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MOTOR CONTROL DEVICE AND MOTOR DRIVER CIRCUIT

Abstract

According to one embodiment, a motor control device includes a sensor, a detection circuit, and a controller. The sensor is at a position between a winding of a first phase and a winding of a second phase in a motor. The motor includes windings of three phases. The detection circuit detects when a magnitude relationship between an induced voltage amplitude of the first phase and an induced voltage amplitude of the second phase is switched. The controller detects a rotational direction based on a sensor signal from the sensor and a detection result sensor from the detection circuit.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION(S) [0001] This application is a continuation of U.S. patent application Ser. No. 18/172,932, filed Feb. 22, 2023, which is based upon and claims the benefit of priority from Japanese Patent Application No. 2022-150514, filed Sep. 21, 2022, the entire contents of each of which are incorporated herein by reference.

FIELD

[0002] Embodiments described herein relate generally to a motor control device and a motor driver circuit.

BACKGROUND

[0003] A motor control device may perform predetermined processing in addition to normal driving. In this case, it is desired to perform the predetermined processing with high accuracy.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. 1 is a diagram illustrating a configuration of a motor control device according to a first embodiment.

[0005] FIG. 2 is a diagram illustrating a configuration of a motor and a sensor in a first embodiment.

[0006] FIG. 3 is a waveform diagram illustrating an operation of the motor control device according to a first embodiment.

[0007] FIG. 4 is a diagram related to measurement of a delay time in a first rotation direction in a first embodiment.

[0008] FIG. 5 is a diagram related to measurement of a delay time in a second rotation direction in a first embodiment.

[0009] FIG. 6 is a diagram illustrating a configuration of a motor control device according to a modification of a first embodiment.

[0010] FIG. 7 is a waveform diagram illustrating an operation of a motor control device according to a second embodiment.

[0011] FIG. 8 is a diagram related to processing for detecting a rotation direction when a motor is idling in a second embodiment.

[0012] FIG. 9 is a waveform diagrams illustrating an operation of a motor control device according to a third embodiment.

[0013] FIG. 10 is a waveform diagram illustrating a phase adjustment range on an advancement angle side in a third embodiment.

DETAILED DESCRIPTION

[0014] Embodiments provide a motor control device and a motor driver circuit that can accurately perform processing related to operational adjustments and delay time and rotation direction detection.

[0015] In general, according to one embodiment, a motor control device includes a sensor, a detection circuit, and a controller. The sensor is at a position between a winding of a first phase and a winding of a second phase in a motor. The detection circuit detects when a magnitude

relationship between a signal corresponding to an induced voltage amplitude of the first phase and another signal corresponding an induced voltage amplitude of the second phase is switched. The controller performs processing based on a sensor signal from the sensor and a detection result signal from the detection circuit to detect a rotational direction of the motor. For example, the rotational direction may be determined during an idle (or non-driven) period or state.

[0016] Motor control devices according to certain example embodiments will be described below with reference to the accompanying drawings. The present disclosure is not limited by these particular example embodiments.

First Embodiment

[0017] A motor control device according to a first embodiment accurately performs certain adjustment processing in addition to processing for normal driving operations. A motor control device **1** in this example is configured as illustrated in FIG. **1**.

[0018] The motor control device **1** controls the driving of a motor M. The motor control device **1** is also called a motor driver circuit in some contexts. The motor M may be a three-phase AC motor. The motor control device **1** drives the motor M by supplying AC power of three phases (U-phase, V-phase, W-phase).

[0019] The motor control device **1** includes a drive circuit **10**, a sensor **20**, a detection circuit **30**, and a controller **40**. The drive circuit **10** is connected between the motor M and the detection circuit **30** and controller **40**. The detection circuit **30** is connected between the controller **40** and the drive circuit **10**.

[0020] The drive circuit **10** is, for example, an inverter. The drive circuit **10** converts DC power into AC power and drives the motor M by supplying the converted AC power to the motor M. The drive circuit **10** includes a plurality of switching elements SW. When the motor M is a three-phase AC motor, the drive circuit **10** includes switching elements SWUU, SWVU, SWWU, SWUL, SWVL, and SWWL corresponding to the three phases (U-phase, V-phase, W-phase). The switching elements SWUU, SWVU, and SWWU form an upper arm. The switching elements SWUL, SWVL, and SWWL form a lower arm.

[0021] The motor M may have a configuration in which each stator ST is an electromagnet and a rotor is a permanent magnet, or a configuration in which each stator ST is a permanent magnet and the rotor is an electromagnet. In the following example, in the motor M, each stator ST is an electromagnet and the rotor is a permanent magnet.

[0022] The motor M includes stators STU, STV, and STW and a rotor RT, as illustrated in FIG. **2**. FIG. **2** is a diagram illustrating a configuration of the motor M and the sensor **20**, and schematically shows a cross section including a rotation axis of the motor M. FIG. **2** illustrates a cross section viewed from a front side (power transmission destination side).

[0023] The stator STU includes a U-phase winding WU. The stator STV includes a V-phase winding WV. The stator STW includes a W-phase winding WW. A rotor RT includes n pole pairs including north and south poles, where n is an integer of 1 or more. Regarding the rotation direction of the rotor RT, a rotation direction CW (clockwise) and a rotation direction CCW (counterclockwise) is set as depicted in FIG. **2**.

[0024] A node NU (illustrated in FIG. **1**) is connected to the U-phase winding WU of the motor M. A node NV (illustrated in FIG. **1**) is connected to the V-phase winding WV of the motor M. A node NW (illustrated in FIG. **1**) is connected to the W-phase winding WW of the motor M.

