

MOTOR CONTROL DEVICE, AND WASHING MACHINE OR WASHING AND DRYING MACHINE HAVING SAID MOTOR CONTROL DEVICE INSTALLED THEREIN

BACKGROUND

1. Technical Field

[0001] The present disclosure relates to a motor control device configured to exercise sensorless control of the rotation of a brushless motor (a permanent magnet synchronous motor) including a rotor having a salient pole structure, and relates to a washing machine or a washing and drying machine having the motor control device installed therein.

2. Description of the Related Art

[0002] Patent Literature 1 discloses a motor control device configured to perform sensorless driving of a brushless motor including a rotor having a salient pole structure and determine the polarity of a magnetic pole at start-up. The motor control device is configured to convert direct-current power into alternating-current power and use the alternating-current power as motor power, and drive the brushless motor including the rotor having the salient pole structure. The motor control device includes a current detector, a three-phase dq-axis converter, a dq-axis current controller, a dq-axis three-phase converter, an alternating-current alternating-voltage generator for magnetic pole position estimation, a magnetic pole position estimation unit, a d-axis current direct-current bias generator, and an NS determination unit. The current detector is configured to detect a motor current flowing from an inverter to the brushless motor. The three-phase dq-axis converter is configured to perform dq-axis conversion of an alternating-current detected value detected by the current detector and output a d-axis current detected value and a q-axis current detected value. The dq-axis current controller is configured to calculate a d-axis voltage command and a q-axis voltage command which are respectively followed by the d-axis current detected value and the q-axis current detected value in response to a d-axis current command input and a q-axis current command input. The dq-axis three-phase converter is configured to convert the d-axis voltage command and the q-axis voltage command into a three-phase alternating-current voltage command and give the three-phase alternating-current voltage command as a control signal to the inverter. The alternating-current alternating-voltage generator for magnetic pole position estimation is configured to superimpose an auxiliary alternating-current alternating-voltage on the d-axis voltage

command. The magnetic pole position estimation unit is configured to estimate a magnetic pole position of a permanent magnet synchronous motor from the q-axis current detected value and the auxiliary alternating-current alternating-voltage. The d-axis direct-current bias generator is configured to use, as a d-axis, the direction of the magnetic pole position estimated by the magnetic pole position estimation unit, and add a d-axis direct-current bias current having a constant waveform alternately switched to be positive-and-negative symmetric in response to the d-axis current command, and input the d-axis current command obtained after the bias addition into the dq-axis current controller. The NS determination unit is configured to calculate a d-axis applied voltage and a d-axis current change rate at the positive-and-negative switching timing of the d-axis direct-current bias current, determine the direction of the N-pole or S-pole of a permanent magnet of the permanent magnet synchronous motor from the relationship between the calculated d-axis applied voltage and the calculated d-axis current change rate, and output an NS determination signal.

Citation List

[0003] Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2008-79489

SUMMARY

[0004] The present disclosure provides a motor control device capable of correctly detecting magnetic poles even when an initially estimated d-axis direction is incorrectly shifted by 90° or 270° from a correct direction, and provides a washing machine or a washing and drying machine having the motor control device installed therein.

[0005] The motor control device in the present disclosure is configured to control a brushless motor including a rotor with a salient pole structure and driven by an inverter circuit. The motor control device in the present disclosure includes the inverter circuit, a current detector, an initial phase estimation unit, and a polarity determination unit. The current detector is configured to detect a current flowing through the brushless motor. The initial phase estimation unit is configured to estimate an initial phase of the brushless motor, based on the current detected by the current detector. The polarity determination unit is configured to determine the polarity of a magnetic pole of the brushless motor for the initial phase estimated by the initial phase estimation unit, based on the current detected by the current detector. The polarity determination unit is configured to

determine the polarity of the magnetic pole of the brushless motor, based on the differences between current amplitudes in the positive and negative directions of the d- and q-axes, the differences being detected by the current detector by superimposing voltages in the positive and negative directions of the d- and q-axes, respectively, and correct the initial phase.

[0006] The washing machine or the washing and drying machine in the present disclosure has the motor control device in the present disclosure installed therein.

[0007] The motor control device in the present disclosure is capable of correctly detecting magnetic poles even when an initially estimated d-axis direction is incorrectly shifted by 90° or 270° with respect to a correct direction.

[0008] Furthermore, since the washing machine or the washing and drying machine in the present disclosure has the above-described motor control device in the present disclosure installed therein, the washing machine or the washing and drying machine is capable of smoothly rotating a washing tub or a drum, for example.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a diagram illustrating the configuration of a motor control device in Embodiment 1.

FIG. 2 is a block diagram illustrating the configuration of a sensorless estimation unit of the motor control device in Embodiment 1.

FIG. 3 is a block diagram illustrating the detailed configuration of an inductance driver of the motor control device in Embodiment 1.

FIG. 4 is a block diagram illustrating the detailed configuration of an induced voltage driver of the motor control device in Embodiment 1.

FIG. 5 is a flow chart illustrating a flow of motor drive control processing of the motor control device in Embodiment 1.

FIG. 6A is a diagram for explaining problems about estimation of an initial phase of a rotor.

FIG. 6B is a diagram for explaining the problems about the estimation of the initial phase of the rotor.

FIG. 6C is a diagram for explaining the problems about the estimation of the initial phase of the rotor.

FIG. 7 is a diagram illustrating a magnetic saturation characteristic of an electromagnetic steel sheet used for common brushless motors.

FIG. 8 is a flow chart illustrating a flow of polarity determination processing performed by the motor control device in Embodiment 1.

FIG. 9 is a diagram illustrating an example of applied voltage and current in d-axis determination performed by the motor control device in Embodiment 1.

FIG. 10 is a diagram illustrating an example of applied voltage and current in d-axis and q-axis determination performed by the motor control device in Embodiment 1.

FIG. 11 is a diagram for explaining applied voltage and current at offset correction in polarity determination performed by the motor control device in Embodiment 1.

FIG. 12 is a diagram for explaining the outline of polarity determination when current control is performed in a motor control device in Embodiment 2.

DETAILED DESCRIPTIONS

[0010] A motor control device in the present disclosure is configured to control a brushless motor including a rotor with a salient pole structure and driven by an inverter circuit. The motor control device in the present disclosure includes the inverter circuit, a current detector, an initial phase estimation unit, and a polarity determination unit. The current detector is configured to detect a current flowing through the brushless motor. The initial phase estimation unit is configured to estimate an initial phase of the brushless motor, based on the current detected by the current detector. The polarity determination unit is configured to determine the polarity of a magnetic pole of the brushless motor, based on the current detected by the current detector. The polarity determination unit is configured to determine the polarity of the magnetic pole of the brushless motor for the initial phase estimated by the initial phase estimation unit, based on differences between current amplitudes in the positive and negative directions of the d- and q-axes, the differences being detected by the current detector by superimposing voltages in the positive and negative directions of the d- and q-axes, respectively, and correct the initial phase.

