging with a bolt is able to assist in clamping a component to the electrical conductor 1.

[0106] Further, it should be noted, that an electrical conductor as illustrated or a complete electrical conductor comprising a plurality of electrical conductors such as the above described may have more than one first end 2 or more than one second end 3. Hence, one end of an electrical conductor 1 may branch off in e.g. three terminals
5 each with a terminal hole. This may be advantageous in that the geometry of the electrical conductor is then designed specifically to the component to which it is to be connected. Branching off the ends into several terminals may also improve heat dissipation capacity at the possibly denser terminal portions, improve electrical connection between the conductor and components, and avoid additional connection
10 pieces or shunts in order to connect adjacent components to a common conductor.

[0107] The middle segment 4 may comprise one, but preferably a plurality of conductor branches 5. The conductor branches 5, like the end segments 2, 3, are at least partly made of an electric conductive material such as copper or aluminium or alloys thereof, enabling the electrical conductor 1 to conduct a current between its
15 terminals 7, 8. The design of the conductor branch(es) 5 may be optimized according to a specific purpose such as cooling, material consumption, flexibility (control in a particular direction), footprint, etc. Thus, depending on which parameter(s) the electrical conductor 1 is designed according to, the conductor branches may be designed as longitudinal cylinders (or other geometries such as oval, square, etc.), web,
20 bionic, gyroid-like design, lattice-like design, branch-like design, or sponge-like design, coil or solenoidal designs, spirals, etc.

[0108] Thus, the electrical conductor may have a perforated surface, a non-perforated surface, a massive structure or a structure with internal channels optimizing the electrical conductor according to skin-effect and cooling, etc.

25 [0109] Two or more conductor branches 5 may meet in an intersection point 9 and two or more conductor branches 5 may branch off from an intersection point 9. This has the effect, that an electrical conductor is established that maintain a desired strength (determined yield point) with a minimum of material. Among others, this may reduce the cost of the electrically conductive material and reduce the weight of the
30 conductor. It should be mentioned that two conductor branches meeting in the

intersection point 9 may be the same two conductor branches leaving that intersection point 9. Alternatively, two other conductor branches may leave the intersection point, however this may be a question of definition of a conductor branch. Further one conductor branch may branch off to a plurality of conductor branches and a plurality
5 of conductor branches may meet and form a lower number of conductor branches.

[0110] Further, it should be mentioned that the electrical conductor 1 may be designed as a plurality of electrical conductors, e.g. as a combination of three phase conductors or as a wire harness or printed circuit board traces of a printed circuit board used for mounting in an electric panel.

10 [0111] At least a first end 2 and a middle segment 4, but preferably also the second end 3, of the electrical conductor 1 of the present invention are monolithically formed, since they are manufacturing from a single bulk of material, which is machined to provide the electrical conductor 1. Here bulk of material should be understood as the material such as electrically conductive material of which the electrical conductor 1 is
15 made, e.g. a solid, powder, liquid, wire, etc. Here machined should be understood as manufactured by additive manufacturing, i.e. the electrical conductor 1 is made in one piece without any mechanical connections of the first end 2, second end 3 and middle segment 4.

[0112] Note that more than one type of material, e.g. two bulks of material, may be
20 used to manufacture the electrical conductor. One of such two or more bulks of material may be electrically non-conductive.

[0113] Note that in some embodiments it may be necessary to manufacture the electrical conductor in more than one piece. In this situation the electrical conductor may be referred to as a complete or final electrical conductor which comprises a
25 plurality of electrical conductors 1 as described above. This may be the case e.g. if the electrical conductor needs to be mounted in a location where it cannot be inserted unless the electrical conductor is separated in two or more pieces or if the complete electrical conductor has to be larger than what is possible to manufacture by additive manufacturing. In such situation, terminals of two electrical conductors are connected,

extending the length of the middle section and thereby the current path between the first end 2 and the second end 3 and thus of the complete electrical conductor. Such connection may be prepared by designing terminal holes in the conductor where, e.g., fish plates or other joints may be fastened and thereby connecting the two middle
5 segments.

[0114] It should be noted that the electrical conductor 1 may have a non-uniform geometry / design. The design / geometry may take any machinable / printable shape. Such shape may be optimized according to conducting current (skin effect), cooling, guidance of flow of cooling fluid, other components in a panel, resistance, power loss
10 or current displacements, etc.

[0115] In a particular embodiment, the electrical conductor 1 may have a non-uniform diameter (measured in a transversal direction) along the lengthwise direction. A well-defined diameter may nevertheless be determined e.g. at a transversal plane at which that electrical conductor 1 has its smallest diameter.

15 [0116] Moreover, in an embodiment of the invention the perimeter length of the electrical conductor 1 or its conductor branch(es) 5 may vary in transversal planes at different positions in the lengthwise direction of the electrical conductor 1. The perimeter length of a given part of the middle segment may simply be measured as the sum of all lengths of perimeters of branches in a given transversal plane. Hence, the
20 perimeter length at a given part may thus be the length of the perimeter of conductor branches measured across / perpendicular to the longitudinal direction of the electrical conductor at that part. A part of a conductor may also be referred to as a portion of a conductor and should be understood as a reference to a specific portion of the conductor such as an end or middle segment.

25 [0117] The perimeter length of the conductor branches 5 may be the sum of lengths of perimeters of all individual conductor branches 5. As one conductor branch may split from a stem to two or more twigs, i.e. branches of a branch, the perimeter at one part of the conductor branch may be different from one part (e.g. a twig part) to another part (e.g. a stem part). Hence, the sum of lengths of perimeters of the conductor

branches may be the sum of all individual twigs or of all the individual stems. In case of multiple different possible perimeter lengths for the conductor parts along the length of the electrical conductor, the smallest perimeter length may preferably be used in calculation of current conduction capability of the electrical conductor 1.

5 [0118] In the same way, the cross-sectional area of an electrical conductor at a given part is measured as the sum of the cross-sectional area of all conductor branches at a given part along the length of the electrical conductor. The cross-sections at that part should be measured perpendicular to the longitudinal direction of the electrical conductor.

10 [0119] In an embodiment, the electrical conductor 1 may comprise one or more cooling channels, where the cooling channel may be placed inside the one or more conductor branches, transversally and/or longitudinally.

[0120] The manufacturing of the electrical conductor 1 may be done by an additive manufacturing process. Such manufacturing process may be based on, but not limited to, one of the following additive manufacturing processes: 3D printing, layer by layer printing, Wire Arc Additive Manufacturing, Fused Deposition Modeling FDM, Direct Energy Deposition, Direct Metal Deposition, sintering based processes, laser based processes, for example Powder Bed Fusion PBF, such as selective laser melting SLM or selective laser sintering SLS, cold spray additive manufacturing CSAM, binder jetting or binder jet 3D printing, etc. It should be mentioned that the actual additive manufacturing process used to print or build the electrical conductor 1 may not be important as long as the material of which the electrical conductor is built is an electrically conductive material.

25 [0121] Fig. 2 illustrates method steps for machining an electrical conductor 1 according to an embodiment of the invention. The particular method relates to forming an electrical conductor with two ends or two terminals, namely a first end / terminal and a second end / terminal via a middle segment, but may be used for producing any kind of electrical conductor of the present invention.

[0122] It should be mentioned that this may include manufacturing both ends and the middle segment in one process. Hence, with additive manufacturing along the longitudinal direction of the conductor, the method may start by manufacturing, such as printing, one end, then a transition to the middle segment, possibly one or more conductor branches, then the middle segment, then a transition to the second end and finally the second end. In another embodiment, the additive manufacturing occurs transversal to the conductor's longitudinal direction, thereby for example manufacturing portions of both ends and the middle segment simultaneously, increasing the cross section with each applied layer. In another embodiment, the additive manufacturing is radial, or even arbitrary, to the conductor's longitudinal direction, for example using cold spraying CSAM or Fused Deposition Modeling FDM while rotating or freely moving either the conductor unit being built or the nozzle, or both. Preferably, the mentioned segments are manufactured in one process, e.g. as one segment is manufactured, the next segment is being manufactured. A transition part may be made between such two segments which may start or include the first segment. Similarly, the second segment may include a transition part or is connected to such transition part.

