Furthermore, comprising such a permanent magnet (350, 450, 50), are described.

(57) Abstract: It is described a mould (660, 760) for manufacturing a permanent magnet (350, 450, 550), particularly a flux focusing permanent magnet (350, 450, 550). The mould (660, 760) comprises a first mould part (661) comprising a first curved surface (681) having a first radius (671), a second mould part (662) comprising a second curved surface (682) having a second radius (672), wherein the first mould part (661) and the second mould part (662) are made of a ferromagnetic material. The mould (660; 760) further comprises a third mould part (663) having a moulding chamber (664), wherein in the third mould part (663) is arranged between the first mould part (661) and the second mould part (662), and wherein the first mould part (661) and the second mould part (663) are made of a different material with respect to the third mould part (663). The first curved surface (681) and the second curved surface (682) are formed such that a magnetic flux through the first mould part (661), the second mould part (662) and the third mould part (663) is directed in such a manner that in the moulding chamber (664) a spread magnetic flux is generated. Further described is a system (790) for manufacturing such a magnet, a method for manufacturing a permanent magnet (350, 450, 550), particularly a flux focusing permanent magnet (350, 450, 550), a permanent magnet (350, 450, 550) which has been manufactured with such a method. Furthermore, an electromechanical transducer (130) and a wind turbine (100) comprising such a permanent magnet (350, 450, 50), are described.
DESCRIPTION

Mould and method for manufacturing flux focusing permanent magnets comprising spread magnetic flux lines

Field of invention

The present invention relates to a mould for manufacturing a permanent magnet. Further, the present invention relates to a system for manufacturing a permanent magnet, a method for manufacturing a permanent magnet, a permanent magnet being manufactured with the described method and to an electromechanical transducer as well as a wind turbine comprising at least one of such a permanent magnet.

Art Background

Permanent magnetic materials are used in a plurality of different fields of application. Probably the technically and economically most important field of application are electromechanical transducers, i.e. electric motors and electric generators. An electric motor being equipped with at least one permanent magnet converts electric energy into mechanical 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 permanent magnet 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 converts mechanical energy into electric energy.

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. hydroelectric power installations, tidal power installations, and wind power installations also denominated wind turbines.
The efficiency of an electric generator is probably the most important factor for optimizing the production of electric energy. In permanent magnet electrical machines, including generators for direct-drive wind turbines, the torque/power production is determined by the air gap flux density which is produced by the permanent magnets. It is known that the flux and hence the torque may be increased by utilizing flux focusing permanent magnets.

Magnetic flux focusing offers a large increase in the air gap flux density leading to higher torque/power of electro-mechanical transducers such as electric generators for direct-drive wind turbines.

It is known that the air gap flux density may be increased by using a magnet having a higher magnet grade. However, it is also known that there are physical and technological limits for increasing the magnet grade of a magnet. Another commonly known way to increase the air gap flux density is to make the used magnet thicker. However, it is also known that there is a limit where the increasing gets saturated. This is linked to increasing costs because more magnetic material is needed.

There may be a need for providing a mould and a method which allow to manufacture permanent magnets, particularly flux focusing permanent magnets, in an efficient manner.

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 mould for manufacturing a permanent magnet, particularly a flux focusing permanent magnet. The mould comprises (a) a
first mould part comprising a first curved surface having a first radius, (b) a second mould part comprising a second curved surface having a second radius, wherein the first mould part and the second mould part are made of a ferromagnetic material. The mould further comprises (c) a third mould part having a moulding chamber, wherein the third mould part is arranged between the first mould part and the second mould part. The first mould part and the second mould part are made of a different material with respect to the third mould part, and the first curved surface and the second curved surface are formed such that a magnetic flux through the first mould part, the second mould part and the third mould part is directed in such a manner that in the moulding chamber a spread magnetic flux is generatable.

The described apparatus is based on the idea that by choosing an appropriate geometric shape, particularly an appropriate radius, of the first curved surface of the ferromagnetic first mould part and the second curved surface of the ferromagnetic second mould part, the magnetic flux in the moulding chamber, and hence in the resulting flux focusing permanent magnet, is an adapted spread magnetic flux. Hence, a flux focusing permanent magnet having flux focusing implemented magnetic properties may be directly and cost-efficiently manufactured. Additionally, the mould according to the present invention may be placed in a magnetic field which may be provided in a commonly known manner.

The mentioned ferromagnetic material of which the first mould part and the second mould part are formed may be low-carbon steel or ferro-cobalt alloy. It may be understood that the first mould part and the second mould part may also be made of different ferromagnetic materials. However, the first mould part and the second mould part are preferably made of the same ferromagnetic material. By providing the first mould part and the second mould part made of the same ferromagnetic material, the resulting spread magnetic flux in the moulding chamber is precisely adjustable. However, it may be under-
stood that the first mould part and the second mould part may be made of different ferromagnetic materials.

