

(19) **DANMARK**

(10) **DK/EP 3741034 T3**



Patent- og
Varemærkestyrelsen

(12) Oversættelse af
europæisk patentskrift

-
- (51) Int.Cl.: **H 02 P 23/04 (2006.01)** **H 02 K 16/04 (2006.01)**
- (45) Oversættelsen bekendtgjort den: **2022-09-12**
- (80) Dato for Den Europæiske Patentmyndigheds bekendtgørelse om meddelelse af patentet: **2022-07-27**
- (86) Europæisk ansøgning nr.: **18706643.6**
- (86) Europæisk indleveringsdag: **2018-01-16**
- (87) Den europæiske ansøgnings publiceringsdag: **2020-11-25**
- (86) International ansøgning nr.: **EP2018050987**
- (87) Internationalt publikationsnr.: **WO2019141346**
- (84) Designerede stater: **AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**
- (73) Patenthaver: **ABB Schweiz AG, Bruggerstrasse 66, 5400 Baden, Schweiz**
- (72) Opfinder: **MANTERE, Juhani, c/o ABB Oy, Strömbergintie 1, 00380 Helsinki, Finland**
SZÜCS, Áron, c/o ABB Oy, Strömbergintie 1, 00380 Helsinki, Finland
ISLAM, Jahirul, c/o ABB AB, Forskargränd 7, 721 78 Västerås, Sverige
- (74) Fuldmægtig i Danmark: **Dennemeyer & Associates S.A, P.O. Box 700425, DE-81304 Munich, Tyskland**
- (54) Benævnelse: **FREM GANGSMÅDE TIL STYRING AF EN ELEKTRISK SYNKRON DOBBELTSTATORMASKINE**
- (56) Fremdragne publikationer:
JP-A- 2002 369 467
US-A1- 2008 169 720

DESCRIPTION

FIELD

[0001] Method for controlling a synchronous double stator electric machine.

BACKGROUND

[0002] A synchronous double stator electric machine may be formed of at least one double stator unit comprising a rotor and two stators connected to the rotor. The rotor may comprise a first side provided with a first set of magnetic poles and an opposite second side provided with a second set of magnetic poles. A first stator may be positioned facing towards the first side of the rotor. A second stator may be positioned facing towards the second side of the rotor. The first stator may be connected to a first frequency converter which is controlled with a first controller. The second stator may be connected to a second frequency converter which is controlled by a second controller. Each of the stators may thus be controlled individually. The rotor and the first stator may form a first electric machine and the rotor and the second stator may form a second electric machine.

[0003] Cogging torque of electrical machines is the torque due to the interaction between the permanent magnets of the rotor and the stator slots of electric machine. It is also known as detent or "no-current" torque. This torque is position dependent and its periodicity per revolution depends on the number of magnetic poles and the number of teeth on the stator. Cogging torque is an undesirable component for the operation of the electric machine. It is especially prominent at lower speeds, with the symptom of jerkiness. Cogging torque results in torque as well as speed ripple. There exists prior art solutions to eliminate the cogging torque. One solution is to shift the first stator and the second stator mechanically by a predetermined angle in relation to each other in a synchronous double stator electric machine. The shift between the first stator and the second stator may be half slot pitch in a situation in which the first stator and the second stator has an equal number of slots. The cogging torque of the first electric machine and the cogging torque of the second electric machine will in such case be in an opposite phase due to the shift of half slot pitch between the first stator and the second stator. The cogging torque of the synchronous double stator electric machine may thus be reduced. The side effect of this shift is that also the power and/or the torque of the synchronous double stator electric machine is reduced.

[0004] The stator field lags the rotor field in a synchronous generator and vice a versa in a synchronous motor. This lagging expressed in angle is called the load angle. The term load angle is in this application used for the angle between the rotor flux and the stator flux in an electric machine i.e. in a synchronous electric motor and in a synchronous electric generator.

[0005] JP 2002 369467 discloses a dynamo-electric machine and a pulley drive unit using the dynamo-electric machine. The dynamo-electric machine can increase a torque with a limited shaft length and it can also reduce a torque ripple without reducing the torque. Two sets of permanent magnets are fixed to a yoke of a rotor fixed to a rotary shaft and arranged in series in a direction vertical to the center axis of the rotary shaft. A first stator is provided to face the first set of permanent magnets and a second stator is provided to face the second set of permanent magnets. This dynamo-electric machine has a first motor and a second motor, comprising the rotor and the respective stator and a respective variable power supply which drive the first motor and the second motor independently.

[0006] US 2008/0169720 discloses a synchronous electromechanical transformer that can be used as a multi-phase motor and generator. The transformer has a high specific torque, a small or negligible stop moment, a small moment irregularity. The transformer can be quietly operated, and has good heat permeability between the windings and the housing. It contains a rotor having uniformly distributed magnetic poles, and two stators with concentrated windings of at least two electrical phases. The individual stator contains the same number of similarly arranged electromagnetic poles of each of at least two electrical phases arranged in related groups of at least two electromagnetic poles of the same electric phase. The stator poles can contain magnetically permeable polar cores and can be uniformly or non-uniformly distributed. The number of electromagnetic poles of the stator differs from that of the rotor by the product between the number of stator groups, the electromagnetic poles of said stator groups pertaining to the same electrical phases, and a natural number that is not a multiple of the number of electrical phases. A radial, axial and linear embodiment of the transformer is possible.

SUMMARY

[0007] An object of the present invention is to achieve an improved method for controlling a synchronous double stator electric machine.

[0008] The method for controlling a synchronous double stator electric machine according to the invention is defined in the independent claims.

[0009] The mechanical shifting of the first electric machine in relation to the second electric machine will reduce the cogging torque, which is a desired feature. The side effect of the mechanical shifting is, however, that also the power and/or the torque of the synchronous double stator electric machine is reduced due to loss of magnetization in the synchronous double stator electric machine.

[0010] When we load the synchronous double stator electric machine, there will be a change in the cogging torque. The magnetic flux from the rotor to the stator or from the stator to the rotor will be increased and the magnetic flux will also bend in accordance with the loading. The magnetic flux will bend towards the direction of rotation of the rotor in a synchronous electric

motor and against the direction of rotation of the rotor in a synchronous electric generator. The amplitude of the cogging torque will also change due to the loading of the synchronous double stator electric machine so that a bigger load causes a bigger amplitude of the cogging torque. The waveform of the torque of the synchronous double stator electric machine will also be more distorted in a loaded condition.

[0011] The cogging torque will still at least partly be cancelled out also in the loaded condition due to the mechanical shifting of predetermined angle between the two electric machines. A problem in the loaded condition is the reduced performance (reduced power and/or reduced torque) of the synchronous double stator electric machine due to the mechanical shifting with the predetermined angle between the two electric machines. The mechanical shift with the predetermined angle between the first electric machine and the second electric machine will result in a substantial reduction in performance in case the first electric machine and the second electric machine are connected directly in series due to loss of magnetization.

[0012] The invention provides a solution to this loss of magnetization in the mechanically shifted synchronous double stator electric machine. The solution is to produce an electrical shift to the control of at least the mechanically shifted electric machine with the respective frequency converter in order to at least partly compensate for the mechanical shift in the mechanically shifted electric machine.

