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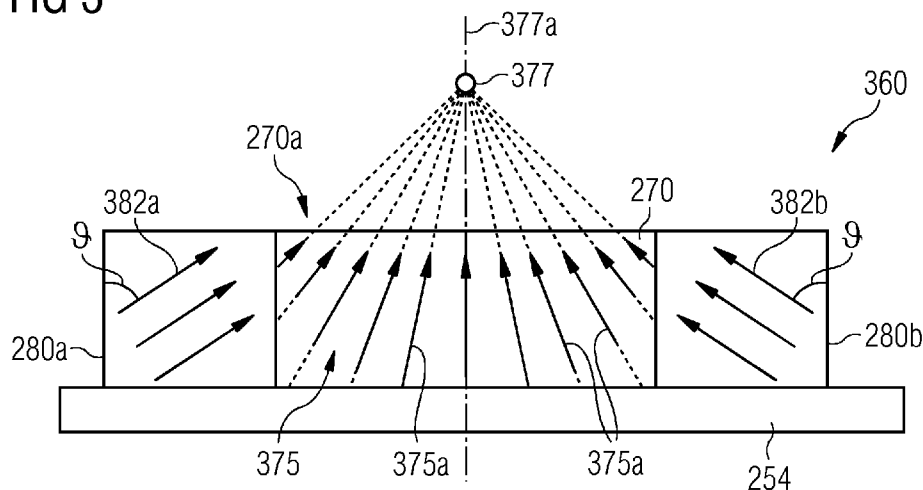
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(54) Title: PERMANENT MAGNET ASSEMBLY COMPRISING THREE MAGNET DEVICES WITH DIFFERENT MAGNETIC DOMAIN ALIGNMENT PATTERNS

FIG 3



(57) Abstract: It is described a permanent magnet assembly (360, 460) comprising a first side magnet device (280a), a second side magnet device (280b) and a central magnet device (270, 470) in between. The central magnet device (270, 470) has a spread angular distribution of magnetic domain alignment directions (375, 475) resulting in a focused magnetization defining a focal point (377). Both side magnet devices (280a, 280b) have only a single magnetic domain alignment direction (382a, 382b) resulting in a parallel magnetization. The single magnetic domain alignment direction (382a, 382b) is slanted with respect to a magnetic axis (377a) being defined by the shortest distance between the focal point (377) and a main surface (270a) of the central magnet device (270, 470). It is further described a rotor assembly (150) with such a permanent magnet assembly (360, 460), an electromechanical transducer (140) with such a rotor assembly (150), and a wind turbine (100) with such an electromechanical transducer (140).



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DESCRIPTION

Permanent magnet assembly comprising three magnet devices
with different magnetic domain alignment patterns

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Field of invention

The present invention relates to the technical field of per-
manent magnets having a non-uniform magnetic domain alignment
pattern. The present invention further relates to a rotor as-
sembly for an electromechanical transducer, which rotor as-
sembly comprises at least one of such a permanent magnet.
Furthermore, the present invention relates to an electrome-
chanical transducer comprising such a rotor assembly and to a
wind turbine comprising such an electromechanical transducer.

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15Art Background

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Permanent magnetic materials are used in a plurality of dif-
ferent fields of application. Probably the technically and
economically most important field of applications are elec-
tromechanical transducers, i.e. electric motors and electric
generators. An electric motor being equipped with at least
one permanent magnet (PM) converts electric energy into me-
chanical energy by producing a temporary varying magnetic
field by means of windings or coils. This temporary varying
magnetic field interacts with the magnetic field of the PM
resulting e.g. in a rotational movement of a rotor assembly
with respect to a stator assembly of the electric motor. In a
physically complementary manner, an electric generator, also
called a dynamo electrical machine, converts mechanical ener-
gy into electric energy.

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An electric generator is a core component of any power plant
for generating electric energy. This holds true for power
plants which directly capture mechanical energy, e.g. hydroe-

lectric power installations, tidal power installations, and wind power installations also denominated wind turbines. However, this also holds true for power plants which (i) first use chemical energy e.g. from burning fossil fuel or from nuclear energy in order to generate thermal energy and which (ii) second convert the generated thermal energy into mechanical energy by means of appropriate thermodynamic processes.

It is obvious that the efficiency of an electric generator is probably the most important factor for optimizing the production of electric energy. For a PM electric generator it is essential that the magnetic flux produced by the permanent magnets (PMs) is strong. Presently, this can probably best be achieved with sintered rare earth magnets, e.g. using a FeNdB material composition. However, also the spatial magnetic field distribution produced by PMs has an impact on the generator efficiency. In the latter case it is often of advantage when PM devices or PM arrangements are used which have a non-uniform magnetic domain alignment pattern resulting in an intentionally inhomogeneous magnetic field strength or magnetic flux density in particular in an air gap between a rotor assembly and a stator assembly.

WO 2012/141932 A2 discloses PM magnet arrangements where differently magnetized PMs are combined such that a "magnetic focusing" is achieved. The differently magnetized PMs may be mounted on a common back plate made e.g. from iron.

EP 3 276 642 A1 discloses a sintered rare earth PM having a focusing magnetic alignment pattern with an integrally formed or single piece PM body.

EP 2 762 838 A2 discloses apparatuses and methods for manufacturing PMs, wherein during a sintering process a non-uniform external magnetic field is applied in order to magnetize different regions of a PM in different directions. With a proper external magnetic field also magnetic domain

alignment patterns can be produced which form bent magnetization lines within the PM body.

WO 2009 017430 A1 discloses a magnet device having magnetic domains aligned non-isotropic in order to form a magnetic domain alignment pattern, wherein the direction of corresponding magnetization direction varies substantially continuously across at least a part of the magnet device between its lateral edges from at least partially radial to at least partially tangential.

All above mentioned known PMs and PM devices are not easy to manufacture because an appropriate external non-homogenous magnetic field is necessary in order to provide for a proper alignment of magnetic domains.

There may be a need for providing a PM assembly which can be manufactured easily and which, in many applications, contributes to an improved efficiency of electromechanical transducers.

Summary of the Invention

This need may be met by the subject matter according to the independent claims. Advantageous embodiments of the present invention are described by the dependent claims.

According to a first aspect of the invention there is provided a permanent magnet assembly comprising a central magnet device; a first side magnet device being arranged at a first side of the central magnet device; and a second side magnet device being arranged at a second side of the central magnet device. The provided permanent magnet assembly further comprises the following features:

(a) The central magnet device is sandwiched between the first side magnet device and the second side magnet device.