The mentioned first radius and second radius are different from each other. Particularly, according to one exemplary embodiment of the invention, the first radius is smaller than the second radius.

The mentioned third mould part is made of a different material than the first mould part and the second mould part. With other words, the material of the third mould part has to be a material different from each of the materials of the first mould part and the second mould part. By providing the third mould part made of a different material than the first mould part and the second mould part, the first curved surface and the second curved surface are adequately distinguishable and defined.

The mentioned mould chamber is formed by a hollow space inside of the third mould part. According to the present invention, the moulding chamber is spaced apart from each of the limitations/outer surfaces of the third mould part. In other words, the moulding chamber is distanced to each of the first mould part and the second mould part.

The mentioned spread magnetic flux is such that a spread angular distribution of magnetic flux lines is provided in the moulding chamber.

The spread angular distribution of magnetic flux lines may be used in particular for causing, within a permanent magnet block which is moulded in the moulding chamber, a spread angular distribution of magnetic flux lines which may result in a focused magnetization of the flux focusing permanent magnet block. Thereby, outside from the bulk of the permanent magnet block a magnetic focal point or at least a magnetic focal region may be defined. In this point or in this region the magnetic flux density caused by the respective flux focusing
permanent magnet is increased as compared to points or regions outside from the focal point respectively the focal region.

By designing an electric generator in such a manner that the focal point respectively the focal region is located within an air gap between a stator assembly and a rotor assembly the electric power which can be produced by the generator can be increased significantly.

According to an exemplary embodiment of the invention, the second mould part is a semi-circular part. Additionally or alternatively, the first curved surface of the first mould part is a semi-circular surface. Hence, the first mould part has a semi-circular shaped opening in which the third mould part and the second mould part are at least partially placed.

According to an exemplary embodiment of the invention the third mould part comprises a third surface which is curved and has a third radius corresponding to the first radius of the first curved surface, and a further third surface which is opposed to the third surface, wherein the further third surface is curved and has a further third radius corresponding to the second radius of the second curved surface. Furthermore, the third surface of the third mould part is coupled to the first curved surface of the first mould part and the further third surface of the third mould part is coupled to the second curved surface of the second mould part.

By providing the shape of the third surface corresponding to the shape of the first curved surface and the shape of the further third surface corresponding to the second curved surface, the outer shape of the third mould part may be formed corresponding to the shape of the first mould part and the second mould part. Hence, during a compacting step in which the magnetic material is compacted inside the moulding chamber, the compacting forces may be equally distributed applicable to the magnetic material inside the moulding chamber,
because an entire space between the first mould part and the second mould part is filled with the third mould part and hence with the material of the third mould part. Therefore, the compacting forces may be equally distributed over the entire first curved surface and the entire second curved surface.

According to a further embodiment of the invention, the first curved surface comprises a first circle of curvature having a first centre, and the second curved surface comprises a second circle of curvature having a second centre, wherein a centre distance between the first centre and the second centre is adapted such that an alignment (respectively a density) of the spread magnetic flux in the moulding chamber is adjustable.

According to the present invention, a radius of the first circle of curvature corresponds to the first radius of the first curved surface and a radius of the second circle of curvature corresponds to the second radius of the second curved surface.

Both the centre of the first circle of curvature and the second centre of the second circle of curvature are positioned on a symmetry axis (also denoted as magnetic axis) of the mould running through the first mould part, the second mould part and the third mould part. According to an exemplary embodiment of the invention, the first centre and the second centre are distanced from each other along the symmetry axis. In other words, a centre distance is given between the first centre and the second centre.

Both the first centre and the second centre are located on the symmetry axis inside the second part. The first centre is positioned at a location nearer to the second curved surface than the second centre which is positioned at a location farther from the second curved surface.
A centre distance between the first centre and the second centre is adapted such that an alignment of the spread magnetic flux in the moulding chamber is adjustable.

In other words, by changing the centre distance between the first centre and the second centre, the spread angular distribution of magnetic flux lines may be changed for example by increasing/decreasing the amount of magnetic flux lines running through the moulding chamber and hence by increasing/decreasing the angle between two neighbouring magnetic flux lines. Thereby, a position of a magnetic focal point/region of the manufactured flux focusing permanent magnet may be moved.

Alternatively or additionally, the spread angular distribution of magnetic flux lines may also be changed by changing a first radius of the first circle of curvature and/or by changing a second radius of the second circle of curvature. The spread angular distribution of magnetic flux lines may be changed for example by increasing/decreasing the amount of magnetic flux lines running through the moulding chamber and hence by increasing/decreasing the angle between two neighbouring magnetic flux lines. Thereby, a position of a magnetic focal point/region of the manufactured flux focusing permanent magnet may be moved.