[0011] Thus, the motor control device in the present disclosure can correctly detect magnetic poles even when an initially estimated d-axis direction is incorrectly shifted by 90° or 270° with respect to a correct direction. Therefore, the motor control device in the present disclosure can substantially prevent reverse rotation start-up and start-up failure at the start-up of the brushless motor and thereby accelerate the brushless motor smoothly from the start-up of the brushless motor.

[0012] Furthermore, in the motor control device in the present disclosure, the polarity

determination unit may terminate polarity determination of the brushless motor when the absolute value of the difference between current amplitudes in the positive and negative directions of the d-axis, the difference being detected by the current detector by superimposing voltages in the positive and negative directions of the d-axis, respectively, is larger than a reference value. When the absolute value of the difference between current amplitudes in the positive and negative directions of the d-axis is smaller than the reference value, the polarity determination unit performs the following. That is, the polarity determination unit may determine the polarity of the magnetic pole of the brushless motor, based on the difference between current amplitudes in the positive and negative directions of the q-axis, the difference being detected by the current detector by superimposing voltages in the positive and negative directions of the q-axis, respectively, and the difference between current amplitudes in the positive and negative directions of the d-axis, and correct an initial phase.

[0013] Furthermore, in the motor control device in the present disclosure, the polarity determination unit may use, as an offset current value, a current detected by the current detector immediately before the superimposition of voltage in the positive and negative directions of the d- and q-axes. The polarity determination unit may determine the polarity of the magnetic pole of the brushless motor, based on a value obtained by subtracting the offset current value from a maximum value of current amplitude in each of the positive and negative directions of the d- and q-axes, the maximum value being detected by the current detector by superimposing voltages in each of the positive and negative directions of the d- and q-axes, and correct the initial phase.

[0014] Furthermore, in the motor control device in the present disclosure, the polarity determination unit may control a current flowing through the brushless motor to 0 during the determination of the polarity of the magnetic pole of the brushless motor.

[0015] The washing machine or the washing and drying machine in the present disclosure has the motor control device in the present disclosure installed therein.

[0016] (Underlying Knowledge Forming Basis of the Present Disclosure)

When the inventors came up with the present disclosure, the technology of performing magnetic polarity determination for an estimated initial phase of a rotor had been already known. An initial phase of a rotor is estimated at the sensorless driving of a brushless motor having a salient pole structure, the start of driving of the brushless motor, and the stop of the brushless motor prior to the driving.

[0017] In initial phase estimation, the difference in inductance L between the direction of

a magnetic pole (d-axis direction) as a feature of the rotor having a salient polarity and a direction perpendicular to the magnetic pole (q-axis direction) is made use of. In the initial phase estimation, low-amplitude high-frequency or pulsed voltage and current are applied to a stator winding, whereby the direction of the rotor is estimated. At this time, the direction of the rotor can be estimated, but the polarity (NS) of the magnetic pole cannot not determined, hence, polarity determination is performed to determine whether the magnetic pole is the N-pole or the S-pole.

[0018] In the polarity determination, a certain level of pulsed voltage and current is applied to the stator winding in both the positive and negative directions of the estimated d-axis, and, from the difference between the absolute values of the applied voltage or the detected current at that time, the directions of the magnetic poles NS are estimated. Thus, the rotation of the brushless motor can be smoothly started up without reverse-rotation start-up and a failure in start-up at the time of the start of driving of the brushless motor.

[0019] However, a state arises with a certain frequency, in which, although a d-axis direction estimated in the initial phase estimation should be correctly equal to the direction of a magnetic pole, an estimated value indicates a direction perpendicular to the magnetic pole (q-axis direction). The inventors found a problem in which, in the above-mentioned case, even when polarity determination is performed, the correct direction of the rotor cannot be determined, and consequently the phenomenon of reverse rotation or a rotation failure caused by step-out at the time of the start of driving of the brushless motor sometimes occurs. To solve the problem, the inventors accomplished configurations about the subject matters of the present disclosure.

[0020] Therefore, an object of the present disclosure is to provide a motor control device capable of correctly detecting a magnetic pole in polarity determination even when a d-axis direction estimated in initially phase estimation is incorrectly shifted by 90° or 270° with respect to the correct direction.

[0021] Hereinafter, embodiments will be described in detail with reference to the drawings. Descriptions that are more detailed than necessary may, however, be omitted. For example, detailed descriptions on already well-known matters and overlapping descriptions on substantially the same configurations may be omitted. This is for avoiding unnecessary redundancy of the following descriptions and facilitating understanding by those skilled in the art.

[0022] Note that the accompanying drawings and the following descriptions are provided to help those skilled in the art fully understand the present disclosure, and do not intend to

thereby restrict the subject matter recited in the claims.

[0023] (Embodiment 1)

Hereinafter, motor control device 10 in Embodiment 1 will be described using FIG. 1 to FIG. 11.

[0024] [1-1. Configuration]

[1-1-1. Configuration of Motor Control Device]

FIG. 1 is a diagram illustrating the configuration of motor control device 10 in Embodiment 1.

[0025] Motor control device 10 is configured to receive electric power from alternating-current power source 30. Rectifier circuit 11 is configured to transform the received alternating-current power into direct-current power and supply the direct-current power to inverter circuit 13 via smoothing capacitor 12 for direct-current power. Inverter circuit 13 includes 3 sets of paired switching elements connected in series, that is, six switching elements 14a, 14b, 14c, 14d, 14e, and 14f in total.

[0026] Inverter circuit 13 is configured to drive brushless motor 40 by PWM driving for ON/OFF of switching elements 14a, 14b, 14c, 14d, 14e, and 14f via later-mentioned control circuit 20.

[0027] Out of switching elements 14a, 14b, 14c, 14d, 14e, and 14f, connected in-series on a two-by-two basis, of inverter circuit 13, the emitter-side portions of lower-side switching elements 14d, 14e, and 14f are connected to ends of resistances 15a, 15b, and 15c, respectively. Other ends of resistances 15a, 15b, and 15c are connected to one output side of each of rectifier circuit 11 and smoothing capacitor 12. Voltage at both ends of resistances 15a, 15b, and 15c is inputted into current detector 21 in control circuit 20. As described later, various types of control are performed using a current value detected by current detector 21.