(b) The central magnet device has a spread angular distribution of magnetic domain alignment directions resulting in a focused magnetization defining a focal point,

(c) Both the first side magnet device and the second side magnet device have only a single magnetic domain alignment direction resulting in a parallel magnetization.

(d) The single magnetic domain alignment direction is slanted with respect to a magnetic axis being defined by the shortest distance between the focal point and a main surface of the central magnet device.

The described permanent magnet (PM) assembly is based on the idea that by assembling three magnet devices, wherein only one magnet device, namely the central magnet device, comprises a non-uniform distribution of magnetic domain alignment directions resulting in a focused magnetization, and the other magnet devices comprise a (usual) parallel magnetization direction, a reasonable tradeoff can be achieved between (i) the overall effort for producing the entire PM assembly, (ii) the strength of the magnet flux produced by the PM assembly, and (iii) the degree of magnetic focusing. Specifically, it is only necessary to use one comparatively sophisticated and difficult to manufacture magnet device, namely the central magnet device, in order to end up with a PM assembly producing, for many applications, (i) a sufficiently strong magnetic field or magnetic flux and (ii) a desired spatial distribution of magnetic field (lines) or magnetic flux (lines).

The term "magnetic axis being defined by the shortest distance between the focal point and a main surface of the central magnet device" may particularly mean that the magnetic axis is oriented perpendicular to (the plane of) a main surface of the central magnet device and that the focal point is located on the magnetic axis. In this respect the magnetic axis may be seen as to correspond to an optical axis of a focusing optical element, e.g. a refractive lens.

In this document the term "magnetic domain alignment direction" may also be referred to as magnetization direction within the bulk of the respective magnet device.

5 It is pointed out that the focusing of the central magnet device may not be perfect. Hence, the spread angular distribution of magnetic domain alignment directions may result not in an exact or sharp focal point but in a (distributed) focal region around a desired exact or sharp focal point.

10 According to an embodiment of the invention the magnetic axis is a symmetry axis of the central magnet device, wherein the symmetry is given by the spatial shape and dimension of the central magnet device and/or by the spread angular distribution of magnetic domain alignment directions.

15 Configuring the central magnet device in a symmetric manner may provide the advantage that, as compared to a non-symmetric configuration, the central magnet device can be manufactured comparatively easily with known procedures and apparatuses for inhomogeneously magnetizing the central magnet device e.g. during a sintering procedure.

20 According to a further embodiment of the invention the magnetic axis is a symmetry axis of the entire permanent magnet assembly, wherein the symmetry is given by the spatial shape and dimension of the entire permanent magnet assembly and/or by the entire distribution of magnetic domain alignment directions.

30 Descriptively speaking, the described symmetry of the entire PM assembly may mean that with regard to the symmetry axis the two (outer) side magnet devices are mirror symmetric to each other. This may hold true for the spatial shape and dimension of the two side magnet devices and/or for single magnetic domain alignment directions of the two side magnet devices. This may provide the advantage that the described PM

assembly can be designed and realized in a comparatively simple and effective manner.

5 In preferred configurations, the two side magnet devices are of the same type. Hence, for building up the described PM assembly only two different types of magnet devices are necessary, i.e. the focusing central magnet device and the (double used) non-focusing side magnet device. When assembling the PM assembly one of the two side magnet devices may simply be
10 oriented in a reversed manner as compared to the other one of the two side magnet devices.

In this document the term "entire distribution of magnetic domain alignment directions" may refer to the magnetic domain
15 alignment distributions of or within all magnet devices of the magnet assembly including the central magnet device and the two side magnet devices. In case the magnet assembly comprises additional magnet devices the "entire distribution of magnetic domain alignment directions" may also include the
20 distribution of magnetic domain alignment magnetization directions in these additional magnet devices.

The described mirror symmetric PM assembly may provide the advantage that it can be designed and manufactured even more
25 easily as compared to a PM assembly wherein only the central magnet device is symmetric and the entirety of the two outer side magnet devices is asymmetric.

According to a further embodiment of the invention at least
30 one of the central magnet device, the first side magnet device, and the second side magnet device is formed as a single magnet piece. This may provide the advantage that three different magnet pieces are sufficient in order to realize the described PM assembly.

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In the context of this document the term "single magnet piece" may particularly mean that the respective magnet de-

vice is integrally or monolithically formed by means of a single bulk material.

5 According to a further embodiment of the invention at least one of the central magnet device, the first side magnet device, and the second side magnet device comprises at least two magnet pieces.

10 Descriptively speaking, in this embodiment at least one magnet device of the (at least) three magnet devices is composed of at least two single magnet pieces. This may provide the advantage that the entire PM assembly and in particular the central magnet device can be realized by composing or assembling smaller magnet pieces. Although assembling the different magnet pieces may require some effort this effort will, 15 in most cases, be overcompensated because only smaller magnet pieces have to be produced. This holds true because in particular for focusing magnet pieces it is easier to manufacture two or more small focusing magnet pieces than to manufacture one large focusing magnet piece. 20

Forming a magnet device with at least two magnet pieces may not only provide an advantage with regard to a manufacturing procedure of the magnet device but also with regard to the 25 operational efficiency of a generator being equipped with a "multi piece" magnet device. In this context eddy currents being produced within the body of the magnetic device because of magnetic retroactive effects can be reduced. Specifically, a time varying current being induced in a stator coil because 30 of the time varying magnetic field caused by the moving magnet device results in a time varying magnetic field produced by the respective stator coil. This time varying magnetic field again causes eddy currents within the body of the magnet device. Hence, it should be clear that an interface between 35 different magnet pieces may provide a barrier for such eddy currents. This barrier may be strengthened when there is provided an electrically insulating medium, e.g. a non-conductive glue, between the different magnet pieces.

According to a further embodiment of the invention the two magnet pieces directly abut against each other.

5 A PM assembly with directly abutting magnet pieces may provide the advantage that it can be realized within a compact design. A further advantage may be that at the interface between two neighboring magnet pieces there may be, at least approximately, no distortion of magnet flux lines. Such a
10 distortion of magnet flux lines would most probably occur if there would be a gap in between the two respective magnet pieces.

In this document the term "directly abut" may mean that there
15 is no intended gap between the two magnet pieces. This means that e.g. a small layer of adhesive and/or a surface protection or passivation layer in between the actual magnetic materials of the two magnet pieces does not mean that the two magnet pieces do not directly abut against each other.

20 According to a further embodiment of the invention at least one of the central magnet device, the first side magnet device, and the second side magnet device is a sintered magnet, in particular a sintered magnet comprising NdFeB.

