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(71) Applicant: **VESTAS WIND SYSTEMS A/S** [DK/DK]; Hedeager 42, 8200 Aarhus N (DK).

(72) Inventor: **MONGEAU, Peter**; 37 Kenwood Circle, Center Conway, New Hampshire 03813 (US).

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(54) **Title:** METHOD AND APPARATUS FOR DETERMINING AN AIR GAP DIMENSION FOR AN ELECTRICAL GENERATOR IN A WIND TURBINE

FIG. 5a

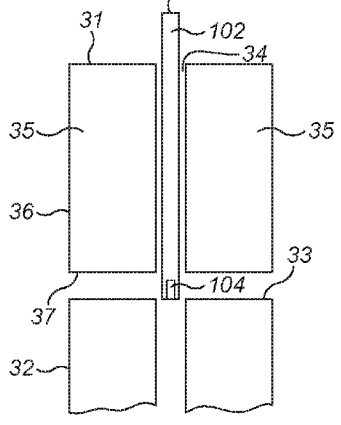


FIG. 5b

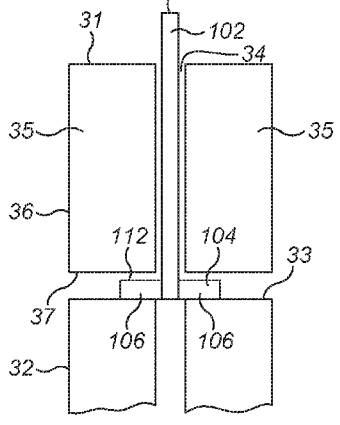
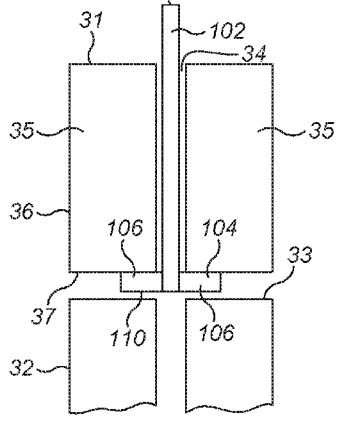


FIG. 5c



(57) **Abstract:** A method of determining a dimension of an air gap in an electrical power generator for a wind turbine. The generator comprises a stator with a rotor mounted within the stator such that an air gap is defined between a radially outward rotor surface and a radially inward stator surface. The stator has a stator aperture that penetrates the stator radially from a radially outward stator surface to the radially inward stator surface. The air gap is measured by inserting an air gap measurement tool through the stator aperture so that a measurement head of the measurement tool protrudes into the air gap. The measurement tool is used to determine the radial dimension of the air gap at the respective stator aperture position. An apparatus for determining an air gap in an electrical generator, and a wind turbine comprising the apparatus is also disclosed.

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METHOD AND APPARATUS FOR DETERMINING AN AIR GAP DIMENSION FOR AN ELECTRICAL GENERATOR IN A WIND TURBINE

TECHNICAL FIELD

The invention relates to a power generator for a wind turbine. The generator is of the internal rotor type, in which the generator comprises a rotor that spins inside a stator. The generator is equipped with a tool that assists with more effective radial positioning of the rotor with respect to the stator.

BACKGROUND

As is well-known, wind turbines convert kinetic energy from the wind into electrical energy. A typical Horizontal Axis Wind Turbine (HAWT) comprises a tower, a nacelle on top of the tower, a rotating hub mounted to the nacelle and a plurality of blades coupled to the hub. The nacelle houses many functional components of the wind turbine, including for example a generator, gearbox, drive train and rotor brake assembly, as well as convertor equipment for converting the mechanical energy at the hub into electrical energy for provision to the grid. The gearbox steps up the rotational speed of the low speed main shaft and drives a gearbox output shaft. The gearbox output shaft in turn drives the generator, which converts the rotation of the gearbox output shaft into electricity. The electricity generated by the generator may then be converted as required before being supplied to an appropriate consumer, for example an electrical grid distribution system.

In a typical power generator for a wind turbine, a rotor includes a plurality of ring-shaped rotor laminations or magnet packages that are coaxially arranged into a cylindrical structure. The rotor rotates within a stator around a rotational axis. The magnetic flux generated by the rotor interacts with the windings of the stator to induce electrical current. In order to maximise efficiency, the air gap between the radially outer surface of the rotor and the radially inner surface of the stator should be as small as possible to minimise reluctance and flux leakage. However, the air gap must be set to allow sufficient clearance between the rotor and the stator so that these components do not come into contact whilst the rotor rotates.

To ensure optimised and symmetric electrical power generation, it is critical to ensure that the rotor is well centred within the stator and that the air gap between the rotor and stator is symmetrical. In existing generators it is typical to rely on manufacturing and assembly tolerances to achieve this. This is a particular challenge for generators which have the rotor mounted on, and supported only by, the gearbox output shaft as the relative position of the rotor with respect to the stator is reliant on the position the gearbox output shaft and its bearings.

It is against this background that the invention has been devised.

SUMMARY OF THE INVENTION

According to a first aspect of the invention, there is provided a method of determining a dimension of an air gap in an electrical power generator for a wind turbine, the generator comprising: a stator comprising a stator core, wherein the stator defines a cylindrical interior volume of the stator, a rotor comprising a rotor core mounted within the cylindrical interior volume of the stator, wherein the air gap is defined between a radially outward surface of the rotor core and a radially inward surface of the stator core; at least one stator aperture that penetrates the stator radially from a radially outward surface of the stator to a radially inward surface of the stator; wherein the method comprises: inserting an air gap measurement tool in a radial direction through at least one stator aperture so that a measurement head of the measurement tool protrudes into a measurement gap defined between the radially inward surface of the stator and the radially outward surface of the rotor at a respective stator aperture position; and using the air gap measurement tool to determine the radial dimension of the measurement gap at the respective stator aperture position.

Optionally, if the measurement gap does not correspond to the air gap, the determined radial dimension of the measurement gap may be used to determine a dimension of the air gap.In cases where the measurement gap corresponds to the air gap, the air gap may be measured directly.

The method is advantageous as the air gap can be measured without the need to dismantle any part of the generator. The gap may be measured in a factory during manufacture, during installation, and when the generator is in-situ mounted within the nacelle of a wind turbine.

Optionally, using the air gap measurement tool to determine the radial dimension of the air gap comprises: moving the air gap measurement tool in a radial direction to a first position so that a first surface of the measurement head contacts the radially outward surface of the rotor; moving the air gap measurement tool in a radial direction to a second position so that a second surface of the measurement head contacts the radially inward surface of the stator; and wherein the radial distance of the air gap at the stator aperture position is determined based on the distance that the measurement tool moves between the first and second positions.

The air gap measurement tool may be held in a first orientation as it is inserted through the stator aperture, and then placed into a second orientation when it is used to determine the radial dimension of the measurement gap.

The step of using the air gap measurement tool to determine the radial dimension of the air gap may optionally performed at a plurality of stator aperture positions to determine the size of the air gap at different positions along and/or around the stator.

The step of using the air gap measurement tool to determine the radial dimension of the air gap may optionally be performed at a plurality of different angular positions of the rotor with respect to the stator in order to produce a “map” of air gap sizes at different stator positions with respect to the frame at different rotor positions with respect to the stator. In this way, the stator position can be optimised as far as possible for a uniform air gap size for all rotor positions.