[0028] Besides the above-mentioned current detector 21, control circuit 20 further includes initial phase estimation unit 22, polarity determination unit 23, and sensorless estimation unit 24. Note that motor control device 10 includes a computer system including a processor and a memory. When the processor executes a program stored in the memory, the computer system functions as control circuit 20. Herein, the program to be executed by the processor is beforehand stored in the memory of the computer system, but may be stored in a non-transitory recording medium, such as a memory card, and provided, or may be provided via a telecommunication line, such as the Internet.

[0029] [1-1-2. Configuration of Sensorless Estimation Unit]

FIG. 2 is a block diagram illustrating the configuration of sensorless estimation unit 24 of motor control device 10 in Embodiment 1.

[0030] Sensorless estimation unit 24 includes inductance driver 24b using an inductance-based system, induced voltage driver 24c using an induced voltage-based system, and drive system switching unit 24a. Inductance driver 24b using the inductance-based system is configured to estimate the phase of a magnetic pole by making use of the salient polarity of rotor 41 of brushless motor 40, rotor 41 having a salient pole structure. Induced voltage driver 24c using the induced voltage-based system is configured to estimate a magnetic pole position by making use of a counter electromotive force in the rotation of brushless motor 40. Drive system switching unit 24a is configured to switch a magnetic pole position estimation system between the inductance-based system and the induced voltage-based system.

[0031] [1-1-3. Configuration of Inductance Driver]

Inductance L changes with the phase of a magnetic pole of rotor 41 of brushless motor 40. Therefore, inductance driver 24b using the inductance-based system applies a high frequency current unrelated to motor drive current to the motor to detect a motor current, and, using the motor current, calculates the amount of position estimation error resulting from a change in inductance. Then, inductance driver 24b estimates a magnetic pole position so as to cause the amount of position estimation error to converge to zero.

[0032] FIG. 3 is a block diagram illustrating the detailed configuration of inductance driver 24b of motor control device 10 in Embodiment 1.

[0033] Inductance driver 24b includes $uvw \rightarrow dq$ current converter 24ba, position estimate ϕ calculation unit 24bb, high-frequency current control unit 24bc, angular speed ω calculation unit 24bd, position angle θ calculation unit 24be, speed current control unit 24bf, and $dq \rightarrow uvw$ voltage converter 24bg. $uvw \rightarrow dq$ current converter 24ba is configured to receive, as input, three phase current values (I_u , I_v , I_w) of brushless motor 40 (see FIG. 1) detected by current detector 21 and output a dq current value. Position estimate ϕ calculation unit 24bb is configured to estimate the position of a magnetic pole from the dq current and output a position estimate ϕ . High-frequency current control unit 24bc is configured to control a high frequency current that is to be superimposed on a drive current. Angular speed ω calculation unit 24bd is configured to calculate an angular speed ω from the position estimate ϕ and output the angular speed ω . Position angle θ calculation unit 24be is configured to calculate a position angle θ from the position estimate ϕ and the angular speed ω and output the position angle θ . Speed current control unit 24bf is

configured to give feedback on a deviation between the estimated angular speed (angular speed ω) and a speed command value ω^* , and perform speed calculation (PI control) to determine a current command value of brushless motor 40, and output the current command value. dq→uvw voltage converter 24bg is configured to calculate voltages (V_u , V_v , V_w) from the position angle θ and the current command value, and output the voltages (V_u , V_v , V_w) to control circuit 20.

[0034] dq↔uvw conversion and speed feedback control are common systems, and therefore, descriptions about uvw→dq current converter 24ba, speed current control unit 24bf, and dq→uvw voltage converter 24bg will be omitted here.

[0035] Position estimate φ calculation unit 24bb is configured to calculate a position estimate φ , based on the following Equation 1.

[0036] [Equation 1]

$$\varphi \propto di/dt$$

[0037] The motor to be driven in Embodiment 1 is brushless motor 40 including rotor 41 having a salient pole structure (d-axis inductance $L_d \neq$ q-axis inductance L_q), and therefore, inductance L (magnetic resistance) changes with the phase of a magnetic pole. The change in inductance L appears in the current flowing through brushless motor 40, and therefore, the amount of position estimation error is calculated in accordance with the amount of change in the current flowing through brushless motor 40.

[0038] High-frequency current control unit 24bc is configured to control a high frequency current unrelated to a motor drive current. In Embodiment 1, a pulsed current of approximate 0.4 A and a 2.56-ms cycle is applied in the d-axis direction, and the difference between a q-axis current value obtained when the pulsed current is applied and a q-axis current value obtained when the pulsed current is not applied is calculated.

[0039] Position angle θ calculation unit 24be and angular speed ω calculation unit 24bd calculate a position angle θ and an angular speed ω , based on the following Equation 2 and Equation 3, respectively.

[0040] [Equation 2]

$$\theta = \int \omega \cdot dt - \sum \varphi$$

[0041] [Equation 3]

$$\omega = d\theta/dt$$

[0042] The position angle θ is calculated by using, as input, the amount of position

estimation error and the time integral of an angular speed ω . The angular speed ω is calculated as the time derivative of the position angle θ . Both the position angle θ and the angular speed ω are calculated so as to cause the amount of position estimation error to converge to zero, based on feedback control.

[0043] [1-1-4. Configuration of Induced Voltage Driver]

The induced voltage generated by the rotation of brushless motor 40 changes with a magnetic pole position. Therefore, induced voltage driver 24c calculates induced voltage proportional to the speed of brushless motor 40 from the voltage and current applied to brushless motor 40, and estimates a magnetic pole position so as to cause voltage error to converge to zero.

[0044] FIG. 4 is a block diagram illustrating the detailed configuration of induced voltage driver 24c of motor control device 10 in Embodiment 1.

[0045] Induced voltage driver 24c includes uvw→dq current converter 24ca, position estimate $\varepsilon\gamma$ calculation unit 24cb, angular speed ω calculation unit 24cc, position angle θ calculation unit 24cd, speed current control unit 24ce, and dq→uvw voltage converter 24cf. uvw→dq current converter 24ca is configured to receive, as input, three phase current values (I_u , I_v , I_w) of brushless motor 40 detected by current detector 21 and output a dq current value. Position estimate $\varepsilon\gamma$ calculation unit 24cb is configured to estimate the position of a magnetic pole from the dq current value and output a position estimate $\varepsilon\gamma$. Angular speed ω calculation unit 24cc is configured to calculate an angular speed ω from the position estimate $\varepsilon\gamma$ and output the angular speed $\varepsilon\gamma$. Position angle θ calculation unit 24cd is configured to calculate a position angle θ from the position estimate $\varepsilon\gamma$ and the angular speed ω and output the position angle θ . Speed current control unit 24ce is configured to give feedback on a deviation between the estimated angular speed (angular speed ω) and a speed command value ω^* , perform speed calculation (PI control) to determine a current command value for the motor, and output the current command value. dq→uvw voltage converter 24cf is configured to calculate voltages (V_u , V_v , V_w) from the position angle θ and the current command value and output the voltages (V_u , V_v , V_w) to control circuit 20.