According to an exemplary embodiment of the present invention, the centre distance is changed such that the magnetic focal point respectively the magnetic focal region is located on the symmetry axis together with the first centre and the second centre. At the same time, the magnetic focal point is distanced from the first centre and the second centre and is provided outside the second mould part and at the same time outside the mould.

The "alignment of the spread magnetic flux" according to the present invention may denote the amount of magnetic flux lines and the spatial orientation of the magnetic flux lines.
running through the moulding chamber. In other words, the
"alignment of the spread magnetic flux" may denote an angle
between adjacent magnetic flux lines inside the moulding
chamber.

According to a further embodiment of the invention, a ratio
of the first radius and the second radius is adapted such
that an alignment of the spread magnetic flux in the moulding
chamber is adjustable.

In other words, by changing the ratio of the first radius and
the second radius, the spread angular distribution of magnet-
ic flux lines may be changed and this will increase/decrease
the amount of magnetic flux lines running through the mould-
ing chamber and hence will increase/decrease the angle be-
tween two neighbouring magnetic flux lines. Thereby a posi-
tion of a magnetic focal point/region of the manufactured
flux focusing permanent magnet may be moved.

According to an exemplary embodiment of the present inven-
tion, the magnetic focal point respectively the magnetic fo-
cal region is located on the symmetry axis together with the
first centre and the second centre. At the same time, the
magnetic focal point is distanced from the first centre and
the second centre and is provided outside the second mould
part and at the same time outside the mould.

The "alignment of the spread magnetic flux" according to the
present invention may denote the amount of magnetic flux
lines and the spatial orientation of the magnetic flux lines
running through the moulding chamber. In other words, the
"alignment of the spread magnetic flux" may denote an angle
between adjacent magnetic flux lines inside the moulding
chamber.

According to a further embodiment of the invention, the third
mould part is made of a metal having a hardness higher than
400 HV.
The hardness higher than 400 HV according to the present application means that the material when tested by Vickers hardness test has a hardness of higher than 400 HV.

The basic principle of the Vickers test is to observe the ability of a material to withstand plastic deformation from a standardized source. HV is the Vickers pyramidal number and is calculated by the load over the surface.

The metal having a hardness higher than 400 HV is a very hard metal. During compacting a magnetic material inside the moulding chamber, high loads are acting on the third mould part. Hence, forming the third mould part from a metal having a hardness higher than 400 HV may have the advantage that a wearing of the third mould part may be minimized.

Particularly, the material of the third mould part has a magnetic polarization intensity of less than 0.6 T (Tesla). The magnetic polarization density characterizes a magnetic state of a material and is calculated as a magnetic moment of a volume. In other words the magnetic polarization density describes the density of permanent magnetic dipole moments in a magnetic material.

Forming the third mould part from a metal having a magnetic polarization intensity of less than 0.6 T may have the advantage that a magnetizing of the third mould part during magnetizing a permanent magnet material accommodated inside the moulding chamber may be minimized.

According to a further embodiment of the invention, the moulding chamber comprises a first side surface facing the first curved surface of the first mould part and a second side surface opposite to the first side surface. Furthermore, the moulding chamber is positioned in the third mould part such that each of two opposing corners of the first side surface, being positioned closest to the first curved surface of
the first mould part, has a distance to the first curved surface in a range of 4 mm to 10 mm, and/or such that a position of the second side surface being positioned closest to the second curved surface of the second mould part has a distance to the second curved surface of the second mould part in a range of 4 mm to 10 mm.

The first side surface of the moulding chamber is limited by a plurality, preferably four, side edges and a plurality of corners, particularly four corners. The moulding chamber is provided in the third mould part and the first side surface of the moulding chamber is positioned adjacent to the first curved surface. The two of the plurality of corners being positioned closest to the first curved surface are each distanced from the first curved surface. The distance is measured between a point on the first curved surface and the respective corner and is in the range of 4 mm to 10 mm. Thereby, a mould damage and poor conductivity may be prevented.

The second side surface of the moulding chamber may be spatially shaped. Advantageously, the second side surface is curved. A position of the second side surface being closest to the second curved surface of the second mould part is distanced to the second curved surface by a distance in the range of 4 mm to 10 mm. Thereby, a mould damage and poor conductivity may be prevented.

By providing all three of the above-defined distances in the range of 4 mm to 10 mm, a mould damage and poor conductivity and leakage may be even better prevented.

According to a further embodiment of the invention, the moulding chamber comprises a first side surface facing the first curved surface of the first mould part and a second side surface opposite to the first side surface. The first side surface is a first curved side surface and/or the second side surface is a second curved side surface. Furthermore, the first curved side surface and/or the second curved side
surface is designed in such a manner that a shrinkage of a sintered block which has been obtained by magnetizing, compacting and sintering a powder provable in the moulding chamber is compensated at least partially.