[0025] The switching elements SWUU and SWUL each correspond to the U phase and respectively have one end connected to the node NU. The switching element SWUU has another end connected to a power supply voltage VDD. The switching element SWUL has another end connected to a ground voltage via a resistor element R.

[0026] The switching elements SWVU and SWVL each correspond to the V phase and respectively have one end connected to the node NV. The switching element SWVU has another end connected to the power supply voltage VDD. The switching element SWVL has the another connected to the

ground voltage via the resistor element R.

[0027] The switching elements SWWU and SWWL each correspond to the W phase and respectively have one end connected to the node NW. The switching element SWWU has another end connected to the power supply voltage VDD. The switching element SWWL has another end connected to the ground voltage via the resistor element R.

[0028] The sensor **20** (illustrated in FIG. **1**) detects a rotational position of the motor M. That is, the sensor **20** detects a position (rotational position) of the rotor RT. The sensor **20** may include a Hall element H (see FIG. **2**) and use this Hall element H to detect the rotational position of the rotor RT.

[0029] For example, the Hall element H is located at a position between two phase windings Wu and Ww of the three phase windings Wu, Wv, and Ww in the motor M, as illustrated in FIG. **2**. A level of a Hall signal output from the Hall element H changes when a magnetic pole boundary of the rotor RT passes through the sensor position between the two phase windings Wu and Ww.

[0030] As a result, the sensor **20** can detect the timing at which the magnetic pole boundary of the rotor RT passes through the sensor position between the two phase windings Wu and Ww ($2n$ times per a single rotation of the rotor RT). When the number of pole pairs is one ($n=1$), the sensor **20** twice detects the magnetic pole boundary of the rotor RT passing through the position between the two phase windings Wu and Ww during one rotation of the rotor RT.

[0031] The detection circuit **30** (illustrated in FIG. **1**) detects when a magnitude relationship between a signal of one phase (a first phase) and a signal of another phase (a second phase) is switched. In some examples, the detection circuit **30** may detect the timing at which a magnitude relationship between an induced voltage amplitude of one phase and an induced voltage amplitude of another phase is switched. The detection circuit **30** may detect the timing at which a magnitude relationship between an amplitude of a W-phase induced voltage VW and an amplitude of a U-phase induced voltage VU is switched.

[0032] The detection circuit **30** may include a comparator **31** and a plurality of detection nodes. The comparator **31** compares the induced voltage detected at the detection node of one phase with the induced voltage detected at the detection node of another phase. The comparator **31** may compare the induced voltage VW detected at the W-phase detection node NW and the induced voltage VU detected at the U-phase detection node NU. The comparator **31** has a non-inverting input node (+) connected to the W-phase detection node NW, an inverting input node (−) connected to the U-phase detection node NU, and an output node connected to the controller **40**. The comparator **31** supplies a comparison result to the controller **40**. A level of the comparison result is inverted at the timing at which a magnitude relationship between the W-phase induced voltage amplitude and the U-phase induced voltage amplitude switches. The comparator **31** can indicate the timing at which the magnitude relationship between the induced voltage amplitude of one phase and the induced voltage amplitude of another phase switches by an edge timing at which the comparison result is inverted (switches).

[0033] The controller **40** performs adjustment processing on the motor M based on the signal from the sensor **20** and the detection result from the detection circuit **30** during a maintenance period such as at a startup. The adjustment processing may be related to any adjustment that makes driving of the motor M more efficient. The controller **40** drives and controls the motor M based on the signal from the sensor **20** in a normal operating state after the adjustment processing is performed. Thereby, the controller **40** can more efficiently control the motor M.

[0034] The controller **40** includes a control circuit **41** and a processing circuit **42**. The control circuit **41** drives and controls the motor M. The processing circuit **42** calculates an offset amount and a delay amount based on the signal from the sensor **20** and the detection result from the detection circuit **30**.

[0035] The offset amount indicates an amount of deviation from a midpoint position between the winding of one phase and the winding of another phase for the arrangement position of the sensor **20** (Hall element H) in terms of electrical angle (electrical phase angle). For example, in the case of

FIG. 2, when the arrangement position of the U-phase winding WU is used as a reference position, the arrangement position of the W-phase winding WW at an angle α from the reference position, and the midpoint position is at an angle $\alpha/2$. The arrangement position of the Hall element H is at an angle β . An offset amount ΔOF , which indicates the amount of deviation between the midpoint position and the arrangement position of the Hall element H in terms of an electrical (phase) angle, is expressed by Equation 1 below:

$$[00001] \quad OF = \frac{\alpha}{2} - \beta$$

[0036] A delay amount ΔD indicates as an electrical angle how much the edge timing of the signal of the sensor 20 is delayed from a proper timing. The delay amount ΔD mainly includes an operation delay of the Hall element H, a delay of the wiring connecting the Hall element H and the processing circuit 42, an operation delay of the circuit in the processing circuit 42, and the like.

[0037] The processing circuit 42 notifies the control circuit 41 of the offset amount ΔOF and the delay amount ΔD . The control circuit 41 drives and controls the motor M after correction according to the offset amount ΔOF and the delay amount ΔD .

[0038] The control circuit 41 drives and controls the motor M as in the normal operating state. The control circuit 41 drives and controls the motor M in the rotation direction CW. The control circuit 41 supplies the U-phase output voltage UU, the V-phase output voltage VU, the W-phase output voltage WU, the U-phase output voltage UL, the V-phase output voltage VL, and the W-phase output voltage WL, as illustrated in FIG. 3, to control terminals of the switching elements SWUU, SWVU, SWWU, SWUL, SWVL, and SWWL, respectively. FIG. 3 is a waveform diagram illustrating the operation of the motor control device 1.