In another aspect, the present invention provides apparatus for determining an air gap in an electrical generator for a wind turbine, the apparatus comprising an electrical generator and a measurement tool, wherein the electrical generator comprises: a stator including a stator core and a rotor including a rotor core, wherein the stator defines a cylindrical interior volume, within which the rotor is mounted so as to define a rotational axis; wherein the rotor core and the stator core define an annular air gap between a radially outward surface of the rotor core and a radially inward surface of the stator core; wherein the stator is configured to define one or more stator apertures which penetrate the stator radially from a radially outward stator surface to the radially inward stator surface; and wherein the measurement tool includes a measurement head that is configured to pass through a selected one of the one or more stator apertures and is shaped to be contactable with the radially outward rotor surface and a radially inward stator surface.

Optionally, the apparatus may comprise a plurality of stator apertures to allow measurement of the air gap at a number of different positions of the stator.

A first group of at least two stator apertures may be provided proximal to a first axial end of the stator, and at least two of the stator apertures in the first group may optionally provide at angularly-spaced positions about the rotational axis.

Similarly, a second group of at least two stator apertures may be provided proximal to a second axial end of the stator, and at least two of the stator apertures in the second group may be provided at angularly-spaced positions about the rotational axis.

The stator and rotor are preferably housed within a generator housing which includes one or more removable access panels which, when removed from the generator housing, provide access to the one or more stator apertures.

The measurement head of the measurement tool may optionally be asymmetric. This may be beneficial, for example, for accessing difficult to reach spaces.

The or each stator aperture may be slot-like in form, and the measurement head of the measurement tool may be sized and shaped to complement the shape of the stator aperture.

Optionally, the measurement tool may include an elongate handle, and the measurement head may include an arm that extends transversely to the handle.

The or each stator aperture may be defined by a respective axial spacing between neighbouring stator laminations.

According to another aspect of the present invention, there is provided a wind turbine comprising the apparatus substantially as described hereinabove. In particular, the wind turbine comprises a wind turbine tower, a nacelle rotatably coupled to the tower, a rotating hub mounted to the nacelle, and a plurality of wind turbine blades coupled to the hub. The nacelle comprises the electrical power generating assembly.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other aspects of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic plan view of a horizontal axis wind turbine;

Figure 2 is a schematic perspective view of functional components of a nacelle of the wind turbine;

Figure 3 is a schematic cross-sectional perspective view of a vertical plane taken through a generator of the wind turbine;

Figure 4 is a detailed view of part of Figure 3 focused on a stator mounting bay of the generator with part of the housing removed;

Figures 5a to 5c are schematic cross-sectional views taken through the stator between two field windings in a radial plane;

Figure 6 is a schematic perspective view of a frame to which a stator of the generator is mounted; and

Figure 7 is a schematic perspective view of a measurement tool in use mounted to the stator.

Note that features that are the same or similar in different drawings are denoted by like reference signs.

SPECIFIC DESCRIPTION

A specific embodiment of the present invention will now be described in which numerous features will be discussed in detail in order to provide a thorough understanding of the inventive concept as defined in the claims. However, it will be apparent to the skilled person that the invention may be put in to effect without the specific details and that in some instances, well known methods, techniques and structures have not been described in detail in order not to obscure the invention unnecessarily.

In order to place the embodiments of the invention in a suitable context, reference will firstly be made to Figure 1, which illustrates a typical Horizontal Axis Wind Turbine (HAWT) 1. Although this particular image depicts an on-shore wind turbine, it will be understood that equivalent features will also be found on off-shore wind turbines. In addition, although the wind turbines are referred to as 'horizontal axis', it will be appreciated by the skilled person that for practical purposes, the axis is usually slightly inclined to prevent contact between the blades and the wind turbine tower in the event of strong winds.

The wind turbine 1 comprises a tower 2, a nacelle 4 rotatably coupled to the top of the tower 2 by a yaw system 6, a rotating hub 8 mounted to the nacelle 4 and a plurality of wind turbine blades 10 coupled to the hub 8. The nacelle 4 and blades 10 are turned and directed into the wind direction by the yaw system 6.

The nacelle 4 houses the functional components of the wind turbine as illustrated in Figure 2, including, for example, a shaft housing 20, a gearbox 22 and a generator 24. A main shaft extends through the shaft housing 20, and is supported on bearings (not shown). The main shaft is connected to, and driven by, the hub 8 and provides input drive to the gearbox 22. The gearbox 22 steps up the rotational speed of the low speed main shaft via internal gears (not shown) and drives a gearbox output shaft. The gearbox output shaft in turn drives the generator 24, which converts the rotation of the gearbox output shaft into electricity. The electricity generated by the generator 24 may then be converted by other components (not shown) as required before being supplied to an appropriate consumer. So-called "direct drive" wind turbines that do not use gearboxes are also known. The gearbox may therefore be considered optional.

The gearbox 22 and generator 24 may be coupled together in an integrated unit in which context the present invention is described. The generator 24 and the gearbox 22 are separate sub-assemblies that themselves have been coupled together to create a single assembly that is comparatively compact.

With reference firstly to the gearbox 22, a gearbox housing 30 is generally cylindrical in form and is oriented such that its major rotational axis is horizontal, in the orientation of the drawings. The cylindrical configuration of the gearbox housing 30 is due to the specific type of gearbox that is used in the illustrated embodiment, which is an epicyclic gearbox. As the skilled person would know, an epicyclic gearbox comprises a series of planet gears that are arranged about a central sun gear, and which collectively are arranged within an encircling ring gear. The ratio of the number of teeth between the ring gear, the planet gear and the sun gears determines the gear ratio of the gearbox. For clarity, fine detail of the gearbox will not be described in further detail here as the gearbox is not the principal subject of the invention. Suffice to say that other gearbox configurations could also be used, although it is currently envisaged that an epicyclic gearbox provides an elegant solution fit for the confines of a wind turbine nacelle.

Turning now to the generator 24, the output shaft of the gearbox 22 interfaces with a rotor 32 of the generator 24. As such, the major axis of the gearbox output shaft defines the rotational axis of the generator 24 which corresponds to the central axis of the stator 36. The stator 36 therefore also defines the central axis of the generator

The generator 24 in the illustrated embodiment is an IPM (interior permanent magnet) electric machine having an external stator 36 (Figure 3) which surrounds the rotor 32. . The rotor 32 has a rotor core 92 made up of a plurality of rotor laminations 90 (described in further detail below). Similarly, the stator 36 has a stator core 27 made up of a plurality of stator laminations 35 (described in further detail below). An air gap 80 is defined between the radially outward surface 33 of the rotor core 92 and the radially inward surface 37 of the stator core 27 (Figure 4).

Referring to Figure 4, the stator core 27 is made up of a plurality of ring-shaped laminations 35 that are coaxially arranged in a cylindrical structure. The stator laminations 35 are axially spaced from one another such that slot-like apertures 34 are defined by the respective axial spacing between neighbouring stator laminations 35. Field windings 26 of

a conductive material such as copper are supported in circumferentially spaced arrangement by the laminations 35 of the stator core 27. The stator 36 defines a cylindrical interior volume of the stator.