According to the present invention, preferably the first side surface and the second side surface are curved. Hence, the moulding chamber is provided with two curved side surfaces that will compensate for the shrinkage effects and reduce the machining on the final magnet block, after sintering.

According to an exemplary embodiment of the invention, the first side surface and the second side surface are curved such that, seen from an inside of the moulding chamber, the first side surface is convex and the second side surface is concave.

According to the present invention, the first curved side surface and/or the second curved side surface is designed in such a manner that a shrinkage of a sintered block which has been obtained by compacting and sintering a magnetic powder provable in the moulding chamber is compensated at least partially. In other words, unwanted deformation effects, which typically result from a shrinkage during sintering, can be compensated with pre-accounting by means of a properly shaped moulding chamber being different to the shape of the finally manufactured flux focusing permanent magnet. This may provide the advantage that expected and unwanted deformations can be compensated to a large extent. This holds true in particular for shrinkage effects which occur when the sintered permanent magnet cools down.

According to a further aspect of the invention there is provided a system for manufacturing a permanent magnet, particularly a flux focusing permanent magnet. The system comprises a mould. The mould comprises a first mould part comprising a first curved surface having a first radius, a second mould part comprising a second curved surface having a second
radius, wherein the first mould part and the second mould part are made of a ferromagnetic material. The mould further comprises a third mould part having a moulding chamber, wherein the third mould part is arranged between the first mould part and the second mould part, and wherein the first mould part and the second mould part are made of a different material with respect to the third mould part. The system further comprises (b) a first magnetic device positioned adjacent to the first mould part, and (c) a second magnetic device positioned adjacent to the second mould part, wherein a linear magnetic field between the first magnetic device and the second magnetic device is generatable by the first magnetic device and the second magnetic device, and wherein the first curved surface and the second curved surface are formed such that a magnetic flux through the first mould part, the second mould part and the third mould part is directed in such a manner that in the moulding chamber a spread magnetic flux is generatable.

Also the described system is based on the idea that a permanent magnet having flux focusing implemented magnetic properties, particularly a flux focusing permanent magnet, may be directly and cost-efficiently be manufactured in the described system.

With regard to the moulding chamber the first magnetic device and the second magnetic device are located at opposing sides. Additionally, the first magnetic device and the second magnetic device, called alignment coils, are both positioned outside the mould.

The first magnetic device and the second magnetic device are configured such that a linear magnetic field may be provable between the first magnetic device and the second magnetic device. The first magnetic device respectively the second magnetic device may be a magnetic coil. Particularly, the first magnetic device may be configured to be a north pole and the second magnetic device may be a south pole. It may be
understood that the first magnetic device may be configured to be a south pole and the second magnetic device may be configured to be a north pole.

By providing the above-described mould between the first magnetic device and the second magnetic device, the first curved surface and the second curved surface are formed such that a magnetic flux through the first mould part, the second mould part and the third mould part is directed in such a manner that in the moulding chamber a spread magnetic flux is generatable.

According to a further aspect of the invention there is provided a method for manufacturing a permanent magnet, particularly a flux focusing permanent magnet. The method comprises

(a) providing a mould. The mould comprises a first mould part comprising a first curved surface having a first radius, a second mould part comprising a second curved surface having a second radius, and a third mould part having a moulding chamber, wherein the third mould part is arranged between the first mould part and the second mould part, wherein the first mould part and the second mould part are made of a different material with respect to the third mould part, and wherein the first curved surface and the second curved surface are formed such that a magnetic flux through the first mould part, the second mould part and the third mould part is directed in such a manner that in the moulding chamber a spread magnetic flux is generatable. The method further comprises

(b) placing a powder of a magnetic material into the moulding chamber, (c) generating a magnetic field for aligning the powder being accommodating within the moulding chamber, wherein the magnetic field comprises the spread magnetic flux in the moulding chamber, (d) compacting the powder being accommodated within the moulding chamber, in the magnetic field, wherein the magnetizing and compacting resulting in a magnetized compacted block of the powder having spread magnetic flux lines. The method afterwards further comprises (e)
sintering and aging the un-magnetized, just magnetically aligned compacted block of the powder.

Also the described method is based on the idea that a flux focusing permanent magnet having flux focusing implemented magnetic properties may be directly and cost-efficiently be manufactured in the described system.

Typically, the step of (c) generating a magnetic field in order to obtain a magnetic alignment and the step of (d) compacting the powder are accomplished at least partially at the same time.