[0123] It should also be mentioned that the method could in some embodiments comprise manufacturing the middle segment and afterwards connect the end segments. The end segments could be connected while being additive manufactured or could be connected with an additive manufacturing thermal paste or glue after being made. The end segments could also be welded, glued or connected in any other way to the middle segment, e.g. by cold spraying CSAM.

[0124] An additional embodiment of the invention could be a manufacturing method that comprises two or more middle segments being additive manufactured. The two or more middle segments could be additive manufactured in the same process with the two end segments to form the electrical conductor. The two or more middle segments could also be additive manufactured separately and connected afterwards to form the electrical conductor.

[0125] The two or more middle segments could be identical or could be two differently shaped or otherwise characterized middle segments depending on where the electrical conductor should be placed in e.g., an electrical cabinet.

5 [0126] A transition may straightforwardly be defined as a change of size of a layer compared to a previous layer. In this way a transition may be formed as a perpendicular transition between an end segment and a conductor branch of the middle segment. Alternative, subsequent layers may change in cross-sectional area and thus form a transition as a rounded transition which may be advantageous in terms of a reduced resistance for current conducted between the ends of the electrical conductor.

10 [0127] A monolithic conductor according to the present invention is made from one material. One or more additional materials may be used e.g. as isolation, for heat dissipation, etc. in this case the conductor may be referred to as a polyolithic conductor. No matter the number of materials, a conductor produced by additive manufacturing is produced bit-by-bit starting at a first spatial coordinate (x, y, z) and ending at a
15 second spatial coordinate. At least when the conductor is finished the first and second spatial coordinates are electrically / mechanically connected. As mentioned several methods of manufacturing a conductor exists all including some kind of material depositing, joining or soldering to manufacture a conductor in one monolithic form.

[0128] In this document a conductor may be referred to as being manufactured layer-
20 by-layer no matter the additive manufacturing method used. Hence, if a conductor is sliced (no matter in which orientation) and one is looking at the cross-section of the conductor it is easy to imagen that the conductor is manufactured starting with material in first point, then with material in a second point and so on. Since the conductor is volumetric i.e. has a three dimensional geometry the first point is different from the
25 second and subsequent points at least in one of the spatial X, Y and Z directions / plans. Thus, with reference to the spatial X, Y and Z planes a conductor could be said to be built from a plurality of subsequent layers even though when manufactured all material in one plane such as $X=1$ and $Y=0$ and $Z=0$ is not provided as a one layer or in one layer before material in a next layer (e.g. an $X=2$ layer) is provided.

[0129] Hence, no matter which of the processes of manufacturing a three-dimensional object such as a conductor that is used, it can be said that the conductor is manufactured layer-by-layer even though some of these manufacturing processes are based on deposited, joined or solidified with material being added together in areas, lines, pointwise, etc. This is because no matter the additive manufacturing process the conductor is manufactured one point after the other. A plurality of points in the same plan (e.g. $X=3$) is considered one layer also if they are not physically connected in this plane. And when all points of this layer are added, points of the next layer (e.g. $X=4$) is added to the points in the $X=3$ layer. As mentioned, a layer may be defined in any of the planes of a spatial Cartesian coordinate system.

[0130] Alternatively, the ends may be separate segments that are connected via the middle segment. The middle segment may be printed, and during the manufacturing of the middle segment it may be attached to the ends such as printed, heated, glued or the like onto the ends. The middle segment may be joined to the ends by means of welding, printing, soldering, etc.

[0131] It should be noted that the ends may comprise terminals for connecting the electrical conductor to other electric parts / conductors / windings of an electric system. Such terminals may be manufactured like the rest of the electrical conductor by additive manufacturing i.e. monolithically formed with the ends.

[0132] In a step S1 of this particular method, considering additively manufacturing a conductor in its longitudinal direction from the first end towards the second end, the first end segment and middle segment in the form of conductor branches of a plurality of conductor branches are monolithically formed via individual transitions that may or may not include rounded connections to shape concavely rounded interior corners between the first end segment and conductor branches of the plurality of conductor branches and to spatially separate conductor branches of said plurality of conductor branches.

[0133] The step of monolithically forming the first end segment and conductor branches may be implemented using various methods, for example methods such as

additive manufacturing such as 3D printing, casting, and simply removing of material, via machining, from a bulk metal slab to form conductor branches combined with a first end segment.

[0134] More specific, a known massive conductor such as a main busbar with a length of e.g. 3-5m may conduct 1-2A per mm². If the same busbar was made in an airy design and e.g. with an internal cooling, then due to the improved cooling the same 1-2A per mm² may be conducted with the same efficiency despite the removal of material. Typical conductor materials such as aluminium and copper have temperature coefficients at approximately 0.4%/deg C. If such conductor is efficiently cooled so that the temperature is e.g. 25 deg C lower compared to a conventional conductor, the resistance is reduced by approximately 10%. Hence approximately 10% of the material can be removed without compromising the losses. Furthermore, in AC conductors the current is not evenly distributed across the conductor volume. Typically, the current density is reduced towards the center of the conductor. Taking such considerations into account can allow for further removal of material without compromising the efficiency of the conductor.

[0135] In a step S2 of the method, the first end segment becomes electrically coupled and mechanically coupled to a second end segment via the middle segment of the electrical conductor formed by the plurality of conductor branches. This may also be monolithically achieved, e.g. by continuing the additive manufacturing, as described in step S1.

[0136] The coupling of the end segments to the middle segment could also be done by welding, gluing, male/female locking mechanism or any other way that would connect the segments both mechanically and electrically.

[0137] An optional, additional step of the method of manufacturing the conductor of the invention comprises a step prior to the step of additive manufacturing any of the first, second or middle segments. The step prior to manufacturing the electrical conductor is a step where a digital representation of the electrical conductor is designed in a software program, e.g. a 3D CAD software. The step of designing the digital

representation of electrical conductor in a software program includes taking the electrical, mechanical, structural, geometry and other aspects of the physical electrical conductor into account. Thus, based on these inputs, e.g. provided by a user of the 3D CAD software, a digital representation of the conductor is provided by the 3D CAD software. When the digital representation of the electrical conductor is complete the additive manufacturing process can be started.

[0138] The middle segment may in principle have any design / geometry, for example providing flexibility thereto allowing the electrical conductor to deform. It may be formed by conductor branches being solid or having internal cavities to reduce the amount of material that is needed to manufacture the electrical conductor. It may be formed by a web or as a hybrid between conductor branches or web just to mention a few possible designs.

[0139] Internal cavities may be used as cooling channels and / or additional surface for conducting high frequency current. Accordingly, the end segments and middle segments may be designed for the particular panel / electric system in which it is used, for a particular type of current to conduct, for having a desired or dual functionality, etc.

[0140] One such functionality, beside the above-mentioned may be as a structural support. Hence, if needed the electrical conductor may be designed to assist in carrying the weight of electric components connected thereto. Hence, its dimensions may be larger than what is needed by it for carrying the required current. Similarly, its geometry may be designed for the combined purpose of mechanical support and electric conductance. This is especially true if such support is flexible / deformable in that it may both assist in supporting and at the same time assist in absorbing vibrations.

[0141] It should be mentioned that the electrical conductor 1 may be manufactured in two or more resolutions. In case of additive manufacturing resolution may be defined by thickness of the layers of which the electrical conductor is built (another word for machined and processed). A first resolution that is finer i.e. having thinner layer size than a second resolution may be used when manufacturing the interface

between the electrical conductor and the part to which it is connected. Such interface may be the part of the terminal that is in contact with the other part. Alternatively, resolution may be determined by material deposition rate, material flow rate, etc. depending on the type of additive manufacturing used.

