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EP-A2- 1 437 287
WO-A1-2014/207858
WO-A1-2018/193095
WO-A1-2018/193096
DE-A1- 102011 013 885
DE-A1- 102013 009 776
FR-A1- 2 966 301
US-A1- 2018 183 298
US-B1- 6 392 905
US-B2- 9 694 845
JIA HONGYUN ET AL: "Design and analysis of a bearingless doubly salient permanent magnet machine", 2017 20TH INTERNATIONAL CONFERENCE ON ELECTRICAL MACHINES AND SYSTEMS (ICEMS), IEEE, 11 August 2017 (2017-08-11), pages 1 - 5, XP033161409, DOI: 10.1109/ICEMS.2017.8056432
IYAMA Y ET AL: "A novel middle-point current-injection type bearingless motor for vibration suppression", ENERGY CONVERSION CONGRESS AND EXPOSITION (ECCE), 2010 IEEE, IEEE, PISCATAWAY, NJ, USA, 12 September 2010 (2010-09-12), pages 1693 - 1698, XP031787325, ISBN: 978-1-4244-5286-6

Description

The present invention concerns electric motors and, in particular, electric motors for high rotational speeds. The electric motors may be used universally. However, particular reference is made to the use in a heat pump.

- 5 EP 2 549 113 A2 discloses a magnetic rotor and a rotary pump with a magnetic rotor. The rotor for conveying a fluid in a pump housing is drivable and storable in a magnetic and contactless manner within a stator of the rotation pump. In addition, the rotor is encapsulated by an outer encapsulation comprising fluorinated hydrocarbon. Within the encapsulation, the rotor includes a
10 permanent magnet encased in a metal jacket. The rotary pump includes a pump housing with an inlet for supplying a fluid and an outlet for dissipating the fluid. For example, the fluid is a chemically aggressive acid with a proportion of a gas, e.g. sulfuric acid with ozone. To convey the fluid, a magnetic rotor is stored in a magnetic and contactless manner in the pump housing.
- 15 The rotor is further provided with a magnetic drive that comprises electric coils. The stator is formed with laminated iron that is in operative magnetic connection with the permanent magnet of the rotor. The drive is configured as a bearingless motor in which the stator is designed as a bearing stator and a drive stator at the same time. The rotor is configured as a disc armature, the
20 axial height of the rotor being smaller or equal to half a diameter of the rotor.

- The dissertation ETH Nr. 12870, "Der lagerlose Scheibenmotor" (the bearingless disc motor), N. Barletta, 1998, discloses disc motors using magnet bearings. Magnetic bearings operate completely free of contact, wear, maintenance and lubrication. To actively stabilize a degree of freedom, two control-
25 lable electromagnets including electronic drive are needed. The bearingless disc motor is used within a bearingless blood pump as a bearingless disc motor with an active axial bearing, as a miniature disc motor, or as a bearingless biological reactor. By combining passive reluctance magnetic bearings and a bearingless motor, it is possible to fully store a disc rotor with only two actively
30 stabilized radial degrees of freedom. Requirements for a large air gap needed

in hermetic systems are met by choosing a bearingless synchronized motor that permanent-magnetically excited. A bearingless disc motor suitable for driving an axial pump for cardiac support is designed for speeds of 30.000 revolutions per minute, resulting in a smaller structural size.

- 5 Commercial electric disc motors are also known as “pancake motors”. The motor concept illustrated in the two previous references is characterized by the stator extending around the motor. Such motors are also known as inrunners.

10 With the inrunner concept, there is the problem that the stator has to be larger than the rotor, i.e. that the size and the configuration of the rotor is limited by the stator housing, or that the rotor dominates the configuration of the stator. This limits the area of application of such a disc motor configured as an inrunner.

15 In addition, disc motors are fundamentally subject to the problem that the rotor, regardless of whether it is designed as an inrunner or an outrunner, is subjected to pressure differentials or pressures in certain directions. These pressures cause a bearing to be stressed in the direction of the pressure acting on the rotor, thus increasing wear, or if the deflection of the rotor is allowed, the rotor will be deflected in that direction and, thus, clearances have to
20 be provided for that deflection. In particular, if the pump is used to pump a medium from a pressure area with a first pressure to a pressure area with a second pressure, or to generate such a pressure difference in the first place, elaborate constructional measures have to be taken so as to achieve a wear resistance needed or to provide a clearance for any deflection that occurs.

- 25 A disadvantage of electric motors, and in particular electric motors that are operated in warm environments or that are intended to achieve high performance, is the omnipresent generation of heat. High temperatures in electric motors affect, on the one hand, the permanent magnets typically arranged at the rotor. Thus, if the stator of a motor becomes too warm, the heat is transferred via the motor gap to the rotor and the permanent magnets located
30 there, with all the associated problems. On the other hand, heating of the sta-

tor itself is also critical. The stator is typically provided with coils. Heating of the coils may lead to a high thermal stress. This high thermal stress in the coils may lead to fatigue of the coil wire insulation in the long run. In addition, problems with respect to a delamination of the sheet metal body, i.e. the stator
5 body consisting of a sheet metal body, may occur. Furthermore, due to increased temperatures or high continuous thermal stress, deformations and/or warping in the stator may lead to the motor no longer running as smoothly as it should or could.

Particularly in the case of high-speed motors with rotational speeds above
10 30.000 rpm, even if a lower pressure prevails in the motor gap compared to the ambient pressure, the friction with the gas located there is nevertheless large enough that the permanent magnets of the rotor that are directly arranged in the motor gap are subject to this high friction energy in the motor gap and thus to the heat generated there. Permanent magnets have the prop-
15 erty that their functionality/magnetization will deteriorate if they become too hot. In certain cases, this damage is even non-reversible and can lead to complete failure of the entire electric motor. However, it is also of great importance for all parameters during operation of the electric motor that the permanent magnets are kept in an optimum temperature range, which is by no
20 means guaranteed due to the high heat generation caused by the friction in the motor gap.

EP 2 975 731 A2 discloses a disc rotor for an electric machine with a circular or annular disc-like armature body and permanent magnets arranged on the armature body adjacent to each other in the circumferential direction. In par-
25 ticular, the armature body includes a first material for dissipating heat in a radial direction, and further includes in the area of the permanent magnets a second electrically non-conductive material. Furthermore, in order to reliably hold the permanent magnets at the carrier element, the carrier element is provided with a surrounding edge at which the permanent magnets can be sup-
30 ported toward the outside. Like the area in which the permanent magnets are inserted, this edge is made of a material with good thermal conductivity, such as aluminum.

In press release 107/2014 of Oct. 24, 2014, Vienna University of Technology reports on electric motors that do not require error-prone sensors. Normally, sensors measure the position of the magnet in such electric motors with magnetic bearings and forward the data to control electronics that control the electromagnets. However, such sensors have the same problems. The sensor technology causes costs, needs space, and is particularly prone to failure. Thin wires and fine solder joints on the sensors fail easily and are therefore responsible for many motor failures. The synchronized-machine system developed at Vienna University of Technology takes a different approach. Here, the cables present anyway are used to supply power to the electromagnet. Short electrical test impulses are sent through the cables, and the current position of the rotor may be inferred from the electrical response to them. The electrical pulses needed for this only last a few millionths of a second. Appropriately designed electronics adjust to the rotational speed of the motor and control the electromagnets.

In press release 27/2015 of Vienna University of Technology, floating rotors are illustrated, e.g. in electric motors, using a sensorless control of magnetic bearings. Contactless bearings are particularly important where friction losses have to be at a minimum, and where, such as in the case of vacuum pumps, abrasion has to be avoided at all costs. Magnetic bearings are also used in drive shafts that have to achieve a particularly high rotational speed. The position of the rotor is electronically fixed in magnetic bearings. Electromagnets used for readjusting the rotor position are also used as sensors at the same time. The rotor and the electromagnetic coil are coupled by means of the magnetic field. Through the measurement of the temporal variation of the current in the coil, the position of the rotor may be calculated.

What is possibly problematic about such approaches is that additional signals have to be used so as to measure the position of the rotor in the magnetic bearing. These ultra-short test pulses have to be generated and evaluated. US 9,694,845 B2 discloses an engine control device, a power steering system and a vehicle with a redundancy-concept for power steering with two coil groups with different star points.

The US 6,392,905 B1 discloses a device and a circuit for reducing a battery ripple current in a multi-inverter system.

The academic subject publication D3: "Jia Hongyun et al: "Segin and analysis of a bearingless doubly salient permanent magnet machine" reveals a bearingless permanent magnet machine.

The academic subject publication D4: Ilyama Yet al.: „A novel middle-point current-injection type bearingless motor for vibration suppression" discloses a bearingless motor for vibration suppression.

DE 102013009776 A1 discloses a motor drive system with a brushless motor having coils divided into a group A and a group B.

US 2018/183298 A1 discloses a design for the development of various bearingless motors.

The object of the present invention is to create a more efficient and fail-safe concept for an electric motor.

This object is achieved by an electric motor according to patent claim 1 or a method for producing an electric motor according to patent claim 20 or a method for operating an electric motor according to patent claim 21.

An electric motor according to an exemplary embodiment includes a rotor and a stator. The stator has pole feet, with coils being wound around the pole feet. A pole foot encompasses a circular sector smaller than a circular sector encompassed by a permanent magnet. The coils wound around the pole feet are divided into two groups. A first group of the coils is electrically connected to each other via a first star point. In addition, a second group of coils is electrically connected to each other via a second star point, wherein the two star points are electrically insulated from each other.

Furthermore, a coil of the first group is arranged between two coils of the second group. A controller is provided so as to apply drive signals to the coils of

the first group of coils in order to provide the rotor with a torque with respect to the stator. In addition, the controller is configured to apply a control signal that differs from the drive signals to at least one coil of the second group of coils.

5 The driving of the coils of the second group of coils may be done completely independently of the driving of the coils of the first group since the two groups of coils are separated from each other due to the fact that they have different star points. Applying a potential to a coil of the first group, e.g. the group that is used for driving the motor in a certain time interval, essentially has no effect on a coil of the second group of coils. The reason for that is that the two star
10 points of the groups of coils are separated from each other, i.e. electrically insulated or, depending on the implementation, even fully galvanically separated from each other. Furthermore, since the arrangement and the dimensions of the pole feet wound around the coils are configured with respect to the permanent magnets such that a pole foot encompasses a circular sector
15 that is smaller than a circular sector of the permanent magnets, there will be the case that only one groups of the two groups of coils, i.e. one star point group, is needed to drive the motor.

On the other hand, the second star point group is available for any other action of the motor. Typically, a group of coils that were the drive coils in a first
20 time interval become in the second time interval the group of so-called “follower coils”, which do not or only slightly contribute to the generation of a torque in the electric motor. Therefore, there is great freedom regarding the driving of these “follower coils” in the time interval in which these coils do not contribute to driving the electric motor.

25 One possibility of driving the follower coils, i.e. the second group of coils are the drive coils in this time interval, is a rotational speed control. Namely, the voltage signal needed for the torque may be applied to the second group of coils during the first time interval at a certain switch-on time, wherein this switch-on time is freely adjustable and wherein a change of the switch-on time
30 directly affects the current that flows in the coil, if the coil contributes to driving. After the two groups of coils are galvanically separated from each other, for example, due to the fact that they have different star points, the driving of

the coils with voltages is freely adjustable in the interval when the coils do not contribute to the drive, but immediately contributes to the drive when the coils contribute to the drive, i.e., when they are near a gap between two permanent magnets. By previously setting the current through a coil in advance simply on
5 the basis of the switch-on time of the voltage applied at this coil in the time interval in which the coil is only the follower coil, the coil is, in a sense, already rendered ready so as to then be optimally energized in the interval in which it contributes to the drive of the motor.

An alternative way of driving the follower coil is to provide a closed-loop position control for a magnetic bearing. If the motor is operated as a contactless-
10 supported motor with a magnetic bearing, the follower coils may easily be used for the closed-loop position control of the magnetic bearing. By sensing the currents in the coils currently driving the motor, the position of the rotor relative to the stator may be inferred so as to achieve a control signal for the
15 follower coils in the same time interval or in the next time interval. Since the follower coils do not contribute to the drive, i.e. due to the fact that they have a different star point than the drive coils, they may be controlled with voltages/currents through which a closed-loop position control is achieved in that, e.g., two opposite coils of the stator are each provided with a positive and a
20 negative reference potential, or a positive potential and ground. Thus, a force is exerted onto the rotor, since, due to this bipolar driving, an attraction is generated on one side between the follower coil and the permanent magnet opposite to it, while, on the other side, a repulsion or a comparatively small attraction is generated on the opposite side between the follower coil and the
25 permanent magnet opposite to this coil. This force vector generated leads to a change in the position of the rotor and to a corresponding compensation of a positional deviation of the rotor in order to stabilize the contactless-supported electric motor, i.e. to electronically fix the same.