The powder of the magnetic material is placed into the moulding chamber and a magnetic field is applied. The applied magnetic field is adjusted such that the magnetic field inside the moulding chamber has a magnetic polarization intensity in the range of 0.8 T to 1.6 T.

The magnetic powder accommodated inside the moulding chamber is compacting with a density of 3.7 g/cm³ to 4.3 g/cm³ in the magnetic field.

In a subsequent step, the resulting flux focusing permanent magnet block is sintered and aged. After that the shape of the permanent magnet block is properly shaped according to the desired needs and the alignment direction of the magnetic grains of the flux focusing permanent magnet block are spread or with other words are radial.

According to another embodiment of the present invention, the compacting may be an isostatic pressing.

According to an embodiment of the invention, the powder comprises a rare earth material, in particular NdFeB (Neodymium Iron Boron). This may provide the advantage that very strong permanent magnets can be manufactured having a desired permanent magnet geometry and flux focusing properties.
In this respect it is mentioned that other compositions of the permanent magnet material may include ferrite and/or SmCo.

According to a further aspect of the invention there is provided a permanent magnet, particularly a flux focusing permanent magnet, being produced by carrying out a method as described above.

According to a further aspect of the invention there is provided an electromechanical transducer, in particular an electric generator. The electromechanical transducer comprises (a) a stator assembly and (b) a rotor assembly. The rotor assembly comprises a support structure and at least one flux focusing permanent magnet as described above.

The provided electromechanical transducer is based on the idea that it may be built up with a rotor assembly comprising a directly and cost-efficiently be manufactured flux focusing permanent magnet having flux focusing implemented magnetic properties.

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

The provided wind turbine, also denominated a wind energy installation, is based on the idea that the above-described electromechanical transducer allows to realize the wind turbine, with regard to the flux focusing permanent magnet being used, in a cost saving manner. This may contribute for improving the attractiveness of wind turbine technology for re-
generative power production compared to other technologies such as solar plants.

It has to be noted that embodiments of the invention have been described with reference to different subject matters. In particular, some embodiments have been described with reference to method type claims whereas other embodiments have been described with reference to apparatus type claims. However, a person skilled in the art will gather from the above and the following description that, unless other notified, in addition to any combination of features belonging to one type of subject matter also any combination between features relating to different subject matters, in particular between features of the method type claims and features of the apparatus type claims is considered as to be disclosed with this document.

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.

25 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 flux focusing permanent magnet produced in accordance with an embodiment of the invention.

Figure 4 shows a further flux focusing permanent magnet produced in accordance with an embodiment of the invention.
Figure 5 shows a further flux focusing permanent magnet produced in accordance with an embodiment of the invention.

Figure 6 shows a mould for manufacturing a flux focusing permanent magnet in accordance with an embodiment of the invention.

Figure 7 shows a mould for manufacturing a flux focusing permanent magnet in accordance with an embodiment of the invention together with a magnetic field generating structure.

**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.

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.

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.

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 130. The electromechanical transducer is a generator 130.

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 143 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 130 comprises a stator assembly 135 and a rotor assembly 140. In the embodiment described here the generator 130 is realized in a so called "inner stator - outer rotor" configuration, wherein the rotor assembly 140 surrounds the stator assembly 135. This means that non-depicted permanent magnets respectively magnet assemblies of the rotor assembly 140 travel around an arrangement of a plurality of non-depicted coils of the inner stator assembly 135 which coils produce an induced current resulting from picking up a time varying magnetic flux from the traveling permanent magnets.

According to the embodiment described here each permanent magnet assembly comprises at least three flux focusing permanent magnet devices which are particularly made from a NdFeB material composition.

Figure 2 shows in a cross sectional view a schematic representation of the generator 130. The generator 130 comprises a stator assembly 135. The stator assembly 135 comprises a stator support structure 237 comprising a stack of a plurality of lamination sheets and a plurality of stator windings 239 being accommodated within the stator support structure 237. The windings 239 are interconnected in a known manner by means of non-depicted electrical connections.

A rotor assembly 140 of the generator 130, which is separated from the stator assembly 135 by an air gap denominated with reference ag, comprises a rotor support structure 242 providing the mechanical base for mounting a plurality of flux focusing magnet segmentations 250. In Figure 2 the rotational
axis 110a of the rotor assembly 140 is denominated with reference numeral 230a.

In the exemplary embodiment described here at each angular position of the rotor assembly 140 there are arranged three flux focusing permanent magnets arranged next to each other. It is mentioned that in Figure 2 only three flux focusing segmentations 250 of one permanent magnet being assigned to one angular position are depicted for the sake of ease of illustration. In reality, depending on the dimension of the generator 130, a plurality of flux focusing magnet segmentations 250 are mounted to the rotor support structure 242. The flux focusing magnet segmentations 250 are preferably arranged in a matrix like structure around a curved surface area of the support structure 242 having a basically cylindrical geometry around the generator axis 240a.