25 The formation of the described PM assembly by means of different magnet devices, wherein each of them may be formed by one or more (permanent) magnet pieces, may be in particular of advantage when taking into account that typically sintered
30 magnets are very rigid and/or brittle structures such that a further processing of the respective sintered magnet is not easy. This may hold true in particular for magnets comprising a typical NdFeB material composition.

35 By using at least two comparatively small sized sintered magnet devices or pieces instead of one larger sized sintered magnet device or piece the risk of mechanically damaging a magnet device or piece during a further processing may be

significantly reduced. Such a further processing may include for instance a procedure of providing a protection layer at the outer surface of the magnet piece.

5 In order to avoid any misunderstanding with regard to the (internal) magnetization structure of the sintered magnet it is pointed out that a magnetic domain alignment direction described above is based on or is directly related with a preferred direction of grain orientations. This means that it is
10 not necessary that all grains (contributing to a particular magnetic domain alignment direction or magnetization line) have to be oriented exactly in the same direction. It is rather only necessary that among a certain distribution of grain orientations there is (in average) a preferred grain
15 orientation.

According to a further embodiment of the invention the spread angular distribution of magnetic domain alignment directions comprises straight lines.

20 Having focusing magnetization directions along straight lines may provide the advantage that the process of manufacturing the central magnet device, e.g. during a sintering procedure, may be facilitated. This holds true in particular because for
25 producing the magnetic domain alignment (pattern) of the central magnet device an external magnetic field having a corresponding and necessary inhomogeneity can be generated comparatively easily with a proper spatial arrangement of external magnet coils. Preferably, all magnetic domain alignment lines
30 within the central magnet device are straight lines.

According to a further embodiment of the invention the spread angular distribution of magnetic domain alignment directions (within the central magnet device) comprises bent magnetic
35 domain alignment lines.

Providing bent or arcuate magnetic domain alignment lines may provide the advantage that at the interface between the cen-

tral magnet device and at least one of the two side magnet devices there can be a smooth transition of the orientation angles of the magnetic domain alignment directions or magnetic domain alignment lines. This may mean that at this interface a difference between the angle of the bent magnetic domain alignment lines of the central magnet device and the respective side magnet device can be small. In preferred embodiments this angle difference is at least approximately zero. In other words, at this interface there is no (significant) stepwise change of the orientation of the magnetic domain alignment lines.

A smooth transition of the orientation of the magnetic domain alignment lines may provide the advantage that the magnetic field or magnetic flux focusing behavior of the central magnet device towards the focal point will not be disturbed. Such a disturbance would result in an increased focusing region. Instead, the side magnet device may significantly increase the magnetic strength of the entire magnet assembly such that, compared to a single focusing (central) magnet device, the strength of the magnetic field in particular at the focal point will be increased.

According to a further embodiment of the invention, for the central magnet device, (a) first angles between (i) the magnetic domain alignment directions and (ii) the magnetic axis at the main surface are smaller than (b) second angles between (i) the magnetic domain alignment directions and (ii) the magnetic axis at an interface between the central magnet device and at least one of the two side magnet devices.

The described angle relationship may mean, descriptively speaking, that with respect to the plane of the main surface (i) the direction of the magnetic domain alignment of magnetization lines "leaving" the central magnet device at the main plane is steeper than (ii) the direction of the magnetic domain alignment of magnetization lines "entering" the central magnet device at the respective interface.

Preferably, magnetization lines "entering" the central magnet device at one interface and "leaving" the central magnet device at the main surface are bent towards the "left hand side" and magnetization lines "entering" the central magnet device at the opposing other interface and also "leaving" the central magnet device at the main surface are bent towards the "right hand side". This may provide the advantage that also a configuration with a central magnet device having bent magnetic domain alignment lines can be realized in a (mirror) symmetric manner.

According to a further embodiment of the invention, for at least one of the first side magnet device and the second side magnet device, a slanting angle between the single magnetic domain alignment direction and the magnetic axis is within a range of 20° and 70° , preferably within a range of 30° and 60° and more preferably within a range of 40° and 50° . Most preferably, the described slanting angle may be at least approximately 45° .

The straight lines may be oriented such that they are inclined towards the magnetic axis. Thereby, in an advantageous manner, the magnetic focusing of the central magnet will be supported by the two side magnet devices.

According to a further embodiment of the invention each one of the magnet devices comprises a height and a width, wherein the height is measured along a direction being parallel to the magnetic axis and the width is measured along a direction being parallel to a common normal vector of the mutually facing side surfaces of the two side magnet devices. The described magnet assembly comprises at least one of the following features (A), (B), and (C):

Feature (A): The central magnet device comprises an aspect ratio in the range between 0.2 and 1.0, in particular between 0.4 and 1.0 and more in particular between 0.6 and 1.0.

Thereby, the aspect ratio is defined by the ratio between the height and the width of the central magnet device.

With regard to feature (A) the inventors found out that a
5 proper aspect ratio of the focusing central magnet device may have a significant effect on the magnetic flux which can be realized within an airgap of a generator. Specifically, by contrast to not focusing magnet devices, which are typically dimensioned by machine designers with a minimum height (in
10 particular for cost reasons), a focusing magnet device may provide a significant bigger efficiency for producing a strong magnetic flux. This significant bigger efficiency may be a reason for designing the focusing magnet device with a bigger magnet volume, which of course is associated with more
15 costs or expenses for the necessary magnet material.

The width of the central magnet device may be, at least for generators being suitable for wind turbines, in a range between 25mm and 200 mm and in particular in a range between 50
20 and 100 mm. In this respect the inventors have further found out that an optimum aspect ratio may depend on the absolute value of the width. For example, for a magnet device having a width of 50 mm a beneficial aspect ratio may be in the range between 0.4 and 0.8. For a magnet device having a width of
25 100 mm a beneficial aspect ratio may be in the range between 0.2 and 0.6. In these considerations also the expenses for magnetic material may be taken into account.

Feature (B): The height of the central magnet device is different, in particular bigger, than the height of at least one
30 of the side magnet devices.

With regard to feature (B) the inventors found out that with a not uniform height of the described permanent magnet assembly the (upper) surface of the permanent magnet assembly can
35 approximate a curved (sinusoidal) surface which may spatially shape respectively modify the magnetic flux density in particular within an air gap between a rotor assembly and a sta-

tor assembly in such a manner that a smooth operation of a corresponding electromechanical transducer (small cogging torque, vibrations, etc.) can be obtained.