Other possibilities, or applications, of the electrical driving of the follower coils
30 in the interval in which the follower coils do not contribute to the drive of the motor may also be used and may possibly be combined with the application possibilities of the rotational speed control and the closed-loop position con-

trol. The rotational speed control and the closed-loop position control may also be combined with each other during operation. For example, if it is determined that the closed-loop position control is currently not required since the rotor is running in a stable manner with respect to the stator, it may be possible to

5 switch from the closed-loop position control mode to the rotational speed control mode so as to perform a requested speed increase or speed reduction, for example. For various reasons, a deliberate positional change from an optimal position may also have to be performed, e.g., to break the motor or to perform other measures. All these measures may easily be performed at the follower

10 coils, since an energization, or a supply of the corresponding follower coils with voltages, does not have any effect on the supply of the drive coils of the corresponding other group of coils with drive signals.

Embodiments of the present invention will be detailed subsequently referring to the appended drawings, in which:

15 FIG. 1 shows a schematic top view of a motor with an external rotor with permanent magnets and an internal stator with coils;

FIG. 2A shows, in a table, an illustration of the use of different coil groups in different time intervals as drive coils or follower coils;

FIG. 2B shows, in a table, an illustration of the driving and the selection of the

20 drive coils of FIG. 1;

FIG. 3 shows a schematic illustration of the relatively arranged coil groups with the different star points **1** and **2**;

FIG. 4 shows an electric circuit for a coil connection;

FIG. 5 shows a schematic illustration of the two star point groups in a corre-

25 sponding controller;

FIG. 6 shows an illustration of the complete driving for the four drive coils or the four follower coils in the embodiment shown in FIG. 1;

FIG. 7 shows time diagrams for the currents measured for the individual coils so as to illustrate a rotational speed control via the switch-on time in the “neutral” interval;

FIG. 8 shows driving of the drive coils with a single driving potential MM;

- 5 FIG. 9 shows driving of the follower coils so as to achieve a closed-loop position control in a corresponding direction;

FIG. 10 shows diagrams of currents in coils for sensing a rotor offset;

FIG. 11 shows a flow diagram for illustrating the steps performed for the closed-loop position control in an embodiment;

- 10 FIG. 12 shows an overview illustration for an example of a maximum motor gap and the corresponding driving for the closed-loop position control;

FIG. 13 shows, in a table, an illustration for sensing the position of the rotor offset and the corresponding driving for the closed-loop position control due to a temporal change of the coil currents;

- 15 FIG. 14 shows a schematic cross section for a heat pump with an inventive electric motor comprising the two star points.

- FIG. 1 shows a top view of an electric motor. The electric motor comprises a rotor **100** arranged on the outer side in FIG. 1. Thus, the example shown in FIG. 1 is an outrunner. However, the present invention is equally applicable to an inrunner in which the stator is arranged around the rotor and thus the rotor is arranged internally relative to the stator. In the following, however, the present invention is illustrated only by way of example with reference to the outrunner. However, the invention is readily transferrable and applicable to inrunners.
- 20

- 25 The rotor **100** includes a first number of permanent magnets **101**, **102**, **103**, **104**, with each permanent magnet including a first circular sector. The circular sector in the embodiment with four permanent magnets shown in FIG. 1 is in each case 90°, or an angle that is slightly smaller, since,

as is exemplarily illustrated in FIG. 1, after the permanent magnets are separated from each other and are differently polarized, so that, e.g., the permanent magnet **102** has a north pole toward the motor gap, whereas the permanent magnet **101** or **103** has its south pole toward the motor gap. Although FIG. 1 shows a rotor with four permanent magnets, rotors with three or more than four permanent magnets may easily be used. It is advantageous that each permanent magnet includes the essentially same circular sector so that, when using three permanent magnets, e.g., each permanent magnet would encompass 120°, or slightly less than 120°, e.g., whereas in the use of eight permanent magnets, each permanent magnet would encompass approximately 45°.

The electric motor further includes a stator **200** with a second number of pole feet, shown in dashed lines in FIG. 1 and denoted by circled numerals {circle around (1)}, {circle around (2)}, {circle around (3)}, {circle around (4)}, {circle around (5)}, {circle around (6)}, {circle around (7)}, {circle around (8)}, these circled numerals also denoting corresponding coils wound around the pole foot. There is a second number of pole feet. In the example shown in FIG. 1, the second number of pole feet is greater than the first number of permanent magnets on the rotor. In particular, eight pole feet are used and therefore eight coils, while four permanent magnets are used. However, other ratios may also be used, provided that the number of the pole feet is larger than the number of the permanent magnets.

Accordingly, each pole foot, or each coil wound around the corresponding pole foot, encompasses a second circular sector smaller than the first circular sector encompassed by the permanent magnets.

In particular, a first group of coils **A1**, **A2**, **A3**, **A4** is electrically connected to each other via a first star point, as is shown in FIG. 3. The first group of coils is denoted by **301**, **302**, **303**, **304**. The first star point SP is shown at **311**. In addition, a second group of coils **L1**, **L2**, **L3**, **L4**, in FIG. 3 also denoted by **321**, **322**, **323**, **324**, is connected to a second star point SP2, denoted by **331**. The second star point **331** is electrically insulated from the first star point **311**. Further, as is shown in FIG. 3 and as can also be inferred from FIG.

1, a coil of the first group of coils is arranged between two coils of the second group of coils.

In addition, a controller **500**, shown in FIG. 5, is provided so as to apply drive signals to the coils of the first group of coils, i.e. the drive coils, so as to provide the rotor with a torque relative to the stator. The controller **500** further includes a functionality for performing the follower control, i.e. to apply a control signal that differs from a drive signal to at least one coil of the second group of coils, which do not contribute to the drive of the motor. For example, the control signal that may be applied to one coil of the second group of coils is a control signal for opening a switch so as to disconnect a reference potential that has been applied in the preceding time interval, for example. Alternatively, the control signal may control signal applied to a switch so as to ground a connection of a coil that is not connected to the star point. Alternatively, the control signal may also be a control signal at a switch so as to apply a reference potential that has previously not been applied to a coil. However, the control signal may also include a voltage at one or several coils or a current through a coil or currents through several coils for the drive coils and the follower coils.

Advantageously, for the rotational speed control, a reference potential is applied at a certain point in time, based on of which, in case of a known current rise, a certain current flows through the coil at the start of the next interval in which the follower coil again becomes a drive coil. If the switch-on time is selected to be earlier, the time of the rise until the coil again becomes the drive coil is larger, and the current will be higher so as to increase the rotational speed. However, if the switch-on time is selected to be later in the time interval in which the coil is not the drive coil, the current will be smaller, and there will be a gradual decrease of the rotational speed.

In alternative embodiments, applying at least one coil of the second group of coils with a control signal is a control for the closed-loop position control. Here, at a certain coil of the, e.g., four coils of the second group of coils, a signal may control a switch such that a reference potential is applied to the coil, while a ground potential or a negative reference potential is applied at a coil ar-

ranged opposite thereto, for example. This exerts a force on the rotor to vary the position of the rotor such that an offset of the rotor relative to the stator, or an unevenly large motor gap, is evened out, or the offset is compensated or eliminated.

5 FIG. 2A shows, in a table, an illustration as to which coils are the drive coils and which coils are the follower coils at a certain interval. In the state of the rotor **100** relative to the stator **200** shown in FIG. 1, the first group of coils **A1**, **A3**, **A2**, **A4**, also denoted by **1**, **3**, **5**, **7**, is the group of drive coils, since the coils are each opposite to a boundary between two oppositely polarized per-

10 manent magnets. On the other hand, the second group of coils **L2**, **L3**, **L4**, **L1**, also denoted by **2**, **4**, **6**, **8**, does not sense any magnetic field change. Thus, this group of coils does not contribute to the drive. This is true for the interval **k**. For the interval **k+1**, the rotor has reached a certain rotation so that the boundary between two oppositely polarized permanent magnets is no longer

15 opposite the coil **A2**, but opposite the coil **L3**. Thus, the coil **L3** becomes the drive coil, and the coil **A2** and the coil **A3** become follower coils in this time interval. This is illustrated in the second line of the table of FIG. 2A. If the rotor has then continued to rotate so that the rotor is arranged in such a way that the transition between two oppositely polarized permanent magnets is again

20 opposite the drive coil **A3**, e.g., the first group of coils is again the group of drive coils and the second group of coils are the follower coils. This is shown at the interval **k+2**. Thus, in the embodiment shown in FIG. 2A, an interval has a temporal length that is one fourth of the temporal length needed for an entire revolution of the rotor around the stator.

25 FIG. 2B shows, in a table, a summary of the driving and the selection of the drive coils. For example, in the interval **k?1**, the coils **3**, **7** are positively connected, and the coils **1**, **5** are on a negative voltage, or on ground. Then, in interval **k**, the coils **4**, **8** are positive, and the coils **2**, **6** are on a negative voltage or on ground. Then, in the subsequent interval **k+1**, the coils **5**, **1** are posi-

30 tive, and the coils **7**, **3** are negative, or on ground. In the subsequent interval **k+2**, the coil **6**, **2** are positive, and the coils **4**, **8** are negative, and in the interval **k+3**, the coils **3**, **7** are positive, and the coils **1**, **5** are negative or on

ground. The last line of the table in FIG. 2B shows the follower coils whose drive signals may be selected as desired, since they do not affect the respectively other coil group due to the different star points for the coil groups. In the interval $k+4$, there is the same situation as in the interval k , and so on. This achieves that the rotor rotates with respect to the stator, as is known for such rotational field machines.

FIG. 3 shows the arrangement of the coils of the different groups such that one coil of the one group is arranged between two coils of the other group. FIG. 4 shows an embodiment for a switch element that may be used to control a coil. A control potential **400**, denoted by $U_{\text{sub},n}$, may be applied between a positive connection and a ground connection. In addition, there is a first switch **L1**, denoted by **401**, and a second switch **L2**, denoted by **402**. In addition, in an embodiment, the switch **S2** may be bypassed, for example with a freewheeling diode **403**. A corresponding freewheeling diode, shown in dashed lines in FIG. 4, may also bypass the switch **S1** such that the reverse direction of the diode is as shown in dashed lines in FIG. 4.

The switch element drawn in FIG. 4 is advantageously arranged at each coil connection in FIG. 3, with each coil connection of the first group advantageously having its own reference potential and therefore also its own ground potential, such that, overall, each star point group has its own reference potential and its own ground potential. As is shown in FIG. 5, this schematically results in a first star point group **501** with four coils and eight switches, and a second star point group **502** with four coils and four switches, all controlled by the controller **500**. In particular, the controller **500** is configured to provide all control signals for the corresponding switches **S1**, **S2** for each coil connection.

Furthermore, particularly if the follower coils are each used for the closed-loop position control, each star point group is provided with corresponding current sensors so as to sense the currents in the coils of the drive group, and to determine and to transfer, depending on the sensed currents, the closed-loop position control signals, which are in turn control signals to corresponding switches, in the same time interval or in the next time interval.

FIG. 6 shows a complete circuit with coils **301**, **302**, **303**, **304**, and switch groups **S11**, **S12** for the first coil **301**, **S21**, **S22** for the second coil **302**, **S31**, **S32** for the third coil **303**, and **S41**, **S42** for the fourth coil **304**. In particular, it is advantageous to use only a single reference potential $U_{sub.M}$. This reference potential is present between a connection **600** and a ground connection **601**. The switch **S41** for the fourth coil **304**, the switch **S11** for the first coil **301**, the switch **S21** for the second coil **302**, and the switch **S31** for the third coil **303** are connected at a first node **602**. For clarity, this node **602** is drawn multiple times in FIG. 6. Furthermore, the respective second switch is attached in an intermediate node, denoted by **604**, e.g., as is shown at **604** for **S42**. The second switch **S32** is attached at the intermediate node **605**, i.e. between this intermediate node **605** and the ground potential **601**. In addition, the switch **S22** is attached at a further intermediate node **606**, i.e. between this intermediate node and the mass. In addition, the switch **S12** is also connected between an intermediate node **607** and the ground potential **601**.

Thus, each coil has a switch to the reference potential and a further switch to the ground potential at the connection that is not connected to the star point SP, wherein the respective intermediate node, e.g. the intermediate node **604**, **605**, **606**, **607**, is exactly this coil connection that is in each case not connected to the star point. In addition, at least every second switch, e.g. **S12**, **S22**, **S32**, **S42**, advantageously includes a freewheeling diode **611**, **612**, **613**, and **614**, respectively. In addition, a current sensor, denoted by **621** for the first coil, **622** for the second coil, **623** for the third coil, and **624** for the fourth coil, is provided for each coil.

Each current sensor measures a current through the corresponding coil, i.e. **11**, **12**, **13**, **14**. For example, a resistor with a known magnitude may be used as a current sensor, wherein the voltage dropped across that resistor is measured to sense the current. Alternatively, a Hall current element or the like may be provided.