[0039] The phases of the U-phase output voltage UU, the V-phase output voltage VU, and the W-phase output voltage WU are sequentially offset by about $+120^\circ$. The phases of the U-phase output voltage UU and the U-phase output voltage UL are offset by about 180° . The phases of the V-phase output voltage VU and the V-phase output voltage VL are offset by about 180° . The phases of the W-phase output voltage WU and the W-phase output voltage WL are offset by about 180° . As a result, the switching elements SWUU, SWVU, SWWU, SWUL, SWVL, and SWWL are switching-controlled on and off as necessary.

[0040] Accordingly, a U-phase motor current IU, a V-phase motor current IV, and a W-phase motor current IW flow with a phase difference of about $+120^\circ$ from each other, and are respectively supplied to the U-phase winding Wu, the V-phase winding Wv, and the W-phase winding Ww. As a result, the rotor RT rotates in the rotation direction CW, and the U-phase induced voltage VU, the V-phase induced voltage VV, and the W-phase induced voltage VW are generated with a phase difference of about $+120^\circ$. The U-phase induced voltage VU, the V-phase induced voltage VV, and the W-phase induced voltage VW change according to the rotational position of the rotor RT.

[0041] Then, the control circuit 41 stops driving of the motor M. In this case, the rotor RT continues initially to rotate in the rotation direction CW at a substantially constant rotational speed due to its inertia. As a result, as illustrated in FIG. 4, the U-phase induced voltage VU, the V-phase induced voltage VV, and the W-phase induced voltage VW are continuously generated with a phase difference of about $+120^\circ$. FIG. 4 is a diagram illustrating the measurement of a delay time ΔTCW in the rotation direction CW.

[0042] In this state, the sensor 20 detects the rotational position of the rotor RT and supplies a detection result to the processing circuit 42. The Hall element H supplies a Hall signal as illustrated in FIG. 4 to the processing circuit 42. The level of the Hall signal output from the Hall element H changes when the magnetic pole boundary of the rotor RT passes through the sensor position between the two phase windings Wu and Ww. For example, the Hall signal transitions from H level to L level at a time t_0 , transitions from L level to H level at a time t_{01} , and transitions from H level to L level at a time t_2 . When the number of pole pairs is one ($n=1$), a period $\Delta TP1$ from the time t_0 to the time t_2 corresponds to one cycle of the Hall signal and also corresponds to the period over which the rotor RT rotates once in the rotation direction CW.

[0043] The detection circuit **30** detects the timing at which the magnitude relationship between the induced voltage amplitude of one phase and the induced voltage amplitude of another phase is switched, and supplies the detection result to the processing circuit **42**. The comparator **31** compares the W-phase induced voltage VW and the U-phase induced voltage VU, and inverts the comparison result at the timing when the magnitude relationship between the amplitude of the W-phase induced voltage VW and the amplitude of the U-phase induced voltage VU is switched.

[0044] For example, the comparison result from the comparator **31** transitions from H level to L level at a time t_1 . This timing is the timing of transition from a state in which the induced voltage VW is greater than the induced voltage VU to a state in which the induced voltage VW is less than the induced voltage VU. In addition, this timing is the timing of the zero cross in terms of a waveform of a difference $VW - VU$ between the induced voltage VW and the induced voltage VU. A waveform of a difference $VU - VW$ is illustrated for reference.

[0045] The processing circuit **42** obtains the time t_0 and the time t_2 according to the Hall signal output from the sensor **20**. The processing circuit **42** obtains the time t_1 according to the comparison result from the detection circuit **30**. According to these signals, the processing circuit **42** calculates a period $\Delta TP1$ (length of time from t_0 to t_2), and obtains the delay time ΔTCW from the time t_1 to the time t_2 .

[0046] Also, the control circuit **41** drives and controls the motor M in the rotation direction CCW. The rotation direction CCW is a rotation direction opposite to the rotation direction CW. Although not illustrated, the control circuit **41** generates the U-phase output voltage UU, the V-phase output voltage VU, and the W-phase output voltage WU so that their phases are offset by about -120° in order, and supplies them to the switching elements SWUU, SWVU, and SWWU, respectively. The control circuit **41** generates the U-phase output voltage UU and the U-phase output voltage UL so that the phases thereof are offset by about 180° from each other, and supplies them to the switching elements SWUU and SWUL. The control circuit **41** generates the V-phase output voltage VU and the V-phase output voltage VL so that phases thereof are offset from each other by about 180° , and supplies them to the switching elements SWVU and SWVL. The control circuit **41** generates the W-phase output voltage WU and the W-phase output voltage WL so that the phases thereof are offset from each other by about 180° , and supplies them to the switching elements SWWU and SWWL. As a result, the switching elements SWUU, SWVU, SWWU, SWUL, SWVL, and SWWL are controlled for switching.

[0047] Accordingly, a U-phase motor current IU, a V-phase motor current IV, and a W-phase motor current IW flow with a phase difference of about -120° from each other, and are supplied to the U-phase winding Wu, the V-phase winding Wv, and W-phase winding Ww, respectively. As a result, the rotor RT rotates in the rotation direction CCW, and the U-phase induced voltage VU, the V-phase induced voltage VV, and the W-phase induced voltage VW are generated with a phase difference of about -120° . The U-phase induced voltage VU, the V-phase induced voltage VV, and the W-phase induced voltage VW change according to the rotational position of the rotor RT.