5 Preferably, the central magnet device has a first height and the two side magnet devices have a second height. This may provide the advantage that also permanent magnet assemblies having magnet devices with different heights can be realized in a spatially (mirror) symmetric shape.

10 Feature (C): The width of at least one of the side magnet devices is different, in particular bigger, than the width of the central magnet device.

15 With regard to feature (C) the inventors found out that by choosing appropriate widths the permanent magnet assembly can be realized with a further degree of freedom in design. Also this further degree of freedom can be exploited in order to realize, for each application, a permanent magnet assembly
20 which contributes to a smooth operation of an electromechanical transducer.

Preferably, the central magnet device has a first width and the two side magnet devices have a second width. This may
25 provide the advantage that also permanent magnet assemblies having magnet devices with different widths can be realized in a spatially (mirror) symmetric shape.

According to a further aspect of the invention there is provided a rotor assembly for an electromechanical transducer,
30 in particular for a generator of a wind turbine. The provided rotor assembly comprises a support structure, and at least one permanent magnet assembly as described above. The permanent magnet assembly is mounted to the support structure.

35 The provided rotor assembly is based on the idea that with the above described PM assembly a rotor assembly for an electromechanical transducer can be built up, which in operation,

due to its magnetic focusing, produces an effective operation. In particular, unwanted effects such as e.g. cogging torque, vibrations, etc. can be reduced which results not only in a high efficiency factor but also in a low noise operation of the electromechanical transducer.

According to a further aspect of the invention there is provided an electromechanical transducer, in particular a generator of a wind turbine. The provided electromechanical transducer comprises a stator assembly, and a rotor assembly as described above.

The provided electromechanical transducer is based on the idea that with the above described rotor assembly one can design a PM electromechanical transducer with which, due to the reduction of at least some unwanted effects, a high operational efficiency can be achieved at comparatively low manufacturing costs for the at least one PM assembly.

According to a further aspect of the invention there is provided a wind turbine for generating electrical power. The provided wind turbine comprises a tower, a wind rotor, which is arranged at a top portion of the tower and which comprises at least one blade, and an electromechanical transducer as described above. The electromechanical transducer is mechanically coupled with the wind rotor.

The provided wind turbine, also denominate a wind energy installation, is based on the idea that the above described electromechanical transducer representing a generator for the wind turbine may allow for an increased power production efficiency and/or a reduced operational noise while at the same time keeping the manufacturing expenses for the at least one PM assembly small. This may contribute for improving the attractiveness of wind turbine technology for regenerative power production compared to other technologies such as solar plants.

The aspects defined above and further aspects of the present invention are apparent from the examples of embodiment to be described hereinafter and are explained with reference to the examples of embodiment. The invention will be described in more detail hereinafter with reference to examples of embodiment but to which the invention is not limited.

Brief Description of the Drawing

Figure 1 shows a wind turbine in accordance with an embodiment of the present invention.

Figure 2 shows in a schematic representation the generator of the wind turbine of Figure 1.

Figure 3 shows a permanent magnet (PM) assembly producing a focused magnetic field with a central magnet having a spread angular distribution of magnetic domain alignment directions along respectively straight lines having different orientations.

Figure 4 shows a PM assembly with a central magnet device having bent magnetic domain alignment lines.

Figure 5 shows a two part central magnet device having straight magnetic domain alignment lines.

Figure 6 shows a two part central magnet device having bent magnetic domain alignment lines.

Figure 7 shows, for different magnet devices having different widths, the magnetic flux density achievable within an airgap as a function of the aspect ratio.

Detailed Description

The illustration in the drawing is schematic. It is noted that in different figures, similar or identical elements or features are provided with the same reference signs or with reference signs, which are different from the corresponding reference signs only within the first digit. In order to avoid unnecessary repetitions elements or features which have

already been elucidated with respect to a previously described embodiment are not elucidated again at a later position of the description.

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Figure 1 shows a wind turbine 100 according to an embodiment of the invention. The wind turbine 100 comprises a tower 120 which is mounted on a non-depicted fundament. On top of the tower 120 there is arranged a nacelle 122. In between the tower 120 and the nacelle 122 there is provided a yaw angle adjustment device 121 which is capable of rotating the nacelle 122 around a non-depicted vertical axis being aligned with the longitudinal extension of the tower 120. By controlling the yaw angle adjustment device 121 in an appropriate manner it can be made sure that during a normal operation of the wind turbine 100 the nacelle 122 is always properly aligned with the current wind direction.

The wind turbine 100 further comprises a wind rotor 110 having three blades 114. In the perspective of Figure 1 only two blades 114 are visible. The rotor 110 is rotatable around a rotational axis 110a. The blades 114, which are mounted at a hub 112, extend radially with respect to the rotational axis 110a.

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In between the hub 112 and a blade 114 there is respectively provided a blade angle adjustment device 116 in order to adjust the blade pitch angle of each blade 114 by rotating the respective blade 114 around a non-depicted axis being aligned substantially parallel with the longitudinal extension of the respective blade 114. By controlling the blade angle adjustment device 116 the blade pitch angle of the respective blade 114 can be adjusted in such a manner that at least when the wind is not too strong a maximum wind power can be retrieved from the available mechanical power of the wind driving the wind rotor 110.

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As can be seen from Figure 1, within the nacelle 122 there is provided a gear box 124. The gear box 124 is used to convert the number of revolutions of the rotor 110 into a higher number of revolutions of a shaft 125, which is coupled in a known manner to an electromechanical transducer 140. The electromechanical transducer is a generator 140.

At this point it is pointed out that the gear box 124 is optional and that the generator 140 may also be directly coupled to the rotor 110 by the shaft 125 without changing the numbers of revolutions. In this case the wind turbine is a so called Direct Drive (DD) wind turbine.

Further, a brake 126 is provided in order to stop the operation of the wind turbine 100 or in order to reduce the rotational speed of the rotor 110 for instance in case of emergency.

The wind turbine 100 further comprises a control system 153 for operating the wind turbine 100 in a highly efficient manner. Apart from controlling for instance the yaw angle adjustment device 121 the depicted control system 153 is also used for adjusting the blade pitch angle of the rotor blades 114 in an optimized manner.

In accordance with basic principles of electrical engineering the generator 140 comprises a stator assembly 145 and a rotor assembly 150. In the embodiment described here the generator 140 is realized in a so called "inner stator - outer rotor" configuration, wherein the rotor assembly 150 surrounds the stator assembly 145. This means that non-depicted permanent magnet devices respectively magnet assemblies of the rotor assembly 150 travel around an arrangement of a plurality of non-depicted coils of the inner stator assembly 145 which coils produce an induced current resulting from picking up a time varying magnetic flux from the traveling permanent magnet devices.