The circuit shown in FIG. 6 is implemented advantageously in exactly the same way for the first star point group **501** and for the second star point group **502**, however, advantageously using different voltage sources to supply

the reference voltage $U_{\text{sub.M}}$ between the connections **600** and **601**, and advantageously even using galvanically separated ground potentials, and, however, wherein at least the two star points of the two circuits are electrically insulated from each other. For example, insulation resistances of 1 k Ω may
 5 already be sufficient in certain embodiments. However, much higher insulation resistances in the range of more than 10 M Ω or even 100 M Ω are advantageous in order to achieve true galvanic separation between the two star point groups in such a way that as little interference as possible takes place between the drive control by a first star point group and the follower control by
 10 the second star point group.

FIG. 8 shows an advantageous circuit of the first star point group for the drive. In particular, the coils **A1**, **A2**, **A3**, **A4** are connected as is shown in FIG. 8. Thus, a voltage that is equal to the reference voltage $U_{\text{sub.M}}/2$ is present at the coils **A1**, **A3**. In addition, a voltage that is equal to the negative half reference voltage $U_{\text{sub.M}}/2$ is present at the two other coils **A4**, **A2**. In addition,
 15 the star point **SP1** is on a potential $U_{\text{sub.M}}/2$ with respect to the ground.

With regard to the switch control, the circuit the drive exemplarily shown in FIG. 8 means the following for a certain interval, namely for the interval $k+1$ of FIG. 2B. The switch **S41** is open and the switch **S42** is closed. On the other
 20 hand, the switch **S11** of FIG. 6 is closed, while the switch **S12** is open. In addition, the switch **S31** of FIG. 6 is closed, while the switch **S32** is open. In addition, the switch **S22** is closed, while the switch **S21** is open. This results in the voltage situation of the interval $k+1$ of FIG. 2B to achieve a drive control.

On the other hand, FIG. 9 shows an exemplary circuit for a closed-loop control
 25 in the direction **R** in the schematic coordinate system drawn in the upper part of FIG. 9. The closed-loop control along the direction **R** represents a closed-loop control in the negative x direction and/or positive x direction, and the negative y direction and/or positive y direction, as is illustrated by the arrow **901**. To this end, one of the coils **L1**, **L3** is connected to the ground, while
 30 the respectively other coil is connected to the reference potential $U_{\text{sub.M}}$. The two other coils **L2**, **L4** are open when closed-loop control is to take place along the direction **901**. Again considering the circuit in FIG. 6, this means

that, to put the coil **L1** onto the reference potential, the switch **S11** and the switch **S12** are open. In addition, the switch **S31** for the coil **L3** is open, and the switch **S32** is closed. Thus, the full potential $U_{sub.M}$ is present at the coils **L1**, **L3**, and, when the coils **L2**, **L4** are not driven at the same time, a force is
 5 exerted in the direction of the arrow **R 901**. In order to switch the coils **L2**, **L4** accordingly, advantageously all switches **S41**, **S42** and **S21**, **S22** are fully open, so that the intermediate nodes **604**, **602** are floating.

Alternatively, to achieve closed-loop control in the direction of the arrow **R'902**, the two coils **L2**, **L4** have to be between the reference potential $U_{sub.M}$ and
 10 ground, while the two coils **L1**, **L3** are floating. To this end, the switches **S21**, **S42** would have to be closed and the switches **S22**, **S41** would have to be opened. The same also applies for the switches **S12**, **S11**, **S32**, **S31**, which also would have to be opened to bring the coils **L1**, **L3** into the floating state.

On the other hand, if it is advantageous to achieve control along another di-
 15 rection than the direction **901**, **902**, it is advantageous to apply the voltage to **L1** and **L2** and to put **L3** and **L4** to ground. Then, a force along the x-axis and/or y-axis of the diagram in FIG. 9 would be exerted onto the rotor. Since each direction may be set by accordingly combining two orthogonal directions in the sense of a parallelogram of forces, closed-loop control in each direction
 20 is therefore possible qualitatively but also quantitatively, depending on the implementation.

For example, to connect the coils **L1**, **L2** to the reference potential, the switches **S11**, **S21** would have to be closed, and the switches **S12**, **S22** would have to be opened. On the other hand, the switches **S41**, **S31** would have to be
 25 opened, and the switches **S42**, **S32** would have to be closed.

In the following, FIG. 7 illustrates a first aspect for controlling the rotational speed of the motor via the switch-on time. The intervals are each shown
 in FIG. 7 at **700**. In addition, the respective ordinate axes in the time diagrams in FIG. 7 each show the current through a coil. In particular, the current pro-
 30 gression of a coil that is in the drive mode in the first interval **k** is shown, i.e. that belongs to the first star point group, however, that belongs to the second

star point group in the second interval $k+1$ and is therefore a follower coil. In addition, FIG. 7 shows in the upper diagram a situation in which the dashed line respectively represents the current progression of another coil that is in the other group. This shows that the solid current progression in interval k is the current progression of a drive coil, and the dashed current progression is a decreasing current progression of a follower coil. Since the follower coil has no influence on the drive, it is not problematic that the current slightly decreases in the interval k . In the same way, the current could also drop completely, as is subsequently illustrated with reference to FIG. 10. However, if the current drops slightly, this is achieved, e.g., by setting certain switch positions of the switches, as has been illustrated based on FIG. 6. In any case, each coil is provided with a corresponding inductance L . Moreover, the relationship between voltage and current across a coil is such that the voltage across the coil is equal to the product of the inductance of the coil and the dissipation of the current through the coil over time. Thus, if a coil currently operates as a follower coil, when a voltage is applied at a given time **705**, the current will constantly increase, as is illustrated by the dotted line in FIG. 7, i.e. with a constant rate of increase, since the inductance of the coil is constant. Thus, at the time **705**, shortly before the start of interval k , a voltage is applied to the coil considered in the first diagram in FIG. 7 by setting the switches accordingly, as is shown in FIG. 6, whereupon the current increases, that is up to its value h .

The point in time at the current value $I_{\text{sub.1}}$ determines the start of the interval k , this means that the considered coil changes from being the follower coil to being the drive coil. Due to this fact, there is a mutual inductance, and the current $I_{\text{sub.1}}$ does not further increase but remains constant as long as this coil contributes to the drive. At the end of the interval k , the coil no longer contributes to the drive signal but again becomes a follower coil, and the current through the coil in this interval does not play a particularly important role, for example, it can therefore drop slightly, as is shown by the solid line in interval $k+1$.

The situation in FIG. 7 is achieved if the time interval $\Delta t_{\text{sub.1}}$ between the switch-on time **705** and the start of the interval k , or $k+1$, has a corresponding value. With this, a certain current $I_{\text{sub.1}}$ with a certain magnitude is reached.

However, if, as is shown in FIG. 7 in the second diagram, the switch-on time **706**, which is earlier with respect to the switch-on time **705**, is now selected, the switch-on time interval $\Delta t_{\text{sub.2}}$ becomes larger. Due to the constant increase of the current in a coil if the coil is just a follower coil, a maximum current $I_{\text{sub.2}}$ is now reached. This maximum current $I_{\text{sub.2}}$ does no longer increase if the rotor has moved to such an extent that the considered coil is no longer a follower coil but a drive coil that contributes to the drive.

This current $I_{\text{sub.2}}$ remains constant until a transition takes place from the interval k to the interval $k+1$. At this point in time, the circuit in FIG. 6 is driven with a control signal or several control signals so as to disconnect the reference potential in any manner possible so that the current no longer increases, e.g., but decreases, as is shown in FIG. 7. Simultaneously, another coil that was the follower coil in the interval k is again turned on with the larger time interval $\Delta t_{\text{sub.2}}$ so as to achieve the current $I_{\text{sub.2}}$ when the interval $k+1$ starts, etc. This results in the switch-on interval $\Delta t_{\text{sub.2}}$, selected to be larger than $\Delta t_{\text{sub.1}}$, leading to the fact that the current in the coil becomes larger when the coil becomes the drive coil. Since the current is proportional to the rotational speed, this achieves a larger rotational speed so that, at a larger time interval $\Delta t_{\text{sub.2}}$, the rotational speed $\omega_{\text{sub.2}}$ is larger than the rotational speed $\omega_{\text{sub.1}}$ when the time interval $\Delta t_{\text{sub.1}}$ is smaller.

Similarly, a reduction in rotational speed may also be achieved if the switch-on time **707** is shifted closer to the interval limit than the switch-on time **705**. This reduces the current achieved in the coil to the value $I_{\text{sub.3}}$, which is smaller than $I_{\text{sub.1}}$, when the coil becomes the drive coil. Thus, a rotational speed that is smaller than the speed Q_i achieved in the situation in the upper diagram of FIG. 7 is achieved.

What becomes apparent is that a rotational speed control may be achieved solely by the selection of the switch-on time under consideration of the linear increase of the current due to the constant inductance of the coil and due to

the constant applied voltage, wherein all switching measures are performed at the follower coils. This avoids that a corresponding unrest is brought into the operation of the motor, since the motor runs particularly smoothly due to the fact that the drive coils are already “prepared” for the correct state in the corresponding time intervals in which the drive coils are still follower coils themselves. Therefore, the electric motor does not see any rises and drops of the current through the coils, which would cause an uneven operation, but the electric motor only sees constant currents from one interval to the next, however, alternating from one coil of the first star point group or a coil of the second star point group.

Alternatively or additionally, however, the fact that there are two star point groups, and therefore drive coils and follower coils, may also be used for a closed-loop position control of a magnetic bearing. This is schematically illustrated in FIG. 10. FIG. 10 again shows intervals k , $k+1$, $k+2$, wherein the solid progression is a progression of a coil of the second star point group, and the dashed progression is the current progression of a coil of the first star point group. For the uppermost current progression shown in FIG. 10, the situation is such that the rotor is perfectly aligned relative to the stator, and the motor gap is constant over an entire revolution for the considered coil. Therefore, the current I in a coil is constant when the coil is the drive coil. A constant current indicates that there is no offset. When the drive coil becomes the follower coil, such as in the interval $k+1$ for the coil of the second star point group SP2, the current may also be fully brought to zero, e.g., unlike in the embodiment shown in FIG. 7. For example, this could be achieved by placing the connection of the coil to ground, i.e. the intermediate node, e.g. **604**, **605**, **606**, **607**, of FIG. 6 of the respective coil is put to ground by the corresponding switch as **S42**, **S32**, **S22**, **S12**. Then, the coil would discharge and the current would drop, as illustrated in FIG. 10. Switch-on may be performed at an appropriate switch-on time, e.g., wherein this switch-on time may be selected as is described in FIG. 7 if certain rotational speed increases or rotational speed decreases are to occur. However, if the rotational speed is to remain the same, the switch-on time would be selected in the corresponding interval Δt before the interval limit.

However, if a progression as in the second illustration of FIG. 10 would be measured by means of a current sensor, where the current increases in the interval, this means that the motor gap the considered coil “sees” becomes larger in the course of the revolution of the rotor around the considered coil,
 5 i.e. there is a “positive offset”, so to speak. This means that the rotor and the stator do not have the same exact central axis, but that the central axes of the two motor elements are offset. In particular, as has already been said, the increasing current indicates an increasing gap.

10 In contrast, as shown in FIG. 10, a falling current across the interval indicates a decreasing gap that the considered coil “sees” when the rotor rotates past the coil, in turn indicating a negative offset.

The evaluation of these currents is advantageously used to determine whether there is an offset at all, and which direction the offset exists in so as to generate a corresponding closed-loop position control by accordingly driving the
 15 follower coils in the same interval the measurement takes place in, or in the next interval, i.e. in the interval that follows the interval of the measurement.

To this end, reference is made to FIG. 13. FIG. 13 shows a table with different gap positions, in particular a position of a maximum gap and of a minimum gap. Furthermore, to illustrate the nomenclature, the drive coils **1, 3, 5, 7** are
 20 illustrated in FIG. 13, approximately corresponding the drive coils of the same numerals in FIG. 1. In addition, the currents $i_{\text{sub.L1}}$, $i_{\text{sub.L3}}$, $i_{\text{sub.L5}}$ and $i_{\text{sub.L7}}$ through the coils are illustrated. In addition, the table contains the dissipations of these currents **D1, D3, D5, D7** according to the time, i.e. with respect to a qualitative formation, i.e. whether the change of the current is positive,
 25 indicating an increasing gap, or whether the change is negative, indicating a decreasing gap, or whether the change is zero when considered as a whole, indicating an optimal alignment or that there is both an increase and a decrease in current in this interval, i.e. the dissipation is on average equal to zero or very small.

30 It should be noted that the dissipation may be calculated arbitrarily as long as a momentary or average change in current is calculated over time. Thus, for

example, the dissipation could be calculated by forming a difference from two current values in the interval. Depending on the implementation, this is already sufficient, since the corresponding evaluation as to how the closed-loop position control is performed takes place in a qualitative manner in the embodiment shown in FIG. 13 anyway.