[0046] As in the case of inductance driver 24b described above, dq↔uvw conversion and speed feedback control are common systems, and therefore, descriptions about uvw→dq current converter 24ca, speed current control unit 24ce, and dq→uvw voltage converter 24cf will be omitted here.

[0047] Position estimate $\varepsilon\gamma$ calculation unit 24cb is configured to calculate a position

estimate $\varepsilon\gamma$, based on the following Equation 4.

[0048] [Equation 4]

$$\varepsilon\gamma = Vd - (Ra \cdot Id - \omega \cdot Lq \cdot Iq)$$

[0049] In accordance with Equation 4, the position estimate $\varepsilon\gamma$ is calculated by inputting a d-axis current Id , a q-axis current Iq , a d-axis voltage Vd , and an angular speed ω and using parameters of q-axis inductance Lq and resistance Ra of brushless motor 40.

[0050] Angular speed ω calculation unit 24cc and position angle θ calculation unit 24cd calculate an angular speed ω and a position angle θ , based on the following Equation 5 and Equation 6, respectively.

[0051] [Equation 5]

$$\omega = - \int Ki \cdot \varepsilon\gamma \cdot dt$$

[0052] [Equation 6]

$$\theta = \int (\omega - K\theta \cdot \varepsilon\gamma) dt$$

[0053] Angular speed ω calculation unit 24cc calculates the angular speed ω by using PI (proportional integral) so that the position estimate $\varepsilon\gamma$ converges to zero, and furthermore calculates the time integral of ω , whereby the resultant is outputted as an estimated phase (position angle θ).

[0054] [1-1-5. Configuration of Drive System Switching Unit]

Drive system switching unit 24a in the block diagram of sensorless estimation unit 24 illustrated in FIG. 2 is configured to switch between inductance driver 24b and induced voltage driver 24c in accordance with, for example, the number of rotations of brushless motor 40. Specifically, drive system switching unit 24a delivers a position angle θ , an angular speed ω , motor current/voltage, and an angular speed feedback control parameter, which are necessary for motor control, in real time to realize instant switchover.

[0055] [1-2. Operation]

The operation of motor control device 10 configured as described above will be described below.

[0056] [1-2-1. Operation of Motor Drive Control]

FIG. 5 is a flow chart illustrating a flow of motor drive control processing of motor control device 10 in Embodiment 1.

[0057] As illustrated in FIG. 5, motor control device 10 starts motor drive control at Step

S001. Motor control device 10 performs initial phase estimation at Step S002. At Step S003, motor control device 10 performs polarity determination and, in accordance with a determination result, corrects a phase estimated by the initial phase estimation. Details of the initial phase estimation at Step S002 and the polarity determination at Step S003 will be described later

[0058] Motor control device 10 performs motor start-up control in inductance driver 24b at Step S004, and determines whether the number of rotations of brushless motor 40 is equal to or higher than a certain level at Step S005. If the number of rotations of brushless motor 40 is equal to or higher than the certain level (YES at Step S005), motor control device 10 performs switching on the drive system at Step S006. In other words, drive system switching unit 24a switches from inductance driver 24b to induced voltage driver 24c. Subsequently, motor control device 10 performs motor steady rotation control in induced voltage driver 24c at Step S007, and performs motor speed reduction control at Step S008, and terminates the motor drive control at Step S009.

[0059] [1-2-2. Operation of Initial Phase Estimation Unit]

FIG. 6A to FIG. 6C are diagrams for explaining problems about initial phase estimation for rotor 41. Note that, in FIG. 6A to FIG. 6C, an initial phase estimation d-axis and an initial phase estimation q-axis are indicated by solid lines, meanwhile an actual d-axis and an actual q-axis are indicated by dashed lines.

[0060] FIG. 6A illustrates a state in which there is a correct relationship between rotor 41 including magnet 42 disposed inside brushless motor 40 and the d- and q-axes. The d-axis runs along the magnetic pole direction, meanwhile the q-axis runs along a direction perpendicular to the d-axis. The direction of the N-pole is the positive direction of the d-axis, meanwhile the direction of the S-pole is the negative direction of the d-axis.

[0061] Initial phase estimation unit 22 is configured to estimate an initial phase of rotor 41 in inductance driver 24b. Specifically, for 100 ms, a drive period in which both a command value for the number of rotations of the motor and a command value for the current flowing through the motor are 0 is provided to estimate the initial phase of rotor 41.

[0062] Inductance driver 24b is configured to estimate a phase by making use of the difference ($L_d \neq L_q$) in inductance L between the d-axis direction and the q-axis direction, the difference being a feature of rotor 41 with the salient pole structure of brushless motor 40. In other words, inductance driver 24b determines whether the direction is horizontal (d-axis) or perpendicular (q-axis) to rotor 41, but, as illustrated in FIG. 6B, inductance driver 24b cannot determine whether the direction of the d-axis is toward the N-pole or the

S-pole. Furthermore, as illustrated in FIG. 6C, the inductance L of the d- and q-axes exhibits 2θ periodicity in rotor 41, and therefore a problem arises in which the initial phase is incorrectly estimated to be along the q-axis direction shifted by 90° or 270° with respect to the actual d-axis. Against the above-described problem, motor control device 10 according to Embodiment 1 of the present disclosure takes countermeasures by using the following polarity determination unit 23.

[0063] [1-2-3. Operation of Polarity Determination Unit]

FIG. 7 is a diagram illustrating a magnetic saturation characteristic of an electromagnetic steel sheet used as a rotor core for common brushless motors.

[0064] As illustrated in FIG. 7, based on a voltage equation related to inductance L , $v = L \times (di/dt)$, when the inductance L is larger, the time derivative of current (di/dt) is smaller and the amount i of change in current per unit time is smaller. In contrast, when the inductance L is smaller, the time derivative of current (di/dt) is larger and the amount i of change in current per unit time is larger. In other words, when the inductance L changes, the current i also changes.