According to the embodiment described here each permanent magnet (PM) assembly comprises at least three sintered permanent magnet devices which are made from a Nd-Fe-B material composition.

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Figure 2 shows in a cross sectional view a schematic representation the generator 140. The generator 140 comprises a stator assembly 145. The stator assembly 145 comprises a stator support structure 247 comprising a stack of a plurality of lamination sheets and a plurality of stator windings 249 being accommodated within the stator support structure 247. The windings 249 are interconnected in a known manner by means of non-depicted electrical connections.

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A rotor assembly 150 of the generator 140, which is separated from the stator assembly 145 by an air gap ag , comprises a rotor support structure 252 providing the mechanical base for mounting a plurality of permanent magnet (PM) assemblies 260 each comprising three magnet devices, a central magnet device 270, a first side magnet device 280a and a second side magnet device 280b. The central magnet device 270 is located in between or is sandwiched by the two side magnet devices 280a, 280b. A main surface of the central magnet device 270 is denominated with reference numeral 270a.

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It is mentioned that in Figure 2 only one PM assembly 260 is depicted for the sake of ease of illustration. In reality, depending on the dimension of the generator 140, a plurality of PM assemblies 260 are mounted to the rotor support structure 252. The PM assemblies 260 are preferably arranged in a matrix like structure around a curved surface area of the support structure 252 having a basically cylindrical geometry around a generator axis 240a.

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As can be seen from Figure 2, the PM assemblies 260 are not mounted directly to the rotor support structure 252. Instead, for each PM assembly 260 there is provided a back plate 254

made from a ferromagnetic material, e.g. iron. The back plate 254 is provided in order to ensure a proper guidance of magnetic flux. This significantly reduces in a beneficial manner the intensity of magnetic stray fields.

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Figure 3 shows a permanent magnet (PM) assembly 360 in accordance with an embodiment of the invention. The PM assembly 360 comprises the three magnet devices, which are also shown in Figure 2 and which have been mentioned above. The magnet devices 280a, 270, and 280b are mounted to a back plate 254.

As can be seen from Figure 3, the central magnet piece 270 is magnetized in such a manner that there is given a spread angular distribution of magnetic domain alignment directions 375 which each follow a straight magnetization line 375a. The straight lines 375a are angled or inclined with respect to each other in a fan like manner. Specifically, the spread angular distribution of the straight magnetization lines 375a produces, in the region above the main surface 270a, a focal point 377 being characterized by a local maximum of the magnetic field respectively the magnetic flux density.

According to the exemplary embodiment described here the magnetic domain alignment pattern is symmetric with respect to a symmetry axis 377a. In this document the symmetry axis 377a is also denominated magnetic axis. The magnetic axis 377a is a normal axis to the main surface 270, which runs through the focal point 377.

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The two side magnet devices 280a, 280b each have only a single magnetic domain alignment direction which results in a non-focusing magnetization. The constant angle ϑ (theta) between the alignment direction and the magnetic axis 377a is, in this embodiment, approximately 40° . Since the magnetization of the two side magnet devices 280a, 280b is supposed to support the strength of the magnetic field respectively the magnetic flux density in the region of the focal point 377,

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the angle θ (theta) could be varied depending on the magnetic focal length, i.e. the distance between the focal point 377 and the main surface 270a.

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Figure 4 shows a PM assembly 460 with a central magnet device 470 having a spread angular distribution of magnetic domain alignment directions 475. As can be seen from this Figure, the corresponding magnetic domain alignment pattern has bent magnetic domain alignment lines 475a. All lines 475a "leave" the central magnet device 470 at the main surface 470a in such a manner that at least a certain degree of magnetic focusing is achieved. A magnetic symmetry axis is denominated with reference number 477a.

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As can be further seen from Figure 4, in this "symmetric" embodiment one half of the magnetic domain alignment lines 475a "enters" the central magnet device 470 from its right lateral surface or from the right portion of the bottom surface being opposite to the main surface 470a. Along this direction these lines 475a are bent to the right.

15

Correspondingly, the other half of the magnetic domain alignment lines 475a "enters" the central magnet device 470 from its left lateral surface or from the left portion of the bottom surface being opposite to the main surface 470a. Along this direction these other lines 475a are bent to the left.

20

It is pointed out that the terms "leave" and "enter" are arbitrary, because they refer to the magnet direction from South to North. When taking the opposite magnet direction all the lines 475a "enter" the central magnet device 470 via the main surface 470a.

25

30

Figure 5 shows a two part central magnet device 570 having straight magnetic domain alignment lines. The central magnet

35

device 570 is composed of two magnet pieces, a first magnet piece 571 and a second magnet piece 572.

In Figure 5, just for the sake of illustration, the two magnet pieces 571, 572 are depicted spaced apart from each other with a small gap in between. In order to form a focusing magnet device which produces, as far as possible, an undisturbed magnetic field it is typically preferred to arrange the magnet pieces 571, 572 without a gap in between.

Composing or assembling the central magnet device 570 with two comparatively small magnet pieces 571, 752 may provide the advantage that it is not necessary to manufacture a (sintered) single magnet piece having the entire spread angular distribution of magnetic domain alignment directions resulting in a focused magnetization. It is rather sufficient to manufacture only smaller magnet pieces having only a portion, e.g. one half, of the entire focusing magnetic domain alignment pattern. The manufacturing effort for a larger number of smaller focusing magnet devices may be significantly smaller than the manufacturing effort for a smaller number of larger focusing magnet devices. Hence, in many applications it might be of advantage to assemble the central focusing magnet device by means of two or more single focusing magnet pieces.

It is mentioned that of course the central magnet device 570 may also be composed of three or more magnet pieces.

Figure 6 shows a two part central magnet device 670 having bent magnetic domain alignment lines. The central magnet device 670 is composed of two magnet pieces, a first magnet piece 671 and a second magnet piece 672. With regard to the manufacturing effort the same considerations and advantages as described above for the central magnet device 570 apply.

Also the central magnet device 670 may be composed of three or more different magnet pieces.