[0048] Then, the control circuit **41** stops driving of the motor M. In this case, the rotor RT rotates in the rotation direction CCW at a substantially constant rotational speed due to its inertia. As a result, as illustrated in FIG. 5, the U-phase induced voltage VU, the V-phase induced voltage VV, and the W-phase induced voltage VW are continuously generated with a phase difference of about -120° . FIG. 5 is a diagram illustrating the measurement of a delay time $\Delta TCCW$ in the rotation direction CCW.

[0049] In this state, the sensor **20** detects the rotational position of the rotor RT and supplies the detection result to the processing circuit **42**. For example, the Hall element H supplies a Hall signal as illustrated in FIG. 5 to the processing circuit **42**. The level of the Hall signal output from the Hall element H changes at the timing when the magnetic pole boundary of the rotor RT passes through the position between two phase windings Wu and Ww. For example, the Hall signal transitions from H level to L level at a time t_{10} , transitions from L level to H level at a time t_{101} , and

transitions from H level to L level at a time **t11**. When the number of pole pairs is one ($n=1$), a period $\Delta TP2$ from the time **t10** to the time **t11** is one cycle of the Hall signal and corresponds to the period during which the rotor RT rotates once in the rotation direction CCW.

[0050] The detection circuit **30** detects the timing at which the magnitude relationship between the induced voltage amplitude of one phase and the induced voltage amplitude of another phase is switched, and supplies the detection result to the processing circuit **42**. The comparator **31** compares the W-phase induced voltage VW and the U-phase induced voltage VU, and inverts the comparison result at the timing when the magnitude relationship between the amplitude of the W-phase induced voltage VW and the amplitude of the U-phase induced voltage VU is switched.

[0051] For example, the comparison result from the comparator **31** transitions from L level to H level at a time **t12**. This timing is the timing of transition from a state in which the induced voltage VW is lower than the induced voltage VU to a state in which the induced voltage VW is higher than the induced voltage VU. In addition, this timing is the timing of the zero cross in terms of the waveform of the difference VW-VU between the induced voltage VW and the induced voltage VU. The waveform of the difference VU-VV is illustrated for reference.

[0052] The processing circuit **42** obtains the time **t10** and the time **t11** according to the Hall signal from the sensor **20**. The processing circuit **42** obtains the time **t12** according to the comparison result from the detection circuit **30**. According to these, the processing circuit **42** calculates a period $\Delta TP2$ from **t10** to **t11**, and obtains the delay time $\Delta TCCW$ from the time **t11** to the time **t12**.

[0053] Here, the offset amount ΔOF is an angle indicating the displacement of the arrangement position of the sensor **20** (Hall element H). Since the offset amount ΔOF is a physical quantity that depends on the rotation direction of the rotor RT, it is contained in the delay time with the sign inverted between the rotation direction CW and the rotation direction CCW. Therefore, the processing circuit **42** can calculate the offset amount ΔOF (in units of degree $^\circ$) by the following Equation 2 (below) using the delay time ΔTCW in the rotation direction CW and the delay time $\Delta TCCW$ in the rotation direction CCW. Equation 2 is as follows:

$$[00002] \quad OF = (360 \times TCW / TP1 - 360 \times TCCW / TP2) / 2$$

[0054] The delay amount ΔD is a deviation due to the operation delay of the Hall element H, the delay of the wiring connecting the Hall element H and the processing circuit **42**, the operation delay of the circuit in the processing circuit **42**, and the like. Since the delay amount ΔD is a physical quantity that does not depend on the rotation direction of the rotor RT, it is contained in the delay time with the same sign in the rotation direction CW and the rotation direction CCW. Therefore, the processing circuit **42** can calculate the delay amount ΔD (in units of degree $^\circ$) by Equation 3 (below) using the delay time ΔTCW in the rotation direction CW and the delay time $\Delta TCCW$ in the rotation direction CCW. Equation 3 is as follows:

$$[00003] \quad D = (360 \times TCW / TP1 + 360 \times TCCW / TP2) / 2$$

[0055] As a result, during a maintenance period such as at startup, the controller **40** can perform adjustment processing for correcting the offset amount ΔOF calculated by Equation 2 and the delay amount ΔD obtained by Equation 3 for the signal (Hall signal) of the sensor **20**. In a state where this adjustment processing is performed, the controller **40** drives and controls the motor M based on the signal from the sensor **20** in a normal state. Thereby, the controller **40** can efficiently control the motor M.

[0056] In the first embodiment, the controller **40** calculates the offset amount and the delay amount based on the signal from the sensor **20** and the detection result from the detection circuit **30** during the maintenance period. For example, the controller **40** drives the motor M in the rotation direction CW, maintains states of all the switching elements to OFF states, and measures the delay time ΔTCW in the rotation direction CW. The controller **40** also drives the motor M in the rotation direction CCW, maintains states of all the switching elements to the OFF states, and measures the delay time $\Delta TCCW$ in the rotation direction CCW. The controller **40** uses the delay time ΔTCW and the delay time $\Delta TCCW$ to obtain the offset amount and the delay amount. Since the delay

times ΔTCW and $\Delta TCCW$ measured while the rotational speed of the motor M is steady are used, the offset amount and the delay amount can be obtained with high accuracy.