For example, if it is determined that the dissipations **D1**, **D3** are positive, and that the dissipations **D5**, **D7** are negative, a difference between **D1** and **D5** would lead to a large positive value, and a difference between **D3** and **D7** would lead to a large value. If these two combination quantities, i.e. the difference of **D1** and **D5** on the one hand and the difference of **D3** and **D7** on the other hand would both result in large values, this means that the maximum gap is between the coils **3** and **4**, and **3** and **5**, respectively, and the minimum gap is between the coils **7** and **8**, and **7** and **1**, respectively, of FIG. 1. On the other hand, if the maximum gap would be between **7** and **8**, and **3** and **4**, for example, the dissipations **D1**, **D3** would be negative, and the dissipations **D1**, **D7** would be positive, so that the two combination values **D1-D5** on the one hand and **D3-D7** on the other hand would lead to large negative values, as is illustrated in column **1300** of FIG. 13. Accordingly, e.g., an evaluation would also lead to the fact whether the maximum gap and therefore also the minimum gap is at a position as illustrated in one of the last four columns. For example, if the maximum gap would oppose the coil **7**, as is exemplary illustrated at **1302**, the minimum gap would oppose the coil **3**. **D1** would be negative, **D3** would be approximately zero, **D5** would be positive, and **D7** would be approximately zero. **D1-D5** would lead to a large negative value and **D3-D7** would lead to a value of approximately zero. Accordingly, due to the different evaluations of the combination sizes **D1-D5** on the one hand and **D3-D7** on the other hand, which could be greatly positive, greatly negative and also zero, a different localization of the maximum and/or minimum gap could be inferred, as is illustrated in the two first lines in FIG. 13.

The last two lines in FIG. 13 again illustrate which coils may be controlled for the closed-loop position control. A distinction is made as to whether the closed-loop position control is still performed in the same interval or in the next

interval, i.e. when the roles of the drive coils and the follower coils are swapped. Depending on the implementation, if the intervals are large enough, the closed-loop position control may be performed in the same interval. For the first line **1301**, where the maximum gap is between the coils **3** and **4**,
 5 and **3** and **5**, respectively, i.e. somewhere opposite to the coil **4**, e.g., a positive potential could easily be applied to the coil **4** and a negative potential, or a ground potential, could be applied to the coil **8**, with a polarity that would cause the rotor to be attracted to the coil **4** so as to significantly reduce the motor gap. If, on the other hand, a closed-loop position control would not take
 10 place in the same interval but in the next interval, in the case of a rotation direction such as that shown at **111** in FIG. 1, the coil **3** or the coil **5** would be used for the closed-loop position control, and would be used to apply a positive potential, e.g., since the coils **3** and **5** in the interval $k+1$ would then no longer be the drive coils but the closed-loop position control coils.

15 Similarly, for example, as shown in column **1302**, a closed-loop position control would be performed in the same interval in which the maximum gap is opposite to the coil **7** in FIG. 1, using the closed-loop position control coils **6**, **8**, e.g., to apply a positive potential, and the other coils **2**, **4** to apply a negative potential or ground. However, if the closed-loop position control is performed
 20 in the next interval, the coil **7** itself may be easily used to apply a positive signal to the same and to apply to the opposite coil **3** a ground potential or a negative potential.

This is exemplarily summarized in FIG. 12. For example, if the gap behind the coil **3** is at a maximum, i.e. between **3** and **4** or between **3** and **5**, as is illustrated in the first column in FIG. 13, the coils **1**, **3**, **5**, **7** are the drive coils. This
 25 means that, due to the gap at the stated position, the current in the coils **1**, **3** increases and decreases in the coils **5**, **7**. To now achieve a closed-loop position control, if the closed-loop position control would be performed in the same interval, the follower coil **4** would be set to ground, and the follower
 30 coil **8** would be set to U.sub.M, or vice versa. Alternatively, the follower coil **4** could be set to ground, and the follower coils **8** could be on U.sub.M, or the follower coil **8** could be set to ground and follower coil **4** could be used on

U.sub.M. The alternative applicable to a motor depends on the winding sense of the coils and the orientation, or magnetization, of the permanent magnets.

In general, according to an aspect, the closed-loop position control is carried out such that, in case of a maximum gap, the polarity is selected as it was in
 5 the last drive interval. For example, if the coil **4** was connected positively (with U.sub.M) in the last drive interval, the coil **4** is also connected positively (with U.sub.M) for the closed-loop position control. Thus, an attraction takes place as well as a reduction of the gap as to the coil **3**. However, if the coil **4** was
 10 connected negatively (with ?U.sub.M or ground) in the last drive interval, the coil **4** is also connected negatively (with ?U.sub.M or ground) for the closed-loop position control. This would then also achieve an attraction and reduction of the gap at **3**. Vice versa, the opposite coil is then connected in each case, i.e. coil **8** in this case.

FIG. 11 shows a flowchart for performing various actions executed by the con-
 15 troller **500**, e.g. shown in FIG. 5.

The interval k is considered first. Advantageously, a measurement of currents in the drive coils is performed in the interval k, as shown at **1100**. To this end, e.g., corresponding current progressions are created, as illustrated in FIG.
 7 or FIG. 10. In general, however, it is advantageous to sense a current pro-
 20 gression over time, although a first current value at a first time and a second current value, e.g., at a midpoint of the interval would already suffice. Subsequently, in step **1102**, the currents are dissipated, e.g. so as to form the values D1 to D7, which have been shown in FIG. 13.

In a step **1104**, the dissipations are combined, advantageously for the
 25 coils **1**, **3** on the one hand and **2**, **4** on the other hand, i.e. for opposite coils according to the nomenclature as illustrated in FIG. 3. Considered as a whole and with respect to a nomenclature as illustrated in FIG. 13, coils **1** and **5**, and **3** and **7** are opposite coils.

In a step **1106**, a detection of a positional offset of the rotor is carried out in
 30 order to find out in which direction the rotor is offset. For example, this is done

by evaluating the two lines **1310** and **1311** of FIG. 13 in order to be able to draw conclusions from the first two lines or to appropriately drive the follower coils in order to reduce the positional offset, as shown by the last two lines in FIG. 13. For example, if line **1310** has a large positive value and

5 line **1311** has a large negative value, according to the fifth line in FIG. 13, this would result in the coils **2, 6** being driven for the closed-loop position control if the closed-loop position control is performed still in the same interval, or in the coils **1, 2** being driven if the closed-loop position control takes place in the next interval.

10 Driving of the follower coils is illustrated at **1108** in FIG. 11. If the intervals are large enough or the measurement of only a fraction of the interval is sufficient to determine the rotor offset with a reasonable certainty, the follower coils may be driven in the same interval to reduce the positional offset, as is illustrated at **1108** in FIG. 11. However, if the entire interval is used to perform the

15 steps **1100-1106**, the follower coils will be driven in the next interval $k+1$.

Furthermore, a new measurement takes place in the next interval, as is illustrated at **1110** in FIG. 11. Accordingly, the follower coils are driven after the interval $k+1$ in the interval k due to the positional offset from the interval $k+1$, as is illustrated at **1120** in FIG. 11. Thus, when a closed-loop position control

20 each is performed at next interval, the tracking coils of the next interval will be driven on the basis of the positional offset from the previous interval.

Although the present invention has been illustrated with reference to the various figures and in particular to FIG. 1 with four permanent magnets and eight coils, it should be noted that any other combinations of magnets and coils can

25 also be used, as long as the number of permanent magnets is less than the number of coils. Thus, there is a first group of coils electrically connected to each other via a first star point and used for drive control, while a second group of coils electrically connected to each other via a second star point are follower coils. The number of coils in the drive group and the follower group

30 may be 2, but may also be 3, or as is advantageous, may be 4, although even greater numbers of coils are possible.

In embodiments, the approach, in particular with respect to the closed-loop position control, is based on the fact that a current through a coil, at a constantly applied voltage, increases when the gap of the motor facing the coil increases. In the rotational speed control, for example, it is based on the fact
5 that the current for the drive coils may already be switched on and switched off in the preceding time interval in which the drive coils are still follower coils. Thus, the current needed for a drive coil may be maintained from the start of the time interval to the end of the time interval, since the current may then be switched on or off in the previous or subsequent time interval where the current is still only the follower coil, without affecting the motor behavior. Therefore, it is also irrelevant whether the current through the coil is completely
10 switched off, i.e., switched to zero, or is left at a certain level, in the following interval, i.e. in the interval where a coil is the follower coil.

Particularly for switching the current off, in an embodiment of the present invention in which switches are used as shown in FIG. 4 and FIG. 6, respectively, the corresponding coil is disconnected from the potential, e.g. by the switch **S41** for the coil **304**, while at the same time the switch **S42** is closed. Alternatively, the switch **S42** could also be left open. Still, there is a current equalization and a corresponding discharge of the coils, i.e. particularly via the free-
20 wheeling diodes, which ensure that potentials do not fluctuate to a large extent, but are kept within tolerable limits by the functionality of the freewheeling diode. It is also particularly advantageous that, by the switch off in the interval in which the coil does not contribute to the drive, no current has to be routed through a resistor and is therefore converted into heat. Instead, there is a current flow between the coils on the one hand and the power supply on the other, and in particular a smoothing capacitor in the power supply. This ensures
25 that any energy stored in the coils, which is no longer required, when the coil is in the follower mode, is released to the power supply, and supplied from there in the next cycle. This means that there is no loss of energy, but that
30 there is only an energy oscillation from the motor to the power supply and vice versa, which leads to the cooling requirements in particular being reduced and power requirements being as low as possible.

As to the closed-loop position control, it should be noted that it takes place in a qualitative or advantageously even in a quantitative manner. In particular, proportional closed-loop control is advantageous. For this purpose, a certain current may be applied to the coils, e.g., as determined on the basis of FIG.

5 13 in the last two lines. However, it is advantageous to apply the same reference voltage $U_{sub.M}$ for the closed-loop position control, and to accordingly only control the corresponding switches, as exemplarily illustrated in FIG. 6. For this purpose, it is advantageous to apply corresponding time progressions to the switches, in order to be ultimately driven as a function of a certain
10 measured offset that depends on the quantitative values determined in lines **1310, 1311**.

Depending on the corresponding rotational speed, intervals in the range of microseconds will suffice here. For example, if a rotational speed needed is 2000 revolutions per second, corresponding to about 120.000 revolutions per
15 minute, a rotational cycle has the length of 62.5 microseconds. In such a cycle, e.g., which is divided into four intervals, with each interval being about 15 microseconds, it is sufficient for small to medium deviations to apply the reference potential $U_{sub.M}$ of FIG. 6 for 1 to 3 μ s in the follower interval with an appropriate switch setting in the following interval so as to achieve the closed-
20 loop position control.

Furthermore, it should also be noted that, in particular, the closed-loop position control may be used for motors using magnetic bearings that do not have contact bearings, such as ball or roller bearings. Furthermore, such motors using magnet bearings are advantageously designed as disc motors that are
25 stable along the axial direction of the axis of rotation, but are to be closed-loop controlled along the radial direction, i.e. with respect to the offset of the rotor relative to the stator in the radial direction. However, the rotational speed control may just as well be implemented with motors configured with contact bearings, there is no need for a magnetic bearing so as to implement the rotational
30 speed control in connection with two coil groups with different star points and different driving groups.

FIG. 14 shows an advantageous application of the disc armature motor, i.e. an electric motor with a disc-shaped rotor, in the example of a heat pump. The heat pump includes an evaporator **300**, a compressor **420**, and a condenser **509**, the compressor **420** comprising the electric disc armature motor, described with reference to FIGS. 1A-5.

In addition to the elements of the disc armature motor exemplarily illustrated with reference to one of the previous figures, the compressor further includes a guide chamber **410** radially arranged to convey the working steam, drawn by the evaporator **300**, conveyed by the element **105** to be moved and to ultimately increase the pressure to the pressure needed in the condensation zone **510** in the condenser **509**.

Liquid to be cooled flows into the evaporator via an evaporator inlet **340**. Cooled working liquid flows out of the evaporator via an evaporator outlet **360**. To ensure that the radial impeller **105** draws in only vapor and does not draw in water droplets in addition to a vapor, a droplet separator **306** is also provided. Due to the low pressure in the evaporator inlet **300**, a portion of the working fluid introduced into the evaporator **300** via the evaporator inlet **340** is vaporized and drawn through the droplet separator **306** via the second side **105b** of the radial impeller **105** and conveyed upward and then discharged into the guide chamber **510**. Compressed working scheme is brought from the guide chamber **510** to the condensation zone **510**. The condensation zone **510** is further supplied with working fluid to be heated via a condenser inlet **512**, heated by condensation with the heated steam, and discharged via a condenser outlet **514**. Advantageously, the condenser is configured as a condenser in the form of a "shower" so that a distribution of liquid in the condensation zone **510** is achieved via a distributor **516**. In this way, the compressed working steam is condensed as efficiently as possible and the heat contained therein is transferred to the liquid in the condenser.