Figure 7 shows a diagram wherein a magnetic flux density, which can produced with different magnet devices within an
5 airgap of a generator, is depicted as a function of the aspect ratio of the respective magnet device. In this context for a focusing magnet device the aspect ratio is the ratio between a height and a width of the magnet device, whereby the height is measured along a direction being parallel to
10 the magnetic axis and the width is given by the dimension of the magnet device along a direction being perpendicular to the height direction. For a magnet assembly having two parallel magnetized side magnet devices sandwiching the focusing central magnet device the width is the distance between mutually facing side surfaces of the two side magnet devices.
15

Within the diagram of Figure 7, reference numeral 780 points to a curve depicting, for the purpose of comparing, an airgap flux density which can be achieved with a parallel magnetized
20 magnet device having a width of 50 mm. Curve 782 depicts the corresponding airgap flux density which can be achieved with a focusing magnet device having the same spatial dimensions. From a comparison between the two curves 780 and 782 it can be seen that for larger aspect ratios the difference between
25 the larger flux density produced by the focusing magnet device and the smaller flux density produced by the parallel magnetized magnet device is bigger. With increasing aspect ratio the curve 782 shows a significant increase starting from 0.2 up to 0.6. For aspect ratios larger than 0.8 the
30 achievable airgap magnetic flux density increases only with a much smaller extend.

Curves 784 and 786 show the corresponding curves for magnet devices having a width of 100 mm. Again, the difference between the larger flux density produced by the focusing magnet
35 device (see curve 786) and the smaller flux density produced by the parallel magnetized magnet device (see curve 784) gets

bigger as the aspect ratio increase. For the 100 mm magnet device a saturation is reached for an aspect ratio above 0.4.

5 It is not surprising that for lager magnet devices (here for the magnet device having a width of 100 mm) the absolute value for the magnetic flux density which can be achieved in an airgap is significantly larger.

10 From the above presented considerations it can be seen that the aspect ratio is a further parameter which can be varied in order to increase the airgap flux density. Of course, the degree of flux focusing may also be controlled by altering the location of the focal region.

15 It should be noted that the term "comprising" does not exclude other elements or steps and the use of articles "a" or "an" does not exclude a plurality. Also elements described in association with different embodiments may be combined. It
20 should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.

CLAIMS:

1. A permanent magnet assembly (360, 460) comprising

a central magnet device (270, 470);

5 a first side magnet device (280a) being arranged at a first side of the central magnet device (270, 470); and

a second side magnet device (280b) being arranged at a second side of the central magnet device (270, 470); wherein

10 - the central magnet device (270, 470) is sandwiched between the first side magnet device (280a) and the second side magnet device (280b),

- the central magnet device (270, 470) has a spread angular distribution of magnetic domain alignment directions (375, 475) resulting in a focused magnetization defining a focal point (377),

15 - both the first side magnet device (280a) and the second side magnet device (280b) have only a single magnetic domain alignment direction (382a, 382b) resulting in a parallel magnetization, and

20 - the single magnetic domain alignment direction (382a, 382b) is slanted with respect to a magnetic axis (377a) being defined by the shortest distance between the focal point (377) and a main surface (270a) of the central magnet device (270, 470).

25 2. The permanent magnet assembly (360, 460) as set forth in the preceding claim, wherein

the magnetic axis (377a) is a symmetry axis of the central magnet device (270, 470), wherein the symmetry is given by

30 the spatial shape and dimension of the central magnet device (270, 470) and/or by the spread angular distribution of magnetic domain alignment directions (375, 475).

35 3. The permanent magnet assembly (360, 460) as set forth in the preceding claim, wherein

the magnetic axis (377a) is a symmetry axis of the entire permanent magnet assembly (360, 460), wherein the symmetry is given by the spatial shape and dimension of the entire perma-

nent magnet assembly (360, 460) and/or by the entire distribution of magnetic domain alignment directions (375, 382a, 382b).

5 4. The permanent magnet assembly (360, 460) as set forth in any one of the preceding claims 1 to 3, wherein at least one of the central magnet device (270, 470), the first side magnet device (280a), and the second side magnet device (280b) is formed as a single magnet piece.

10

5. The permanent magnet assembly as set forth in any one of the preceding claims 1 to 3, wherein at least one of the central magnet device (570, 670), the first side magnet device, and the second side magnet device
15 comprises at least two magnet pieces (571, 572, 671, 672).

6. The permanent magnet assembly as set forth in the preceding claim, wherein the two magnet pieces (571, 572, 671, 672) directly abut
20 against each other.

7. The permanent magnet assembly (360, 460) as set forth in any one of the preceding claims, wherein at least one of the central magnet device (570, 670), the
25 first side magnet device (280a), and the second side magnet device (280b) is a sintered magnet, in particular a sintered magnet comprising NdFeB.

8. The permanent magnet assembly (360) as set forth in any
30 one of the preceding claims 1 to 7, wherein the spread angular distribution of magnetic domain alignment directions (375) comprises straight lines (375a).

9. The permanent magnet assembly (460) as set forth in any
35 one of the preceding claims 1 to 7, wherein the spread angular distribution of magnetic domain alignment directions (475) comprises bent magnetic domain alignment lines (475a).

10. The permanent magnet assembly (460) as set forth in the preceding claim, wherein

for the central magnet device (470)

first angles between (i) the magnetic domain alignment directions (475) and (ii) the magnetic axis (477a) at the main surface (470a) are smaller than

second angles between (i) the magnetic domain alignment directions (475) and (ii) the magnetic axis (477a) at an interface between the central magnet device (470) and at least one of the two side magnet devices (280a, 280b).

11. The permanent magnet assembly (360, 460) as set forth in any one of the preceding claims, wherein

for at least one of the first side magnet device (280a) and the second side magnet device (280b)

a slanting angle (θ) between the single magnetic domain alignment direction (382a, 382b) and the magnetic axis (377a) is within a range of 20° and 70° , preferably within a range of 30° and 60° and more preferably within a range of 40° and 50° .

12. The permanent magnet assembly (360, 460) as set forth in any one of the preceding claims, wherein

each one of the magnet devices comprises a height and a width, wherein the height is measured along a direction being parallel to the magnetic axis (377a) and the width is measured along a direction being parallel to a common normal vector of the mutually facing side surfaces of the two side magnet devices (280a, 280b), wherein the magnet assembly comprises at least one of the following features:

(A) the central magnet device (270, 470) comprises an aspect ratio in the range between 0.2 and 1.0, in particular between 0.4 and 1.0 and more in particular between 0.6 and 1.0, wherein the aspect ratio is defined by the ratio between the height and the width of the central magnet device (270, 470);

(B) the height of the central magnet device is different, in particular bigger, than the height of at least one of the side magnet devices; and

(C) the width of at least one of the side magnet devices
5 is different, in particular bigger, than the width of the central magnet device.