[0057] It is possible to calculate the offset amount from a Hall signal of one phase and the induced voltage corresponding to the current flowing in a lower output stage of the one phase. If it is assumed that the upper switching elements SWVU and SWWU of the V/W phases in the drive circuit **10** are turned off and the lower switching elements SWVL and SWWL are turned on, then the offset amount can be detected so that the time from fall of the U-phase Hall signal to fall of the U-phase induced voltage becomes the time corresponding to an electrical angle of 150°. In this case, a braking operation on the rotation of the rotor RT occurs due to turning-on of the switching elements SWVL and SWWU. As a result, the U-phase induced voltage changes, and the fall timing thereof tends to deviate from the timing corresponding to the offset amount. This makes it difficult to accurately detect the offset amount.

[0058] However, in the first embodiment, the controller **40** drives the motor M in the rotation direction CW, maintains the states of all the switching elements to be the OFF states, and measures the delay time ΔTCW in the rotation direction CW. Also, the controller **40** drives the motor M in the rotation direction CCW, maintains the states of all the switching elements to be the OFF states, and measures the delay time $\Delta TCCW$ in the rotation direction CCW. The controller **40** uses the delay time ΔTCW and the delay time $\Delta TCCW$ to calculate the offset amount and the delay amount. This eliminates the need for a braking operation at the time of detection, thereby reducing the occurrence of changes in the induced voltage at the time of detection. Therefore, it becomes easier to accurately detect the offset amount.

[0059] The arrangement position of the Hall element H is not limited to the position illustrated in FIG. 2. For example, the Hall element H may be located between two phase windings Wu and Wv of the three phase windings Wu, Wv and Ww in the motor M. In this case, the detection circuit **30** may detect the timing at which the magnitude relationship between the amplitude of the U-phase induced voltage VU and the amplitude of the V-phase induced voltage VV is switched. The comparator **31** may compare the induced voltage VU detected at the U-phase detection node NU and the induced voltage VV detected at the V-phase detection node NV. The comparator **31** has a non-inverting input node (+) connected to the U-phase detection node NU, an inverting input node (−) connected to the V-phase detection node NV, and an output node connected to the controller **40**.

[0060] Alternatively, the Hall element H may be located at a position between two phase windings WV and WW of the three phase windings Wu, Wv and Ww in the motor M. In this case, the detection circuit **30** may detect the timing at which the magnitude relationship between the amplitude of the V-phase induced voltage VV and the amplitude of the W-phase induced voltage VW is switched. The comparator **31** may compare the induced voltage VV detected at the V-phase detection node NV and the induced voltage VW detected at the W-phase detection node NW. The comparator **31** has a non-inverting input node connected to the V-phase detection node NV, an inverting input node connected to the W-phase detection node NW, and an output node connected to the controller **40**.

[0061] Also, as a modification example of the first embodiment, a detection circuit **30i** in a motor control device **1i**, as illustrated in FIG. 6, may be configured to detect the timing at which the magnitude relationship of motor currents of a plurality of phases is switched instead of the timing at which the magnitude relationship of induced voltages of a plurality of phases is switched. FIG. 6 is a diagram illustrating a configuration of the motor control device **1i** according to this modification of the first embodiment.

[0062] The detection circuit **30i** may detect the timing at which the magnitude relationship between the motor current of one phase and the motor current of another phase is switched. The detection circuit **30i** may detect the timing at which the magnitude relationship between the amplitude of the W-phase motor current IW and the amplitude of the U-phase motor current IU is switched.

[0063] The detection circuit **30i** may include a comparator **31** and current detectors CTw and CTU.

The comparator **31** compares the motor current I detected by the current detector one phase to the motor current I detected by the current detector of another phase. For example, the comparator **31** may compare a motor current I_W detected by a W-phase current detector CTW and a motor current I_U detected by a U-phase current detector CTU. The comparator **31** has a non-inverting input node connected to the W-phase current detector CTW, an inverting input node connected to the U-phase current detector CTU, and an output node connected to the controller **40**. The comparator **31** supplies a comparison result to the controller **40**. A level of the comparison result is inverted (switched) when the magnitude relationship between the W-phase motor current I_W and the U-phase motor current I_U switches. The comparator **31** can detect the timing at which the magnitude relationship between the motor current I of one phase and the motor current I of another phase switches by the edge timing at which the comparison result is inverted.

[0064] Here, as illustrated in FIG. **3**, with respect to the timing at which the magnitude relationship between the induced voltage amplitude of one phase and the induced voltage amplitude of another phase is switched, the timing at which the magnitude relationship between the motor current of one phase and the motor current of another phase is switched has a deviation Δt . In some examples, timing deviation Δt may be experimentally measured and stored in the processing circuit **42** in advance of the adjustment processing. When the processing circuit **42** calculates the timing at which the magnitude relationship between the motor current I of one phase and the motor current I of another phase is switched, the timing may be corrected by the deviation Δt . As a result, since the processing circuit **42** can obtain the timing at which the magnitude relationship between the induced voltage amplitude of one phase and the induced voltage amplitude of another phase is switched, the offset amount and the delay amount can be obtained with high accuracy.

Second Embodiment

[0065] Next, a motor control device **1** according to a second embodiment will be described. The following description will focus on aspects that are different from those of the first embodiment.

[0066] In the first embodiment, the calculating of the offset amount and the delay amount for adjustment processing was performed separately from the normal operation driving (e.g., in a startup period or the like). In the second embodiment the detection of the rotation direction occurs when the motor is idling (not being driven).

[0067] For example, when the motor M is a fan motor, even in a state in which driving by the motor control device **1** is not performed, the fan may rotate due to wind or otherwise, and the motor M to which such rotational force is imparted may be caused to rotate, resulting in movement during idling. When the motor M is idling, if the motor control device **1** does not know the present rotation direction of the motor M , it becomes difficult to drive-control the motor M in the appropriate (intended) rotation direction. Therefore, in the motor control device **1**, it is desired to appropriately detect the rotation direction of the motor M even while idling.