[0013] The electrical shift is produced by rotating the magnetic flux of the respective stator in a direction opposite to the direction of the mechanical shift, or the electrical shift is produced by rotating the magnetic flux of the respective stator back to the position it had in the un-shifted topology, or the electrical shift may be produced by shifting both electric machines electrically so that the values of the respective load angles in the un-shifted topology are restored in the shifted topology, or the electrical shift is produced by shifting both electric machines electrically by rebalancing the power and/or the torque between the two electric machines so that the sum of the torque harmonics of the two electric machines remains under a predetermined value, or the electrical shift is produced by shifting both electric machines electrically by rebalancing the power and/or the torque between the two electric machines so that the amplitude of the torque harmonics in the two electric machines are substantially equal.

[0014] The load angle may be calculated from different characteristic values of the synchronous double stator electric machine. The load angle of a new synchronous double stator electric machine may thus be calculated in advance in a mechanically un-shifted topology of the synchronous double stator electric machine from different characteristic values of the synchronous double stator electric machine throughout the whole operational range of the synchronous double stator electric machine. These calculated values of the load angle of the mechanically un-shifted synchronous double electric machine may then be used as set values in the control of the synchronous double stator electric machine in the shifted topology. Another possibility would be to run tests of the new synchronous double stator electric machine in a mechanically un-shifted topology in order to determine the load angle values of the un-shifted synchronous double stator electric machine throughout the whole operational range of

the synchronous double stator electrical machine.

[0015] The starting point in the invention is a double stator electric machine provided with a mechanical shifting between the rotor and the stator in one of the two electric machines. The invention adds an electrical shifting to the mechanical shifting in at least one of the two electric machines in a double stator electric machine. The electrical shifting in the electric machine may be realized by shifting the magnetic flux of the electric machine. The electrical shifting of the magnetic flux in the electric machine may at least partially compensate for the loss in magnetization that the mechanical shifting of the electric machine causes.

DRAWINGS

[0016] In the following the invention will be described in greater detail by means of preferred embodiments with reference to the attached drawings, in which

Figure 1 shows a cross section of a radial flow synchronous double stator electric machine,

Figure 2 shows a cross section of an axial flow synchronous double stator electric machine,

Figure 3 shows a control system of a synchronous double stator electric machine,

Figure 4 shows a situation in which the permanent magnets on the inner surface and on the outer surface of the rotor are shifted by a predetermined angle,

Figure 5 shows the magnetic fluxes in a synchronous double stator electric machine in which there is no shift between the stators,

Figure 6 shows the magnetic fluxes in a synchronous double stator electric machine in which there is a predetermined angle between the stators,

Figure 7 shows the magnetic fluxes in a synchronous double stator electric machine in which there is a predetermined angle between the stators and the stator flux is repositioned,

Figure 8 shows a flow diagram of a method for controlling a synchronous double stator electric machine.

DETAILED DESCRIPTION

[0017] Figure 1 shows a cross section of a radial flow synchronous double stator electric machine.

[0018] The synchronous double stator electric machine 500 comprises a rotor 100, a first

stator 200 and a second stator 300.

[0019] The rotor 100 is supported on a rotating shaft 10 supported with bearings 20, 30 in a stationary frame 40. The centre of the shaft 10 forms a shaft line X-X. The rotor 100 rotates with the shaft 10. The rotor 100 may have a cup-shape. The rotor 100 may comprise a radially extending disc shaped first portion 110 and an axially X-X from a side surface of the first portion 110 at the outer perimeter of the first portion 110 extending cylindrical second portion 120. The second portion 120 of the rotor 100 may be concentric with the shaft line X-X. The first portion 110 may comprise an opening O1 in the centre of the disc. The shaft 10 may pass through the opening O1 so that the rotor 100 may become attached to the shaft 10 from the edge of the opening O1.

[0020] The cylindrical second portion 120 of the rotor 100 may be provided with a first set of permanent magnets 150 on a first side of the rotor 100 and a second set of permanent magnets 160 on an opposite second side of the rotor 100. The first side of the rotor 100 may be formed by the inner surface of the cylinder 120 and the second side of the rotor 100 may be formed by the outer surface of the cylinder 120. The first set of permanent magnets 150 may be equally distributed along the perimeter of the inner surface of the cylinder 120. The second set of permanent magnets 150 may also be equally distributed along the perimeter of the outer surface of the cylinder 120.

[0021] A cylindrical stationary first stator 200 may be positioned within the inner circumference of the second portion 120 of the rotor 100. The first stator 200 may be supported on the frame 40. A first air gap G1 may be formed between the first set of permanent magnets 150 on the inner surface of the second portion 120 of the rotor 100 and the outer surface of the first stator 200.

[0022] A cylindrical stationary second stator 300 may be positioned outside the outer circumference of the second portion 120 of the rotor 100. The second stator 300 may be supported on the frame 40. A second air gap G2 may be formed between the second set of permanent magnets 160 on the outer surface of the second portion 120 of the rotor 100 and the inner surface of the second stator 300.

[0023] The magnetic flux Ψ between the rotor 100 and the first stator 200 and between the rotor 100 and the second stator 300 is radially directed in the electric machine shown in figure 1. The synchronous double stator electric machine in figure 1 is thus a radial flux synchronous double stator electric machine.

[0024] The first stator 200 and the first set of permanent magnets 150 form a first electric machine 510 within the double stator electric machine 500.

[0025] The second stator 300 and the second set of permanent magnets 160 form a second electric machine 520 within the double stator electric machine 500.

[0026] Figure 2 shows a cross section of an axial flow synchronous double stator electric machine.

[0027] The synchronous double stator electric machine 500 comprises a rotor 100, a first stator 200 and a second stator 300.

[0028] The rotor 100 is supported on a rotating shaft 10 supported with bearings 20, 30 in a stationary frame 40. The centre of the shaft 10 forms a shaft line X-X. The rotor 100 rotates with the shaft 10. The rotor 100 may have a disc shape. The rotor 100 may comprise an opening O1 in the centre of the disc. The shaft 10 may pass through the opening O1 so that the rotor 100 may become attached to the shaft 10 from the edge of the opening O1.

[0029] A first side of the rotor 100 may be provided with a first set of permanent magnets 150 and a second opposite side of the rotor 100 may be provided with a second set of permanent magnets 160. The first side of the rotor 100 may be formed by the left hand surface of the rotor disc and the second side may be formed by the right hand surface of the rotor disc. The first set of permanent magnets 150 may form a ring on the first side of the rotor 100. The second set of permanent magnets 160 may form a ring on the second side of the rotor 100. The first set of permanent magnets 150 may be equally distributed along the perimeter of the first side surface of the rotor 100. The second set of permanent magnets 150 may also be equally distributed along the perimeter of the second side surface of the rotor 100.

[0030] A stationary disc shaped first stator 200 may be positioned outside the first side surface of the rotor 100. The first stator 200 may be supported on the frame 40. A first air gap G1 may be formed between the first set of permanent magnets 150 on the first side surface of the rotor 100 and the first stator 200.

[0031] A stationary disc shaped second stator 300 may be positioned outside the second side surface of the rotor 100. The second stator 300 may be supported on the frame 40. A second air gap G2 may be formed between the second set of permanent magnets 160 on the second surface of the rotor 100 and the second stator 300.

[0032] The magnetic flux Ψ between the rotor 100 and the first stator 200 and between the rotor 100 and the second stator 300 is axially directed in the electric machine shown in figure 2. The synchronous double stator electric machine in figure 2 is thus an axial flux synchronous double stator electric machine.

[0033] The first stator 200 and the first set of permanent magnets 150 form a first electric machine 510 within the synchronous double stator electric machine 500.