[0065] Polarity determination unit 23 makes use of the characteristic of change in inductance L due to magnetic saturation. Polarity determination unit 23, for example, superimposes voltages $+V_d$ and $-V_d$ that have the same absolute value in the positive and negative directions of the estimated d-axis resulting from the initial phase estimation performed by initial phase estimation unit 22, respectively, for the same period of time, and determines polarity by using the amounts of change in flowing current, $+Id_1$ and $-Id_2$.

[0066] Specifically, determination of the polarity of the magnetic pole of the initial phase estimation d-axis is performed by making a comparison between the absolute value $|+Id_1|$ of the amount of change in current when voltage $+V_d$ is applied in the positive direction of the initial phase estimation d-axis and the absolute value $|-Id_2|$ of the amount of change in current when voltage $-V_d$ is applied in the negative direction of the initial phase estimation d-axis. In other words, $|-Id_2| < |+Id_1|$ indicates that the estimated magnetic pole direction is the positive (N-pole) direction. In contrast, $|-Id_2| > |+Id_1|$ indicates that the estimated magnetic pole direction is the negative (S-pole) direction.

[0067] [1-2-4. Operation of Polarity Determination]

FIG. 8 is a flow chart illustrating a flow of polarity determination processing of motor control device 10 in Embodiment 1.

[0068] As illustrated in FIG. 8, polarity determination unit 23 starts polarity determination processing at Step S101. Polarity determination unit 23 performs

initialization processing at Step S102, and performs Id offset calculation when a current on the initial phase estimation d-axis is 0 at Step S103. In other words, immediately before processing at later-described Steps S104 to S107 to superimpose voltages in the positive and negative directions of the d-axis, polarity determination unit 23 stores the d-axis current Id detected by current detector 21 as an offset current value. Details of the offset calculation of the d-axis current Id and the later-described offset calculation of the q-axis current Iq will be described later (see FIG. 11), and therefore, the following description about FIG. 8 will be given without taking the offset current value into consideration.

[0069] Polarity determination unit 23 superimposes voltage +Vd in the positive direction of the initial phase estimation d-axis for a certain period of time at Step S104, and integrates ($\Sigma+Id$) the current amplitude maximum of absolute-value $|+Id|$ of the amount of change in current flowing in the positive direction of the initial phase estimation d-axis at Step S105. Polarity determination unit 23 superimposes voltage -Vd in the negative direction of the initial phase estimation d-axis for a certain period of time at Step S106, and integrates ($\Sigma-Id$) the current amplitude maximum of absolute-value $|-Id|$ of the amount of change in current flowing in the negative direction of the initial phase estimation d-axis at Step S107. Polarity determination unit 23 repeats the processing of Steps S104 to S107 three times. Note that, although the processing of Steps S104 to S107 is repeated three times in Embodiment 1, the number of times of the repetition is not limited to three, but may be two or four, for example. The same goes for the number of times of repetition of the later-described processing of Steps S115 to S118.

[0070] Next, at Step S108, polarity determination unit 23 performs a comparison between the integral of the current amplitude maximum of the absolute value of the amount of change in current after voltage application in the positive direction of the initial phase estimation d-axis and the integral of the current amplitude maximum of the absolute value of the amount of change in current after voltage application in the negative direction of the initial phase estimation d-axis, and performs the processing in accordance with a result of the comparison. Specifically, if $\Sigma-Id > \Sigma+Id$ (YES at Step S108), polarity determination unit 23 proceeds to processing of Step S109. In contrast, if $\Sigma-Id \leq \Sigma+Id$ (NO at Step S108), polarity determination unit 23 proceeds to processing of Step S110.

[0071] At Step S109, there is a possibility that the actual d-axis may be opposite in direction to the initial phase estimation d-axis, and therefore, polarity determination unit 23 adds 180° to the value of a phase estimated at the time of initial phase estimation and stores the obtained value in θ_{tmpD} serving as a temporary storage for phase information.

At Step S110, there is a possibility that the direction of the initial phase estimation d-axis is correct, and therefore, polarity determination unit 23 stores the value of the phase estimated at the time of initial phase estimation in θ_{tmpD} serving as the temporary storage for phase information. Polarity determination unit 23 performs d-axis determination through the above-described processing of Steps S101 to S110, and corrects the estimated phase.

[0072] Next, polarity determination unit 23 checks the accuracy of the d-axis determination for the initial phase estimation d-axis.

[0073] At Step S111, polarity determination unit 23 calculates the absolute-value of the difference $\Delta\Sigma Id = |\Sigma +Id - \Sigma -Id|$ between the integral of the current amplitude maximum of the absolute value of the amount of change in current after voltage application in the positive direction of the initial phase estimation d-axis and the integral of the current amplitude maximum of the absolute value of the amount of change in current after voltage application in the negative direction of the initial phase estimation d-axis, the integrals being obtained through Steps S104 to S107. At Step S112, polarity determination unit 23 determines whether or not the absolute value of the difference $\Delta\Sigma Id$ is greater than a predetermined reference value Id_{th} . If $\Delta\Sigma Id > Id_{th}$ (for example, 1A) (YES at Step S112), polarity determination unit 23 proceeds to processing of Step S113. In contrast, if $\Delta\Sigma Id \leq Id_{th}$ (NO at Step S112), polarity determination unit 23 proceeds to processing of Step S114. At Step S113, polarity determination unit 23 determines that the value stored in θ_{tmpD} serving as the temporary storage for phase information is correct, and then stores the value in an estimated phase, and terminates the polarity determination processing at Step S126.

[0074] In contrast, when polarity determination unit 23 proceeds to the processing of Step S114, there is a possibility that the direction of the initial phase estimation d-axis is incorrect by $+90^\circ$ or $+270^\circ$. This direction is the q-axis direction in the initial phase estimation, and therefore, polarity determination unit 23 performs the determination again for the q-axis direction. Polarity determination unit 23 performs I_q offset calculation when a current is 0 on the initial phase estimation q-axis at Step S114.

[0075] Polarity determination unit 23 superimposes voltage $+V_q$ in the positive direction of the initial phase estimation q-axis for a certain period of time at Step S115, and integrates $(\Sigma +I_q)$ the current amplitude maximum of the absolute-value $|+I_q|$ of the amount of change in current flowing in the positive direction of the initial phase estimation q-axis at Step S116. Polarity determination unit 23 superimposes voltage $-V_q$ in the negative direction of the initial phase estimation q-axis for a certain period of time at Step S117, and

integrates ($\Sigma-I_q$) the current amplitude maximum of the absolute-value $|-I_q|$ of the amount of change in current flowing in the negative direction of the initial phase estimation q-axis at Step S118. Polarity determination unit 23 repeats the processing of Steps S115 to S118 three times.