[0068] In the motor control device **1** illustrated in FIG. **1**, the controller **40** calculates the rotation direction of the motor M based on the signal from the sensor **20** and the detection result from the detection circuit **30**. The controller **40** detects the rotation direction of the motor M when it is idling while the U-phase output voltage U_U , the V-phase output voltage V_U , and the W-phase output voltage W_U are at high impedance, as indicated by the dotted line surrounded region in FIG. **7**. FIG. **7** is a waveform diagram illustrating an operation of the motor control device **1**.

[0069] Even when the U-phase output voltage U_U , the V-phase output voltage V_U , and the W-phase output voltage W_U are at high impedance, as when the motor M is idling, a U-phase induced voltage V_U , a V-phase induced voltage V_V , and a W-phase induced voltage V_W can still be generated. For example, when the motor M is moving in the rotation direction CW while idling, the U-phase induced voltage V_U , the V-phase induced voltage V_V , and the W-phase induced voltage V_W are generated as illustrated in FIG. **4**. When the motor M is moving in the rotation direction CCW while idling, a U-phase induced voltage V_U , a V-phase induced voltage V_V , and a W-phase induced voltage V_W are generated as illustrated in FIG. **5**.

[0070] As illustrated in FIGS. 4 and 5, the controller **40** can detect the rotation direction of the motor M while in an idling state according to a combination of a level of a Hall signal VHU and a comparison result (for example, the magnitude relationship between the W-phase induced voltage VW and the U-phase induced voltage VU) from the comparator **31**. The controller **40** may detect the rotation direction of the motor M during idling, as illustrated in FIG. 8. FIG. 8 is a diagram illustrating processing for detecting the rotation direction when the motor M is idling.

[0071] For example, when a target (intended) rotation direction is the rotation direction CW, if the Hall signal VHU is at H level and the comparison result is at H level (that is, $VW > VU$), the controller **40** determines that the rotation direction is a “forward rotation” direction with respect to the target direction because the motor M is rotating in the rotation direction CW (see FIG. 4).

[0072] When the Hall signal VHU is at H level and the comparison result is at L level (that is, $VW < VU$), the controller **40** determines that the rotation direction is a “reverse rotation” direction with respect to the target direction because the motor M is rotating in the rotation direction CCW (see FIG. 5).

[0073] When the Hall signal VHU is at L level and the comparison result is at H level (that is, $VW > VU$), the controller **40** determines that the rotation direction is the “reverse rotation” direction with respect to the target direction because the motor M is rotating in the rotation direction CCW during the idling state (see FIG. 5).

[0074] When the Hall signal VHU is at L level and the comparison result is at L level (that is, $VW < VU$), the controller **40** determines that the rotation direction is the “forward rotation” direction with respect to the target direction because the motor M is rotating in the rotation direction CW during the idling state (see FIG. 5).

[0075] Alternatively, when a target rotation direction is the rotation direction CCW, if the Hall signal VHU is at H level and the comparison result is at H level (that is, $VW > VU$), the controller **40** determines that the rotation direction is the “reverse rotation” direction with respect to the target direction because the motor M is rotating in the rotation direction CW (see FIG. 4).

[0076] When the Hall signal VHU is at H level and the comparison result is at L level (that is, $VW < VU$), the controller **40** determines that the rotation direction is the “forward rotation” direction with respect to the target direction because the motor M is rotating in the rotation direction CCW (see FIG. 5).

[0077] When the Hall signal VHU is at L level and the comparison result is at H level (that is, $VW > VU$), the controller **40** determines that the rotation direction is the “forward rotation” direction with respect to the target direction because the motor M is rotating in the rotation direction CCW (see FIG. 5).

[0078] When the Hall signal VHU is at L level and the comparison result is at L level (that is, $VW < VU$), the controller **40** determines that the rotation direction is the “reverse rotation” direction with respect to the target direction because the motor M is rotating in the rotation direction CW (see FIG. 5).

[0079] In the second embodiment, the controller **40** in the motor control device **1** calculates the present rotational direction of the motor M based on the signal from the sensor **20** and the detection result from the detection circuit **30**. The controller **40** detects the rotational direction of the motor M when the motor M is idling according to a combination of the level of the Hall signal VHU and the comparison result (for example, the magnitude relationship between the W-phase induced voltage VW and the U-phase induced voltage VU) of the comparator **31**. As a result, the rotational direction of the motor M during idling can be properly determined, and the motor M can be more effectively drive-controlled in the proper rotation direction when the idling state ends.

[0080] It would be possible to detect the rotational direction of the motor M during idling from a Hall signal of one phase and the polarity of the current flowing in a lower output stage of the one phase. For example, if the upper switching element SWVU of the V phase in the drive circuit **10** is turned off and the lower switching element SWVL is turned on, and the rotation direction of the

motor M could be detected from the level of the U-phase Hall signal and the polarity of the U-phase induced voltage. In this case, a braking operation on the rotation of the rotor RT occurs due to turning-on of the switching element SWVL. Therefore, the U-phase induced voltage may change and the polarity may change. As a result, the rotation direction of the motor M might be erroneously detected.

[0081] According to the second embodiment, the controller **40** calculates the rotation direction of the motor M based on the signal from the sensor **20** and the detection result from the detection circuit **30**. As a result, the rotation direction of the motor M when it is idling can be properly determined, and the motor M can be drive-controlled in the proper rotation direction.