[0034] The second stator 300 and the second set of permanent magnets 160 form a second electric machine 520 within the synchronous double stator electric machine 500.

[0035] Figure 3 shows a control system of a synchronous double stator electric machine.

[0036] The first stator 200 of the synchronous double stator electric machine 500 may be connected to a first frequency converter 250 and the first frequency converter may be connected to the grid 400. The first frequency converter 250 may comprise a rectifier, an intermediate circuit and an inverter. The first frequency converter 250 may be operated in both directions i.e. power may be transformed from the first stator 200 to the grid 400 or vice versa. The first frequency converter 250 may be controlled by a first controller 260. The first controller 260 may be a part of the first frequency converter 250 or a separate entity. The first frequency converter 250 controls the first electric machine 510.

[0037] The second stator 300 of the synchronous double stator electric machine 500 may be connected to a second frequency converter 350 and the second frequency converter may be connected to the grid 400. The second frequency converter 350 may comprise a rectifier, an intermediate circuit and an inverter. The second frequency converter 350 may be operated in both directions i.e. power may be transformed from the second stator 300 to the grid 400 or vice versa. The second frequency converter 350 may be controlled by a second controller 360. The second controller 360 may be a part of the second frequency converter 350 or a separate entity. The second frequency converter 350 controls the second electric machine 520.

[0038] The first electric machine 510 and the second electric machine 520 may thus be controlled independently with their respective frequency controller 250, 350.

[0039] The synchronous double stator electric machine 500 may be a three phase synchronous double stator electric machine and the grid 400 may be a three phase electric grid.

[0040] The first stator 200 and the first set of permanent magnets 150 form a first electric machine 510 within the synchronous double stator electric machine 500.

[0041] The second stator 300 and the second set of permanent magnets 160 form a second electric machine 520 within the synchronous double stator electric machine 500.

[0042] The first controller 260 may control the first electric machine 510 through the first frequency converter 250 and the second controller 360 may control the second electric machine 520 through the second frequency converter 350 based on any known control method.

[0043] The control method could be a traditional Pulse Width Modulation (PWM) technique in which the frequency and the voltage is regulated and supplied through a modulator and semiconductor switches to the electric machine. The use of a modulator will, however, produce a delay in the control circuit, whereby the response of the electric machine to the frequency and voltage control is slowed down.

[0044] Another possibility would be to use a Direct Torque Control (DTC) that controls the torque and the magnetic flux of the electric machine directly without the use of a modulator. The DTC is based on an accurate electric model of the electric machine. The nominal values of the electric machine form the initial data in the electric model of the electric machine. The DTC will during the first start examine the electrical quantities of the electric machine and based on this adjust the electric model of the electric machine.

[0045] Figure 4 shows a situation in which the permanent magnets on the inner surface and on the outer surface of the rotor are shifted by a predetermined angle.

[0046] The synchronous double stator electric machine of figure 4 corresponds to the radial flow synchronous double stator electric machine shown in figure 1. The synchronous double stator electric machine comprises a rotor 100, a first stator 200, and a second stator 300. The rotor 100 may have a cylindrical form. The core of the first stator 200 and the core of the second stator 300 may also have a cylindrical form.

[0047] The rotor 100 is rotatable around a shaft axis X-X. The rotor 100 may comprise a first side provided with a first set of magnetic poles 150 and an opposite second side provided with a second set of magnetic poles 160. The rotor 100 may be positioned between the first stationary stator 200 and the second stationary stator 300.

[0048] The first stator 200 may face towards the first side of the rotor 100 so that a first air gap G1 may be formed between the first set of magnetic poles 150 and the first stator 200. The first stator 200 may be positioned inside the rotor 100. The first stator 200 may be connected to the first frequency converter 250 as shown in figure 3.

[0049] The second stator 300 may face towards the second side of the rotor 100 so that a second air gap G2 may be formed between the second set of magnetic poles 160 and the second stator 300. The second stator 300 may be positioned outside the rotor 100. The second stator 200 may be connected to the second frequency converter 350 as shown in figure 3.

[0050] The first side of the rotor 100 may be formed by the inner surface of the cylindrical rotor 100. The first set of permanent magnets 150 may thus be positioned on the inner surface of the rotor 100. The second side of the rotor 100 may be formed by the outer surface of the cylindrical rotor 100. The second set of permanent magnets 160 may thus be positioned on the outer surface of the rotor 100. The figure shows only one permanent magnet in the first set of permanent magnets 150 and only one permanent magnet in the second set of permanent magnets 160. There may, however, be several permanent magnets in the first set of permanent magnets 150 and in the second set of permanent magnets 160 distributed along the respective surface of the rotor 100.

[0051] The first stator 200 and the first set of permanent magnets 150 form a first electric machine 510 within the double stator electric machine 500.

[0052] The second stator 300 and the second set of permanent magnets 160 form a second electric machine 520 within the double stator electric machine 500.

[0053] The first set of permanent magnets 150 and the second set of permanent magnets 160 are mechanically shifted in relation to each other with a predetermined angle γ . The predetermined angle γ may be half slot pitch γ . The slot pitch γ in electrical angle is defined by equation (1):

$$\gamma = \frac{P}{2} \gamma_m \quad (1)$$

where P is the number of poles in the respective stator of the synchronous double stator electric machine and γ_m is the mechanical angle between two adjacent slots in the respective stator of the synchronous double stator electric machine as defined by equation (2):

$$\gamma_m = \frac{2\pi}{S} \quad (2)$$

[0054] Where S is the number of slots in the stator.

[0055] The axial portion of the stator winding is positioned in the axil slots in the stator.

[0056] A mechanical shift between the first stator 200 and the second stator 300 with a predetermined angle γ may be achieved as shown in figure 4 by shifting the first set of permanent magnets 150 on the inner surface of the rotor 100 and the second set of permanent magnets 160 on the outer surface of the rotor 100 with the predetermined angle γ in relation to each other. Another possibility would be to shift the first stator 200 and the second stator 300 with the predetermined angle γ in relation to each other. This shift with the predetermined angle γ between the first stator 200 and the second stator 300 constitutes a mechanical shifting between the first stator 200 and the second stator 300. The predetermined angle γ may be equal to half slot pitch γ .

[0057] The number of slots in the first stator 200 and the number of slots in the second stator 300 may be equal.

[0058] Figure 5 shows the magnetic fluxes in a synchronous double stator electric machine in which there is no mechanical shift between the stators.

[0059] The figure shows the rotor inner magnetic flux Ψ_{ri1} i.e. the magnetic flux in the first, inner magnets 150 in the rotor 100 and the rotor outer magnetic flux Ψ_{ro1} i.e. the magnetic flux in the second, outer magnets 160 in the rotor 100. The figure shows further the stator inner magnetic flux Ψ_{si1} i.e. the magnetic flux in the first, inner stator 200 and the stator outer magnetic flux Ψ_{so1} i.e. the magnetic flux in the second, outer stator 300. The figure shows further the inner load angle δ_{i1} i.e. the load angle between the rotor inner magnetic flux Ψ_{ri1} and the stator inner magnetic flux Ψ_{si1} and the outer load angle δ_{o1} i.e. the load angle between the rotor outer magnetic flux Ψ_{ro1} and the stator outer magnetic flux Ψ_{so1} . The inner load angle δ_{i1} and the outer load angle δ_{o1} are shown to be equal in the figure to emphasize

the optimum load sharing and/or load angle selection in the un-shifted topology without shifted poles. The un-shifted topology refers to the situation in which there is no mechanical shift between the first electric machine 510 and the second electric machine 520. The inner load angle δ_{i1} and the outer load angle δ_{o1} can, however, be different in a situation in which an unequal pair of initial load angles in the first (inner) electric machine 510 and in the second (outer) electric machine 520 result in the best performance option in the un-shifted topology.