In use, an electrical current is induced in the field windings 26 by a fluctuating magnetic field caused by the magnets of the rotor core 92 which is rotated by the hub 8 of the wind turbine 1. Although the example described herein refers to an interior permanent magnet machine, it will be appreciated that in other examples the generator may comprise a rotor 32 having an electro-magnet instead of permanent magnets.

The generator 24 comprises a frame 40 within which the stator 36 is mounted by a stator mounting system. The frame 40 has a drive end face 46 located, in use, adjacent to the gearbox 22, and a non-drive end face 45 located opposite the drive end face 46 and separated therefrom in the direction of the central generator axis. A first axial end 28 of the stator 36 is located adjacent the drive end 46 of the frame 40, and a second axial end 29 of the stator 36 is located adjacent the non-drive end 45 of the frame 40. A plurality of frame members 39, 42 (Figure 6) extend between the drive end face 46 and the non-drive end face 45 to provide structural rigidity to the frame 40 and mounting points for the various panels and systems of the generator 24.

The outer surface of the generator defines a generator housing 25 which comprises the drive end face 46 and non-drive end face 45 of the frame 40. The outer surfaces of the housing 25 between the drive end face 46 and non-drive end face 45 comprise panels 41, 48 which are removably attached to the frame 40. Environmental conditioning modules 10 may be located in one or more corners of the frame 40, the outer surfaces of which, if included, form the corner portions of the generator housing 25.

Referring to Figure 6, the panels 48 each comprise an access opening 47 which provide access to a stator mounting ‘bay’ 52. In this example, the stator mounting system of the generator 24 comprises four stator mounting bays 52 which are equally spaced around the circumference of the stator 36. It will be understood that any suitable number of stator mounting bays 52 may be used and it is not essential that four stator mounting bays 52 be provided. In use, the access openings 47 are covered by an access panel 44 which is removably attached to the frame 40 by mechanical fasteners (not shown).

In this example, each stator mounting bay 52 comprises two adjustable stator mounting modules 54a, 54b. When the stator 36 is mounted in the frame 40 by the stator mounting system, it is supported by the eight stator mounting modules 54a, 54b of the four stator mounting bays 52. Because of the accessible and flexible arrangement of the stator mounting system, it is possible to remove or adjust one or more of the stator mounting modules 54a, 54b when the generator is in situ within the nacelle 4 of the wind turbine 1. If a stator mounting module 54a, 54b needs to be replaced, repaired or adjusted, the access hatch cover 44 can be opened to provide access to the stator mounting modules 54a, 54b. The stator mounting system may be finely tuned in situ to optimise the air gap 80 between the rotor core 92 and the stator core 27. A position adjustment tool (not shown) may be provided for effecting adjustment of the stator mounts 54a, 54b, or the stator mounts 54a, 54b may be provided with an integral position adjustment device (not shown).

Figures 5a to 5c each show a schematic cross-sectional view taken through the stator core 27 between two of the field windings 26 in a radial plane. The slot-like aperture 34 is bounded on each axial side by the stator laminations 35, and on each circumferential side by the field windings 26. In order to determine the size of the air gap 80 at a particular position on the stator 36, a suitable aperture position is selected and a measurement tool 100 (described in greater detail below) is used to directly measure the air gap 80 at that position.

As shown in Figure 5a, the measurement tool 100 is inserted into the selected aperture 34 for measuring the size of the air gap 80 at that aperture position on the stator core 27. The measurement tool 100 comprises an elongate handle 102 and a measurement head 104. The measurement head 104 comprises two arms 106 which extend away from the handle 102 in opposite directions.

The measurement head 104 is sized and shaped to compliment the slot-like form of the apertures 34. As shown in Figure 5a, the measurement tool 100 is inserted into an aperture 34 with the measurement head 102 in alignment with the slot of the aperture 34.

Referring now to Figure 5b, once the measurement head 102 has reached the air gap 80 between the rotor core 92 and the stator core 27, the measurement tool 100 is rotated by 90º so that the measurement head 102 is substantially in line with the central axis of the stator 36. A first surface 110 of the measurement head 104 is placed into contact with the radially outward surface 33 of the rotor core 92, and a first measurement is taken by noting

the position of the radially outward surface 31of the stator core 27, or any other known position, relative to the handle 102 of the measurement tool 100. The handle 102 may carry measurement markings for this purpose.

As shown in Figure 5c, the measurement tool 100 is next raised so that a second surface 112 of the measurement head 104 is placed into contact with the radially inner surface 37 of the stator cure 27, and a second measurement is taken by noting the second position of the radially outward surface 31 of the stator core 27, or any other known position, relative to the handle 102. The dimensions of the measurement head 104 are known such that the size of the air gap 80 at the position of the aperture 34 on the stator core 27 can be determined. To remove the measurement tool 100 from the stator core 27, the tool is again rotated by 90º so that the measurement head 102 is once again in alignment with the slot-shaped aperture 34, so that the measurement tool 100 can be withdrawn.

It is typically desirable to measure the size of the air gap 80 at a number of positions along and around the stator 36 in order to determine whether the size of the air gap 80 is consistent along the axial length of the stator 36 and around the circumference of the stator 36. This is done by taking measurements at a number of aperture positions along the length of the rotational axis and around the circumference of the stator 36 to determine the size of the air gap 80 at the respective aperture positions.

In order to determine tilt or yaw of the stator 36 relative to the frame 40 or rotor 32, the size of the air gap 80 can be measured at two or more aperture positions towards the first end 28 of the stator 36, and two or more aperture positions towards the second end 29 of the stator 36. In one example, the size of the air gap 80 is measured at four aperture positions evenly spaced around the circumference of the stator 36.
It is possible for the size of the air gap 80 to vary with rotational position of the rotor 32 due to manufacturing or bearing irregularities/wear. It is therefore beneficial to adjust the stator mounting system, by suitable adjustment of stator mounts 54a, 54b, to optimise the stator 36 position for as many rotational positions of the rotor 32 as possible. It is impractical to measure the size of the air gap 80 for every rotational position of the rotor 32. However, it is possible to measure the air gap 80 at a number of positions along the axial length of the stator and at a number of circumferential positions, and then to repeat this process for a number of rotor 32 rotational positions. By collecting air gap 80 size data in this way, a ‘map’ of the air gap 80 size variation with stator 36 circumferential

position and rotor 32 rotational position can be ascertained. The stator mounts 54a, 54b can then be adjusted to optimise the size air gap 80 for all stator/rotor positions as far as practically possible.

In order to more readily relate the air gap measurements to the required stator mount adjustments, the measurement positions are ideally located at the top, bottom, and sides of the stator 36 relative to the frame 40. Advantageously, the stator apertures 34 can be accessed via the bays 52 by opening the access panels 44 of the housing 25.