[0076] Next, at Step S119, polarity determination unit 23 performs a comparison between the integral of the current amplitude maximum of the absolute value of the amount of change in current after voltage application in the positive direction of the initial phase estimation q-axis and the integral of the current amplitude maximum of the absolute value of the amount of change in current after voltage application in the negative direction of the initial phase estimation q-axis, and performs the processing in accordance with a result of the comparison. Specifically, if $\Sigma-I_q > \Sigma+I_q$ (YES at Step S119), polarity determination unit 23 proceeds to processing of Step S120. In contrast, if $\Sigma-I_q \leq \Sigma+I_q$ (NO at Step S119), polarity determination unit 23 proceeds to processing of Step S121.

[0077] At Step S120, there is a possibility that the positive direction of the actual d-axis may be the negative direction of the initial phase estimation q-axis, and therefore, polarity determination unit 23 adds 270° to the value of a phase at the time of initial phase estimation and stores the obtained value in θ_{tmpQ} serving as a temporary storage for phase information. In contrast, at Step S121, there is a possibility that the positive direction of the actual d-axis may be the positive direction of the initial phase estimation q-axis, and therefore, polarity determination unit 23 adds 90° to the value of the phase at the time of initial phase estimation and stores the obtained value in θ_{tmpQ} serving as the temporary storage for phase information.

[0078] As described above, polarity determination unit 23 performs q-axis determination through the processing of Steps S114 to S121, and corrects an estimated phase.

[0079] Subsequently, at Step S122, polarity determination unit 23 calculates the absolute-value of the difference $\Delta\Sigma I_q = |\Sigma+I_q - \Sigma-I_q|$ between the integral of the current amplitude maximum of the absolute value of the amount of change in current after voltage application in the positive direction of the initial phase estimation q-axis and the integral of the current amplitude maximum of the absolute value of the amount of change in current after voltage application in the negative direction of the initial phase estimation q-axis, the integrals being obtained through Steps S115 to S118. Polarity determination unit 23 makes a comparison between the absolute value of the difference $\Delta\Sigma I_d$ determined in the d-axis direction and the absolute value of the difference $\Delta\Sigma I_q$ determined in the q-axis direction, and performs processing in accordance with a result of the comparison. Specifically, if

$\Delta\Sigma Id \geq \Delta\Sigma Iq$ (YES at Step S123), polarity determination unit 23 proceeds to processing of Step S124. In contrast, if $\Delta\Sigma Id < \Delta\Sigma Iq$ (NO at Step S123), polarity determination unit 23 proceeds to processing of Step S125.

[0080] At Step S124, polarity determination unit 23 determines that the value stored in θ_{tmpD} serving as the temporary storage for phase information is correct, and then stores the value in an estimated phase. In contrast, at Step S125, polarity determination unit 23 determines that the value stored in θ_{tmpQ} serving as the temporary storage for phase information is correct, and then stores the value in an estimated phase. Finally, polarity determination unit 23 terminates the polarity determination processing at Step S126.

[0081] [1-2-5. Polarity Determination, d-axis Determination]

FIG. 9 is a diagram illustrating an example of applied voltage and current in d-axis determination performed by motor control device 10 in Embodiment 1.

[0082] Hereinafter, using the example illustrated in FIG. 9, the superimposition of voltages and the integration of the current amplitude maximum at Steps S104 to S107 in the flow chart of the polarity determination processing illustrated in FIG. 8 will be specifically described. Note that, in the example in FIG. 9, the difference between stored $+Id$ and $-Id$ is greater than the reference value Id_{th} (for example, 1A). First, voltage $+V_d$ is superimposed in the positive direction of the initial phase estimation d-axis, and the current amplitude maximum of $+Id$ at that point of time is stored. Next, voltage $-V_d$ is superimposed in the negative direction of the initial phase estimation d-axis, and the current amplitude maximum of $-Id$ at that point of time is stored. When the relationship between the stored $+Id$ and $-Id$ satisfies $|-Id| < |+Id|$, the estimated phase estimated by the initial phase determination immediately before the polarity determination is used in the following motor drive control. When the relationship between the stored $+Id$ and $-Id$ satisfies $|-Id| > |+Id|$, an estimated phase obtained by adding 180° to the estimated phase estimated by the initial phase determination immediately before the polarity determination is used in the following motor drive control. In the example in FIG. 9, the estimated phase estimated by the initial phase determination immediately before the polarity determination is used as an estimated phase as it is.

[0083] Thus, even when the d-axis direction estimated by the initial phase estimation is incorrectly shifted by 180° , motor control device 10 can make a correction to the directions of the N- and S-poles.

[0084] [1-2-6. Polarity Determination, d-axis and q-axis Determination]

FIG. 10 is a diagram illustrating an example of applied voltage and current in d-

axis and q-axis determination performed by motor control device 10 in Embodiment 1.

[0085] Hereinafter, using the example illustrated in FIG. 10, the superimposition of voltages and the integration of the current amplitude maximum at Steps S104 to S107 and Steps S115 to S118 in the flow chart of the polarity determination processing illustrated in FIG. 8 will be specifically described. As in the case of the d-axis determination illustrated in FIG. 9, first, voltage +Vd is superimposed in the positive direction of the initial phase estimation d-axis, and the current amplitude maximum of +Id at that point of time is stored.

[0086] Next, voltage -Vd is superimposed in the negative direction of the initial phase estimation d-axis, and the current amplitude maximum of -Id at that point of time is stored. When the difference ($||+Id| - |-Id||$) between the stored +Id and -Id is smaller than the reference value Idth, in other words, when the relationship between the stored +Id and -Id satisfies $|-Id| \div |+Id|$, there is a possibility that the d-axis estimated in the initial phase estimation is shifted by 90° or 270° with respect to the actual d-axis. Therefore, a voltage is superimposed also in the q-axis direction to perform polarity determination. As in the case of the above-described d-axis determination, first, voltage +Vq is superimposed in the positive direction of the initial phase estimation q-axis, and the current amplitude maximum of +Iq at that point of time is stored.

