

DESCRIPTION

WASHING MACHINE

5 TECHNICAL FIELD

[0001] The present disclosure relates to a washing machine.

BACKGROUND ART

[0002] A conventional type of washing machine performs clothing quantity
10 determination which is as follows. The clothing quantity determination refers to weighing
a quantity of clothing in the washing machine. In a proposed method of washing, a water
level and rotational speed are based on the clothing quantity. For improved accuracy, the
clothing quantity determination is based on a current value obtained by accelerated rotation
15 of a washing tub at a constant acceleration and a current value obtained by decelerated
rotation of the washing tub at a constant acceleration (refer to, for example, PTL 1).

[0003] This conventional type of washing machine performs water flow review control
which is as follows. A proposed method prevents washing water in the washing tub from
splashing and involves predicting the splashing on the basis of a current in a certain initial
period following the start of agitation. A larger current predicts the splashing, so that a
20 switch to a weaker water flow is made in advance (refer to, for example, PTL 2).

Citation List

Patent Literatures

[0004] PTL 1: Unexamined Japanese Patent Publication No. 2014-54498

PTL 2: Unexamined Japanese Patent Publication No. 2006-68275

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SUMMARY OF THE INVENTION

[0005] However, this conventional washing machine, which rotates the washing tub, is
easily affected by an imbalance due to lopsided clothing and problematically expends time
in solving the imbalance. Moreover, the conventional washing machine uses position
30 sensors in rotational speed detection, thus problematically being costly and having a
structural limitation.

[0006] The present disclosure provides a washing machine that is capable of easily and
accurately detecting a clothing quantity even without position sensors.

[0007] A washing machine according to the present disclosure includes an impeller rotatable in a washing and spin-drying tub, an electric motor including a permanent magnet and a winding, a power supply circuit that supplies a current to the electric motor, and a current detection unit that detects a current in the electric motor. The washing machine
5 further includes a transmission mechanism that transmits torque of the electric motor to the impeller, a rotational speed control unit that controls the electric motor to obtain a specified rotational speed, and a control unit that performs a set of controls on the electric motor a predetermined number of times, the set of controls including at least one of acceleration control, constant-speed control, and pause control which are performed one
10 after another in sequence, the set of controls being performed alternately for clockwise rotation and counterclockwise rotation of the impeller. The control unit includes a clothing quantity detection unit that detects a quantity of laundry from an average current value in a period of the constant-speed control or a rotation angle in a period of the pause control.

[0008] The washing machine according to the present disclosure is capable of easily and
15 accurately detecting the clothing quantity even without position sensors.

[0009] For large laundry, the conventional washing machine has increased current and a weaker water flow. Therefore, time-consuming washing and unsatisfactory washing performance are problematic when the laundry is large. Moreover, the conventional washing machine uses the position sensors in a water flow review to prevent the washing
20 water from splashing, thus problematically being costly and having the structural limitation.

[0010] The present disclosure provides a washing machine that is capable of securing washing performance by controlling a normal water flow to such a degree that no water splashing occurs even without position sensors.

[0011] A washing machine according to the present disclosure includes an impeller rotatable in a washing and spin-drying tub, an electric motor including a permanent magnet and a winding, a power supply circuit that supplies a current to the electric motor, and a current detection unit that detects a current in the electric motor. The washing machine
25 further includes a transmission mechanism that transmits torque of the electric motor to the impeller, a rotational speed control unit that controls the electric motor to obtain a specified rotational speed, and a control unit that performs a set of controls on the electric motor a predetermined number of times, the set of controls including at least one of acceleration control, constant-speed control, and pause control which are performed one
30 after another in sequence, the set of controls being performed alternately for clockwise

rotation and counterclockwise rotation of the impeller. The control unit reviews a washing water flow based on a rotation angle in a period of the pause control.

[0012] The washing machine according to the present disclosure is capable of predicting washing water splashing regardless of its quantity of laundry. Moreover, this washing

5 machine secures washing performance by controlling a normal water flow to such a degree that no water splashing occurs even without position sensors and prevents the water splashing by making the water flow weaker.

BRIEF DESCRIPTION OF THE DRAWINGS

10 **[0013]** FIG. 1 is a sectional view illustrating an essential part of a washing machine according to a first exemplary embodiment.