[0060] Figure 6 shows the magnetic fluxes in a synchronous double stator electric machine in which there is a predetermined angle between the stators.

[0061] The second, outer set of magnets 160 on the outer surface of the rotor 100 have been mechanically shifted in relation to the first, inner set of magnets 150 on the inner surface of the rotor 100 with a predetermined angle without shifting the magnetic field of the second stator 300 in the second (outer) electric machine 520. The load angle δ_{o2} in the second (outer) electric machine 520 will change. The shift of the second, outer set of magnets 160 on the outer surface of the rotor 100 with the predetermined angle in relation to the first, inner set of magnets 150 on the inner surface of the rotor 100 will in reality affect the load angle δ_{i2} in the first (inner) electric machine 510 as well as the load angle δ_{o2} in the second (outer) electric machine 520 i.e. both load angles δ_{i2} , δ_{o2} will in reality change. This means that the inner load angle δ_{i2} and the outer load angle δ_{o2} seen in figure 6 will be different from the inner load angle δ_{i1} and the outer load angle δ_{o1} seen in figure 5. This is due to the disturbed load sharing between the first (inner) electric machine 510 and the second (outer) electric machine 520. The disturbance in the load sharing is caused by the mechanical shifting of the two electric machines 510, 520 in the synchronous double stator electric machine 500 in a situation in which the mechanical shift between the two electric machines 510, 520 is not compensated by a corresponding electrical shifting between the two electric machines 510, 520 in the synchronous double stator electric machine 500.

[0062] Figure 7 shows the magnetic fluxes in a synchronous double stator electric machine in which there is a predetermined angle between the stators and the stator flux is repositioned.

[0063] The magnet poles 150, 160 in the stators 200, 300 have been mechanically shifted in relation to each other with a predetermined angle and also the magnetic field Ψ_{so3} of the second (outer) stator 300 in the second (outer) electric machine 520 has been shifted in a corresponding way. The magnetic field Ψ_{so3} of the second (outer) stator 300 is repositioned to deliver the same performance as it did in the initial case. This can be done by rebalancing the power and/or the torque between the first (inner) electric machine 510 and the second (outer) electric machine 520.

[0064] The frequency controllers 250, 350 can be configured to control the load angle δ_i , δ_o in each of the electric machines 510, 520 so that the load angle δ_i , δ_o in the shifted topology is restored back to the value of the respective load angle δ_i , δ_o in the un-shifted topology.

[0065] The power and/or the torque between the first electric machine 510 and the second

electric machine 520 may be rebalanced with the frequency converters 250, 350 so that the load angle δ_i , δ_o in the shifted topology is restored back to the value of the respective load angle δ_i , δ_o in the un-shifted topology throughout the whole range of operation of the synchronous double stator electric machine 500.

[0066] The power and/or the torque between the first electric machine 510 and the second electric machine 520 may be rebalanced so that:

$$\delta_{i1} = \delta_{i3} \text{ and } \delta_{o1} = \delta_{o3}$$

[0067] This would in the idealized situation shown in figure 5 where the inner load angle δ_{i1} equals to the outer load angle δ_{o1} mean that:

$$\delta_{i1} = \delta_{i3} = \delta_{o1} = \delta_{o3}$$

[0068] The load angle δ_i of the first electric machine 510 and the load angle δ_o of the second electric machine 520 are thus the same in the shifted topology as they are in the un-shifted topology of the synchronous double stator electric machine 500.

[0069] It may also be possible to apply a control strategy in which the power and/or the torque between the two electric machines 510, 520 is rebalanced so that the sum of the torque harmonics of the two electric machines 510, 520 remains under a predetermined value throughout the whole range of operation of the double stator electric machine 500.

[0070] It may also be possible to apply a control strategy in which the power and/or the torque between the two electric machines 510, 520 is rebalanced so that the amplitude of the torque harmonics in the two electric machines 510, 520 are substantially equal.

[0071] The load angles of the mechanically un-shifted synchronous double stator electric machine may be used as reference values in the rebalancing of the power and/or the torque between the first electric machine and the second electric machine. These reference values may be calculated from characteristic values of the mechanically un-shifted synchronous double stator electric machine. Another possibility to determine the load angles of the un-shifted synchronous double stator electric machine would be to run tests on the un-shifted synchronous double stator electric machine throughout the operational range of the synchronous double stator electric machine.

[0072] The power P of an electric machine may be defined as:

$$P = T \times \omega$$

where T [Nm] is the torque of the electric machine and ω [radius/s] is the angular speed of the electric machine.

[0073] The torque T of an electric machine may be defined as:

$$T = \Psi \times I$$

where Ψ [Vs] is the magnetic flux of the electric machine and I [A] is the current of the electric

machine.

[0074] The power P is thus directly proportional to the torque T and the rotation speed ω of the electric machine. The torque T is on the other hand directly proportional to the magnetic flux Ψ and the current I of the electric machine.

[0075] Figure 8 shows a flow diagram of a method for controlling a synchronous double stator electric machine.

[0076] The first step is to determine 801 the load angle δ of the respective electric machine 510, 520. The second step is to compare 802 the determined load angle δ with a predetermined load angle δ . A difference 803 between the determined load angle δ and the predetermined load angle δ results in an adjustment 804 of the load angle δ .

[0077] A skilled person knows how to determine the load angle δ of a synchronous double stator electric machine. This is explained e.g. in the book "Electrical Machine Drives Control: An Introduction", by Juha Pyrhönen, Valeria Hrabovcova, R. Scott Semken, Nov. 2016, ISBN: 978-1-119-26045-5.

[0078] The control 260, 360 of the respective frequency converter 250, 350 in the synchronous double stator electric machine 500 is not limited to any specific control method. Any control method may thus be used to control the frequency converters 250, 350.

[0079] The predetermined angle defining the mechanical shift between the first stator and the second stator may advantageously be half slot pitch. This is advantageous in the sense that the cogging torque of the first electric machine and the cogging torque of the second electric machine are in this case in an opposite phase. The cogging torque of the synchronous double stator electric machine may thus be reduced. The predetermined angle defining the mechanical shift between the first stator and the second stator need not necessarily be half slot pitch. The mechanical shift could be slightly less or slightly more than half slot pitch. The cogging torques of the two electric machines would still be in nearly opposite phases. The mechanical shift could be in the range of 0.9 times half slot pitch to 1.1 times half slot pitch.

[0080] The use of the invention is not limited to the synchronous double stator electric machine shown in the figures. The invention may be used in any electric machine fulfilling the requirements of the claims. The synchronous double stator electric machine shown in the figures is formed of one double stator unit. The synchronous double stator electric machine could comprise several double stator units, whereby each double stator unit may be controlled in accordance with the inventive method.

[0081] The invention may be used in a radial flux electric machine and in an axial flux electrical machine. Figure 1 shows one example of a radial flux electric machine and figure 2 shows one example of an axial flux electric machine.

[0082] The synchronous double stator electric machine may be a synchronous electric generator or a synchronous electric motor.