In the embodiment shown in FIG. 14, a motor housing **110** that at the same time also forms the upper housing part of the condenser, or liquefier **509**, is drawn in. Furthermore, a connection line **80** for the coils of the stator **200** is connected to a controller **600** in order to carry out the corresponding rotational

speed controls and at the same time also the active support via a advantageously used magnetic bearing, as has been described with reference to FIG. 7. Thus, the controller additionally provides the functions of radial sensing **270** and radial control/closed-loop control **280**.

5 In addition, FIG. 14 shows an implementation in which the disc armature motor includes a solid block **630** of an encapsulant that is sealed with respect to the motor housing **110** via a sealing ring **603** so that there is a pressure-tight separation between the exterior and the interior. Both the coil holder and the coils are surrounded by an encapsulation material, shown in FIG. 14 as being
10 integral with the solid block **630**. However, this does not necessarily have to be the case. However, it is advantageous to provide separation by means of the encapsulation material extending into the motor gap such that the coils are not located in the low pressure region within the motor housing.

Further, in the embodiment shown in FIG. 14, the stator is arranged in a recess defined by an upper side **105a**. In other embodiments, the rotor may be
15 configured without a recess, so that the area made of a magnet **101**, a return element **202**, and a band **203**, as is shown in FIG. 14, is placed on a radial wheel formed to be flat on its top.

It is further apparent from FIG. 14 that the element connected to the rotor **10** and to be moved is the radial impeller, or paddle wheel, **105**, which is to
20 compress and thus to heat the working steam conveyed by the evaporator in cooperation with the guide path **410** so that the heat is pumped from the evaporator to the condenser.

Advantageously, the rotor is supported with respect to the stator by a magnetic bearing and the rotor is held axially with respect to the stator due to the
25 permanent magnets on the rotor side and the electric coils on the stator side, and is not specifically closed-loop controlled. A radial sensing device as well as a radial control/closed-loop control device **500** are provided. The radial detection device detects the position of the rotor with respect to the stator or vice
30 versa. The result of the radial detection is communicated via a sensor line to a radial control/closed-loop control device. The same generates the actuator

signals accordingly via actuator signal lines on the rotor or the stator, depending on the implementation. The coils are driven to position the rotor with respect to the stator on the basis of the actuator signal, such that the motor gap has a similar size around the entire rotor and the rotor does not touch the stator.

In an embodiment, the rotor is arranged on the inside and the stator is arranged on the outside. Therefore, this is an inrunner, in contrast to FIG. 1, for example. In principle, however, the magnet bearing in the example of a reluctance bearing is similar in both cases, in that an axial closed-loop control does not take place, while a radial closed-loop control takes place through the radial sensing device and the radial control/closed-loop control device.

Although certain elements are described as apparatus elements, it is to be noted that this description is equally to be regarded as a description of steps of a method and vice versa.

It should further be noted that a control, e.g., performed by the element **500** may be implemented as software or hardware. The implementation of the control may be carried out on a non-volatile storage medium, a digital or other storage medium, in particular a floppy disc, or a CD with electronically readable control signals, which may interact with a programmable computer system in such a way as to execute the corresponding method for operating a heat pump. In general, the invention therefore also includes a computer program product with a program code stored on a machine-readable carrier to perform the method if the computer program product runs on a computer. In other words, the invention may also be realized as a computer program having a program code for performing the method if the computer program runs on a computer.

LIST OF REFERENCE NUMERALS

80 connection line

100 rotor

101, 102, 103, 104 permanent magnets

105 area to be rotated (e.g. radial impeller)

105a upper side of the radial impeller

105a lower side of the radial impeller

110 motor housing

200 stator

202 magnetic return element

203 band

300 evaporator

301, 302, 303, 304 drive coils

306 droplet dispenser

321, 322, 323, 324 second group of coils

311 first star point SP1

331 second star point SP2

340 evaporator inlet

360 evaporator outlet

400 reference potential U.sub.N

401 first switch

402 second switch

410 guide chamber

420 compressor

500 control

501 first star point group

502 second star point group

509 condenser

510 condensation zone

512 liquefier inlet

514 liquefier outlet

516 liquefier distributor

600 reference node

601 ground node

602 reference potential connection node

603 sealing ring

604, 605, 606, 607 intermediate node

611, 612, 613, 614 freewheeling diodes

621, 622, 623, 624 current sensors

630 stator block

700 interval

705 switch-on time

706 switch-on time

707 switch-on time

901 first closed-loop position control direction

902 second closed-loop position control direction

1100 measuring of currents

1102 dissipating the currents

1104 combining the dissipations

1106 detecting

1108 driving the follower coils

1110 measuring in the interval $k+1$

1120 driving in the interval k

1300, 1301, 1302 column of FIG. 13

1310, 1311 lines of FIG. 13

Patentkrav

1. Elektrisk motor, med følgende kendetegn:

- 5 en rotor (100) med et første antal permanentmagneter (101, 102, 103, 104), hvor hver permanentmagnet omfatter en første sektor;
 en stator (200) med et andet antal polfødde, hvor der om hver polfod af det andet antal polfødde er viklet en spole, og hvor en polfod omfatter en anden sektor, som er mindre end den første sektor,
- 10 hvor en første gruppe af spoler (301, 302, 303, 304) er elektrisk ledende forbundet med hinanden via et første stjernepunkt (311),
 hvor en anden gruppe af spoler (321, 322, 323, 324) er elektrisk ledende forbundet med hinanden via et andet stjernepunkt (331),
 hvor det andet stjernepunkt (331) er elektrisk isoleret fra det første stjernepunkt (311),
- 15 hvor en spole fra den første gruppe af spoler (301, 302, 303, 304) er anbragt mellem to spoler fra den anden gruppe af spoler (321, 322, 323, 324); og
 en styring (500) til påvirkning af den første gruppe af spoler (301, 302, 303, 304) med driftssignaler, med henblik på at påføre rotoren (102) et drejningsmoment i forhold til statoren (200), og til påvirkning af mindst en spole (321, 322, 323, 324) fra den anden gruppe af spoler (321, 322, 323, 324) med et styresignal, som adskiller sig fra driftssignalerne,
- 20 hvor hver spole fra den første og den anden gruppe af spoler har to tilslutninger, hvor hver tilslutning af hver spole er forbundet med det første eller andet stjernepunkt (311, 321),
- 25 hvor den respektive anden tilslutning af hver spole er forbundet med en respektiv styrbar kontakt (401, 403), hvor den styrbare kontakt (401, 403) er udformet til at forbinde den anden tilslutning af hver spole, afhængigt af et styresignal fra styringen (500), med et positivt referencepotentiale, et negativt referencepotentiale eller et massepotentiale eller skifte denne over til tomgang, og
- 30 hvor styringen (500) er udformet til i et første interval at forbinde spolerne fra den første gruppe med hhv. enten det positive referencepotentiale eller det negative referencepotentiale eller massepotentialet og i det første interval at skifte mindst en af spolerne fra den anden gruppe over til tomgang eller i et senere andet interval at forbinde spolerne fra den anden gruppe med hver mindst enten det positive referencepotentiale eller det negative referencepotentiale eller massepotentiale for i det andet interval at udøve et
- 35

drejningsmoment på rotoren (102).

2. Elektrisk motor ifølge krav 1, hvori styringen (500) er udformet til i et første interval at påvirke den første gruppe af spoler (301, 302, 303, 304) med driftssignalerne og i et senere andet interval påvirke den anden gruppe af spoler med driftssignaler for i det andet interval at påføre rotoren (102) et drejningsmoment i forhold til statoren (200), eller

hvor polfødderne, som spolerne er viklet omkring, er anbragt i en cirkelindretning, hvor hver polfod omfatter en cirkelsektor, og hvori der mellem to spoler fra en gruppe er anbragt en spole fra den anden gruppe, eller hvori hver spole enten tilhører den første gruppe eller den anden gruppe og ingen spoler tilhører begge grupper, eller hvori styringen (500) er udformet til at påvirke nabospoler i en gruppe med respektive forskellige potentialer, når gruppen aktiveres i et interval, i hvilket rotoren (102) via spolerne fra den anden gruppe påføres drejningsmomentet, eller hvori den første gruppe har fire spoler, og hvori den anden gruppe har fire spoler, hvor rotoren (102) har fire forskelligt magnetiserede permanentmagnetafsnit, og hvor styringen (500) er udformet til i et interval at påvirke to nabospoler fra den første gruppe med forskellige spændinger som driftssignaler eller påvirke to modsatliggende spoler fra den første gruppe med den samme spænding som driftssignaler.

3. Elektrisk motor ifølge et af de foregående krav,

hvor styringen (500) er udformet til i et første interval at aktivere den første gruppe af spoler (301, 302, 303, 304) med driftssignalerne og i et andet interval at aktivere den anden gruppe af spoler (321, 322, 323, 324) med driftssignalerne, og hvori styringen (500) er udformet til ved en begyndelse af det første interval efter slutningen af det forudgående interval at omskifte den anden gruppe af spoler (321, 322, 323, 324) til et massepotential eller tomgang, og før en slutning af det første interval at indkoble en spændingsforsyning af spolerne fra den anden gruppe af spoler på et indkoblingstidspunkt, nærmere bestemt ved anvendelse af en spændingsværdi for spændingsforsyningen, som er beregnet for det andet interval, i hvilket den anden gruppe af spoler (321, 322, 323, 324) aktiveres med driftssignalerne.

4. Elektrisk motor ifølge krav 3,
hvor i styringen (500) er udformet til at indstille indkoblingstidspunktet afhængigt af et definerbart omdrejningstal hvad angår begyndelsen af det andet interval.
- 5 5. Elektrisk motor ifølge krav 2 eller 3,
hvor i styringen (500) desuden er udformet til med henblik på forøgelse af et omdrejningstal at lægge indkoblingstidspunktet hvad angår slutningen af det første interval tidligere eller med henblik på reducere omdrejningstallet at lægge indkoblingstidspunktet hvad angår slutningen af det første interval senere.
- 10 6. Elektrisk motor ifølge et af de foregående krav,
hvor i styringen (500) har en første styreenhed (500a), som kun er beregnet til den første gruppe af spoler (501), og en anden styreenhed (500b), som kun er beregnet til styring af den anden gruppe af spoler (502), hvor hver styreenhed har sit eget referencepotentiale eller sit eget massepotentiale.
- 15 7. Elektrisk motor ifølge krav 6,
ved hvilket den første styreenhed (500a) eller den anden styreenhed (500b)
20 har styrbare kontakter (S11, S12; S21, S22; S31, S32; S41, S42) pr. spole,
hvor en styrbar kontakt (S21, S31, S41) pr. spole er koblet mellem styreenhedens referencepotentiale (600, 602) og en tilslutning (604, 605, 606, 607) på den respektive spole, som ikke er forbundet med stjernepunktet (311, 331), og
25 hvor en anden styrbar kontakt (S12, S22, S32, S42) er koblet mellem tilslutningen (604, 605, 606, 607) på den respektive spole og den respektive styreenheds massepotentiale (601), hvor den anden kontakt desuden bypasses af en friløbsdioder (611, 612, 613, 614), hvor styringen (500) er udformet til at åbne eller lukke de styrbare kontakter, eller til at øge eller reducere referencepotentialet.
30
8. Elektrisk motor ifølge et af de foregående krav,
hvor i en spole fra den første gruppe af spoler har tilknyttet en sensor (621, 622, 623, 624) med henblik på at registrere strømmen gennem spolen på baggrund af et driftssignal til spolen,
35 hvor styringen (500) er udformet til

som funktion af sensorsignalerne fra sensorerne i den første gruppe af spoler (301, 302, 303, 304) at fastslå en position eller positionsafvigelse fra en central position af rotoren (102), og

5 som funktion af positionen eller positionsafvigelsen at påføre et positionsreguleringssignal på en spole fra den anden gruppe af spoler (321, 322, 323, 324) i det første interval eller på en spole af den første gruppe i et andet interval, som følger efter det første interval, for at reducere eller eliminere positionsafvigelsen fra den centrale position.

10 9. Elektrisk motor ifølge et af de foregående krav,
hvor styringen (500) er udformet til at registrere en induceret strøm i mindst en spole fra den første gruppe af spoler (301, 302, 303, 304) på grund af en radial forskydning af rotoren (102) i forhold til statoren (200) og til at påvirke mindst en spole fra den første eller anden gruppe af spoler med et positionsændringssignal,
15 som er udformet sådan, at forskydningen reduceres eller elimineres.