13. A rotor assembly (150) for an electromechanical transducer (140), in particular for a generator (140) of a wind turbine (100), the rotor assembly (150) comprising
10 a support structure (252), and
at least one permanent magnet assembly (260, 360, 460) as set forth in any one of the preceding claims, wherein the permanent magnet assembly (260, 360, 460) is mounted to the
15 support structure (252).

14. An electromechanical transducer (140), in particular a generator (140) of a wind turbine (100), the electromechanical transducer (140) comprising
20 a stator assembly (145), and
a rotor assembly (150) as set forth in the preceding claim.

15. A wind turbine (100) for generating electrical power, the
25 wind turbine (100) comprising
a tower (120),
a wind rotor (110), which is arranged at a top portion of the tower (120) and which comprises at least one blade (114), and
30 an electromechanical transducer (140) as set forth in the preceding claim, wherein the electromechanical transducer (140) is mechanically coupled with the wind rotor (110).

FIG 1

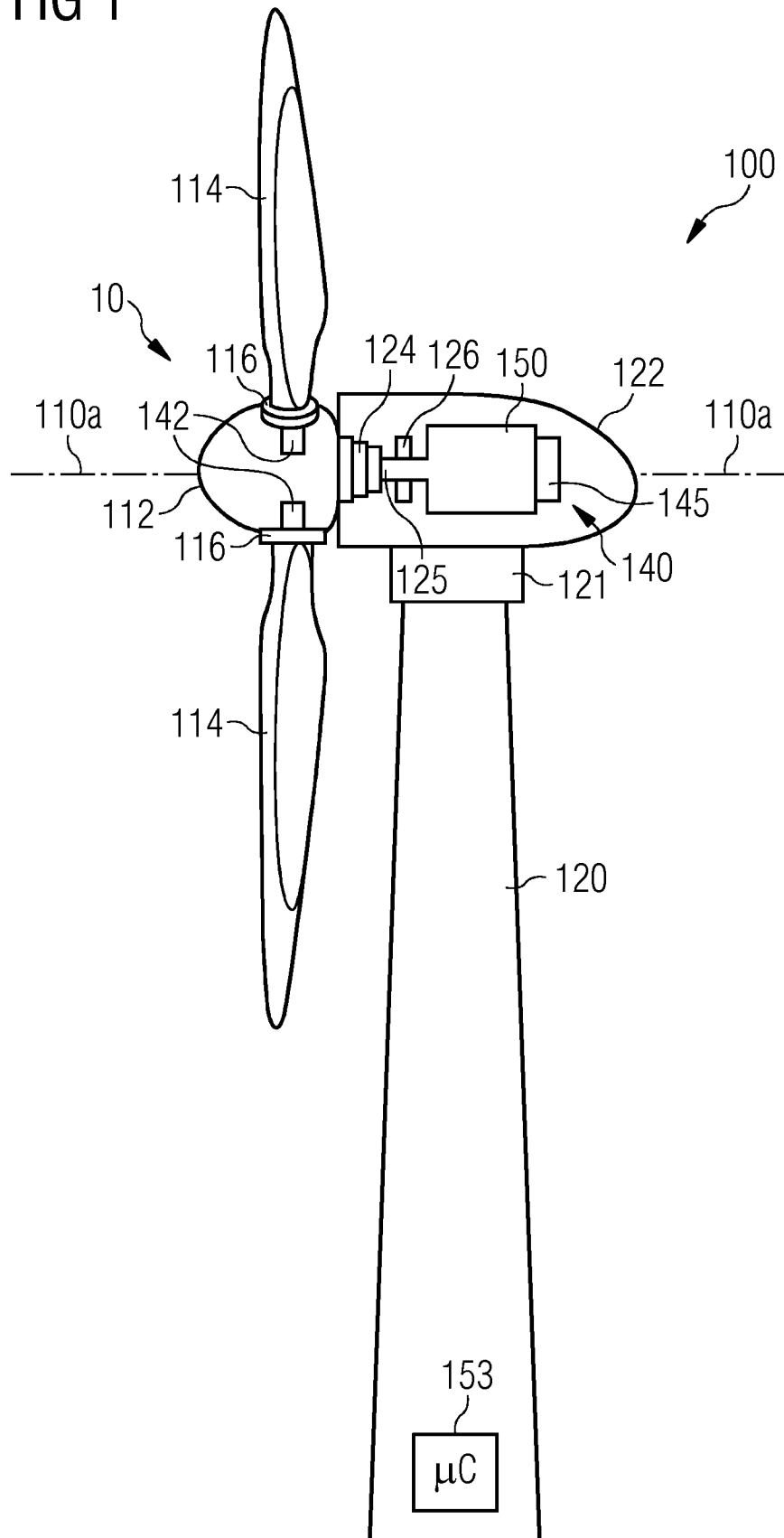


FIG 2

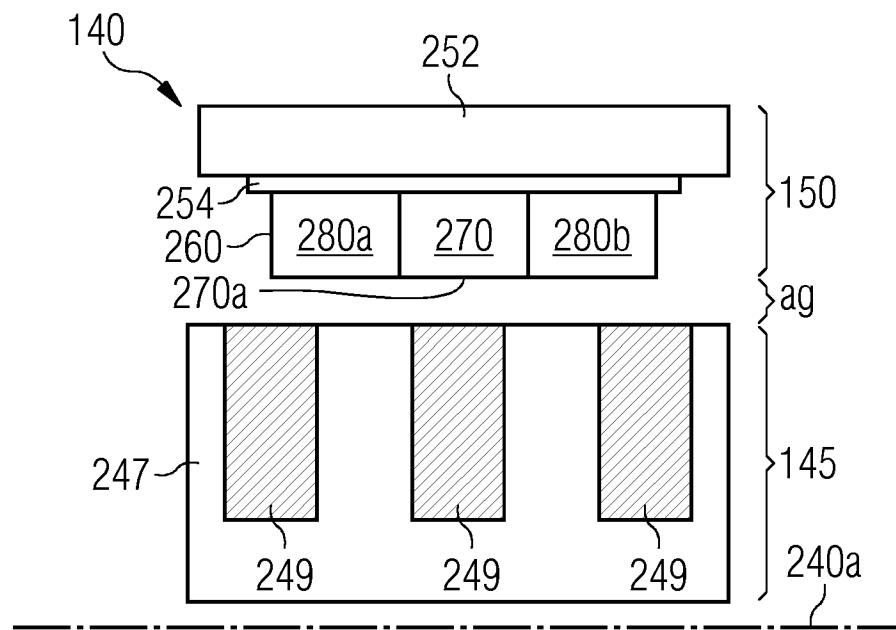


FIG 3

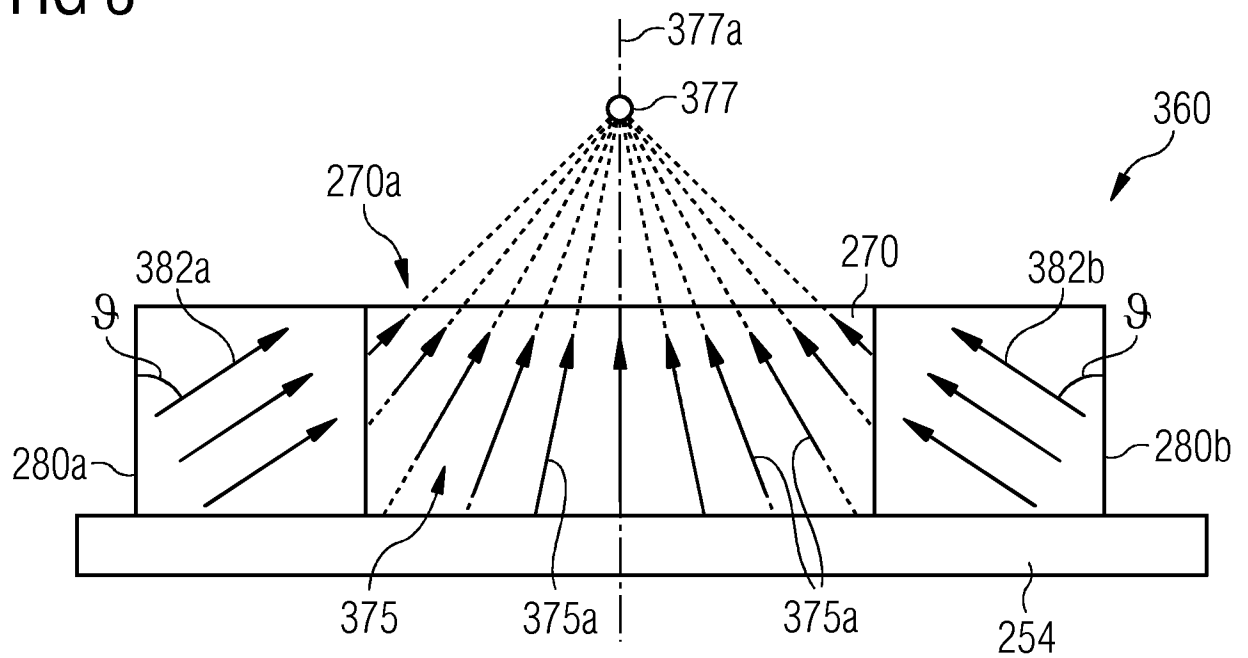


FIG 4

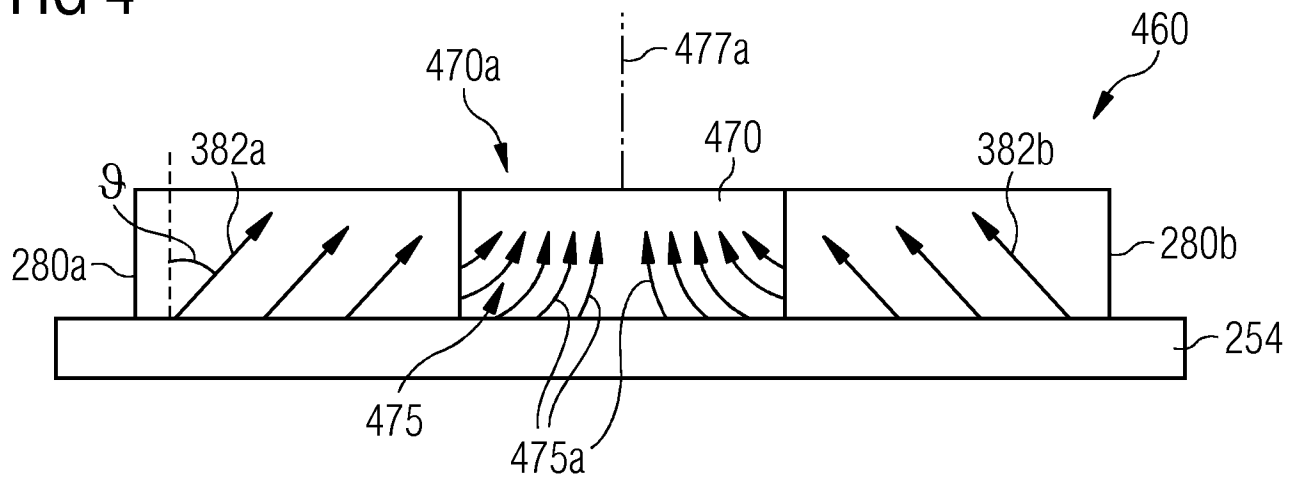


FIG 5

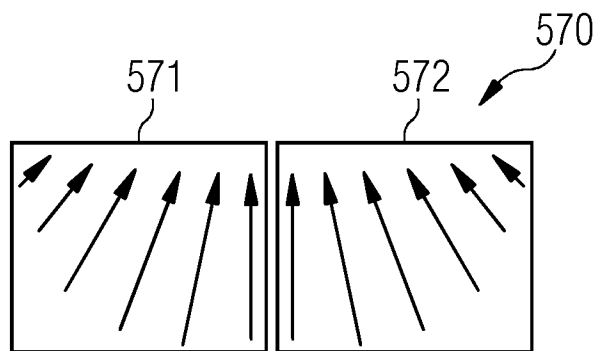


FIG 6

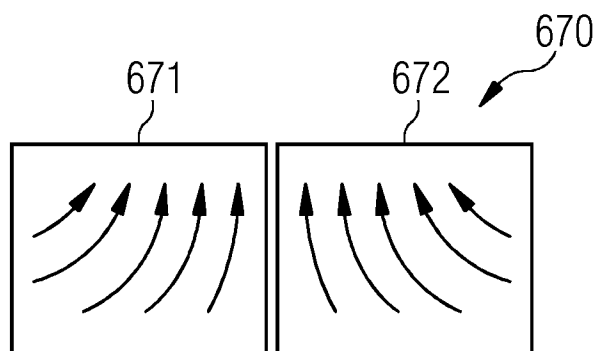


FIG 7