- 5 [0142] To avoid electric losses in connections between two electrical conductors it is preferred that the two parts have mating surfaces, which is most simply achieved by having planar surfaces, but may also be achieved by convex and concave combinations, mortise or finger joints, engaging teeth, cylinder and peg, tongue and groove, slide lock, etc., to further achieve additional advantages, e.g. larger surface
- 10 area of connection, easier assembly of electrical conductors such as busbars in electrical systems by self-locking, etc., as long as good electrical connection is prioritized. The finer these interfaces are manufactured the better / the less post manufacturing processing is needed to ensure sufficiently mating surfaces, such as planar surfaces.
- 15 [0143] The second resolution manufactured e.g. with thicker layers would be more rough leading to more surface area. At least for middle and high frequency currents this may lead to conductance of more current without increasing the need for material / dimensions of the conductor. In fact, the middle segment may be manufactured intentionally with a corrugated surface to increase the current-carrying outer surface
- 20 of the electrical conductor (current-carrying with medium and high frequencies) because of more efficient cooling due to the turbulence of, e.g., cooling air flow created due to the corrugated surface. It should be noted, that if the conductor includes an interior space, the inner surface of the conductors creating such interior space may also be corrugated for the same purpose. A corrugated surface has the effect, apart from
- 25 offering a larger surface area, that it introduces turbulence in the flow of cooling fluid such as air. Increased speed of cooling fluid may lead to higher cooling effect.

- [0144] As an example, the depth into the conductor which is used for conducting current at medium and high frequencies may in a specific embodiment be approximate 1.5mm. In this specific example, the conductor is made of copper with a resistivity of
- 30 approximate $1.68\mu\Omega$ cm, a relative permeability of approximate 1 at a frequency of

2kHz. Thus, a conductor for this particular embodiment may be hollow having conductor thickness of 2 times 1.5mm. In practice such conductor may be manufactured with a thickness of 4-5mm leaving room for a cooling in the interior or simple reduction of conductor material and thereby weight.

- 5 [0145] Knowing that skin effect also appears at e.g. 50Hz, a reference to a medium frequency with respect to skin effect is a reference to frequency starting around 500Hz where the design of the conductor may account for the skin effect. The medium frequency range may be between 500Hz and 10kHz, above 10kHz may be referred to as high frequency where skin effect is a fact (the higher frequency, the closer to the
10 surface the current will be conducted).

[0146] Further, it should be mentioned that the outer surface may also be corrugated or designed with fins for increasing heat dissipation from the electrical conductor.

- [0147] The electrical conductor resulting from the method may be used as an electrical conductor of an electrical installation. The electrical installation may be an
15 electric panel which may be part of a renewable energy facility such as a wind turbine, solar system, grid, substation, etc. The electrical installation or system in which the electrical conductor is used may be an electric vehicle, battery system, power to x facility, ship or other minor or larger electric systems. Further, an electrical conductor resulting from the method can be used inside an electric panel, i.e. in a
20 cabinet/enclosure, or outside such panel, it can be used to connect separated panels, etc.

- [0148] A variant of an electrical conductor according to the present invention is connected to a traditional cable or busbar. In such embodiment, a traditional busbar e.g. in the back of an electric panel or a traditional cable e.g. between two electric
25 panels may be connected to an electrical conductor of the invention. In this way a traditional cable or busbar may be connected to a component via a conductor according to the invention. Thereby, an easy connection is facilitated due to the flexibility of the electrical conductor of the invention.

[0149] However, note that manufacturing the electrical conductor, and thus accomplishing the electrical and mechanical coupling between the first end segment and the second end segment, is typically performed prior to installing the electrical conductor in the electrical installation, and prior to installing the electrical installation in the renewable energy facility. Thus, according to typical embodiments of the invention, the electrical and mechanical coupling is performed prior to installation/integration of the electrical conductor. Nevertheless, methods according to the invention are not necessarily restricted to a particular sequence of steps. Further, various methods according to the invention may comprise additional steps, such as performing digital geometry optimization, additively manufacturing the electrical conductor, and conducting current.

[0150] Summing up, a designer is designing a digital representation of the conductor according to electrical, mechanical, structural, etc. requirements in e.g. a 3D CAD software such as Solidworks. Files (digital representation) from such 3D developing tool is exported to e.g. a 3D printer, where the conductor is printed according to the CAD files.

[0151] As mentioned above, Fig. 1a -1c illustrate various embodiments of an electrical conductor 1 which may comprise air guides 11 according to the present invention. Fig. 3a illustrates in more details view of such conductor 1 having a first end 2, a second end 3 spaced apart by a middle segment 4. Independent if the surface of the middle segment 4 and ends 2, 3 is airy or flat an air guide 11 e.g. as illustrated may be provided. The illustrated air guide 11 is a protrusion and thus may be referred to with reference number 11a.

[0152] The conductor 1 illustrated in fig. 3a is illustrated without any details such as terminals 7, 8, terminal holes 10, etc. as described in relation to fig. 1a-2, only the air guide 11a and a guide fastener 18 is illustrated.

[0153] The air guide 11 is guiding a flow of air or other types of cooling fluid in gaseous form along the conductor and away from the conductor (this is indicated by the arrow).

[0154] The air guide 11 illustrated in fig. 5 is a recess and thus may be referred to with reference number 11b. Note that the conductor of fig. 5 also illustrate a small protrusion 11a which is implemented to guide the flow of air in a desired direction. Such protrusion 11a may however not be necessary in combination with a recess 11b.

- 5 [0155] The two examples of air guides are illustrated as guiding an airflow along the conductor 1 away from the conductor 1 in an angle away from the conductor 1 but still in the plane defined by location and geometry of the air guide 11. With this said, the air guides may twist so that the flow of air is changing direction such as turning away from the conductor. This is illustrated in fig. 3b which illustrates a conductor in a top
10 view.

[0156] In fig. 3b it is clear that the air guide is twisted and that the flow of air indicated by the arrow is moving away from the conductor in more than one of the x, y or z directions. In fig. 3b the air flow indicated by the arrow is changing along all of the x, and z directions.

- 15 [0157] Further, it should be mentioned, that an air guide 11 may also force air into the conductor particularly into a cooling channel or into air gaps 6 between two or more conductor branches 5. In this way, the structure of the conductor may be cooled by such flow of air.

- 20 [0158] An air guide 11 that is guiding a flow of air into the interior of the conductor may be formed as a funnel including a recess 11b in the surface of the conductor and a protrusion 11a over the recess 11b.

- [0159] The illustrated air guides 11 are what could be referred to as transversal air guide in that they are positioned on the conductor in the transversal direction. It should however be noted that that air guides may also be positioned in the longitudinal
25 direction of the conductor. In this way, a conductor with an air guide according to the present invention is able to create air flow corridors and thereby sectionized the cabinet in terms of airflow.

[0160] Further, it should be noted that that the structure of an air guide may be fragile e.g. to reduce material. Thus, to compensate for this, support stands may be provided along the air guide to assist in maintaining a certain structure of the air guide. Such support structure may be manufactured and fastened to the conductor as the air guide
5 11.

[0161] Alternatively, the air guide may comprise support fastening points in the form of an enforcement, an eye or similar where an external support stand or wire may be connected.

[0162] It should be mentioned that air guides may also be manufactured as part of an
10 end or removably fastened to an end. In this way, if a component connected to the conductor is generating heat, such as a reactor or power modules, a focused flow of air may be directed to this component or terminals of this component.

[0163] The guide fastener 18 may by a recess or protrusion used to attach an external or additional air guide. Such guide fastener 18 is advantageous in that not only does
15 they facilitate an easy way of attaching an air guide to the conductor 1, but they also ensure that the location of the removably attached air guide is positioned exactly where it is intended. Such location is typically found from experience or simulation of layout of an electrical cabinet in which the conductor is installed.