Third Embodiment

[0082] Next, the motor control device **1i** according to a third embodiment will be described. The following description will focus on parts that are different from those of the first and second embodiments.

[0083] In the first embodiment, the offset amount and the delay amount are calculated as part of the adjustment processing that is performed separately from the normal driving. In the second embodiment, the rotation direction is detected when the motor M is idling (not being actively driven). In the third embodiment, the phase of the driving voltage of the motor M is adjusted.

[0084] The phase of the induced voltage of the motor M and the phase of the motor current may deviate from each other. For example, in the case of FIG. 3, there is a deviation corresponding to a timing deviation Δt between the phase of the induced voltage of the motor M and the phase of the motor current. If the phase of the induced voltage of the motor M and the phase of the motor current can be matched, the power efficiency of driving of the motor M will generally be improved.

[0085] Therefore, in the motor control device **1i** illustrated in FIG. 6, the controller **40** adjusts the phase of the driving voltage of the motor M based on the signal from the sensor **20** and the detection result from the detection circuit **30i**.

[0086] After the offset amount/delay amount has been adjusted, the control circuit **41** may drive-control the motor M as if in the normal operating state. For example, the control circuit **41** may drive-control the motor M in the rotation direction CW. The control circuit **41** supplies a U-phase output voltage U_U , a V-phase output voltage V_U , and a W-phase output voltage W_U as illustrated in FIG. 9 to control terminals of switching elements SWUU, SWVU, and SWWU, respectively. Similarly, the control circuit **41** can supply, a U-phase output voltage U_L , a V-phase output voltage V_L , and a W-phase output voltage W_L to control terminals of switching elements SWUL, SWVL, and SWWL, respectively. FIG. 9 is a waveform diagram illustrating an operation of the motor control device **1i**.

[0087] In this operating state, the sensor **20** detects the rotation position of the rotor RT and supplies the detection result to the processing circuit **42**. For example, the Hall element H supplies a Hall signal V_{HU} as illustrated in FIG. 9 to the processing circuit **42**. A level of the Hall signal V_{HU} output from the Hall element H changes when the magnetic pole boundary of the rotor RT passes through the sensor position between the two phase windings W_u and W_w . For example, the hall signal V_{HU} transitions from L level to H level at a time t_{21} .

[0088] The detection circuit **30i** detects the timing at which the magnitude relationship between the motor current of one phase and the motor current of another phase is switched, and supplies the detection result to the processing circuit **42**. The comparator **31** compares a W-phase motor current I_W and a U-phase motor current I_U , and inverts (switches) the comparison result when the magnitude relationship between the amplitude of the W-phase motor current I_W and the amplitude of the U-phase motor current I_U is switched. For example, the comparison result from the comparator **31** transitions from L level to H level at a time t_{22} .

[0089] The processing circuit **42** obtains the time t_{21} according to the Hall signal V_{HU} from the sensor **20**. The processing circuit **42** obtains the time t_{22} according to the comparison result from the detection circuit **30i**. Based on these times, the processing circuit **42** calculates a period $\Delta t'$

(time from t_{21} to t_{22}). The processing circuit **42** notifies the control circuit **41** of the calculated period $\Delta t'$. The period $\Delta t'$ indicates that the phase of the motor current deviates from the phase of the induced voltage of the motor M in a timing delaying direction.

[0090] The control circuit **41** selectively advances the W-phase output voltages WU and WL by an electrical angle corresponding to the period $\Delta t'$. The control circuit **41** selectively advances the W-phase output voltages WU and WL as indicated by the dotted vertical line in FIG. **9** while maintaining the U-phase output voltages UU and UL and the V-phase output voltages VU and VL. As a result, the W-phase motor current IW is selectively advanced while the U-phase motor current IU and the V-phase motor current IV are maintained. Thereby, the phase of the induced voltage of the motor M and the phase of the motor current can be matched.

[0091] Although not specifically illustrated, when it is detected that the phase of the motor current deviates in a timing advancing direction from the phase of the induced voltage of the motor M by a period $\Delta t''$, the control circuit **41** may selectively advance the W-phase output voltages WU and WL by an electrical angle corresponding to the period $\Delta t''$. This also makes it possible to match the phase of the induced voltage of the motor M with the phase of the motor current.

[0092] As for the possible range of phase adjustment, as illustrated in FIG. **10**, levels of the output voltages of the two phases (in this case, the U phase and the W phase) used for control are close to each other in the vicinity of the time t_{21} at which the Hall signal VHU rises. Therefore, when selectively advancing one phase (for example, the W phase) in a range in which the balance of the three phases (the U phase, the V phase, and the W phase) can be maintained, an advancement angle value can be up to an electrical angle of 60° at most regardless of the magnitude of the amplitude. That is, the controller **40** can adjust a deviation between the phase of the induced voltage of the motor M and the phase of the motor current up to a period Δt_{\max} . Also, when selectively delaying one phase (for example, the W phase), a delayed angle value can be up to -50° . As a result, the controller **40** can adjust the phase of the induced voltage of the motor M and the phase of the motor current in an electrical angle range of -50° to 60° .

[0093] In the third embodiment, in the motor control device **1i**, the controller **40** adjusts the phase of the driving voltage of the motor M based on the signal from the sensor **20** and the detection result from the detection circuit **30i**. Thereby, the power efficiency of driving the motor M can be improved.