[0083] The techniques described herein may be implemented by various means so that an apparatus implementing one or more functions described with an embodiment comprises not only prior art means, but also specific means for implementing the one or more functions described with an embodiment and it may comprise separate means for each separate function, or specific means may be configured to perform two or more functions. The specific means may be software and/or software-hardware and/or hardware and/or firmware components (recorded indelibly on a medium such as readonly-memory or embodied in hard-wired computer circuitry) or combinations thereof. Software codes may be stored in any suitable, processor/computerreadable data storage medium(s) or memory unit(s) or article(s) of manufacture and executed by one or more processors/computers, hardware (one or more apparatuses), firmware (one or more apparatuses), software (one or more modules), or combinations thereof. For a firmware or software, implementation can be through modules (e.g., procedures, functions, and so on) that perform the functions described herein.

[0084] It will be obvious to a person skilled in the art that, as the technology advances, the inventive concept can be implemented in various ways. The invention and its embodiments are not limited to the examples described above but may vary within the scope of the claims.

REFERENCES CITED IN THE DESCRIPTION

Cited references

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- [JP2002369467A](#) [0005]
- [US20080169720A](#) [0006]

Non-patent literature cited in the description

- **JUHA PYRHÖNEN****VALERIA HRABOVCOVAR. SCOTT SEMKEN**Electrical Machine Drives Control: An Introduction, 2016, 978-1-119-26045-5 [0077]

FREMGANGSMÅDE TIL STYRING AF EN ELEKTRISK SYNKRON DOBBELTSTATORMASKINE

PATENTKRAV

1. Fremgangsmåde til styring af en elektrisk synkron dobbeltstatormaskine (500), der er dannet af mindst én dobbeltstatorenhed, omfattende

en rotor (100), der kan drejes omkring en akse (X-X), hvor rotoren (100) omfatter et første sæt magnetiske poler (150) og et andet sæt magnetiske poler (160),

en første stator (200), der vender mod det første sæt magnetiske poler (150), idet det første sæt magnetiske poler (150) og den første stator (200) danner en første elektrisk maskine (510) i den elektriske dobbeltstatormaskine (500), hvor den første elektriske maskine (510) styres af en første frekvensomformer (250), idet der dannes en første belastningsvinkel (δ_i) mellem den magnetiske flux (Ψ_{si}) af den første stator (200) og den magnetiske flux (Ψ_{ri}) af det første sæt magnetiske poler (150),

en anden stator (300), der vender mod det andet sæt magnetiske poler (160), idet det andet sæt magnetiske poler (160) og den anden stator (300) danner en anden elektrisk maskine (520) i den elektriske dobbeltstatormaskine (500), hvor den anden elektriske maskine (520) styres af en anden frekvensomformer (350), idet der dannes en anden belastningsvinkel (δ_o) mellem den magnetiske flux (Ψ_{so}) af den anden stator (300) og den magnetiske flux (Ψ_{ro}) af det andet sæt magnetiske poler (160), hvor

den første stator (200) og den anden stator (300) har et lige antal noter,

en af de to elektriske maskiner (510, 520) omfatter et mekanisk skift med en forudbestemt vinkel (γ) mellem rotoren (100) og statoren (200, 300), hvilket får den elektriske synkrone dobbeltstatormaskine (500) til at fungere i en forskudt topologi sammenlignet med en ikke-forskudt topologi, hvor rotoren (100) og de to statorer (200, 300) er justeret efter hinanden,

hvilken fremgangsmåde omfatter

frembringelse af et elektrisk skift til styring af i det mindste den mekanisk skiftede elektriske maskine (510, 520) med den respektive frekvensomformer (250, 350) for i det mindste delvist at kompensere for det mekaniske skift i den mekanisk skiftede elektriske maskine (510, 520), kendetegnet ved, at det elektriske skift frembringes ved

rotation af den magnetiske flux (Ψ_{si} , Ψ_{so}) af den respektive stator (200, 300) i en retning modsat retningen af det mekaniske skift eller

rotation af den magnetiske flux (Ψ_{si} , Ψ_{so}) af den respektive stator (200, 300)

tilbage til den position, den havde i den ikke-forskudte topologi, eller

gendannelse af værdierne af belastningsvinklerne (δ_i , δ_o) i den forskudte topologi til værdierne af belastningsvinklerne (δ_i , δ_o) i den ikke-forskudte topologi for begge elektriske maskiner (510, 520) eller

genbalancering af kraften og/eller drejningsmomentet mellem de to elektriske maskiner (510, 520), således at summen af momentoversvingningerne for de to elektriske maskiner (510, 520) forbliver under en forudbestemt værdi, eller

genbalancering af kraften og/eller drejningsmomentet mellem de to elektriske maskiner (510, 520), således at amplituden af momentoversvingningerne i de to elektriske maskiner (510, 520) i det væsentlige er ens.

2. Fremgangsmåde ifølge krav 1, hvor den mekaniske forskydning frembringes ved at forskyde de to statorer (200, 300) mekanisk i forhold til hinanden med den forudbestemte vinkel (γ).

3. Fremgangsmåde ifølge krav 1, hvor det mekaniske skift frembringes ved at forskyde det første sæt magnetiske poler (150) og det andet sæt magnetiske poler (160) på rotoren (100) mekanisk i forhold til hinanden med den forudbestemte vinkel (γ).

4. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 3, hvor den forudbestemte vinkel (γ) er i området fra 0,9 gange halv notdeling (γ) til 1,1 gange halv notdeling (γ).

5. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 3, hvor den forudbestemte vinkel (γ) er halv notdeling (γ).

6. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 5, hvor den elektriske synkrone dobbeltstatormaskine (500) er en elektrisk radialfluxmaskine.

7. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 5, hvor den elektriske synkrone dobbeltstatormaskine (500) er en elektrisk aksialfluxmaskine.

8. Elektrisk synkron dobbeltstatormaskine (500), der er dannet af mindst én dobbeltstatorenhed, omfattende

en rotor (100), der kan drejes omkring en akse (X-X), hvor rotoren (100)

omfatter et første sæt magnetiske poler (150) og et andet sæt magnetiske poler (160),
 en første stator (200), der vender mod det første sæt magnetiske poler (150),
 idet det første sæt magnetiske poler (150) og den første stator (200) danner en første elektrisk maskine (510) i den elektriske dobbeltstatormaskine (500), hvor den første elektriske maskine (510) styres af en første frekvensomformer (250), og idet der dannes en første belastningsvinkel (δ_i) mellem den magnetiske flux (Ψ_{si}) af den første stator (200) og den magnetiske flux (Ψ_{ri}) af det første sæt magnetiske poler (150),

en anden stator (300), der vender mod det andet sæt magnetiske poler (160),
 idet det andet sæt magnetiske poler (160) og den anden stator (300) danner en anden elektrisk maskine (520) i den elektriske dobbeltstatormaskine (500), hvor den anden elektriske maskine (520) styres af en anden frekvensomformer (350), idet der dannes en anden belastningsvinkel (δ_o) mellem den magnetiske flux (Ψ_{so}) af den anden stator (300) og den magnetiske flux (Ψ_{ro}) af det andet sæt magnetiske poler (160), hvor

den første stator (200) og den anden stator (300) har et lige antal noter,

en af de to elektriske maskiner (510, 520) omfatter et mekanisk skift med en forudbestemt vinkel (γ) mellem rotoren (100) og statoren (200, 300), hvilket får den elektriske synkrone dobbeltstatormaskine (500) til at fungere i en forskudt topologi sammenlignet med en ikke-forskudt topologi, hvor rotoren (100) og de to statorer (200, 300) er justeret efter hinanden,