10. Elektrisk motor ifølge et af de foregående krav,

20 hvor styringen (500) er udformet til
at registrere (1100) en strøm eller en ændring af strømmen i en spole fra den første gruppe af spoler (301, 302, 303, 304),
ud fra strømmen eller ændringen af strømmen og en position af den respektive spole at fastslå (1102, 1104, 1106) en indikation af forskydningens retning, og
25 at påvirke en eller to spoler fra den første gruppe af spoler (301, 302, 303, 304) eller den anden gruppe af spoler (321, 322, 323, 324) som funktion af indikationen af forskydningen med et signal for at reducere forskydningen, mens styringen (500) styrer den første gruppe af spoler, eller
at påvirke fastlagte spoler fra den første gruppe, mens styringen (500) i et
30 senere interval aktiverer den anden gruppe med driftssignaler.

11. Elektrisk motor ifølge et af de foregående krav,

35 hvor styringen (500) er udformet til
at registrere (1100) tidsforløb af strømme i den første gruppe af spoler (301, 302, 303, 304) på grund af påførte spændinger som driftssignaler, at fastslå (1102) ændringer i strømmenes tidsforløb,

at kombinere (1104) fastslåede ændringer i tidsforløbene forskelligt for at opnå mindst et registreringssignal, og

5 hvori styringen (500) er udformet til at påføre mindst en spole fra den anden gruppe af spoler (321, 322, 323, 324) et positionsændringssignal som styresignal, der afhænger af det mindst ene registreringssignal (1108, 1120).

12. Elektrisk motor ifølge krav 11,

10

hvor den første gruppe af spoler (301, 302, 303, 304) har fire spoler, som er sådan anbragt på statoren (200), at spoleakser har en vinkel til hinanden på mellem 80 og 100°,

15

hvor styringen (500) er udformet til at kombinere afledningerne fra to spoler, som har en vinkel til hinanden på mellem 160 og 200° for at opnå to respektive registreringssignaler,

hvor styringen (500) er udformet til at analysere forskellige tilstande af registreringssignalerne for at fastslå mindst fire forskellige maksimale eller minimale spaltepositioner, og

20

hvor styringen (500) er udformet til som funktion af de udvalgte mindst to registreringsresultater at udvælge en eller to positionsreguleringsspoler, som påføres et positivt potentiale, mens der på mindst en anden positionsreguleringsspole påføres et negativt potentiale, hvor styringen (500) er udformet til at lægge et positionsreguleringspotentiale sådan, at modsatliggende positionsreguleringsspoler gennemstrømmes af strøm i den samme retning, eller at modsatliggende positionsreguleringsspoler ikke gennemstrømmes af strøm.

25

30

13. Elektrisk motor ifølge et af de foregående krav,

hvor motoren er udformet som skivemotor, og hvori rotoren (102) eller statoren (200) har en radial udvidelse i forhold til en drejeakse af motoren, som er større eller lig med det dobbelte af den aksiale udvidelse, eller
35 som er magnetlejet og ikke har et kontaktleje.

14. Fremgangsmåde til fremstilling af en elektrisk motor med en rotor (100) med et første antal permanentmagneter (101, 102, 103, 104), hvor hver permanentmagnet omfatter en første sektor; en stator (200) med et andet antal polfødder, hvor der om hver polfod af det andet antal polfødder er viklet en spole, og hvor en polfod omfatter en anden sektor, som er mindre end den første sektor, med følgende kendetegn:

- elektrisk ledende forbindelse af en første gruppe af spoler (301, 302, 303, 304) via et første stjernepunkt (311),
- elektrisk ledende forbindelse af en anden gruppe af spoler (321, 322, 323, 324) via et andet stjernepunkt (331), hvor det andet stjernepunkt (331) er elektrisk isoleret fra det første stjernepunkt (311), hvor en spole fra den første gruppe af spoler (301, 302, 303, 304) er anbragt mellem to spoler fra den anden gruppe af spoler (321, 322, 323, 324); og
- forbindelse af en styring (500) med spolerne fra den første og den anden gruppe, til påvirkning af den første gruppe af spoler (301, 302, 303, 304) med driftssignaler, med henblik på at påføre rotoren (102) et drejningsmoment i forhold til statoren (200), og til påvirkning af mindst en spole (321, 322, 323, 324) fra den anden gruppe af spoler (321, 322, 323, 324) med et styresignal, som adskiller sig fra driftssignalerne, hvor hver spole fra den første og den anden gruppe af spoler (321, 322, 323, 324) har to tilslutninger, hvor hver tilslutning af hver spole er forbundet med det første eller andet stjernepunkt (311, 321), hvor den respektive anden tilslutning af hver spole er forbundet med en respektiv styrbar kontakt (401, 403), hvor den styrbare kontakt (401, 403) er udformet til at forbinde den anden tilslutning af hver spole, som funktion af et styresignal fra styringen (500), med et positivt referencepotentiale, et negativt referencepotentiale eller et massepotentiale eller skifte denne over til tomgang, og hvor styringen (500) er udformet til i et første interval at forbinde spolerne fra den første gruppe med hhv. enten det positive referencepotentiale eller det negative referencepotentiale eller massepotentialen og i det første interval at skifte mindst en af spolerne fra den anden gruppe over til tomgang eller i et senere andet interval at forbinde spolerne fra den anden gruppe med mindst enten det positive referencepotentiale eller det negative referencepotentiale eller massepotentiale for i det andet interval at udøve et drejningsmoment på rotoren (102).

15. Fremgangsmåde til drift af en elektrisk motor med en rotor (100) med et første antal permanentmagneter (101, 102, 103, 104), hvor hver permanentmagnet om-
- 5 fatter en første sektor; en stator (200) med et andet antal polfødde, hvor der om hver polfod af det andet antal polfødde er viklet en spole, og hvor en polfod omfatter en anden sektor, som er mindre end den første sektor, hvor en første gruppe af spoler (301, 302, 303, 304) er forbundet elektrisk ledende med hinanden via et første stjernepunkt (311), hvor en anden gruppe af spoler (321, 322, 323, 324) er
- 10 elektrisk ledende forbundet med hinanden via et andet stjernepunkt (331), hvor det andet stjernepunkt (331) er elektrisk isoleret fra det første stjernepunkt (311), hvor en spole fra den første gruppe af spoler (301, 302, 303, 304) er anbragt mellem to spoler fra den anden gruppe af spoler (321, 322, 323, 324), med følgende trin:
- 15 påvirkning af den første gruppe (301, 302, 303, 304) af spoler med driftssignaler, med henblik på at påføre rotoren (102) et drejningsmoment i forhold til statoren (200); og
- påvirkning af mindst en spole (321, 322, 323, 324) fra den anden gruppe af spoler (321, 322, 323, 324) med et styresignal, der adskiller sig fra driftssignalerne,
- 20 hvor hver spole fra den første og den anden gruppe af spoler (321, 322, 323, 324) har to tilslutninger, hvor hver tilslutning af hver spole er forbundet med det første eller andet stjernepunkt (311, 321),
- hvor den respektive anden tilslutning af hver spole er forbundet med en respektiv styrbar kontakt (401, 403), hvor den styrbare kontakt (401, 403) er udformet til at forbinde den anden tilslutning af hver spole, som funktion af et styresignal fra styringen (500), med et positivt referencepotentiale, et negativt referencepotentiale eller et massepotentiale eller skifte denne over til tomgang, og
- 25 hvor styringen (500) er udformet til i et første interval at forbinde spolerne fra den første gruppe med hhv. enten det positive referencepotentiale eller det negative referencepotentiale eller massepotential og i det første interval at skifte mindst en af spolerne fra den anden gruppe over til tomgang eller i et senere andet interval at forbinde spolerne fra den anden gruppe med mindst enten det positive referencepotentiale eller det negative referencepotentiale eller massepotential for i det andet interval at udøve et drejningsmoment på rotoren (102).
- 30
- 35

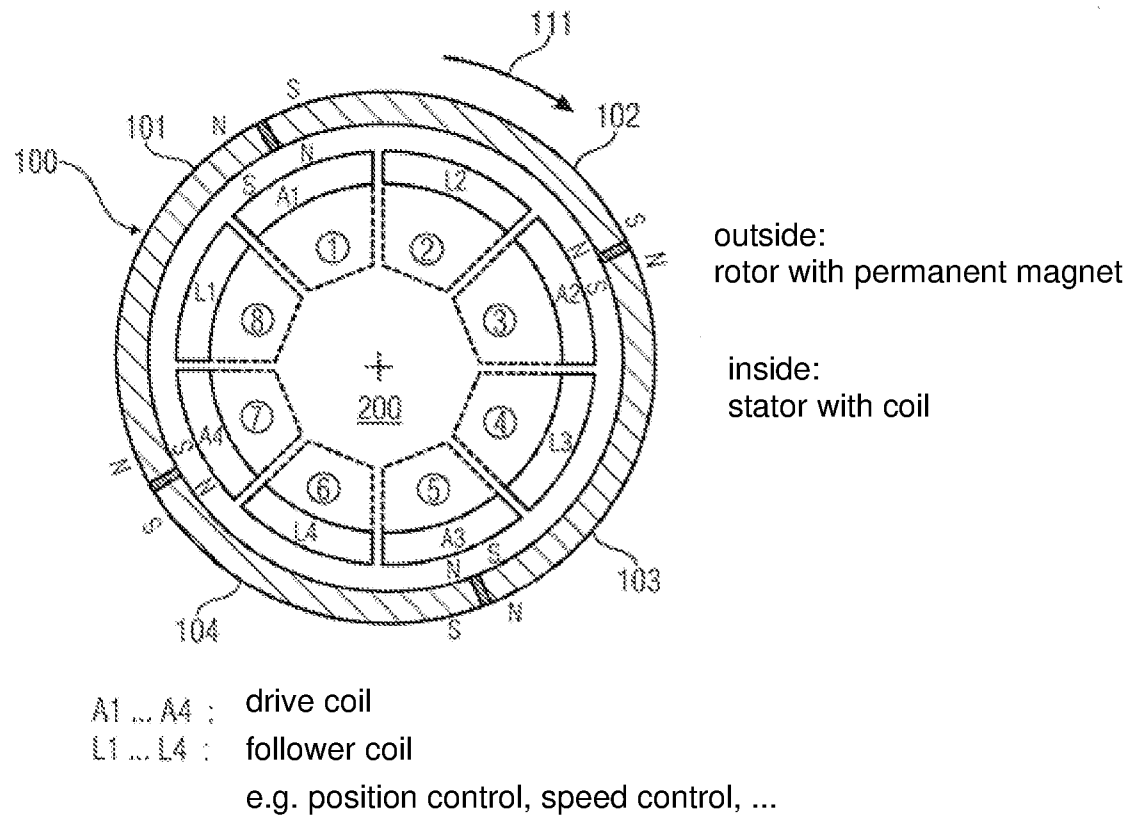


Fig. 1

interval	drive coil	follower coil
k	①, ③, ⑤, ⑦	②, ④, ⑥, ⑧
k+1	②, ④, ⑥, ⑧	①, ③, ⑤, ⑦
k+2	①, ③, ⑤, ⑦	②, ④, ⑥, ⑧
	⋮	⋮

Fig. 2A

interval	k-1	k	k+1	k+2	k+3	
positive voltage	3+ 7+	4+ 8+	5+ 1+	6+ 2+	3+ 7+	...
negative voltage / ground	1- 5-	2- 6-	7- 3-	8- 4-	1- 5-	
follow along	2, 4, 6, 8	1, 3, 5, 7	2, 4, 6, 8	1, 3, 5, 7	2, 4, 6, 8	