As shown in Figure 7, the measurement tool 100 may be provided with digital gauge 215 to obtain and record the two depth measurements and to calculate the depth of the air gap 80. In this example, the handle 102 of the measurement tool 100 is supported by a clamp 203 which is itself supported on a plate 200 which is attached to the stator 36 via fasteners (not shown) which pass through holes 205 in the plate 200 and engage with holes 210 in the stator 36. The clamp 203 is supported above the plate 200 by a pin 201 which is connected to the plate 200 at pin connection hole 202. The clamp 203 has first clamp screw 204 for retention of the handle 102 of the measurement tool 100 in a fixed position relative to the stator 36, and a second clamp screw 206 for retention of the clamp 203 in a fixed position relative to the stator 36. In use, the first clamp screw 204 may be loosened in order to move the head 104 of the measurement tool 100 into the first measurement position and then re-tightened so that the digital gauge may record a reading at the first position. The first clamp screw 204 may then be loosened to allow the head 104 to be moved to the second measurement position and then re-tightened so that the digital gauge may record a reading at the second position. The movement of the head 104 of the measurement tool 100 between the two measurement positions may alternatively be achieved by the loosening and re-tightening of the second clamp screw 206 and movement of the clamp 203 along the pin 201.

In an alternative embodiment (not shown), the handle 102 may be telescopic and comprise a transducer which measures the relative displacement between the telescopic portions of the handle 102 at the two measurement positions. Alternatively, a slider (not shown) may be provided on the handle 102 which may be moved to contact the radially outer surface 31 of the stator core 27 in the first measurement position, moved away from the radially outer surface 31 of the stator core 27 as the measurement tool 100 is raised to the second measurement position, and moved to once again contact the radially outer surface 31 of the stator core 27 in order to take the second reading. As

above, the slider may be provided with a digital transducer to obtain and record the measurements, and to calculate the depth of the air gap 80.

The measurement tool 100 may optionally have an asymmetric head 104 such that only one side of the handle 102 has a measurement head 104.

The examples discussed above have all been given with respect to the air gap 80 being measured directly by accessing the air gap 80 via a slot-shaped aperture 34 in the stator core 27. It is to be understood that the tool 100 may be used at any position on the generator 24 where the air gap 80, or another geometrically related gap, may be accessed by the measuring head 104 of the tool 100 and a measurement taken. All that is required is that the measuring surfaces 110, 112 of the measurement head 104 can be brought into engagement with the surfaces to be measured. It is not necessary that the tool 100 be used to measure the air gap 80 directly. The tool 100 can be used to measure the dimension of any gap that can be correlated to the air gap 80.

As an example of the above, referring once again to Figure 4, a tool 100 may be inserted into a slot-like aperture 94 located between the field windings 26 adjacent to either axial end 28, 29 of the rotor 32. This position is beyond the axial extent of the stator core 27, but is still within the structural axial extent of the rotor 32. In this example the rotor 32 has non-magnetic structural end rings 70 between which the magnetic laminations 90 of the rotor 32 are clamped. The end rings 70 have a different radial dimension to the magnetic laminations 90. However, the radial relationship between the radially outermost surface 71 of the end rings 70 and the radially outermost surface 33 of the magnetic laminations 90 is fixed and known. In view of this, by measuring the gap 95 between the radially outermost surface 71 of the end rings 70 and the radially innermost surface 91 of the field windings 26, the gap 95 at the end ring 70 position can be measured and the associated air gap 80 calculated or extrapolated.

CLAIMS

1. A method of determining a dimension of an air gap (80) in an electrical power generator (24) for a wind turbine (1), the generator (24) comprising:

a stator (36) comprising a stator core (27), wherein the stator (36) defines a cylindrical interior volume of the stator,

a rotor (32) comprising a rotor core (92) mounted within the cylindrical interior volume of the stator (36),

wherein the air gap (80) is defined between a radially outward surface (33) of the rotor core (92) and a radially inward surface (37) of the stator core (27);

at least one stator aperture (34, 94) that penetrates the stator (36) radially from a radially outward surface (31, 93) of the stator (36) to a radially inward surface (37, 91) of the stator;

wherein the method comprises:

inserting an air gap measurement tool (100) in a radial direction through at least one stator aperture (34, 94) so that a measurement head (104) of the measurement tool (100) protrudes into a measurement gap (95) defined between the radially inward surface (37, 91) of the stator (36) and the radially outward surface (33, 71) of the rotor (32) at a respective stator aperture (34, 94) position; and

using the air gap measurement tool (100) to determine the radial dimension of the measurement gap (95) at the respective stator aperture (34, 94) position.

2. The method of Claim 1 wherein, if the measurement gap (95) does not correspond to the air gap (80), using the determined radial dimension of the measurement gap (95) to determine a dimension of the air gap (80).

3. The method of Claim 1, wherein the measurement gap (95) corresponds to the air gap (80).

4. The method of any one of Claims 1 to 3, wherein using the air gap measurement tool (100) to determine the radial dimension of the air gap (80) comprises:

moving the air gap measurement tool (100) in a radial direction to a first position so that a first surface (110) of the measurement head (104) contacts the radially outward surface (33, 71) of the rotor (32);

moving the air gap measurement tool (100) in a radial direction to a second position so that a second surface (112) of the measurement head (104) contacts the radially inward surface (37, 91) of the stator (36);

and wherein the radial distance of the measurement gap (95) at the stator aperture position (34, 94) is determined based on the distance that the measurement tool (100) moves between the first and second positions.

5. The method of any preceding Claim, wherein the air gap measurement tool (100) is held in a first orientation as it is inserted through the stator aperture (34, 94), and is then placed into a second orientation when it is used to determine the radial dimension of the measurement gap (95).

6. The method of any preceding Claim, wherein the step of using the air gap measurement tool (100) to determine the radial dimension of the air gap (80) is performed at a plurality of stator aperture positions (34, 94).

7. The method of any preceding Claim, wherein the step of using the air gap measurement tool (100) to determine the radial dimension of the air gap (80) is performed at a plurality of different angular positions of the rotor (32) with respect to the stator (36).

8. Apparatus for determining an air gap in an electrical generator (24) for a wind turbine (1), the apparatus comprising an electrical generator (24) and a measurement tool (100), wherein the electrical generator (24) comprises:

a stator (36) including a stator core (27) and a rotor (32) including a rotor core (32), wherein the stator (36) defines a cylindrical interior volume, within which the rotor (32) is mounted so as to define a rotational axis;

wherein the rotor core (92) and the stator core (27) define an annular air gap (80) between a radially outward surface (33) of the rotor core (92) and a radially inward surface (37) of the stator core (27);

wherein the stator (36) is configured to define one or more stator apertures (34, 94) which penetrate the stator (36) radially from a radially outward stator surface (31, 93) to a radially inward stator surface (37, 91); and

wherein the measurement tool (100) includes a measurement head (104) that is configured to pass through a selected one of the one or more stator apertures (34, 94) and is shaped to be contactable with the radially outward rotor surface (33, 71) and the radially inward stator surface (37, 91).

9. The apparatus of Claim 8, comprising a plurality of stator apertures (34, 94).

10. The apparatus of Claim 9, wherein a first group of at least two stator apertures (34, 94) are provided proximal to a first axial end (28) of the stator (36).

11. The apparatus of Claim 10, wherein at least two of the stator apertures (34, 94) in the first group are provided at angularly-spaced positions about the rotational axis.

12. The apparatus of any one of Claims 10 or 11, wherein a second group of at least two stator apertures (34, 94) are provided proximal to a second axial end (29) of the stator (36).