i det mindste frekvensomformer (250, 350), der styrer den mekanisk skiftede elektriske maskine (510, 520), der er konfigureret til at frembringe et elektrisk skift til den mekanisk skiftede elektriske maskine (510, 520) for i det mindste delvist at kompensere for det mekaniske skift i den mekanisk forskudte elektriske maskine (510, 520), kendetegnet ved, at det elektriske skift frembringes ved

rotation af den magnetiske flux (Ψ_{si} , Ψ_{so}) af den respektive stator (200, 300) i en retning modsat retningen af det mekaniske skift eller

rotation af den magnetiske flux (Ψ_{si} , Ψ_{so}) af den respektive stator (200, 300) tilbage til den position, den havde i den ikke-forskudte topologi, eller

gendannelse af værdierne af belastningsvinklerne (δ_i , δ_o) i den forskudte topologi til værdierne af belastningsvinklerne (δ_i , δ_o) i den ikke-forskudte topologi for begge elektriske maskiner (510, 520) eller

genbalancering af kraften og/eller drejningsmomentet mellem de to elektriske maskiner (510, 520), således at summen af momentoversvingningerne for de to elektriske maskiner (510, 520) forbliver under en forudbestemt værdi, eller

genbalancering af kraften og/eller drejningsmomentet mellem de to elektriske

maskiner (510, 520), således at amplituden af momentoversvingningerne i de to elektriske maskiner (510, 520) i det væsentlige er ens.

9. Computerprogramprodukt omfattende programinstruktioner, som, når de køres på en computer, får computeren til at udføre en fremgangsmåde ifølge et hvilket som helst af kravene 1 til 7.