FIG. 2 is a block diagram of a motor drive system of the washing machine according to the first exemplary embodiment.

15 FIG. 3 illustrates an equivalent circuit of a motor in the washing machine according to the first exemplary embodiment.

FIG. 4 is a control block diagram including phase estimation for the motor of the washing machine according to the first exemplary embodiment.

FIG. 5 is a detailed block diagram of a speed and phase estimation unit for the motor of the washing machine according to the first exemplary embodiment.

20 FIG. 6A is a vector diagram illustrating estimated coordinates lagging behind in the phase estimation for the motor of the washing machine according to the first exemplary embodiment.

FIG. 6B is a vector diagram illustrating estimated coordinates traveling faster in the phase estimation for the motor of the washing machine according to the first exemplary
25 embodiment.

FIG. 7 is a flowchart for clothing quantity detection control in the washing machine according to the first exemplary embodiment.

FIG. 8 is a flowchart for acceleration control in clothing quantity detection of the washing machine according to the first exemplary embodiment.

30 FIG. 9 is a flowchart for constant-speed control in the clothing quantity detection of the washing machine according to the first exemplary embodiment.

FIG. 10 is a flowchart for deceleration control in the clothing quantity detection of the washing machine according to the first exemplary embodiment.

FIG. 11 is a flowchart for determination output in the clothing quantity detection of the washing machine according to the first exemplary embodiment.

FIG. 12A illustrates a relationship between an average I_q from the determination output in the clothing quantity detection of the washing machine according to the first exemplary embodiment and a clothing quantity determination value.

FIG. 12B illustrates a relationship between a cumulative rotation angle from the determination output in the clothing quantity detection of the washing machine according to the first exemplary embodiment and the clothing quantity determination value.

FIG. 13 is a time chart that is used in detecting an I_q and a rotation angle in the clothing quantity detection of the washing machine according to the first exemplary embodiment.

FIG. 14 is a flowchart for motor speed control in the washing machine according to the first exemplary embodiment.

FIG. 15 is a flowchart for motor pause control in the washing machine according to the first exemplary embodiment.

FIG. 16 is a flowchart for motor current control in the washing machine according to the first exemplary embodiment.

FIG. 17 is a flowchart for constant-speed control in clothing quantity detection of a washing machine according to a second exemplary embodiment.

FIG. 18 is a time chart that is used in detecting an I_q in the clothing quantity detection of the washing machine according to the second exemplary embodiment.

FIG. 19 is a flowchart for water flow review control in a washing machine according to a third exemplary embodiment.

FIG. 20 is a flowchart for acceleration control in a water flow review of the washing machine according to the third exemplary embodiment.

FIG. 21 is a flowchart for constant-speed control in the water flow review of the washing machine according to the third exemplary embodiment.

FIG. 22 is a flowchart for deceleration control in the water flow review of the washing machine according to the third exemplary embodiment.

FIG. 23 illustrates a relationship between a cumulative rotation angle from determination output in the water flow review control of the washing machine according to the third exemplary embodiment and a water flow to be determined in the water flow review control.

FIG. 24 is a time chart that is used in detecting a rotation angle in the water flow review control of the washing machine according to the third exemplary embodiment.

FIG. 25 is a flowchart for motor speed control in the washing machine according to the third exemplary embodiment.

5 FIG. 26 is a flowchart for motor pause control in the washing machine according to the third exemplary embodiment.

FIG. 27 is a flowchart for motor current control in the washing machine according to the third exemplary embodiment.

10 DESCRIPTION OF EMBODIMENTS

[0014] With reference to the drawings, a description is hereinafter provided of exemplary embodiments according to the present disclosure. These exemplary embodiments are not restrictive of the present disclosure.

[0015] FIRST EXEMPLARY EMBODIMENT

15 FIG. 1 is a sectional view illustrating an essential part of a washing machine according to the first exemplary embodiment.

[0016] Washing and spin-drying tub 2 is capable of spin-drying rotation inside water receiving tub 3 and has, at its bottom, pulsator 1 that is capable of clockwise and counterclockwise rotations for agitating laundry. Motor 4 is secured externally to a bottom of water receiving tub 3, and its rotation serves to rotate or brake pulsator 1 or washing and spin-drying tub 2 via motor pulley 31, belt 5, impeller pulley 32, and speed reducer and clutch 6.