As can be seen from Figure 2, the flux focusing magnet segmentations 250 are not mounted directly to the rotor support structure 242. Instead, there is provided a back plate 244 made from a ferromagnetic material, e.g. iron. The back plate 244 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.

Figure 3 shows a flux focusing permanent magnet 350 produced using a mould according to an embodiment of the invention and by a method in accordance with an embodiment of the invention.

The flux focusing permanent magnet 350 is magnetized in such a manner that there is given a spread angular distribution of magnetic flux lines 352. According to the embodiment described here each magnetic flux line 352 follows a straight magnetization line. The straight magnetization lines are angled or inclined with respect to each other in a fan like manner. In other words, the straight magnetization lines are spread. Specifically, the spread angular distribution of the
straight magnetization lines produces, in the region above a main surface 351 of the flux focusing permanent magnet 350, a focal point 354 being characterized by a local maximum of the magnetic field respectively the magnetic flux density produced by the flux focusing permanent magnet 350.

According to the exemplary embodiment described here the depicted magnetic flux line pattern is symmetric with respect to a symmetry axis 349. In this document the symmetry axis 349 is also denominated magnetic axis. The magnetic axis 349 is a normal axis to the main surface 351 and runs through the focal point 354.

As depicted in Figure 3, the main surface 351 is planar and in the cross sectional view of Figure 3, the flux focusing permanent magnet 350 is rectangular. Hence, the flux focusing permanent magnet 350 shown in Figure 3 is in a three-dimensional view a cuboid.

Figure 4 shows a flux focusing permanent magnet 450 produced using a mould according to an embodiment of the invention and by a method in accordance with an embodiment of the invention.

The flux focusing permanent magnet 450 is pre-magnetized in such a manner that there is given a spread angular distribution of magnetic flux lines 452. According to the embodiment described here each magnetic flux line 452 follows a straight magnetization line. The straight magnetization lines are angled or inclined with respect to each other in a fan like manner. In other words, the straight magnetization lines are spread. Specifically, the spread angular distribution of the straight magnetization lines produces, in the region above a main surface 451 of the flux focusing permanent magnet 450, a focal point 454 being characterized by a local maximum of the magnetic field respectively the magnetic flux density produced by the flux focusing permanent magnet 450.
As depicted in Figure 4, the main surface 451 is curved or arced and in the cross sectional view of Figure 4, the flux focusing permanent magnet 350 is shaped like a rectangular with one curved main surface 451. Hence, the flux focusing permanent magnet 450 shown in Figure 4 is in a three-dimensional view shaped like a loaf of bread.

Figure 5 shows a flux focusing permanent magnet 550 produced using a mould according to an embodiment of the invention and by a method in accordance with an embodiment of the invention.

The flux focusing permanent magnet 550 is magnetized in such a manner that there is given a spread angular distribution of magnetic flux lines 552. According to the embodiment described here each magnetic flux line 552 follows a straight magnetization line. The straight magnetization lines are angled or inclined with respect to each other in a fan like manner. In other words, the straight magnetization lines are spread. Specifically, the spread angular distribution of the straight magnetization lines produces, in the region above a main surface 555 of the flux focusing permanent magnet 550, a focal point 554 being characterized by a local maximum of the magnetic field respectively the magnetic flux density produced by the flux focusing permanent magnet 550.

As depicted in Figure 5, the main surface 555 is shaped. Particularly, the main surface 555 comprises three sub portions. The three sub portions are two curved sub portions 556 which are additionally inclined and the planar sub portion 557. Each of the two curved sub portions 556 interconnects one side surface 558 of the flux focusing permanent magnet 550 with the planar sub portion 557. Additionally, the planar sub portion 557 is parallel to another main surface 559 delimiting the flux focusing permanent magnet 550 on an opposite side with respect of the main surface 555. The planar sub portion 557 further intersect the magnetic axis 549 and the main surface 555 is symmetric to the magnetic axis 549. Fur-
ther, the flux focusing permanent magnet 550 is symmetric to the symmetry axis 549.

Figure 6 shows a mould 660 for manufacturing the flux focusing magnet segmentations 250 in accordance with an embodiment of the invention.

The mould 660 comprises a first mould part 661, a second mould part 662 and a third mould part 663. The third mould part 663 comprises a moulding chamber 664 located inside of the third mould part 663. Hence, the moulding chamber 664 is located inside the third mould part 663 such that each of the four sides of the moulding chamber 664 is distanced to the first mould part 661 and the second mould part 662, respectively.

The moulding chamber 664 comprises four sides, particularly a first side surface 665, a second side surface 667, a third side surface 668, and a fourth side surface 669. The first side surface 665 and the second side surface 667 are curved.