DRAWINGS

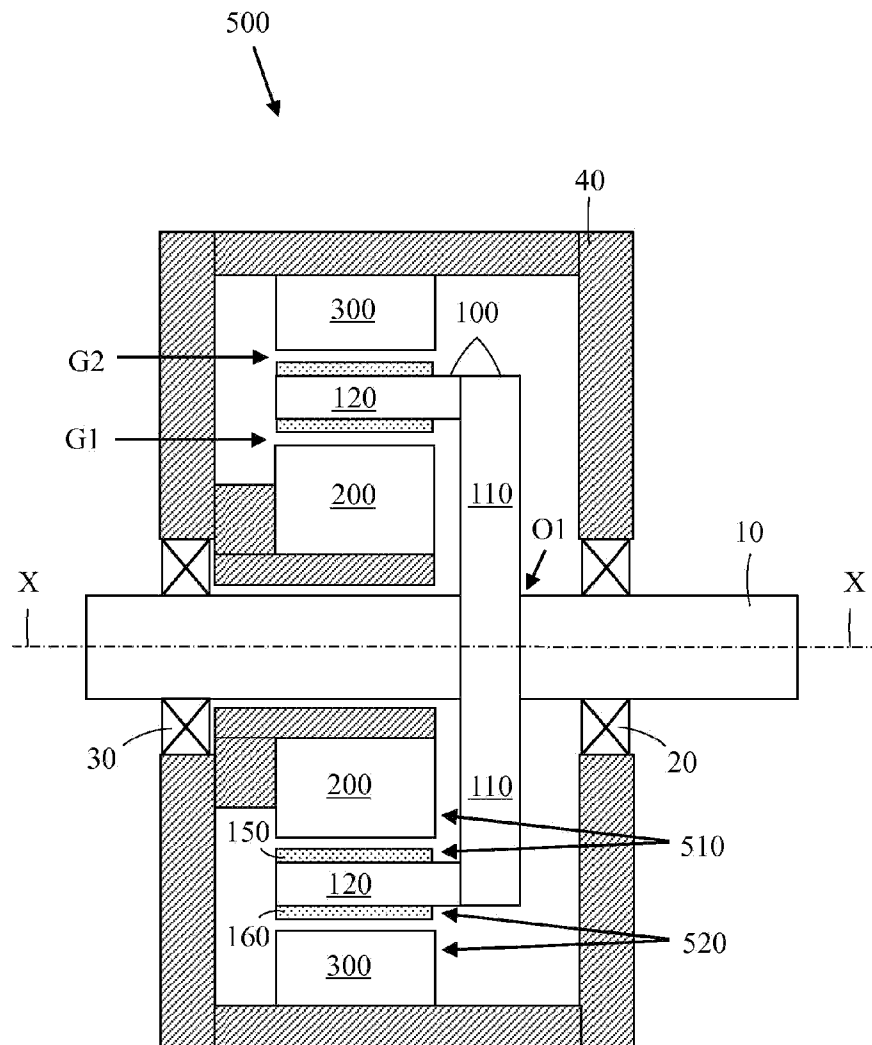


Fig. 1

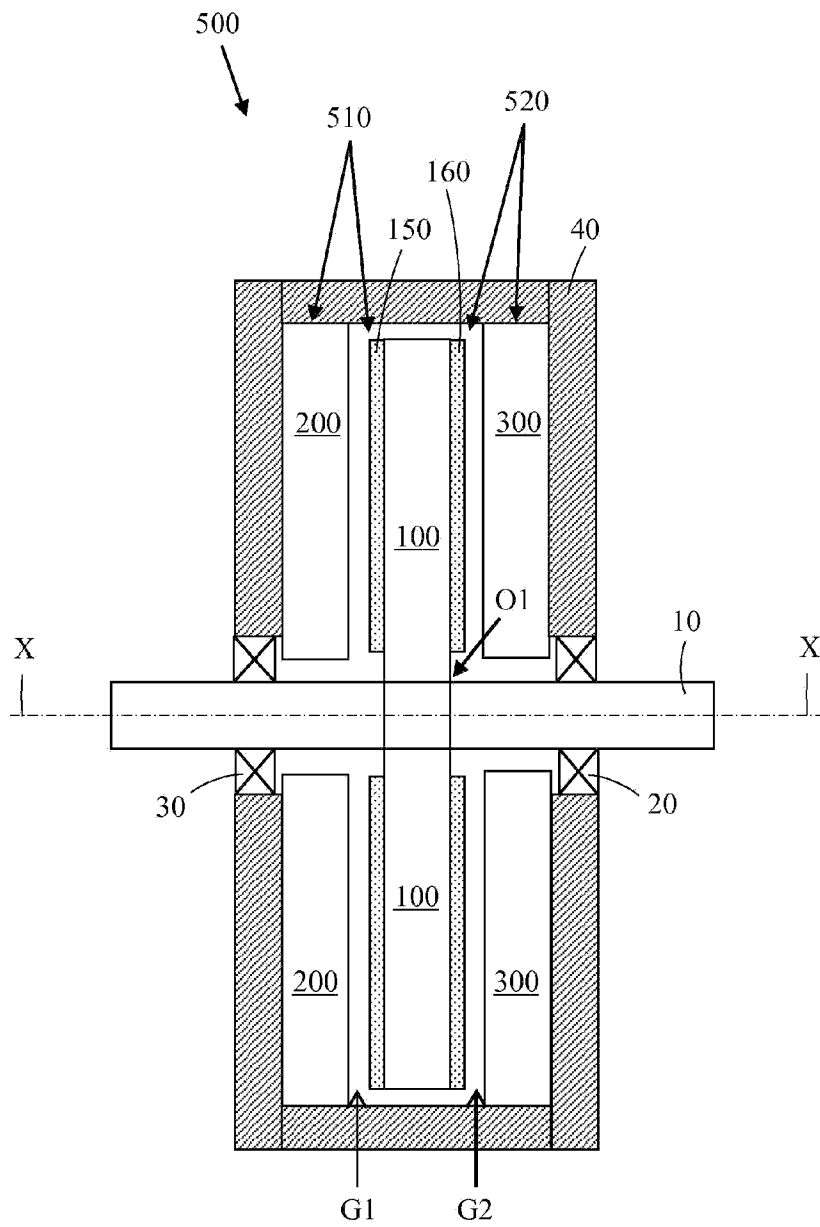
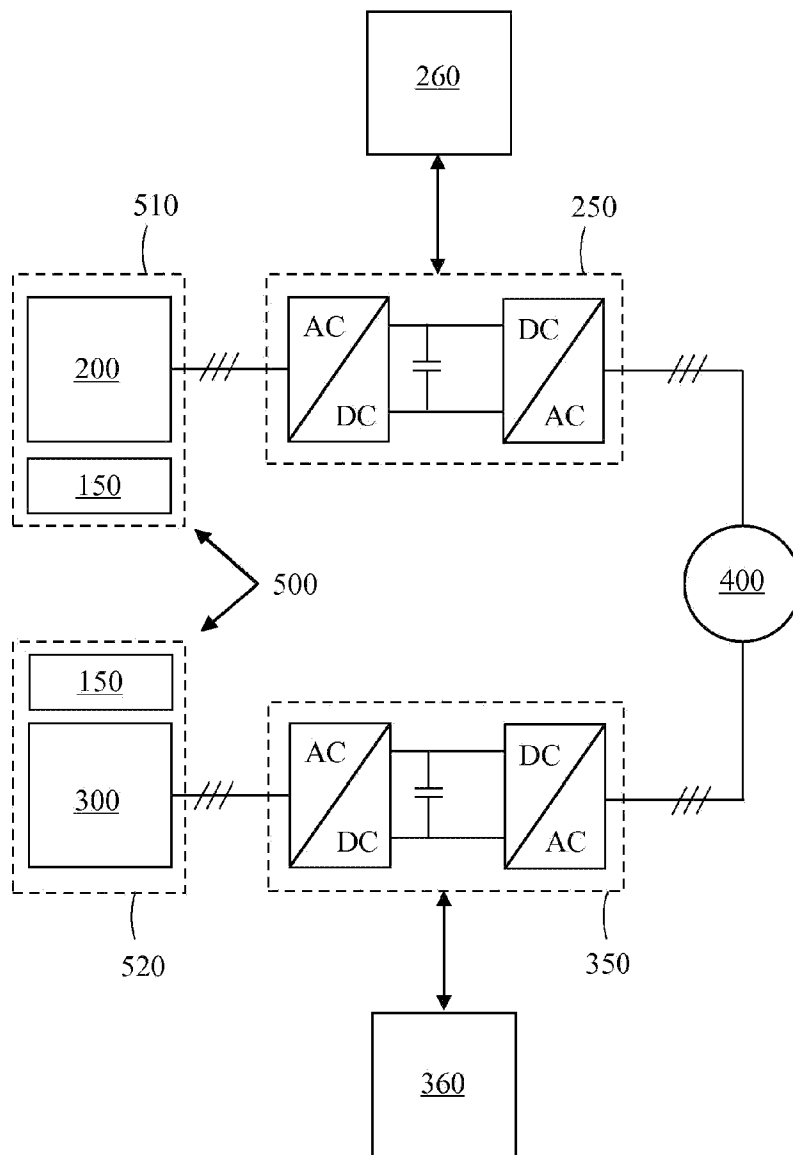
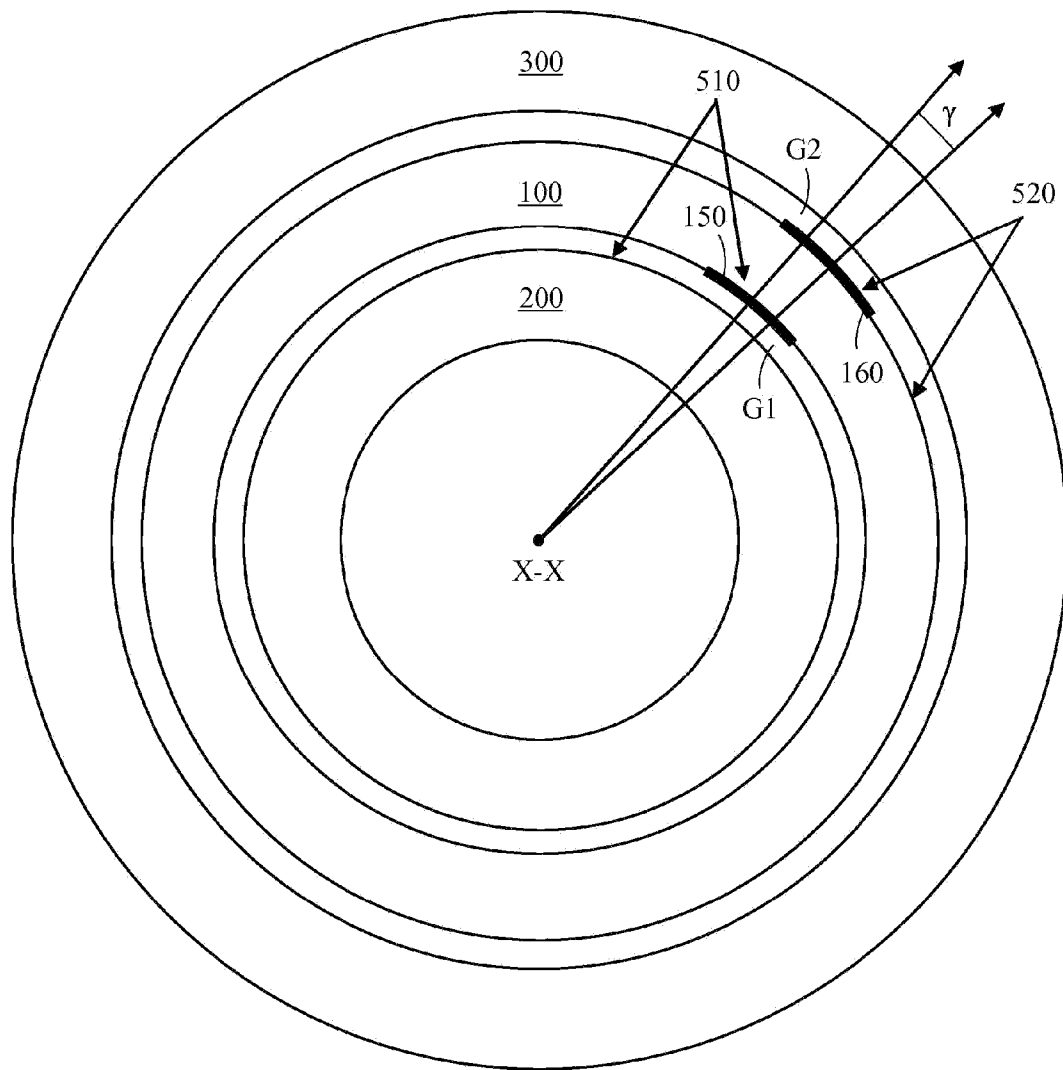
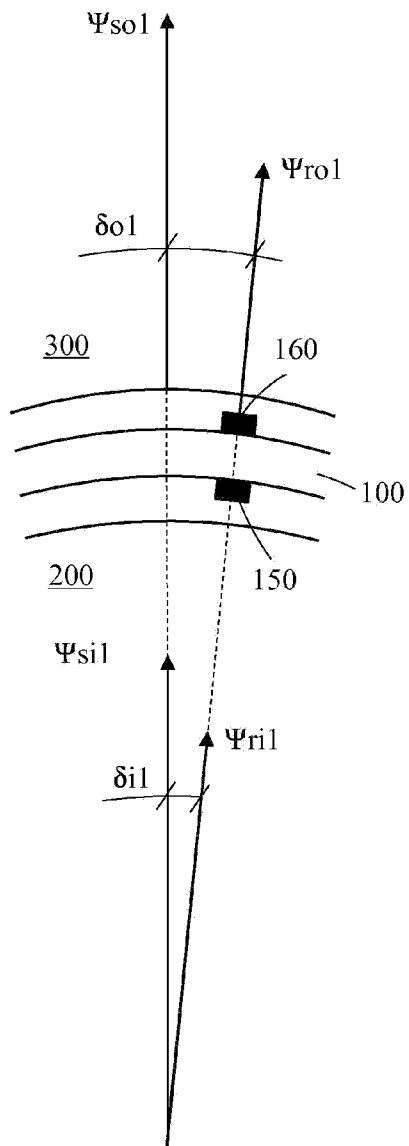
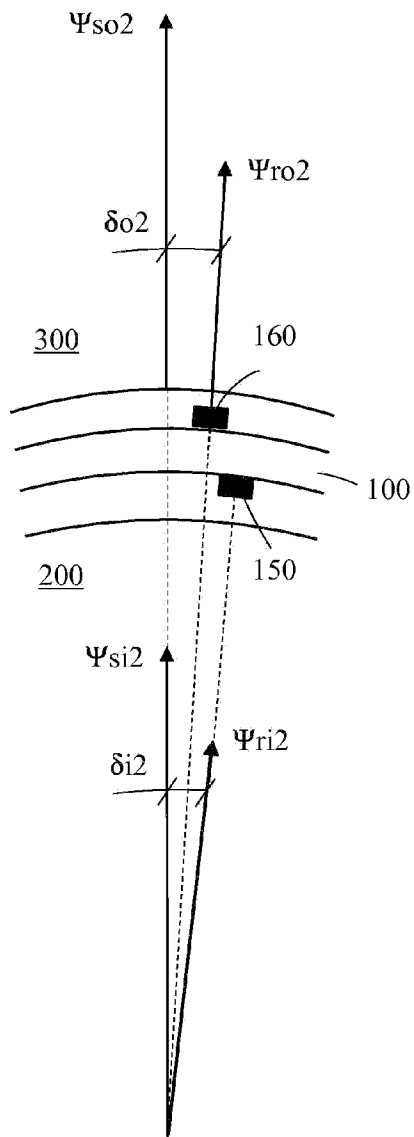