Fig. 2B

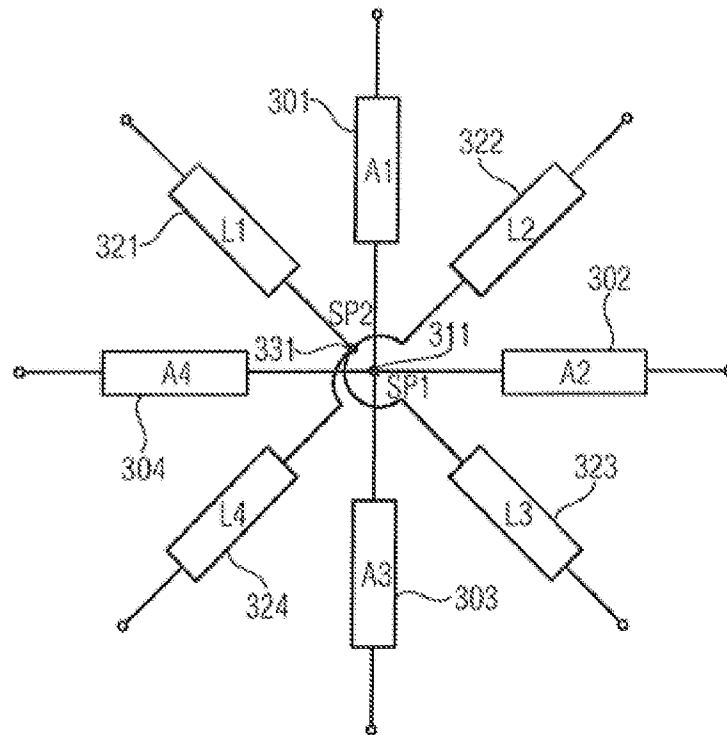


Fig. 3

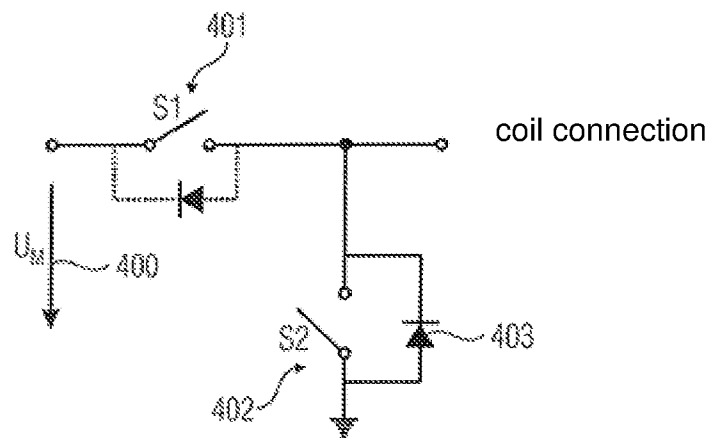


Fig. 4

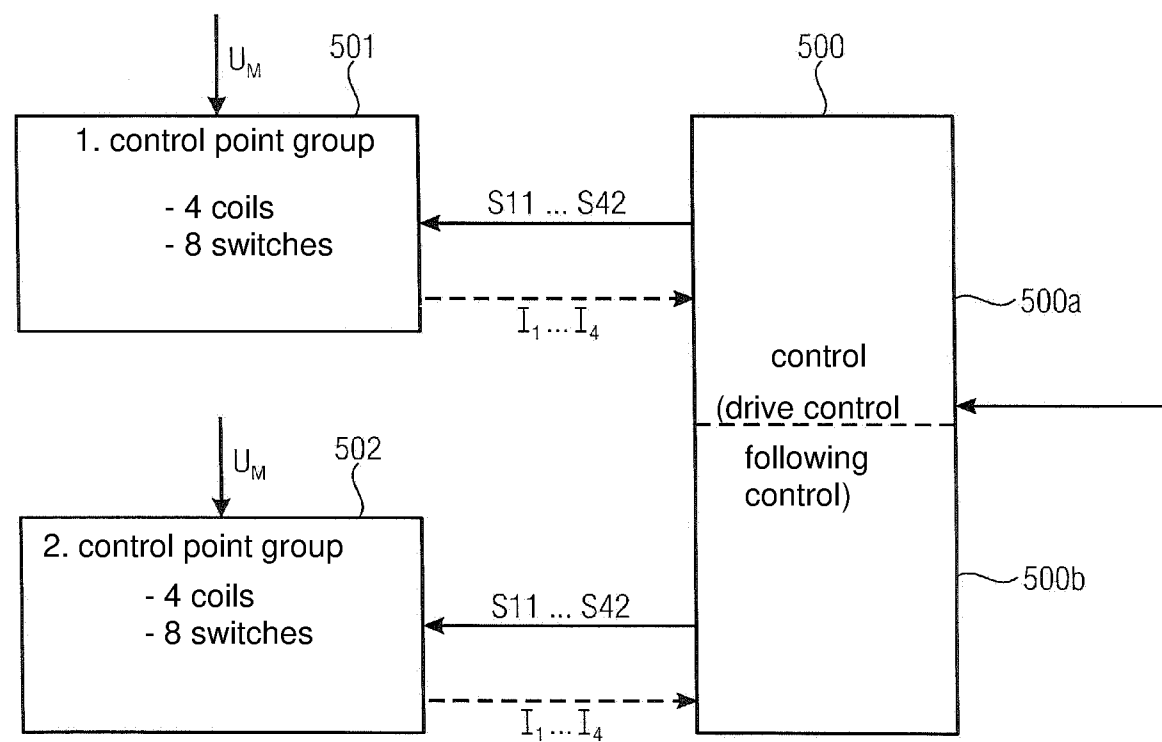


Fig. 5

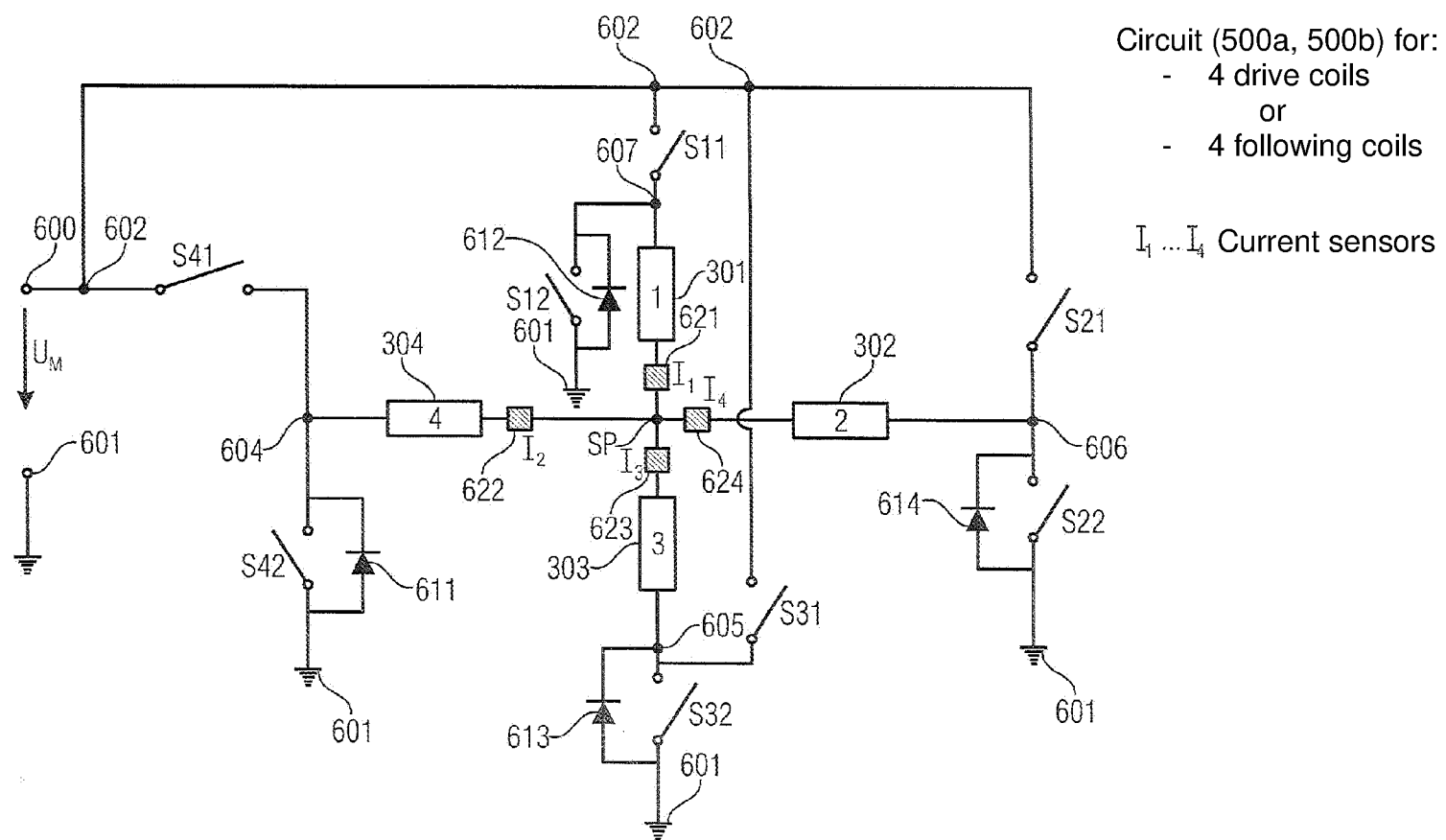
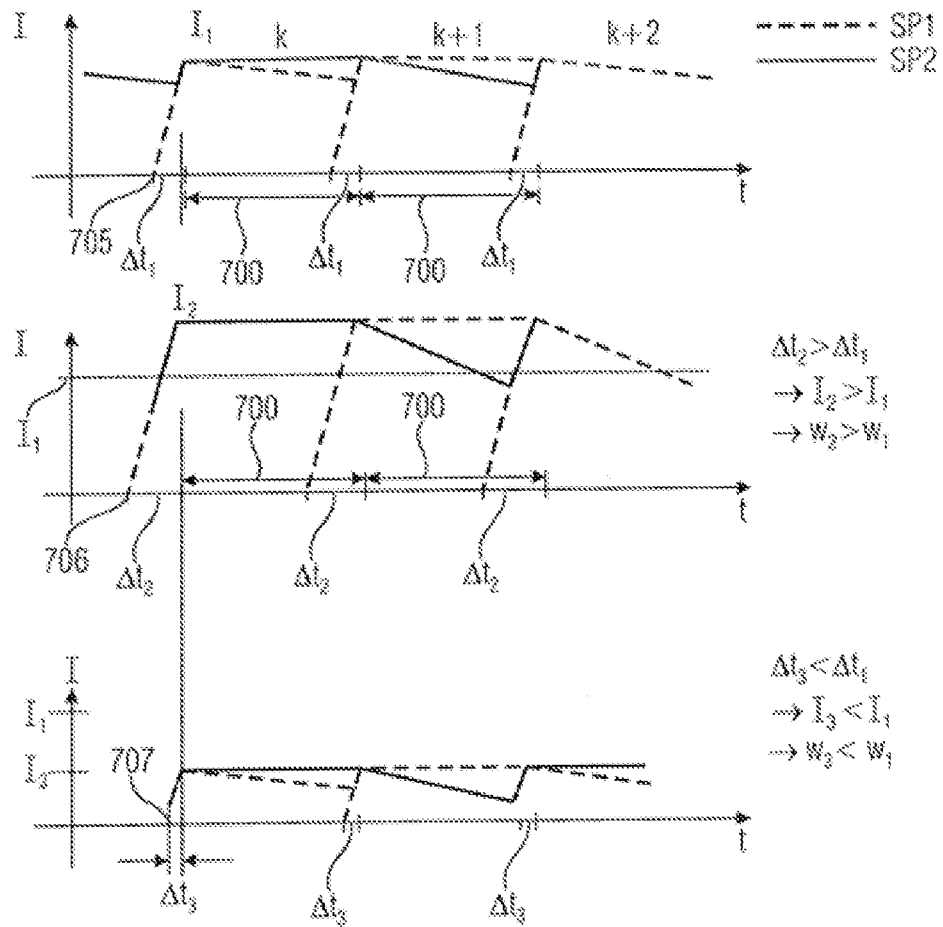