[0087] Next, voltage -Vq is superimposed in the negative direction of the initial phase estimation q-axis, and the current amplitude maximum of -Iq at that point of time is stored. When the stored +Iq and -Iq satisfies a relationship $|-Iq| < |+Iq|$, 90° is added to the estimated phase estimated in the initial phase determination immediately before the polarity determination. In contrast, when the stored +Iq and -Iq satisfies a relationship $|-Iq| > |+Iq|$, 270° is added to the estimated phase estimated in the initial phase determination immediately before the polarity determination. In the example in FIG. 10, the relationship $|-Iq| < |+Iq|$ is satisfied and the difference between +Iq and -Iq is larger than the difference between +Id and -Id, and accordingly, 90° is added to the estimated phase estimated in the initial phase determination immediately before the polarity determination.

[0088] Thus, even when the d-axis direction estimated in the initial phase estimation is incorrect shifted by 90° or 270°, motor control device 10 can make a correction to the correct directions of the N- and S-poles.

[0089] [1-2-7. Polarity Determination, Offset Correction]

FIG. 11 is a diagram for explaining applied voltage and current in offset correction during polarity determination performed by motor control device 10 in Embodiment 1.

[0090] Hereinafter, Id offset calculation at Step S103 and Iq offset calculation at Step S114 in FIG. 8 will be described. Polarity determination unit 23 stores the average value of current in a certain period before voltage superimposition in the d-axis or q-axis direction in FIG. 9 and FIG. 10, as an offset current value. In the processing of Step S105, S107, S116, and S118 in FIG. 8, polarity determination unit 23 detects the current amplitude maximum and then subtracts the stored offset current value from the current amplitude maximum, whereby the final current amplitude maximum is obtained. In other words, when the offset current value is +Id0 and the measured current amplitude maximum is +Id' on the d-axis, +Id as a target for the polarity determination can be calculated as $+Id = +Id' - Id0$ (see FIG. 11). Irrespective of the positive or negative of Id, Id, and Iq, the calculation can be performed in the same manner.

[0091] Thus, by using an initial current as an offset current value to make a correction, motor control device 10 can reduce influence on polarity determination even when a current value does not converge to 0. Therefore, motor control device 10 can perform the determination with higher precision.

[0092] [1-3. Effects]

As described above, in Embodiment 1, motor control device 10 controls brushless motor 40 including rotor 41 with the salient pole structure and configured to be driven by inverter circuit 13. Motor control device 10 includes inverter circuit 13, current detector 21, initial phase estimation unit 22, and polarity determination unit 23. Current detector 21 detects a current flowing through brushless motor 40. Based on the current detected by current detector 21, initial phase estimation unit 22 estimates an initial phase of brushless motor 40. Based on the current detected by current detector 21, polarity determination unit 23 determines the polarity of a magnetic pole of brushless motor 40. Polarity determination unit 23 determines the polarity of the magnetic pole of brushless motor 40, based on the differences between current amplitudes in the positive and negative directions of the d- and q-axes, the differences being detected by current detector 21 by superimposing voltages in the positive and negative directions of the d- and q-axes, respectively, and corrects the initial phase.

[0093] Thus, motor control device 10 can determine a correct magnetic pole direction in the polarity determination even when the d-axis direction is incorrectly estimated to be the q-axis direction in the initial phase estimation. In other words, motor control device 10 can correctly perform magnetic pole detection even when an initially estimated d-axis direction is incorrectly shifted by 90° or 270° with respect to the correct direction. Therefore, motor

control device 10 can smoothly start up and accelerate brushless motor 40 without actions, such as reverse rotation and step-out, at the start-up of brushless motor 40.

[0094] As described in Embodiment 1, when the absolute value of the difference between current amplitudes in the positive and negative directions of the d-axis, the difference being detected by current detector 21 by superimposing voltages in the positive and negative directions of the d-axis, respectively, is larger than the reference value I_{dth} , polarity determination unit 23 of motor control device 10 terminates the polarity determination for brushless motor 40. In contrast, when the absolute value of the difference between current amplitudes in the positive and negative directions of the d-axis is smaller than the reference value I_{dth} , polarity determination unit 23 performs the following. That is, polarity determination unit 23 determines the polarity of a magnetic pole of brushless motor 40, based on the difference between current amplitudes in the positive and negative directions of the q-axis, the difference being detected by current detector 21 by superimposing voltages in the positive and negative directions of the q-axis, respectively, and the difference between the current amplitudes in the positive and negative directions of the d-axis, and corrects an initial phase.

[0095] Thus, motor control device 10 can determine the correct magnetic pole direction in the polarity determination even when the d-axis direction is incorrectly estimated to be the q-axis direction in the initial phase estimation. In other words, motor control device 10 can correctly perform magnetic pole detection even when the initially estimated d-axis direction is incorrectly shifted by 90° or 270° with respect to the correct direction. Therefore, motor control device 10 can smoothly start up and accelerate brushless motor 40 without actions, such as reverse rotation and step-out, at the start-up of brushless motor 40.

[0096] As described in Embodiment 1, polarity determination unit 23 of motor control device 10 uses a current detected by current detector 21 as an offset current value immediately before the superimposition of voltages in the positive and negative directions of the d- and q-axes. Polarity determination unit 23 determines the polarity of a magnetic pole of brushless motor 40, based on a value obtained by subtracting the offset current value from a maximum value of current amplitude in each of the positive and negative directions of the d- and q-axes, the maximum value being detected by current detector 21 by superimposing voltages in each of the positive and negative directions of the d- and q-axes, and corrects an initial phase.

[0097] Thus, motor control device 10 can determine a correct magnetic pole direction

with higher accuracy in the polarity determination. Therefore, motor control device 10 can smoothly start up and accelerate brushless motor 40 without actions, such as reverse rotation and step-out, at the start-up of brushless motor 40.

[0098] (Embodiment 2)

Hereinafter, a motor control device in Embodiment 2 will be described using FIG. 12.

[0099] [2-1. Operation]

[2-1-1. Control of Command Current Value]

A polarity determination unit of the motor control device in Embodiment 2 is different from polarity determination unit 23 of motor control device 10 in Embodiment 1 in that command current values ($\pm I_d$, $\pm I_q$) are controlled to be 0 A during polarity determination.

[0100] FIG. 12 is a diagram for explaining the outline of polarity determination when current control is performed in the motor control device in Embodiment 2.

[0101] FIG. 12 indicates a difference in the behavior of I_d current between a case in which current control is performed and a case in which current control is not performed. Note that, in FIG. 12, the I_d current in the case of performing current control is indicated with a solid line, meanwhile the I_d current in the case of not performing current control is indicated with a dashed line.

[0102] As illustrated in FIG. 12, from the behavior of current in the case of performing current control, it is found that, when current control is performed, current response is faster, so that an I_d current value converges to 0 A faster.