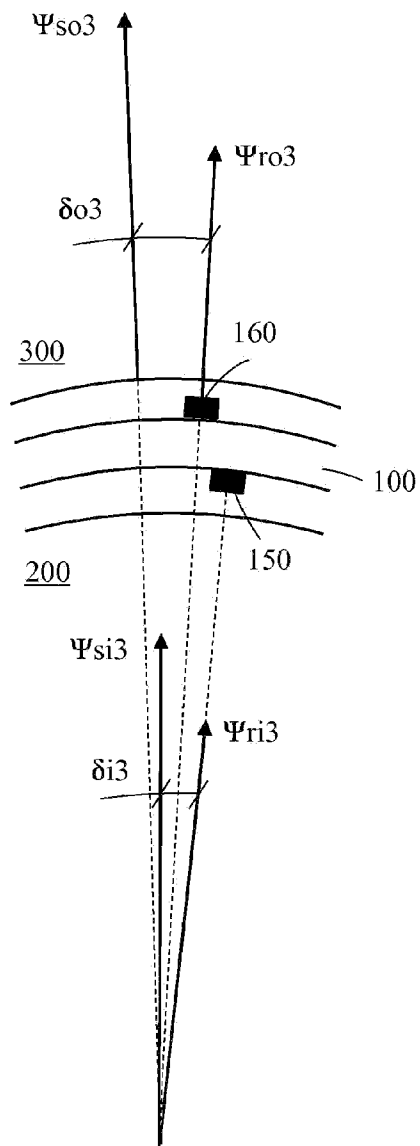
Fig. 2

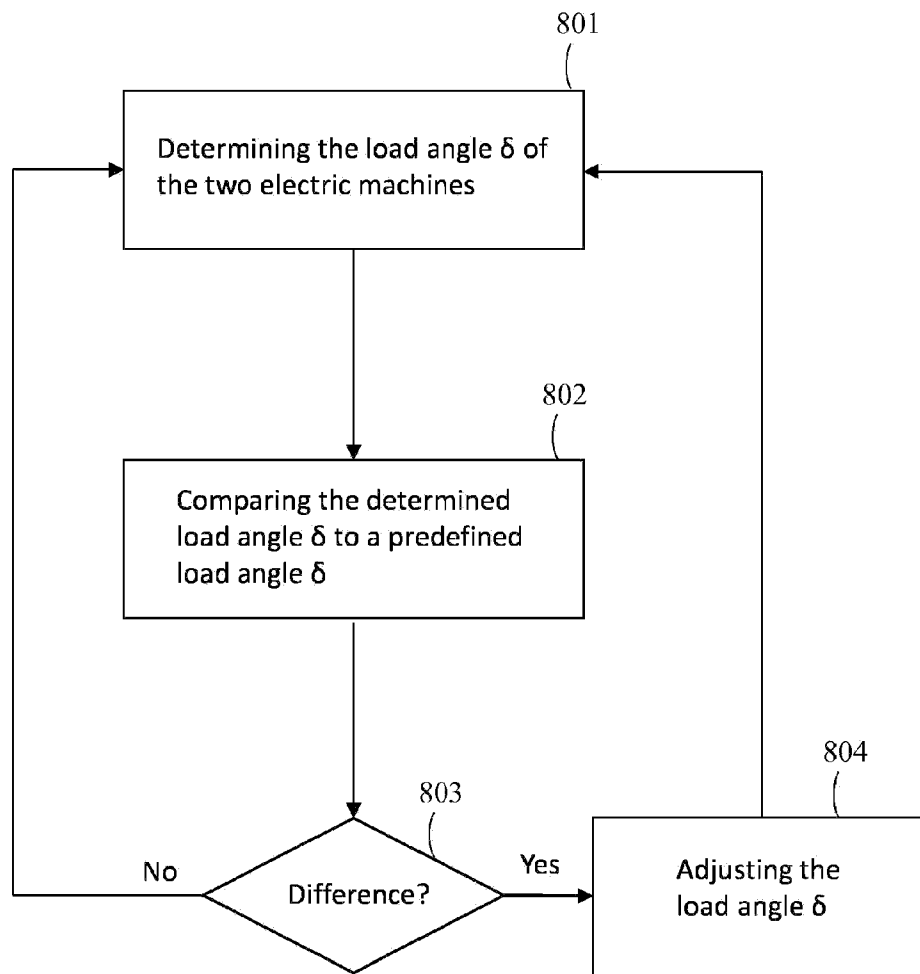
**Fig. 3**

**Fig. 4**

**Fig. 5**

**Fig. 6**

**Fig. 7**

**Fig. 8**