The first mould part 661 comprises a first curved surface 681 having a first radius 671 and the second mould part 662 comprises a second curved surface 682 having a second radius 672. The third mould part 663 comprises a third (curved) surface 683 having a third radius corresponding to the first radius 671 and a further third (curved) surface 684 having a further third radius corresponding to the second radius 672. The third surface 683 is opposite to the further third surface 684.

As may be seen in Figure 6, the third surface 683 is coupled to the first surface 681 and the further third surface 684 is coupled to the second surface 682. Hence, the first surface 681 and the third surface 683 are shaped correspondingly to each other and the second surface 682 and the further third surface 684 are shaped correspondingly to each other.
The first surface 681 comprises a first circle of curvature having a first centre 685 and the second surface 682 comprises a second circle of curvature having a second centre 686. A centre distance 687 is provided between the first centre 685 and the second centre 686. The centre distance 687 is such that the first circle of curvature and the second circle of curvature are nonconcentric. Therefore, the first centre 685 is positioned distanced by the centre distance 687 from the second centre 686. The second centre 686 is positioned on the magnetic axis 649 and on a surface of the second mould part 662 opposite to the second curved surface 682. The first centre 685 is also positioned on the symmetry axis 649 and inside the second mould part 662.

A width 689 of the moulding chamber 664 is larger than twice the second radius 672. Furthermore, the centre distance 687 is larger than 10 mm.

Figure 7 illustrates a system 790 for manufacturing the flux focusing magnet segmentations 250 in accordance with an embodiment of the invention.

The system 790 comprises a mould 760 as described in detail with reference to Figure 6. The system 790 further comprises a first magnetic device 791 being configured as a north pole and a second magnetic device 792 being configured as a south pole. It may be understood that the first magnetic device 791 may also be configured to be a south pole and the second magnetic device 792 may also be configured to be a north pole.

The magnetic flux through the first mould part 761, the second mould part 762 and the third mould part 763 is directed in such a manner that in the moulding chamber 764 the magnetic flux lines 752 are spread respectively are aligned in a fan like manner. The magnetic flux lines 752 in the moulding chamber 764 are spread.
Specifically, the spread angular distribution of the straight magnetizing lines 752 produces, in the region below the second mould part 762, a focal point/region 754 being characterized by a local maximum of the magnetic field respectively the magnetic flux density.

According to the exemplary embodiment described here the depicted magnetic flux line pattern is symmetric with respect to a symmetry axis 749. The magnetic axis 749 is a normal axis to a main surface 792a of the second magnetic device 792 and a main surface 791a of the first magnetic device 791. Additionally, the magnetic axis 749 runs through the focal point 754.

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 should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.
CLAIMS:

1. A mould (660, 760) for manufacturing a permanent magnet (350, 450, 550), particularly a flux focusing permanent magnet (350, 450, 550), the mould (660, 760) comprising
   a first mould part (661) comprising a first curved surface (681) having a first radius (671);
   a second mould part (662) comprising a second curved surface (682) having a second radius (672);
wherein the first mould part (661) and the second mould part (662) are made of a ferromagnetic material, and
   a third mould part (663) having a moulding chamber (664);
wherein the third mould part (663) is arranged between the first mould part (661) and the second mould part (662);
wherein the first mould part (661) and the second mould part (662) are made of a different material with respect to the third mould part (663);
wherein the first curved surface (681) and the second curved surface (682) are formed such that a magnetic flux through the first mould part (661), the second mould part (662) and the third mould part (663) is directed in such a manner that in the moulding chamber (664) a spread magnetic flux is generateable.

2. Mould (660, 760) according to claim 1,
   wherein the third mould part (663) comprises a third surface (683) which is curved and has a third radius corresponding to the first radius (671) of the first curved surface (681), and
   a further third surface (684) which is opposed to the third surface (683);
wherein the further third surface (684) is curved and has a further third radius corresponding to the second radius (672) of the second curved surface (682);
wherein the third surface (683) of the third mould part (663) is coupled to the first curved surface (681) of the first mould part (661) and the further third surface (684) of the
third mould part (663) is coupled to the second curved surface (682) of the second mould part (662).

3. Mould (660, 760) according to claim 1 or 2,

wherein the first curved surface (681) comprises a first circle of curvature having a first centre (685);
wherein the second curved surface (682) comprises a second circle of curvature having a second centre (686);
wherein a centre distance (687) between the first centre (685) and the second centre (686) is adapted such that an alignment of the spread magnetic flux in the moulding chamber (664) is adjustable.

4. Mould (660, 760) according to any one of the claims 1 to 3,

wherein a ratio of the first radius (671) and the second radius (672) is adapted such that an alignment of the spread magnetic flux in the moulding chamber (664) is adjustable.