[0094] It is possible to adjust the advancement angle amount so that a difference between switching of the Hall signal of one phase and a polarity of the current flowing when a lower output stage of the one phase is turned on becomes 30° in an electrical angle. In such a case, when a duty ratio of the driving voltage (for example, the V-phase output voltage VU) of the one phase becomes high, it tends to be difficult to turn on the lower output stage. Therefore, the phase adjustable range tends to be limited near a center of the H level of the driving voltage of one phase. For example, the phase adjustable range may be limited to an electrical angle of -30° to 30° .

[0095] However, according to the present embodiment, a timing difference is detected by the rising edge of a Hall signal of one phase and the switching in the magnitude relationship of the motor currents of two phases, and the driving voltage of one phase is adjusted by the phase amount corresponding to the detected timing difference. Thereby, the phase adjustment can be performed over a wide range of electrical angles, and the robustness of the phase adjustment can be improved. For example, the phase adjustable range can be expanded to an electrical angle range of -50° to 60° .

[0096] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the disclosure. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the disclosure. The accompanying claims and their

equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the disclosure.

Claims

1. A motor control device, comprising: a sensor at a position between a winding for a first phase and a winding for a second phase in a motor including the winding of the first phase, the winding of the second phase, and a winding of a third phase; a detection circuit configured to detect a timing at which a magnitude relationship between a signal of the first phase and a signal of the second phase is switched; and a controller configured to perform processing based on a sensor signal from the sensor and a detection result signal from the detection circuit, wherein the controller is configured to identify a rotation direction of the motor based on the sensor signal and the detection result signal.
2. The motor control device according to claim 1, wherein the detection circuit detects when a magnitude relationship between an induced voltage amplitude of the first phase and an induced voltage amplitude of the second phase is switched and outputs the detection result signal accordingly.
3. The motor control device according to claim 1, wherein the detection circuit detects when a magnitude relationship between a motor current of the first phase and a motor current of the second phase is switched and outputs the detection result signal accordingly.
4. The motor control device according to claim 1, wherein the controller is configured to: calculate an offset of the position of the sensor from the midpoint position between the winding of the first phase and the winding of the second phase based on the sensor signal and the detection result signal, and calculate a delay amount of an edge timing of the sensor signal from a proper timing based on the sensor signal and the detection result signal.
5. The motor control device according to claim 4, further comprising: a drive circuit connected between the controller and the motor and including a plurality of switching elements.
6. The motor control device according to claim 5, wherein the controller is configured to: control the drive circuit to drive the motor in a first rotation direction while maintaining all of the plurality of switching elements in the OFF state to measure a first delay time in the first rotation direction, and control the drive circuit to drive the motor in a second rotation direction while maintaining all of the plurality of switching elements in the OFF state to measure a second delay time in the second rotation direction.
7. The motor control device according to claim 6, wherein the controller uses the first delay time and the second delay time for calculating the offset amount and the delay amount.
8. The motor control device according to claim 1, wherein the controller is configured to identify the rotation direction of the motor during an idling state based on the sensor signal and the detection result signal.
9. The motor control device according to claim 1, wherein the controller is configured to adjust a phase of a driving voltage of the motor based on the sensor signal and the detection result signal.
10. The motor control device according to claim 9, wherein the controller adjusts the phase of the driving voltage of the motor by up to an electrical angle of 60°.
11. The motor control device according to claim 1, wherein the sensor is a Hall sensor.
12. A motor driver circuit for supplying a motor with 3-phase AC power, the motor driving circuit comprising: a first high-side switch connected in series with a first low-side switch between a first power supply terminal and a second power supply terminal; a second high-side switch connected in series with a second low-side switch between the first power supply terminal and the second power supply terminal; a third high-side switch connected in series with a third low-side switch between the first power supply terminal and the second power supply terminal; a first node between the first high-side switch and the first low-side switch and connected to a first winding of a motor; a second

node between the second high-side switch and the second low-side switch and connected to a second winding of the motor; a third node between the third high-side switch and the third low-side switch and connected to a third winding of the motor; a detection circuit connected to the first and second nodes and configured to output a detection result signal indicating when a magnitude relationship between a first voltage signal at the first node and a second voltage signal at the second node switches; and a controller configured to receive the detection result signal from the detection circuit and a sensor signal from a sensor at a position between the first winding and the second winding and perform processing to identify a rotation direction of the motor during an idling state.

13. The motor driver circuit according to claim 12, wherein the detection circuit detects an induced voltage amplitude at the first node and an induced voltage amplitude at the second node.

14. The motor driver circuit according to claim 12, wherein the detection circuit detects a motor current at the first node and a motor current at the second node.

15. The motor driver circuit according to claim 12, wherein the controller is configured to: calculate an offset of the position of the sensor from the midpoint position between the first winding and the second winding based on the sensor signal and the detection result signal, and calculate a delay amount of an edge timing of the sensor signal from a proper timing based on the sensor signal and the detection result signal.

16. The motor driver circuit according to claim 12, wherein the controller is configured to: drive the motor in a first rotation direction to measure a first delay time in the first rotation direction, and drive the motor in a second rotation direction to measure a second delay time in the second rotation direction.

17. The motor driver circuit according to claim 16, wherein the controller uses the first delay time and the second delay time for calculating an offset between the position of the sensor and the actual midpoint position between the first and second windings and a delay amount of an edge timing of the sensor signal from a proper timing.

18. The motor driver circuit according to claim 12, wherein the controller is configured to adjust a phase of a driving voltage of the motor based on the sensor signal and the detection result signal.

19. The motor driver circuit according to claim 18, wherein the controller adjusts the phase of the driving voltage of the motor by up to an electrical angle of 60°.

20. The motor driver circuit according to claim 12, wherein the sensor is a Hall sensor.