Fig. 6



Speed control via switch-on time in the "neutral" interval

Fig. 7

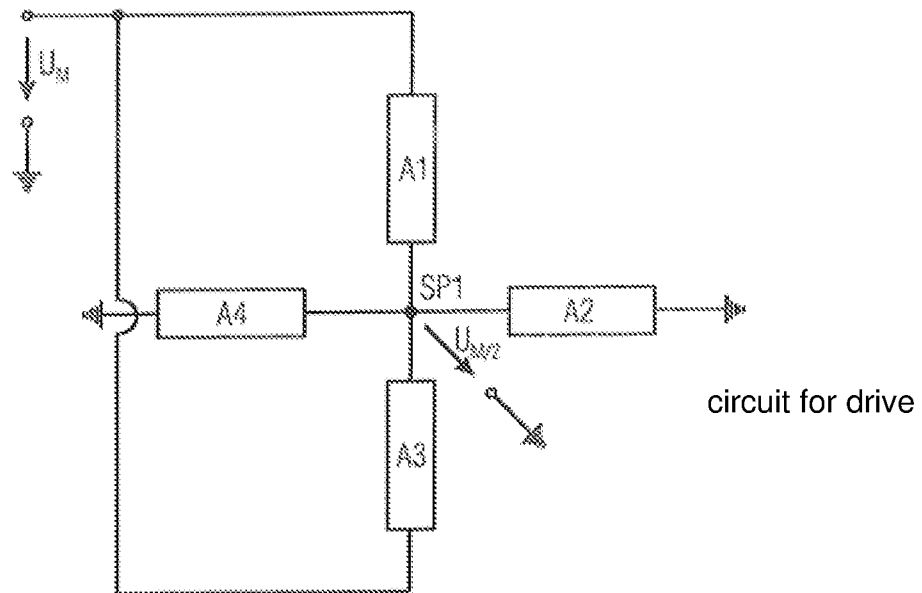


Fig. 8

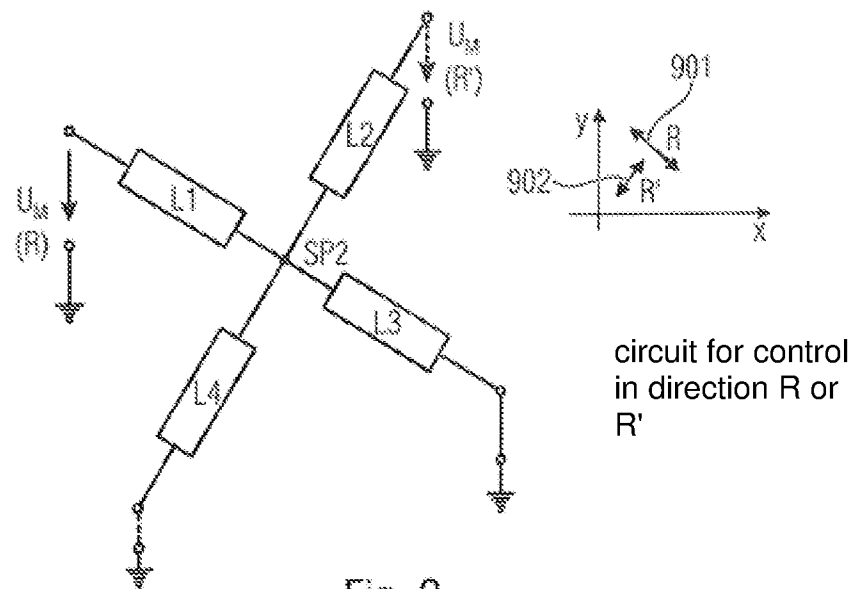


Fig. 9

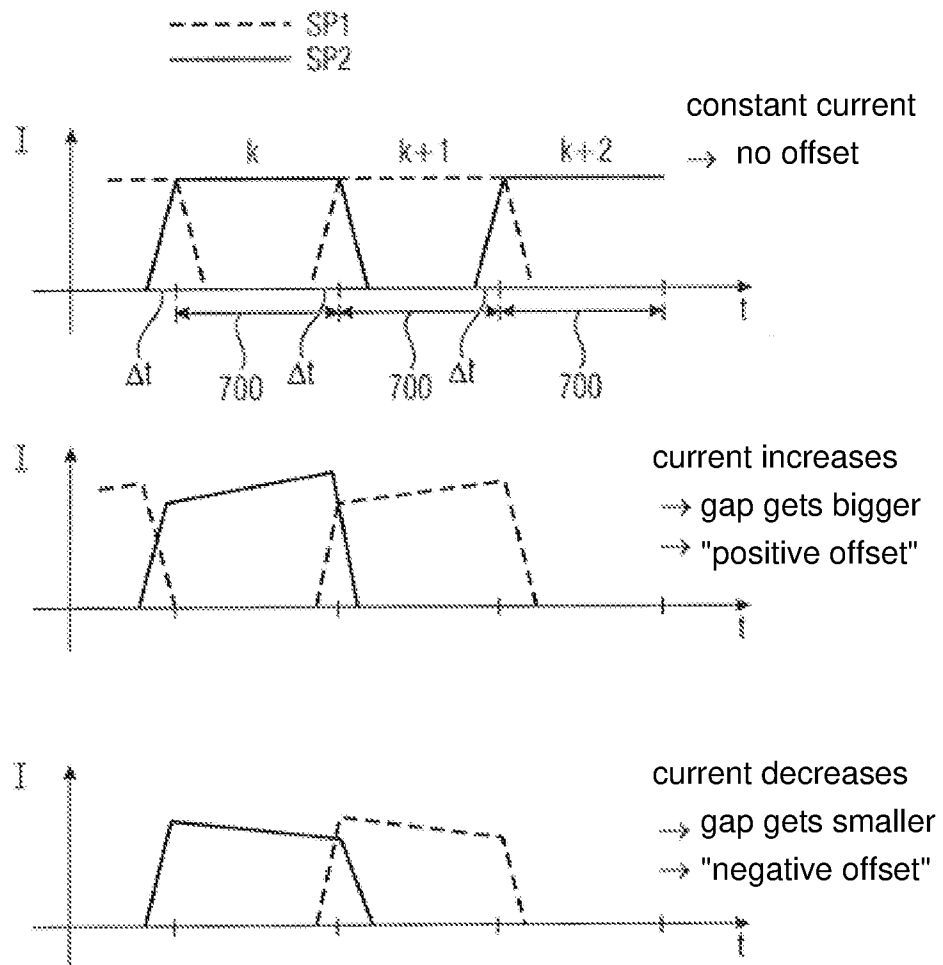


Fig. 10

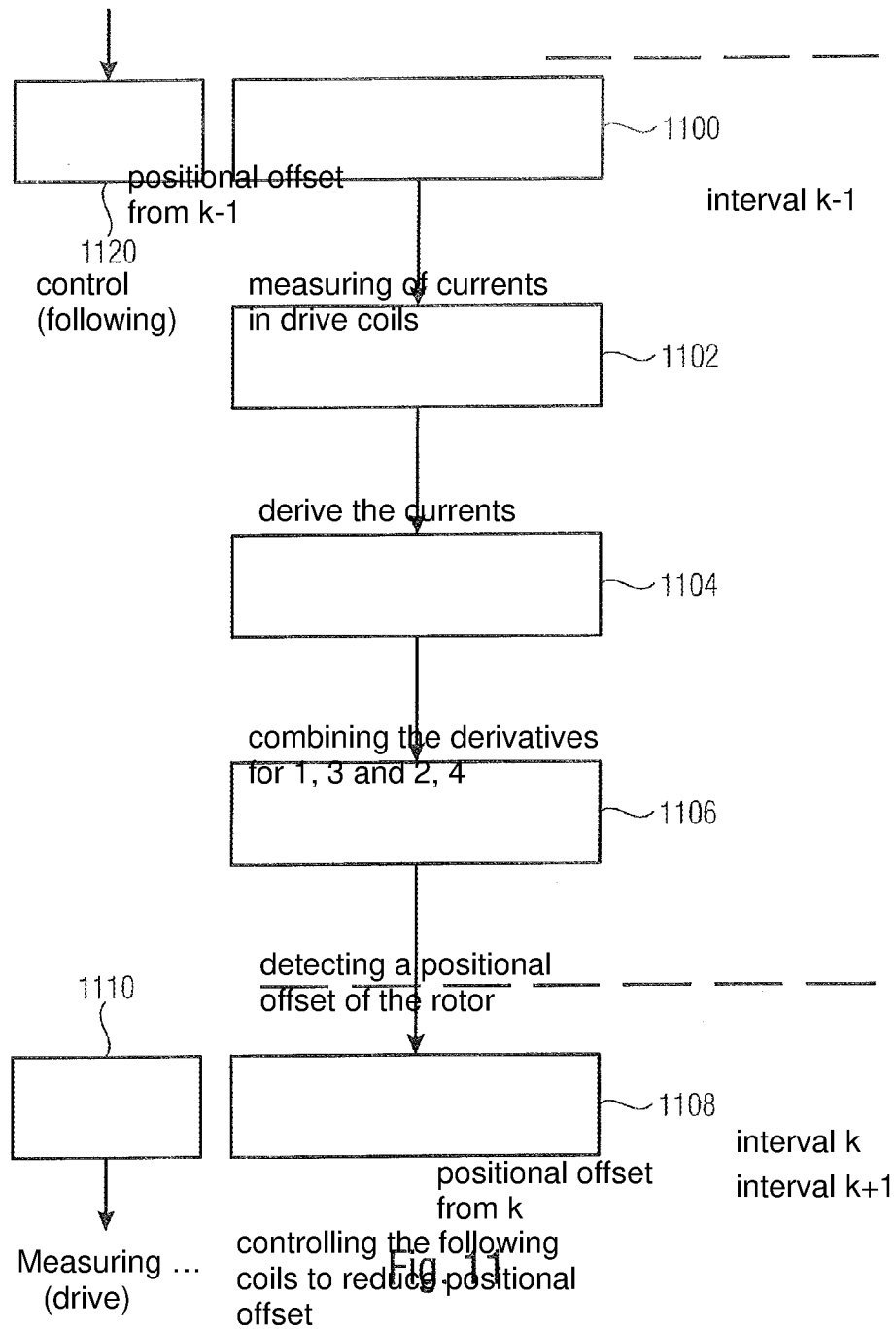


Fig. 11

- * gap is after ③ maximal (between ③ and ④)
- * drive coil ①, ③, ⑤, ⑦
- * current increases in ①, ③
- * Current decreases in ⑤, ⑦ [minimal gap after ⑦
(between ⑦ and ⑧)]
- * follower coil ④, ⑧ on ground
- * Followert coil ⑧, ④ on U_M
 - Polarity depends on the winding direction of the coil and alignment / magnetization of the permanent magnets
 - if e.g. coil ④ was connected in the last drive interval positive (with U_M)
 - coil ⑧ is connected for position control also positive (with U_M)
 - Attraction and reduction of the gap at ③.

Fig. 12

between

between

between

between

between

between

between

between

between

between

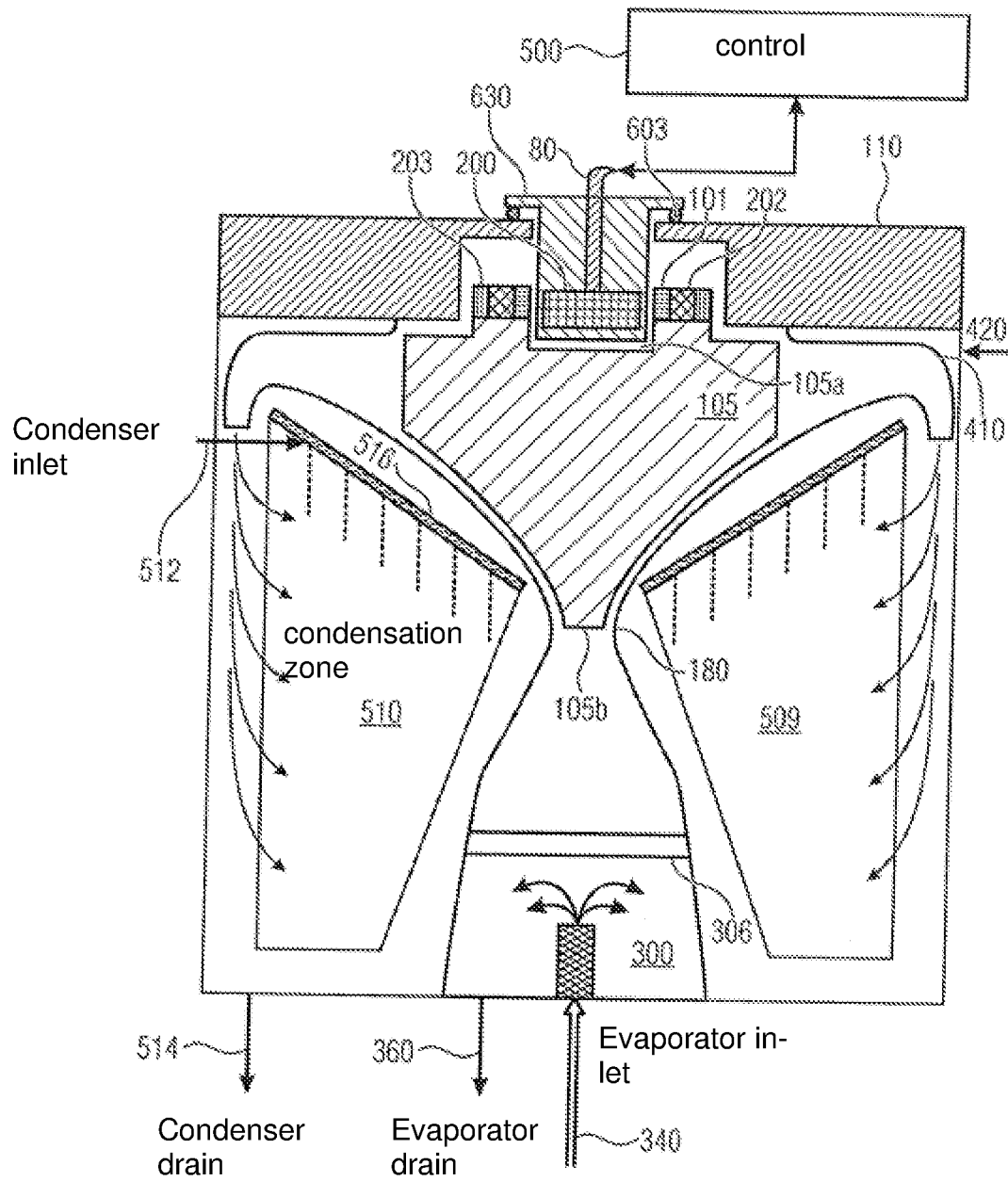


Fig. 14