5. The mould (660, 760) according to any one of the claims 1 to 4,

wherein the third mould part (663) is made of a metal having a hardness higher than 400 HV.

6. The mould (660, 760) according to any one of the claims 1 to 5,

wherein the moulding chamber (664) comprises a first side surface (665) facing the first curved surface (681) of the first mould part (661) and a second side surface (667) opposite to the first side surface (665);

wherein the moulding chamber (664) is positioned in the third mould part (663)
such that each of two opposing corners of the first side surface (665), being positioned closest to the first curved surface (681) of the first mould part (661), has a distance to the first curved surface (681) in a range of 4 mm to 10 mm, and/or
such that a position of the second side surface (667)
being positioned closest to the second curved surface (682)
of the second mould part (662) has a distance to the second
curved surface (682) of the second mould part (662) in a
range of 4 mm to 10 mm.

7. The mould (660, 760) according to any one of the claims 1
to 6,
wherein the moulding chamber (664) comprises a first side
surface (665) facing the first curved surface (681) of the
first mould part (661) and a second side surface (667) oppo-
site to the first side surface (665); and
wherein the first side surface (665) is a first curved side
surface and/or the second side surface (667) is a second
curved side surface;
wherein the first curved side surface and/or the second
curved side surface is designed in such a manner that a
shrinkage of a sintered block which has been obtained by com-
pacting a powder provable in the moulding chamber (664) is
compensated at least partially.

8. A system (790) for manufacturing a permanent magnet (350,
450, 550), particularly a flux focusing permanent magnet
(350, 450, 550), the system (790) comprising
a mould (660, 760) comprising
a first mould part (661) comprising a first curved
surface (681) having a first radius (671);
a second mould part (662) comprising a second
curved surface (682) having a second radius (672);
wherein the first mould part (661) and the second mould
part (662) are made of a ferromagnetic material, and
a third mould part (663) having a moulding chamber
(664);
wherein the third mould part (663) is arranged between
the first mould part (661) and the second mould part (662);
wherein the first mould part (661) and the second mould
part (662) are made of a different material with respect to
the third mould part (663);
wherein the system (790) further comprises

- a first magnetic device (791) positioned adjacent to the first mould part (661); and
- a second magnetic device (792) positioned adjacent to the second mould part (662);

wherein a linear magnetic field between the first magnetic device (791) and the second magnetic device (792) is generatable by the first magnetic device (791) and the second magnetic device (792);

wherein the first curved surface (681) and the second curved surface (682) are formed such that a magnetic flux through the first mould part (661), the second mould part (662) and the third mould part (663) is directed in such a manner that in the moulding chamber (664) a spread magnetic flux is generatable.

9. A method of manufacturing a permanent magnet (350, 450, 550), particularly a flux focusing permanent magnet (350, 450, 550), the method comprising

- providing a mould (660, 760) comprising
  - a first mould part (661) comprising a first curved surface (681) having a first radius (671);
  - a second mould part (662) comprising a second curved surface (682) having a second radius (672); and
  - a third mould part (663) having a moulding chamber (664);

  wherein the third mould part (663) is arranged between the first mould part (661) and the second mould part (662);
  wherein the first mould part (661) and the second mould part (662) are made of a different material with respect to the third mould part (663);

wherein the first curved surface (681) and the second curved surface (682) are formed such that a magnetic flux through the first mould part (661), the second mould part (662) and the third mould part (663) is directed in such a manner that in the moulding chamber (664) a spread magnetic flux is generatable;

wherein the method further comprises
placing a powder of a magnetic material into the moulding chamber (664);
generating a magnetic field for aligning the powder being accommodating within the moulding chamber (664); wherein the magnetic field comprises the spread magnetic flux in the moulding chamber (664);
compactting the powder being accommodated within the moulding chamber (664), in the magnetic field; the aligning and compacting resulting in an aligned compacted block of the powder having spread magnetic flux lines;
afterwards sintering and aging the aligned compacted block of the powder.

10. The method according to claim 9, wherein the powder comprises a rare earth material, in particular NdFeB.

11. A permanent magnet (350, 450, 550), particularly a flux focusing permanent magnet (350, 450, 550), being produced by carrying out a method according to claim 9 or 10.

12. An electromechanical transducer (130), in particular an electric generator, the electromechanical transducer (130) comprising a stator assembly (135), and a rotor assembly (140) comprising a support structure and at least one permanent magnet (350, 450, 550) according to claim 11, wherein the permanent magnet (350, 450, 550) is mounted to the support structure.

13. A wind turbine (100) for generating electrical power, the 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
an electromagnetic transducer according to claim 12, wherein the electromechanical transducer (130) is mechanically coupled with the wind rotor (110).