13. The apparatus of Claim 12, wherein at least two of the stator apertures (34, 94) in the second group are provided at angularly-spaced positions about the rotational axis.

14. The apparatus of any one of claims 8 to 13, wherein the stator (36) and rotor (32) are housed within a generator housing (25), and wherein the generator housing (25) includes one or more removable access panels (44) which, when removed from the generator housing (25), provide access to the one or more stator apertures (34, 94).

15. The apparatus of any one of claims 8 to 14, wherein the measurement head (104) of the measurement tool (100) is asymmetric.

16. The apparatus of any one of claims 8 to 15, wherein the or each stator aperture (34, 94) is slot-like in form, and wherein the measurement head (104) of the measurement tool (100) is sized and shaped to complement the shape of the stator aperture (34, 94).

17. The apparatus of any one of claims 8 to 16, wherein the measurement tool (100) includes an elongate handle (102), and wherein the measurement head (104) includes an arm (106) that extends transversely to the handle (102).

18. The apparatus of any one of claims 8 to 17, wherein the or each stator aperture (34) is defined by a respective axial spacing between neighbouring stator laminations (35).

19. A wind turbine (1) comprising a wind turbine tower (2), a nacelle (4) rotatably coupled to the tower (2), a rotating hub (8) mounted to the nacelle (4), and a plurality of wind turbine blades (10) coupled to the hub (8), wherein the nacelle (4) comprises an apparatus according to any one of claims 8 to 18.