[0164] The removable air guide may comprise a protruding part or recess part which
20 is configure for engaging with the guide fastener 18. The structure of the air guide may be so that it forces the recess / protrusion together or it may comprise a spring that ensures fastening of the air guide to the conductor. In order to remove the air guide a force may be applied a predetermined location of the air guide 11 to release the recess / protrusion from the guide fastener 18.

[0165] If the guide fastener is a protruding part, the removable air guide may
25 comprise a corresponding recess and if the guide fastener 18 is a recess, the removable air guide may comprise a protruding part. Hence, the removable air guide may be connected by engaging the recess / protrusion of the air guide with the corresponding guide fastener 18 on one side of the conductor. Then push the removable air guide to

the recess / protrusion of the conductor and the air guide engages with the guide fastener 18 on the other side of the conductor.

[0166] On fig. 4 air guide fasteners 18 of both the protrusion type 11a and the recess type 11b are illustrated. Other types than the illustrated may naturally also be used.

- 5 Also some that are surrounding the conductor i.e. e.g. a protrusion or recess may circumference the conductor 1.

[0167] The guide fasteners 18 may also simply be a threaded part into or projecting out from the surface of the conductors. Such and other types of guide fasteners 18 may be used for auxiliary functions such as fastening cables or trays, etc. to the conductor

- 10 1.

[0168] The guide fasteners 18 may be used for support of other components than the air guides and heat sinks. In fact, a guide fastener may be a protrusion, recess, threaded part inwards or outwards from the surface of the conductor, holes fitting the head of a bolt, etc. They may be made as auxiliary elements of the conductor for future use.

- 15 [0169] Fig. 6 illustrates an electrical conductor 1 that is branching off in a first and second conductor branch 1a, 1b. The conductor 1 comprises an air guide 11 that is separating an air flow into two separate air flows. The air guide 11 is designed to guide the majority of the air flow along the two conductor branches.

- 20 [0170] It should be noted that even though not illustrated, the air guide 11 may guide an air flow in more than two directions. Hence, in addition to the triangular air guide illustrated in fig. 6, also the upper part (illustrated as parallel to the surface of the conductor) may guide airflow. As example only, such upper part may block air flow, guide it downwards, upwards, etc. in dependency on the design of the air guide 11.

[0171] Fig. 7 illustrates an electrical cabinet 13 comprising an electrical system 19.

- 25 The electrical system may be a high-voltage or high-power electrical system 19 comprising a plurality of conductors 1 and components 12. The cabinet 13 is equipped with a fan 14 at an air inlet 16 and an air outlet 17. Thus, an airflow is established between the inlet 16 and outlet 17, in the direction D1. The direction D1 is determined

by the rotation of the fan 14 i.e. if it is sucking or blowing. As an example, the air flow in an electric cabinet may be in the range of 1m/s. Further as an example, the temperature in an electric cabinet may not increase above a threshold of e.g. 55°C.

5 [0172] As illustrated, several of the conductors 1 are equipped with air guides 11 and thereby, the flow of air is not following the straight path D1 from inlet 16 to outlet 17. Instead, the air guides 11 are guiding the flow of air in flow paths 15a-15n i.e. in directions D2-Dn which are different from the direction D1. This is illustrated by the arrows.

10 [0173] It should be mentioned that if a particular part of a component 12 or a conductor 1 is considered a hotspot i.e., has a higher temperature than other parts, then air guides 11 may be positioned strategically to ensure as much air flow passing such hot spot as possible.

15 [0174] The components 12 may be supplied with power from the conductors 1. It should be noted that some conductors may comprise internal cooling channels and / or have a geometry or design making the conductor work as a heat sink if / when connected to a component 12. Through such geometry, air guides may assist in or provide a flow of air and thereby facilitate cooling of the conductor. Despite the fact that the internal channel is referred to as a cooling channel, it should be mentioned that it may also be used for heating up the conductor if needed.

20 [0175] From the above it is now clear that the invention relates to an electrical conductor comprising an air guide. The air guide is either monolithically formed with one of the ends and / or the middle segment or releasable mounted to the conductor e.g. via guide fasteners.

25 [0176] The air guides are an integrated part that is monolithically formed with the conductor such as provided in one via an additive manufacturing process. It should be mentioned that the air guide may be of a different type of material than the conductor. In such case it may be more correct to refer to a polyolithic formed air guide and conductor.

[0177] Further, the invention relates to a method of cooling a component or conductor or part of a cabinet by guiding a flow of air towards such location. Such method may be implanted in a high-voltage electrical system where a flow of air is predetermined and controlled accordingly by providing air guides on conductors of
5 such cabinet.

[0178] The invention has been exemplified above with the purpose of illustration rather than limitation with reference to specific embodiments. Details of specific embodiment have been provided in order to understand the aim of the invention. Please note, that detailed descriptions of well-known systems, devices, circuits, and methods
10 have been omitted so as to not obscure the description of the invention with unnecessary details.

List

1. Electrical conductor
2. First end
3. Second end
- 5 4. Middle segment
 - a. First end
 - b. Second end
5. Conductor branch
 - a. Longitudinal conductor branch
 - 10 b. Transversal conductor branch
6. Air gap
 - a. Longitudinal airgap (in X direction)
 - b. Transversal airgap (in Y direction)
 - c. Vertical airgap (in Z direction)
- 15 7. First terminal
8. Second terminal
9. Intersection point
10. Terminal hole
11. Air guide
- 20 a. Protrusion
- b. Recess
- c. First additional air guide
- d. Second additional air guide
12. Component
- 25 13. Electrical cabinet
14. Fan
15. Flow of cooling fluid
 - a. First flow part
 - b. Second flow part
- 30 16. Air inlet
17. Air outlet
18. Guide fastener

D1 direction between air inlet and air outlet

D2-Dn directions different from the direction D1

Patentkrav

1. Elektrisk leder (1), der omfatter mindst én første terminal (7) og mindst én anden terminal (8), som er anbragt med indbyrdes afstand ved hjælp af et midtersegment (4), hvilken elektriske leder er konfigureret til at understøtte konduktans for en elektrisk
5 strøm mellem den mindst ene første terminal (7) og den mindst ene anden terminal (8),

kendetegnet ved, at midtersegmentet (4) eller den første endeterminal (7) eller den anden endeterminal (8) omfatter mindst én luftledeskærm (11), hvor den mindst ene luftledeskærm (11):

- er en integreret del af den elektriske leder (1) i form af et fremspring og
10 er konfigureret til at styre en luftstrøm i en ønsket retning,
hvor den ønskede retning styrer luftstrømmen til at passere et varmt punkt i en komponent (12) eller i lederen (1),
hvor det varme punkt er defineret som et punkt i komponenten (12) eller i lederen (1), der har en højere temperatur end andre dele af komponenten (12) eller af lederen
15 (1).

2. Elektrisk leder (1) ifølge krav 1, hvor en flerhed af individuelle luftledeskærme (11) udspringer fra midtersegmentets (4) overflade i forskellige retninger.
3. Elektrisk leder (1) ifølge et hvilket som helst af de foregående krav, hvor midtersegmentets (4) overflade er forsænket.
- 20 4. Elektrisk leder (1) ifølge et hvilket som helst af de foregående krav, hvor den mindst ene luftledeskærm (11) forgrener sig i mindst to yderligere luftledeskærme (11c, 11d).
5. Elektrisk leder (1) ifølge et hvilket som helst af de foregående krav, hvor den mindst ene luftledeskærm (11) er dannet med elektrisk ledende materiale af
25 midtersegmentet (4).