[0017] There is a reduction ratio (of, for example, 1/4) between motor pulley 31 and impeller pulley 32. For four revolutions of motor pulley 31, which is attached to a motor shaft (not illustrated) of motor 4, impeller pulley 32 (or washing and spin-drying tub 2) that is attached to an impeller shaft (not illustrated) of speed reducer and clutch 6 turns one revolution.

[0018] Similarly, between impeller pulley 32 and pulsator 1, speed reducer and clutch 6 has a reduction ratio (of, for example, 1/6). For six revolutions of impeller pulley 32, which is attached to the impeller shaft, pulsator 1, which is attached to a pulsator shaft (not illustrated), turns one revolution.

[0019] Braking methods include a control method that causes application of counter torque to motor 4 and a method of actuating geared motor 7 for mechanically braking washing and spin-drying tub 2 with brake belt 8 in contact with a rotating part. Panel

portion 10 is above outer frame 9 of the washing machine and includes openable and closable lid 11 at its top face and control device 13 internal to its front. Control device 13 performs overall control of steps of the washing machine and includes display unit 12.

[0020] Control device 13 includes control unit 20. Control unit 20 includes a

5 microcomputer that controls operations of motor 4, water supply valve 14, drain valve 15, and others and performs sequential control of a series of steps including washing, rinsing, and spin-drying, among others. Using display unit 12 that includes light-emitting diodes (LEDs), a liquid-crystal display (LCD), or any other light-emitting device, control unit 20 informs a user of progress being made in the step and other various pieces of information
10 that are based on information from an input setting unit the user operates in setting a desired washing course, starting operation or pausing the operation. When an washing operation is started with the input setting unit, the operations of geared motor 7, water supply valve 14, and drain valve 15 are controlled on the basis of data from a water level detection unit and others.

15 **[0021]** FIG. 2 is a block diagram of a motor drive system of the washing machine according to the first exemplary embodiment.

[0022] An alternating-current power supply supplies alternating-current power to rectifier circuit 16. Rectifier circuit 16 is a voltage doubler rectifier circuit that supplies a doubled direct-current voltage to inverter circuit 17. Inverter circuit 17 is a three-phase full-bridge
20 inverter circuit that includes six power switching semiconductor devices and antiparallel diodes. Inverter circuit 17 is normally an Intelligent Power Module (hereinafter referred to as IPM) that includes insulated-gate bipolar transistors (IGBTs), antiparallel diodes, an internal drive circuit, and an internal protection circuit. Inverter circuit 17 has output terminals connected to motor 4 for driving motor 4.

25 **[0023]** A shunt resistor is connected between a negative voltage terminal of inverter circuit 17 and a negative voltage terminal of rectifier circuit 16. Current detection unit 18 detects each of phase currents I_u , I_v , and I_w of motor 4 on the basis of a current that is input to inverter circuit 17 and is calculated from a voltage across the shunt resistor. Since the direct-current voltage that is applied to inverter circuit 17 can result from
30 superimposition on the input from the alternating-current power supply due to regenerative energy that is produced from motor rotation, phase currents I_u , I_v , and I_w are detected at all times.

[0024] Pulse width modulation (PWM) control unit 19 controls PWM signals that switch the IGBTs of inverter circuit 17 in accordance with three-phase motor drive control

command voltages V_{us} , V_{vs} , and V_{ws} from control unit 20. With voltages V_u , V_v , and V_w that are output from the inverter circuit, motor 4 is driven.

[0025] FIG. 3 illustrates an equivalent circuit of the motor in the washing machine according to the first exemplary embodiment.