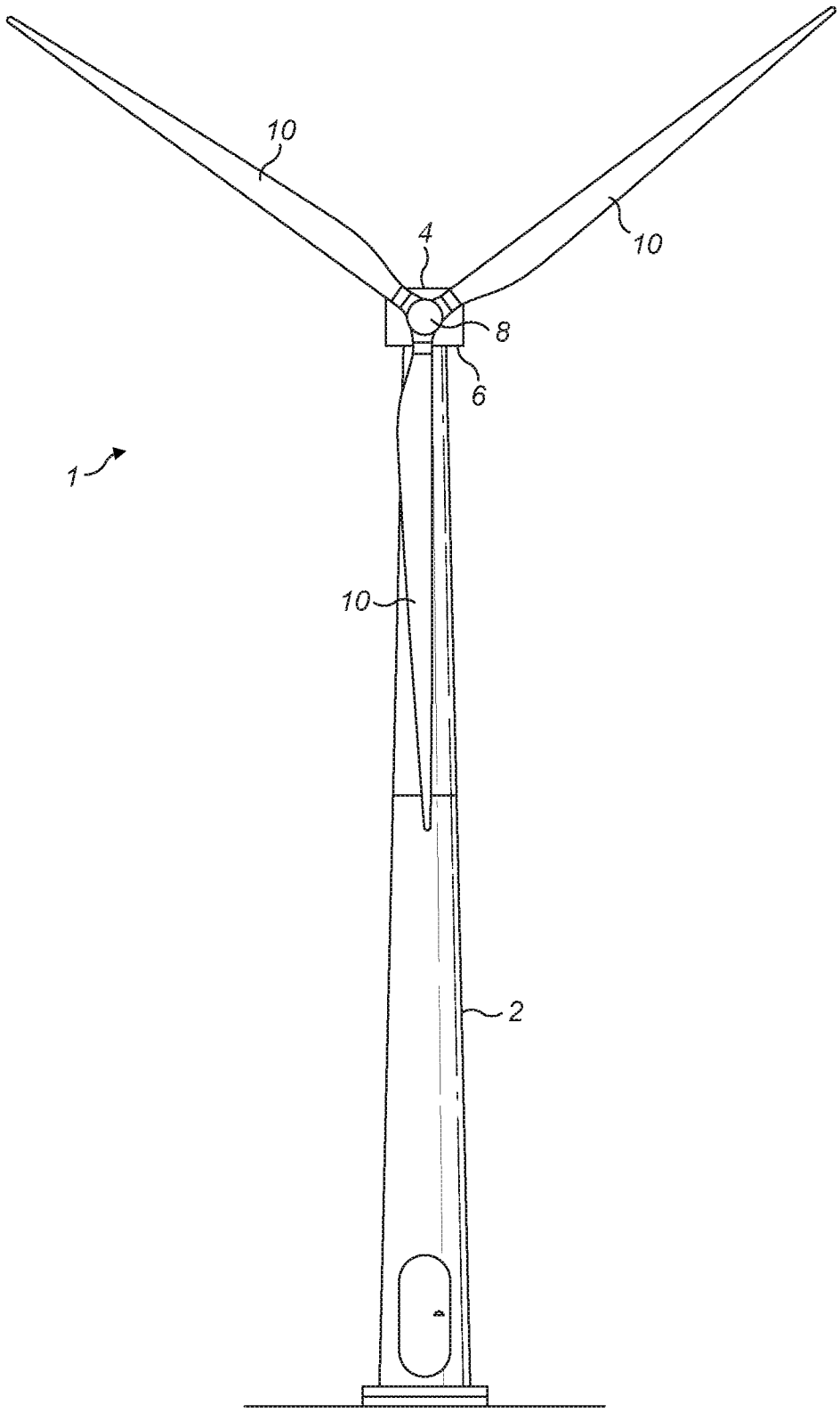

FIG. 1

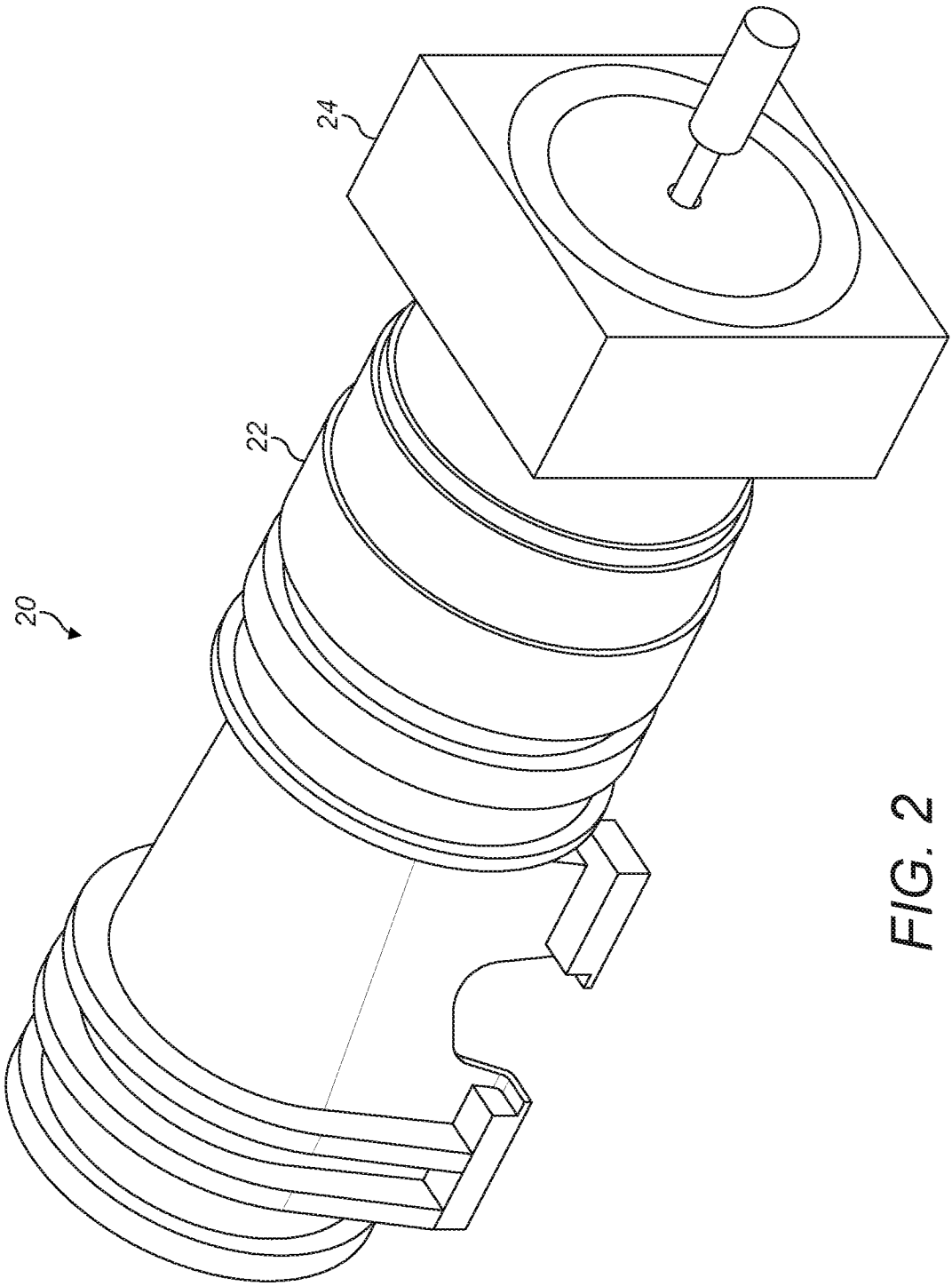

FIG. 2

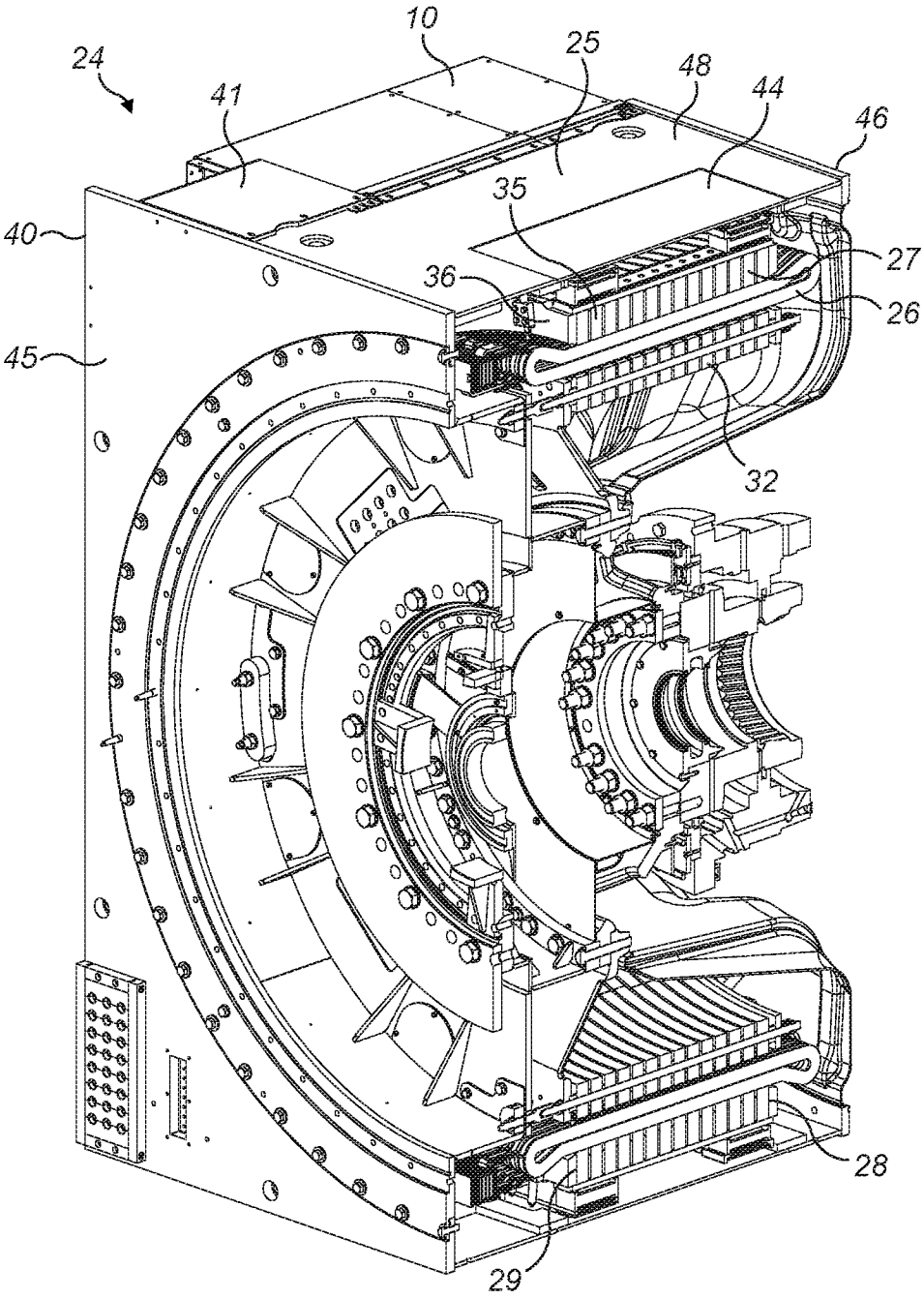

FIG. 3

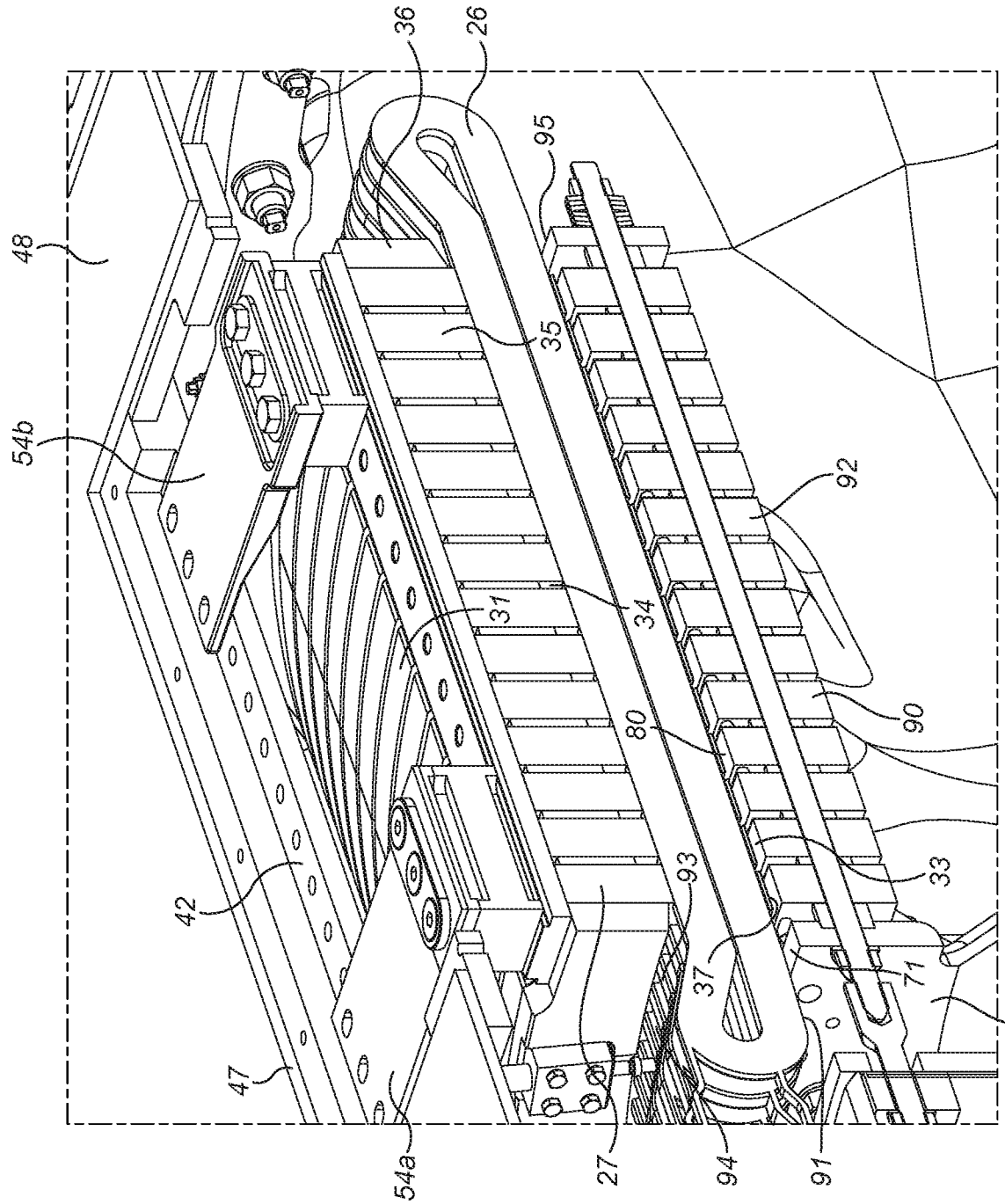

FIG. 4

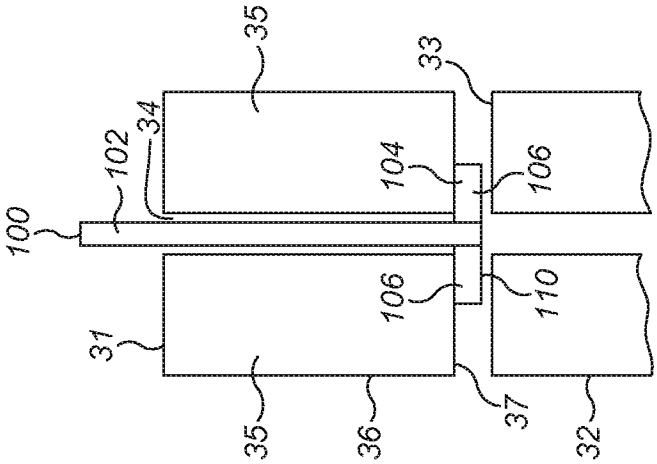

FIG. 5c

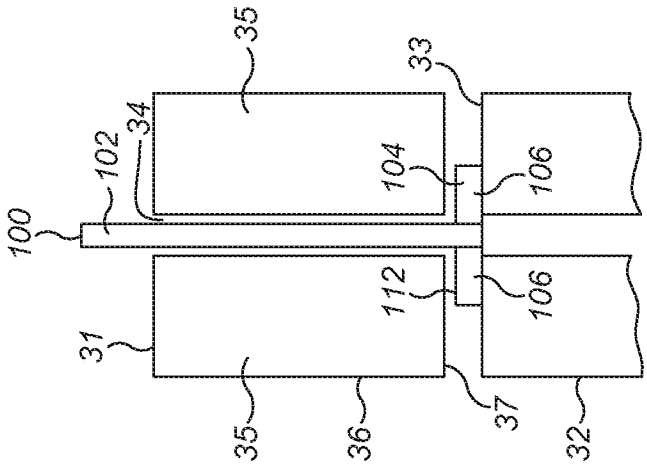

FIG. 5b

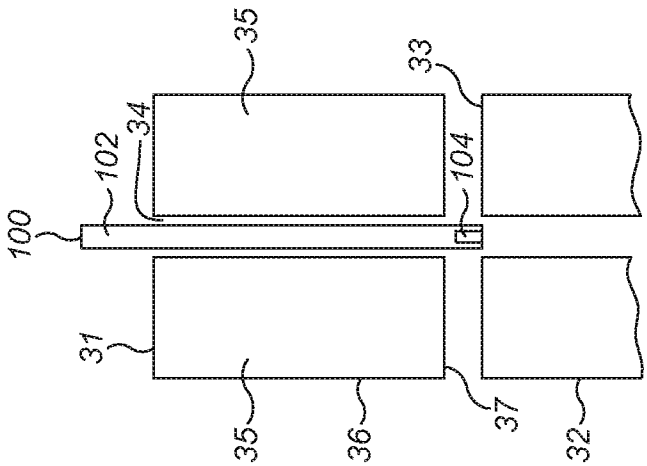

FIG. 5a

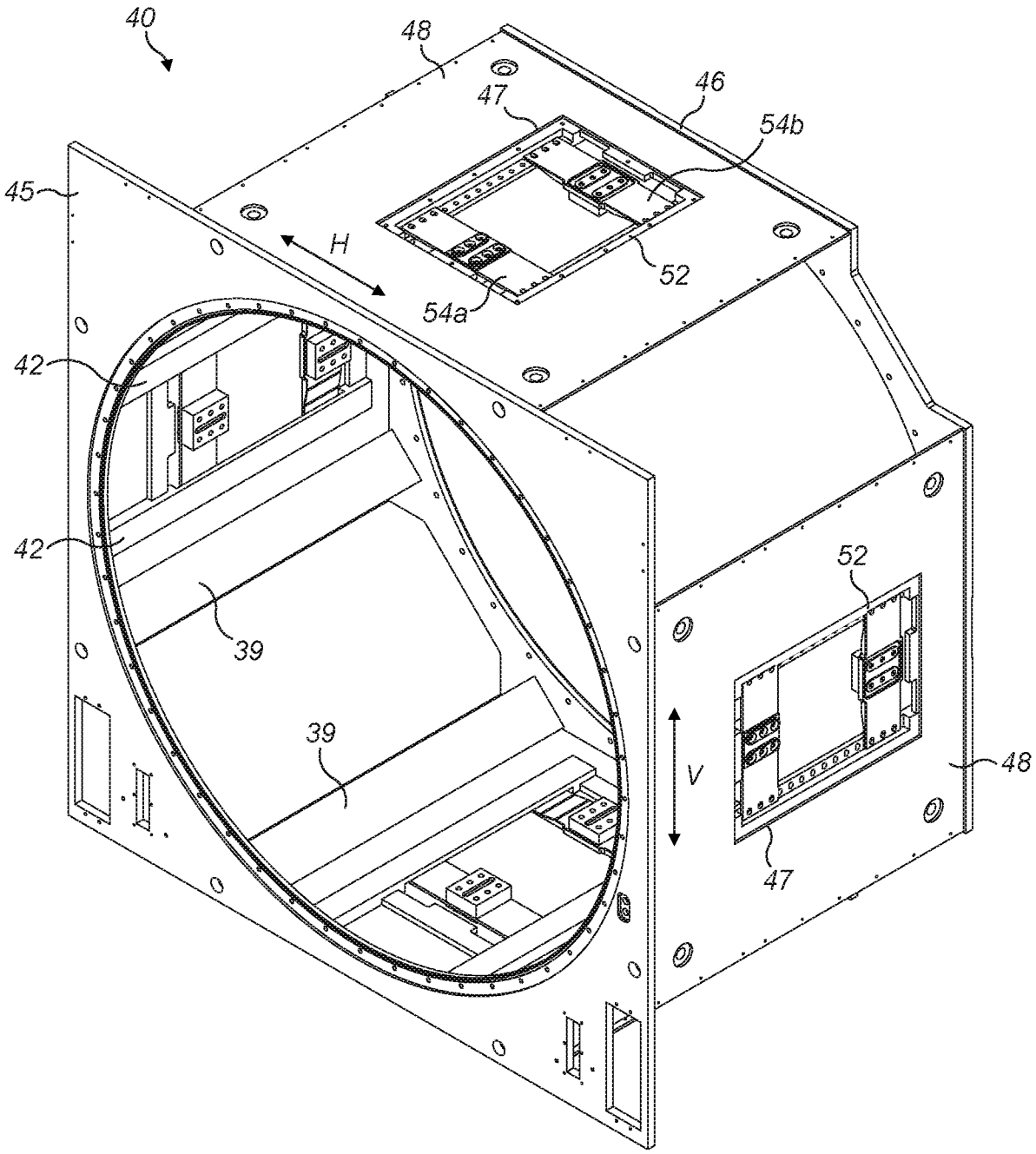

FIG. 6

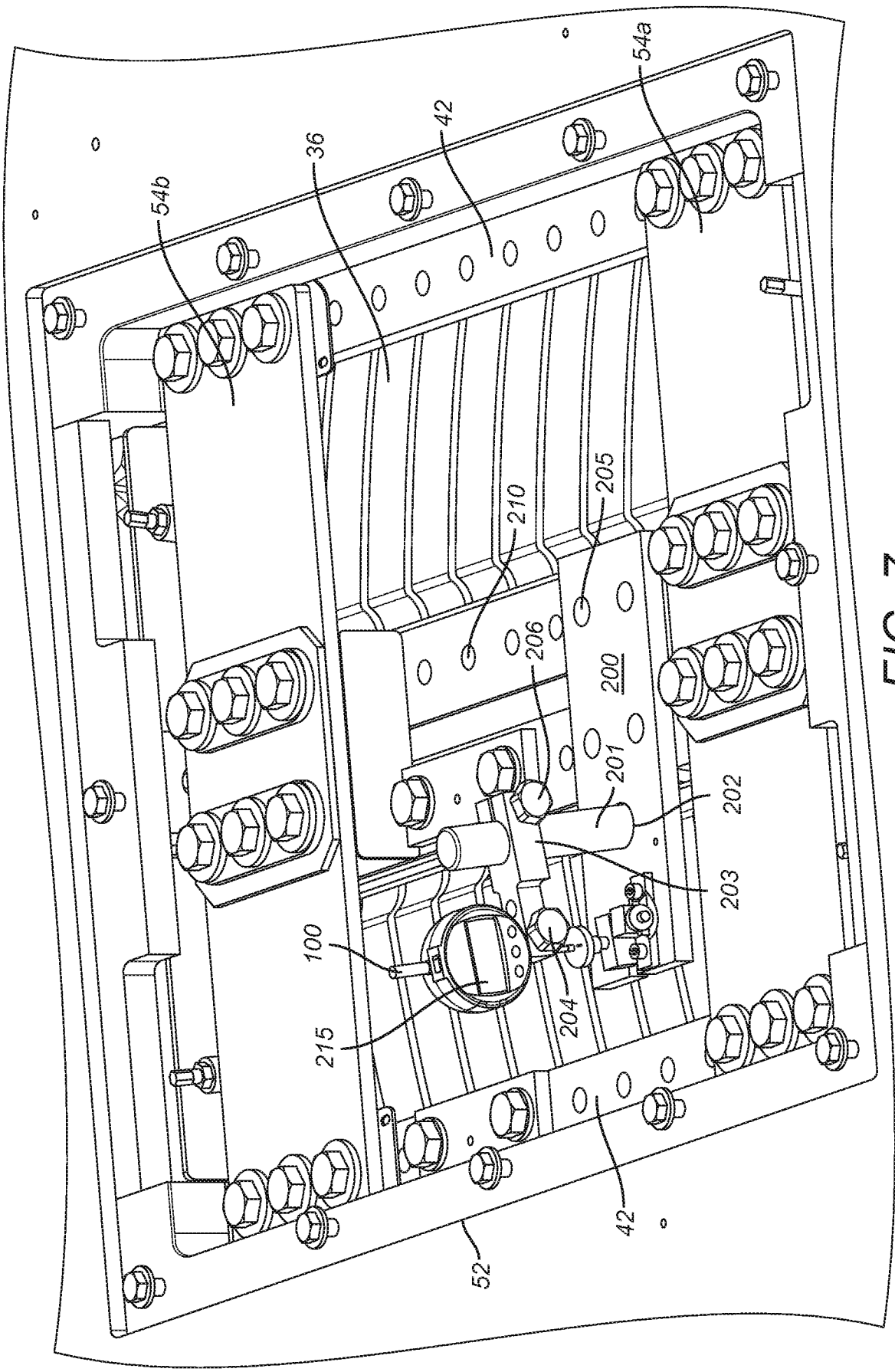

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2020/050188

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02K15/16
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 2 532 885 A1 (SIEMENS AG [DE]) 12 December 2012 (2012-12-12) abstract; figure 3 paragraph [0033] -----	1-19
Y	JP S58 29349 A (TOKYO SHIBAURA ELECTRIC CO) 21 February 1983 (1983-02-21) abstract; figures 3,4 -----	1-19
A	EP 1 207 299 A2 (HENNCHEN NORBERT [DE]) 22 May 2002 (2002-05-22) abstract; figure 1 -----	1-19
A	EP 2 237 398 A1 (SIEMENS AG [DE]) 6 October 2010 (2010-10-06) abstract; figure 1 paragraph [0048] -----	1-19

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 September 2020	17/09/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Güvener, Cem

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INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2020/050188

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 10 2016 122862 A1 (WOBBEN PROPERTIES GMBH [DE]) 30 May 2018 (2018-05-30) abstract; figure 4 -----	1-19

1

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Information on patent family members

International application No
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