6. Elektrisk leder (1) ifølge et hvilket som helst af de foregående krav, hvor den mindst ene luftledeskærm (11) er dannet som en konkav geometri (11a) og som en udragende geometri (11b) i midtersegmentets (4) overflade eller i den ene af den første ende (2) og den anden ende (3).
- 5 7. Fremgangsmåde til afkøling af en komponent (12), hvilken fremgangsmåde omfatter følgende trin:
- tilvejebringelse af en strøm af et kølefluid (15),
 - styring af en del (15a) af strømmen af kølefluidet (15) i en ønsket retning hen til et varmt punkt i komponenten (12),
- 10 **kendetegnet ved, at** delen (15a) af strømmen af kølefluidet (15) styres hen til det varme punkt i komponenten (12) ved hjælp af mindst én luftledeskærm (11), hvor den mindst ene luftledeskærm (11):
- er en integreret del af en elektrisk leder (1) i form af et fremspring, og
- hvor det overophedede punkt er defineret som et punkt i komponenten (12), der
- 15 har en højere temperatur end andre dele af komponenten (12).
8. Fremgangsmåde ifølge et hvilket som helst krav 7, hvor fremgangsmåden yderligere omfatter det trin, at strømmen af kølefluidet (15) ledes rundt inde i et elektrisk kabinet (13) ved hjælp af den mindst ene luftledeskærm (11), hvor den mindst ene luftledeskærm (11) er integreret i midterafsnittets (4) overflade.
- 20 9. Fremgangsmåde ifølge krav 8, hvor det elektriske kabinet (13) omfatter en ventilator (14), hvor ventilatoren (14) etablerer strømmen af kølefluidet (15) i en retning (D1) fra et luftindtag (16) til et luftudtag (17), og
- hvor luftledeskærmen (11) er positioneret i strømmen af kølefluidet (15) med henblik på at styre delen (15a) af strømmen af kølefluidet (15) i en retning (D2), der
- 25 er ikke-parallel med retningen (D1).
10. Elektrisk højeffektssystem (19), der omfatter:

- et elektrisk kabinet (13), der omfatter et luftindtag (16) og et luftudtag (17),
- en flerhed af elektriske ledere (1), der er omfattet i det elektriske kabinet (13),
- mindst én komponent (12), der er omfattet i det elektriske kabinet (13), og
- 5 - en ventilator (14), der er konfigureret til at etablere en luftstrøm mellem et luftindtag (16) og et luftudtag (17),

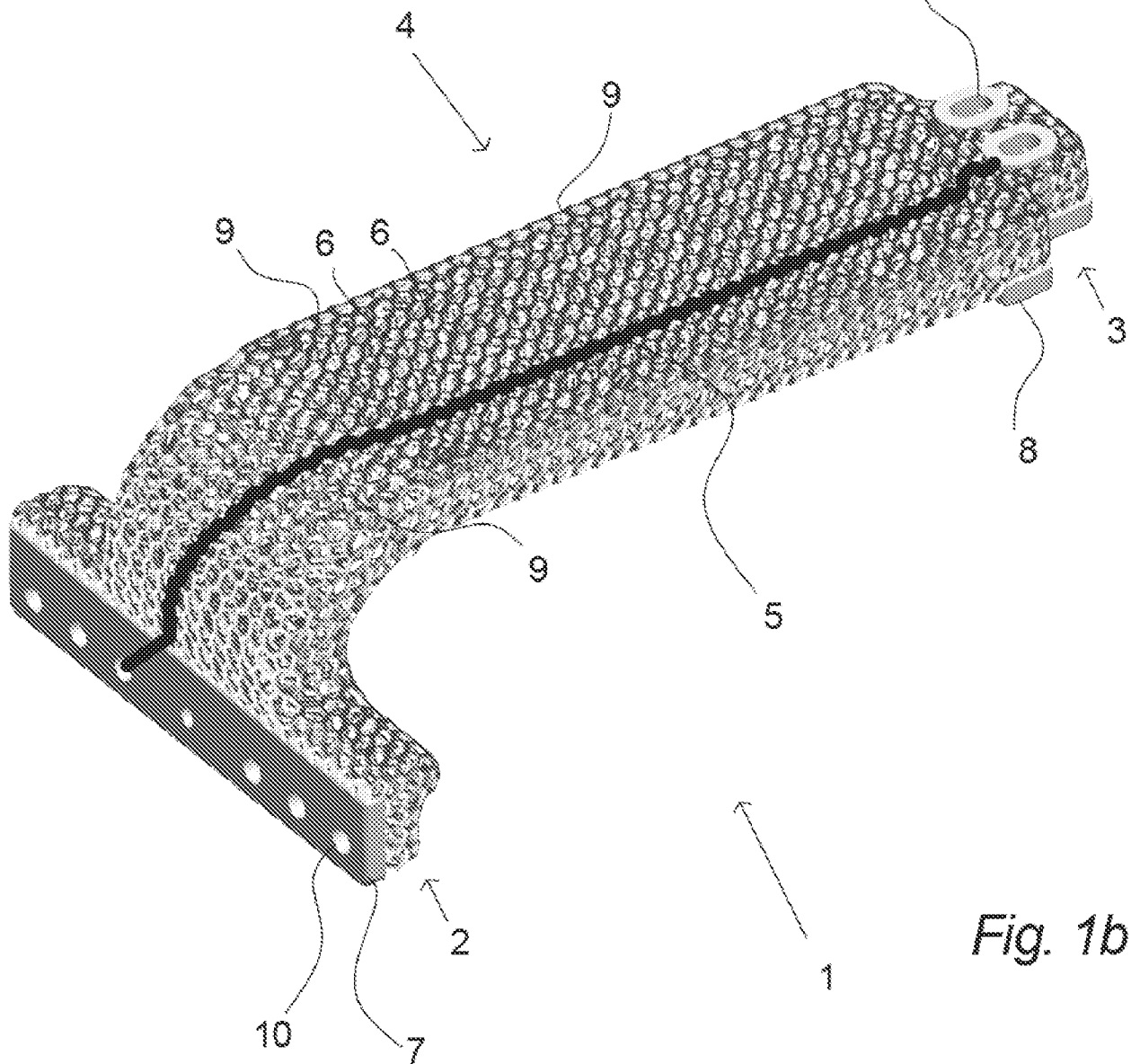
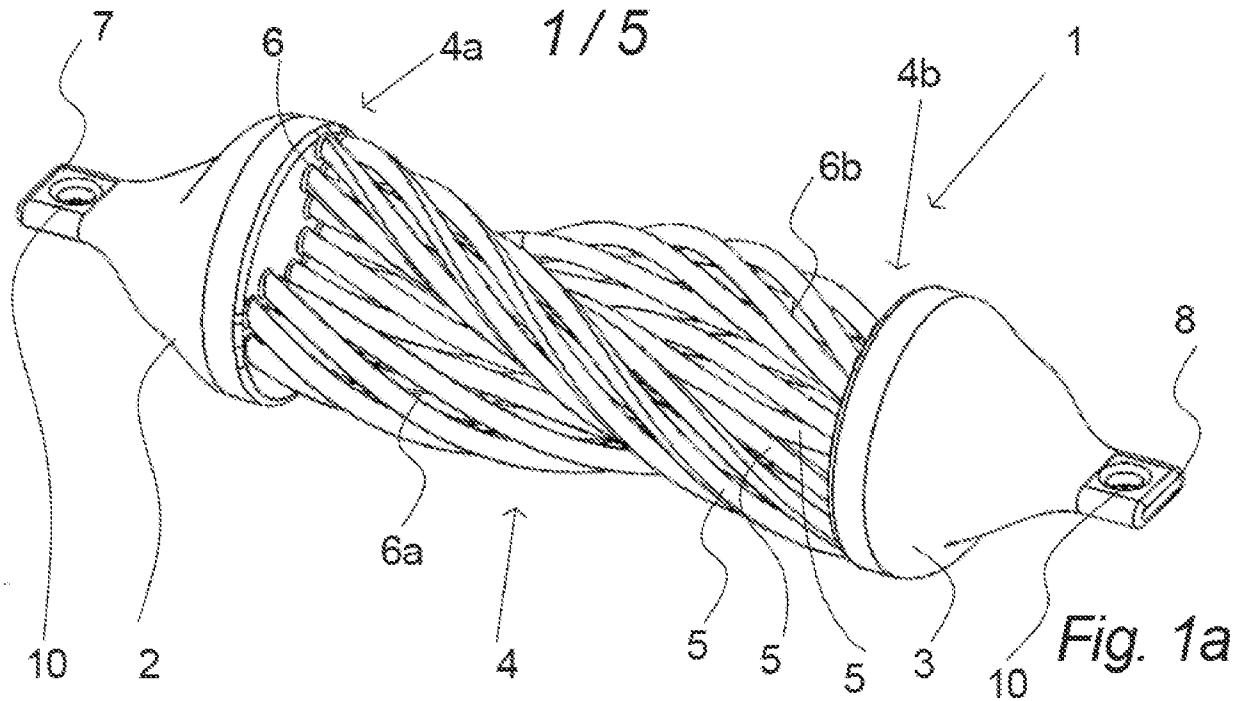
kendetegnet ved, at mindst en del af flerheden af elektriske ledere (1) omfatter mindst én integreret luftledeskærm (11), hvor luftledeskærmene (11) er konfigureret til at ændre luftstrømmens retning inde i det elektriske kabinet,