[0103] [2-2. Effects]

As described above, the polarity determination unit of the motor control device in Embodiment 2 controls a current flowing through brushless motor 40 to 0 during the determination of the polarity of a magnetic pole of brushless motor 40.

[0104] Thus, the motor control device in Embodiment 2 can shorten the interval between voltage superimposition and the subsequent voltage superimposition. Therefore, the motor control device in Embodiment 2 can determine the polarity for a shorter period of time.

[0105] (Other Embodiments)

Embodiments 1 and 2 were described above as illustrative examples of the technology in the present disclosure. However, the technology in the present disclosure is not limited by these embodiments, and is also applicable to embodiments in which modifications, substitutions, additions, omissions, or the likes are made. In addition, the

constituents described in Embodiments 1 and 2 can be combined to provide a new embodiment.

[0106] Hereinafter, other embodiments will be described.

[0107] The motor control device and the brushless motor having the salient pole structure in the present disclosure can be installed in a washing machine or a washing and drying machine. For example, in the case where the brushless motor having the salient pole structure and the motor control device in the present disclosure are respectively used as a brushless motor and a motor control device for driving a drum of a front-loading washing machine, start-up can be smoothly performed and the number of rotations can be increased without the reverse rotation of the stopped drum or without a failure in the start-up of the drum. Thus, the present disclosure can contribute to the enhancement of washing performance and a reduction in operation time, and thereby provide a high-performance washing machine.

[0108] Motor control device 10 in Embodiment 1 and the motor control device in Embodiment 2 (hereinafter, referred to as "the motor control devices in the embodiments") are configured not to include brushless motor 40. However, the configurations of the motor control devices in the embodiments are merely examples of the configuration of the motor control device in the present disclosure, hence the configuration of the motor control device in the present disclosure is not limited to the configurations of the motor control devices in the embodiments. In other words, the motor control device in the present disclosure may be configured to include a brushless motor including a rotor with a salient pole structure and driven by the inverter circuit in the present disclosure.

INDUSTRIAL APPLICABILITY

[0109] The present disclosure is applicable to a motor control device configured to exercise sensorless control of the rotation of a brushless motor (a permanent magnet synchronous motor) including a rotor having a salient pole structure, and is also applicable to a washing machine or a washing and drying machine having the motor control device installed therein. Specifically, the present disclosure is applicable to, for example, a top-loading washing machine, a front-loading washing machine, and a front-loading washing and drying machine.

REFERENCE MARKS IN THE DRAWINGS

[0110] 10...motor control device

11...rectifier circuit
12...smoothing capacitor
13...inverter circuit
14a...switching element
14b...switching element
14c...switching element
14d...switching element
14e...switching element
14f...switching element
15a...resistance
15b...resistance
15c...resistance
20...control circuit
21...current detector
22...initial phase estimation unit
23...polarity determination unit
24...sensorless estimation unit
24a...drive system switching unit
24b...inductance driver
24ba...uvw→dq current converter
24bb...position estimate φ calculation unit
24bc...high-frequency current control unit
24bd...angular speed ω calculation unit
24be...position angle θ calculation unit
24bf...speed current control unit
24bg...dq→uvw voltage converter
24c...induced voltage driver
24ca...uvw→dq current converter
24cb...position estimate $\varepsilon\gamma$ calculation unit
24cc...angular-speed ω calculation unit
24cd...position angle θ calculation unit
24ce...speed current control unit
24cf...dq→uvw voltage converter
30...alternating-current power source

40...brushless motor

41...rotor

42...magnet

WHAT IS CLAIMED IS:

1. A motor control device configured to control a brushless motor, the brushless motor including a rotor with a salient pole structure and being configured to be driven by an inverter circuit, the motor control device comprising:

the inverter circuit;

a current detector configured to detect a current flowing through the brushless motor;

an initial phase estimation unit configured to estimate an initial phase of the brushless motor, based on the current detected by the current detector; and

a polarity determination unit configured to determine a polarity of a magnetic pole of the brushless motor, based on the current detected by the current detector,

wherein, for the initial phase estimated by the initial phase estimation unit, the polarity determination unit

determines the polarity of the magnetic pole of the brushless motor, based on

a difference between a current amplitude in a positive direction of a d-axis and a current amplitude in a negative direction of the d-axis, the difference being detected by the current detector by superimposing a voltage in the positive direction of the d-axis and a voltage in the negative direction of the d-axis, respectively, and

a difference between a current amplitude in a positive direction of a q-axis and a current amplitude in a negative direction of the q-axis, the difference being detected by the current detector by superimposing a voltage in the positive direction of the q-axis and a voltage in the negative direction of the q-axis, respectively, and

corrects the initial phase.

2. The motor control device according to claim 1,

wherein, when an absolute value of the difference between the current amplitude in the positive direction of the d-axis and the current amplitude in the negative direction of the d-axis, the difference being detected by the current detector by superimposing the voltage in the positive direction of the d-axis and the voltage in the negative direction of the d-axis, respectively, is larger than a reference value, the polarity determination unit terminates polarity determination for the brushless motor, and,

wherein, when the absolute value of the difference between the current amplitude

in the positive direction of the d-axis and the current amplitude in the negative direction of the d-axis is smaller than the reference value, the polarity determination unit

determines the polarity of the magnetic pole of the brushless motor, based on

the difference between the current amplitude in the positive direction of the q-axis and the current amplitude in the negative direction of the q-axis, the difference being detected by the current detector by superimposing the voltage in the positive direction of the q-axis and the voltage in the negative direction of the q-axis, respectively, and

the difference between the current amplitude in the positive direction of the d-axis and the current amplitude in the negative direction of the d-axis, and corrects the initial phase.

3. The motor control device according to claim 1 or 2,

wherein, using the current detected by the current detector as an offset current value immediately before superimposition of the voltage in the positive direction of the d-axis and the voltage in the negative direction of the d-axis and superimposition of the voltage in the positive direction of the q-axis and the voltage in the negative direction of the q-axis, the polarity determination unit

determines the polarity of the magnetic pole of the brushless motor, based on a value obtained by subtracting the offset current value from a maximum value of current amplitude in each of the positive and negative directions of the d-axis and the positive and negative directions of the q-axis, the maximum value being detected by the current detector by superimposing the voltage in each of the positive and negative directions of the d-axis and the positive and negative directions of the q-axis, and corrects the initial phase.

4. The motor control device according to any one of claims 1 to 3,

wherein the polarity determination unit controls the current flowing through the brushless motor to 0 during determination of the polarity of the magnetic pole of the brushless motor.

5. A washing machine or a washing and drying machine, comprising the motor control device according to any one of claims 1 to 4.