- 10 hvor den mindst ene luftledeskærm (11) er en integreret del i form af et fremspring af mindst én af flerheden af elektriske ledere (1), og

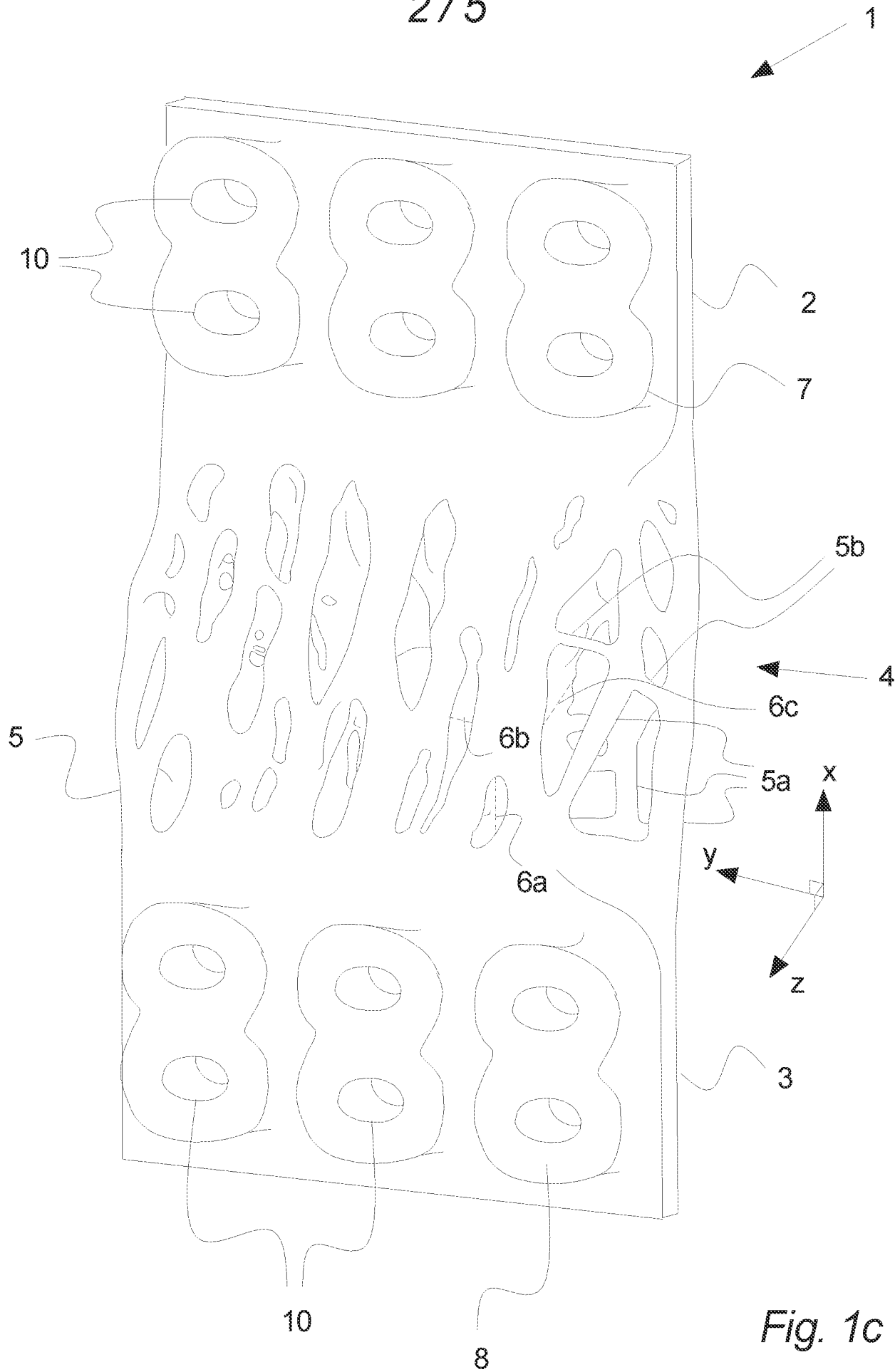
hvor retningen er en ønsket retning, der styrer luftstrømmen til at passere et varmt punkt i den mindst ene komponent (12) eller i flerheden af ledere (1),

- 15 hvor det varme punkt er defineret som et punkt i komponenten (12) eller i lederen (1), der har en højere temperatur end andre dele af den mindst ene komponent (12) eller af flerheden af ledere (1).

11. Anvendelse af en elektrisk leder (1), der omfatter en luftledeskærm (11) ifølge et hvilket som helst af de foregående krav 1-6 til temperaturregulering af det elektriske højeffektsystem ifølge krav 10.



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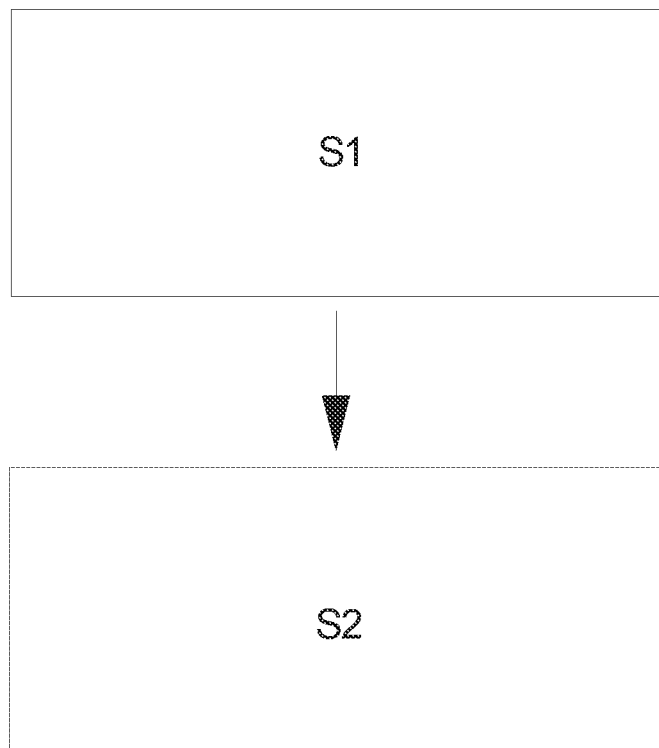


Fig. 2

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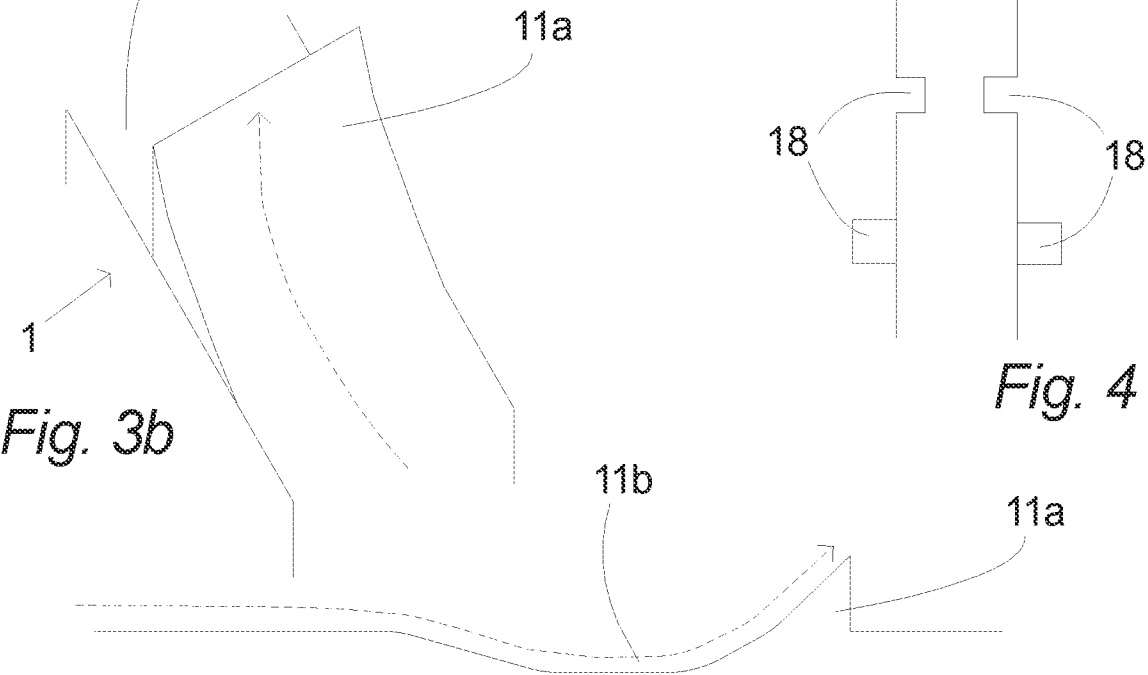
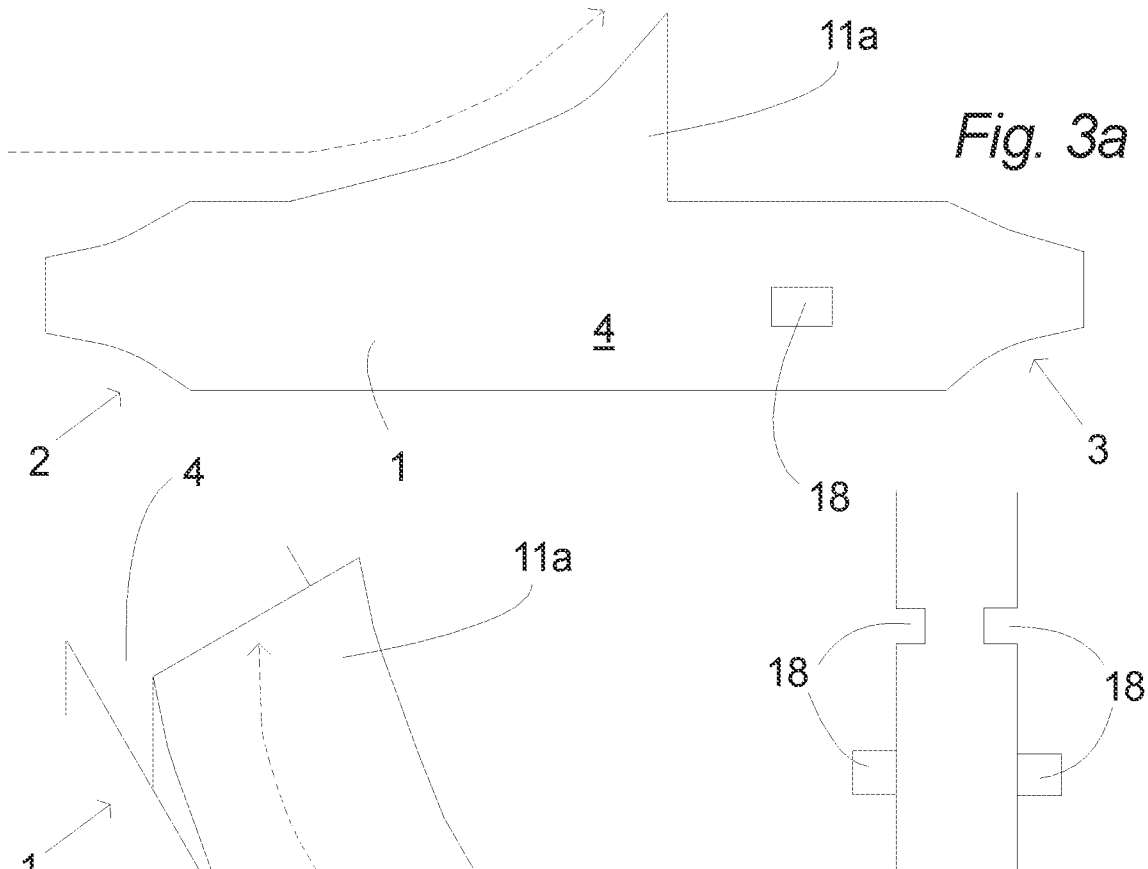
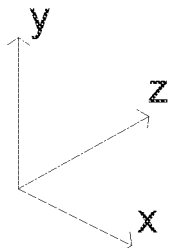
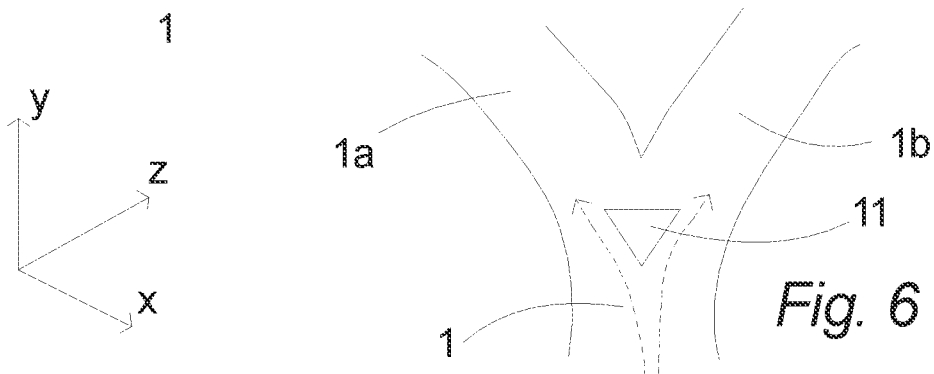
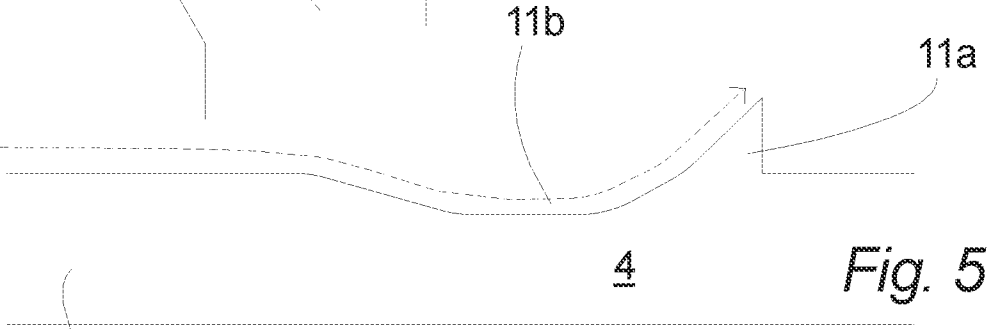
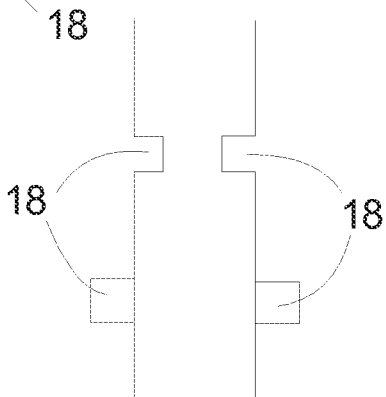
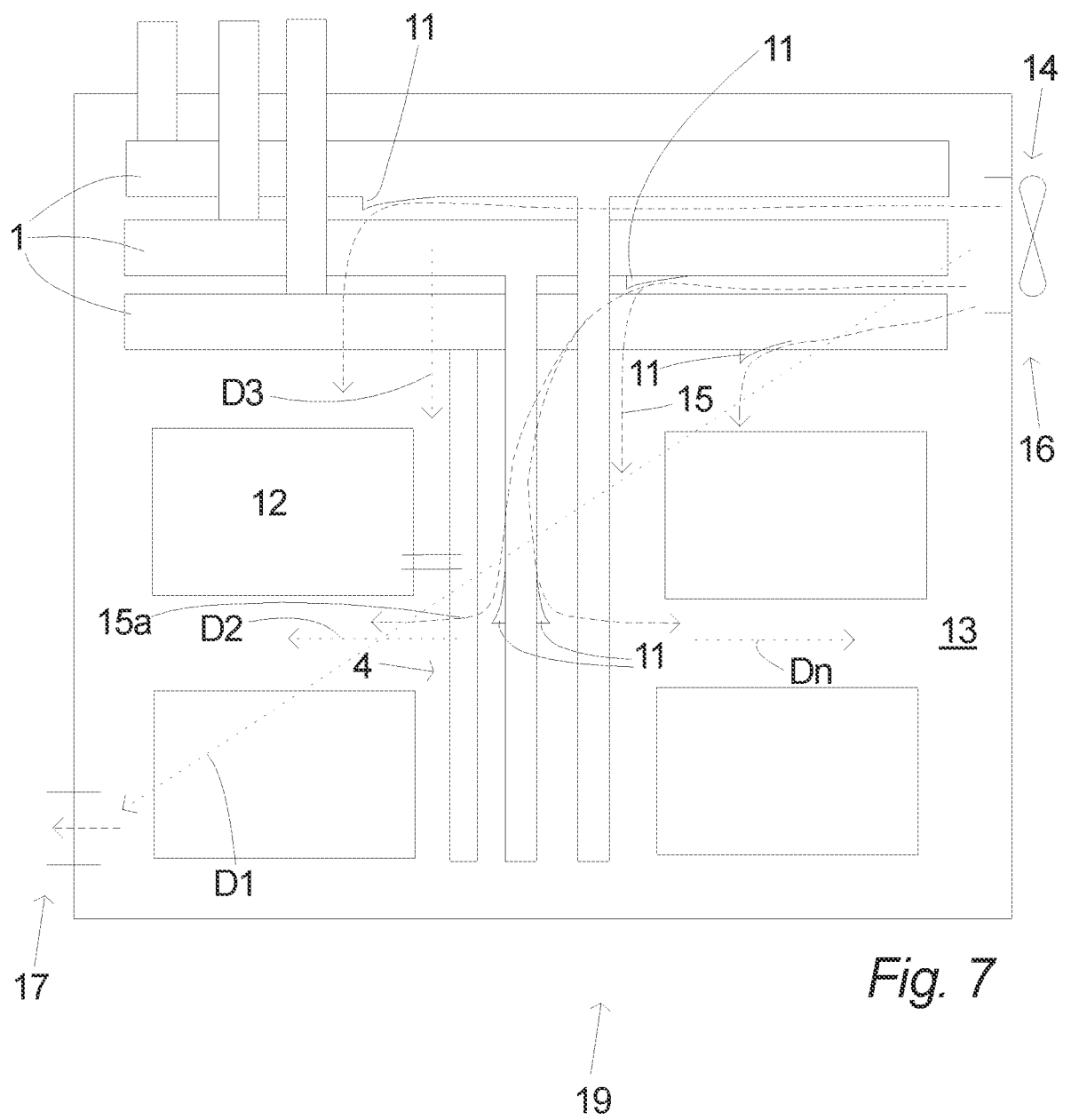


Fig. 4







Search report - patent

Application No.

PA 2023 70260

1. ☐ Certain claims were found unsearchable (See Box No. I).
2. ☐ Lack of unity of invention was found prior to search (See Box No. II).

A. Classification

H01R 9/11 (2006.01), H01B 7/42 (2006.01), H05K 7/20 (2006.01)

According to International Patent Classification (IPC)

B. Fields searched

PCT-minimum documentation searched (classification system followed by classification symbols)

IPC & CPC: H01B, H05K, F21V, H01R, B60L

Documentation searched other than PCT-minimum documentation

None

Electronic database consulted during the search (name of database and, where practicable, search terms used)

EPODOC, WPI, Full Text English

C. Documents considered to be relevant

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant for claim No.
X	<u>US 2021/0241965 A1</u> (WENNERSTROM HANS et al.) 2021.08.05 See in particular [0097], [0146], [0152], [0157], [0219]-[0222], [0259], [0297]-[0298], [0324]-[0332], [0355]-[0356], [0368], [0376], [0382]-[0383], [0392]-[0397] and [0400] and figures 47C - 47E.	1-14
X	<u>CN 107732611 A</u> (SUZHOU JIAMING MACHINERY MFG CO LTD) 2018.02.23 See entire document.	1-14
X	<u>CN 209625887 U</u> (SHENZHEN BUSBAR SCI TECH DEV CO LTD) 2019.11.12 See the entire document.	1-14
A	<u>US 2022/0029329 A1</u> (KEMPF URS et al.) 2022.01.27 See in particular [0105]-[0111] and figures 5-7.	1-14

☐ Further documents are listed in the continuation of Box C

* Special categories of cited documents:

"A" Document defining the general state of the art which is not considered to be of particular relevance.

"D" Document cited in the application.

"E" Earlier application or patent but published on or after the filing date.

"L" Document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified).

"O" Document referring to an oral disclosure, use, exhibition, or other means.

"P" Document published prior to the filing date but later than the priority date claimed.

"T" Document not in conflict with the application but cited to understand the principle or theory underlying the invention.

"X" Document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an essential difference when the document is taken alone.

"Y" Document of particular relevance; the claimed invention cannot be considered to involve an essential difference when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" Document member of the same patent family.

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Date of completion of the search report

08/12/2023

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Search report - patent

Application No.
PA 2023 70260

C. Documents considered to be relevant (continuation)		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant for claim No.



Search report - patent

Application No.

PA 2023 70260

Box No. I Certain claims were found unsearchable

This search report has not been established in respect of certain claims for the following reasons:

1. ☐ Claims Nos.:

because they relate to subject matter not required to be searched. Specifically:

2. ☐ Claims Nos.:

because they relate to parts of the patent application that do not comply with the prescribed requirements to such an extent that no meaningful search can be carried out. Specifically:

3. ☐ Claims Nos.:

because of other matters. Specifically:

Box No. II Lack of unity of invention was found prior to search

Prior to search, multiple independent inventions were found in the patent application. Specifically:



Search report - patent

Application No.

PA 2023 70260

Supplemental Box

Continuation of Box [.]