5 **[0026]** For simplicity, a description is provided here of a two-pole configuration in which a mechanical angle equivalent to one revolution corresponds to an electrical angle equivalent to one revolution. When poles are four in number, the mechanical angle equivalent to one revolution corresponds to an electrical angle equivalent to two revolutions. When the number of poles changes to eight, the mechanical angle equivalent to one revolution corresponds to an electrical angle equivalent to four revolutions. Motor 4 is a three-phase synchronous motor and is configured as the equivalent circuit that includes three U-phase, V-phase, and W-phase windings 4a, 4b, and 4c and permanent magnet 4d that rotates as a rotor about an axis of rotation. In the equivalent circuit, an axis that runs through a north-pole side of the permanent magnet in a positive direction is defined as a
10 direct axis (d axis), and an axis orthogonal to the d axis is defined as a quadrature axis (q axis). With these axes defined thus, it is a magnetic field along the q axis that mainly rules torque of the motor. Phase (electrical angle) serves as rotation angle θ between an axis that runs through the U-phase winding and the d axis. All phases described below refer to electrical angles. When a voltage is applied to produce a magnetic field along the d axis, winding inductance is represented as L_d , and inductance along the q axis is represented as L_q .
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[0027] A three-phase synchronous motor with an embedded magnet has the relation $L_d < L_q$. Since control unit 20, which will be described later, cannot not accurately detect rotor position at first, control unit 20 assumes that the phase is θ_c , so that there is deviation $\Delta\theta$
25 from actual phase θ , as illustrated in FIG. 3. In other words, axes that the microcomputer controls on the basis of assumed phase θ_c are a γ axis (assumed d axis) and a δ axis (assumed q axis), as opposed to the actual d and q axes of the motor. A current component corresponding to torque in the microcomputer is hereinafter represented as δ -axis current I_δ . A current component corresponding to a magnetic flux in the microcomputer is hereinafter represented as γ -axis current I_γ . A voltage component corresponding to the torque in the microcomputer is hereinafter represented as δ -axis command voltage V_δ . A voltage component corresponding to the magnetic flux in the microcomputer is hereinafter represented as γ -axis command voltage V_γ .
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[0028] FIG. 4 is a control block diagram including phase estimation for the motor of the washing machine according to the first exemplary embodiment.

[0029] Control unit 20 includes the microcomputer, an inverter control timer (timer) included in the microcomputer, an analog-to-digital converter, a memory circuit, speed and phase estimation unit 21, three-phase to two-phase converter 22, I δ error amplifier 23, I γ error amplifier 24, two-phase to three-phase converter 25, speed error amplifier 26, and weaker field setting unit 27, among others. Control unit 20 performs inverter control which is as follows.

[0030] A detailed description of speed and phase estimation unit 21 will be provided later. Speed and phase estimation unit 21 receives δ -axis current I δ , γ -axis current I γ , and γ -axis command voltage V γ s and outputs speed (electrical angular velocity) ω and estimated phase θ . All speeds described below refer to electrical angular velocities.

[0031] Using Formula 1, three-phase to two-phase converter 22 calculates γ -axis current I γ and δ -axis current I δ from electrical angle θ , phase currents I u , I v , and I w , and sine wave data (sin and cos data) necessary for transformation from a stationary reference frame into a rotating reference frame.

[0032] Formula 1

$$\begin{bmatrix} I_{\gamma} \\ I_{\delta} \end{bmatrix} = \sqrt{\frac{2}{3}} \times \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2}{3}\pi\right) & \cos\left(\theta - \frac{4}{3}\pi\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2}{3}\pi\right) & -\sin\left(\theta - \frac{4}{3}\pi\right) \end{bmatrix} \times \begin{bmatrix} I_u \\ I_v \\ I_w \end{bmatrix}$$

[0033] I δ error amplifier 23 receives deviation ΔI_{δ} between δ -axis command current I δ s determined by speed error amplifier 26 and δ -axis current I δ determined by three-phase to two-phase converter 22 and outputs δ -axis command voltage V δ s as a result of summation of a proportional component and an integral component.

[0034] Similarly, I γ error amplifier 24 receives deviation ΔI_{γ} between γ -axis command current I γ s determined by weaker field setting unit 27 and γ -axis current I γ determined by three-phase to two-phase converter 22 and outputs γ -axis command voltage V γ s as a result of summation of a proportional component and an integral component.

[0035] Since decomposition into δ -axis current I δ and γ -axis current I γ is performed for separate controls, this is called vector control.

[0036] Using Formula 2, two-phase to three-phase converter 25 calculates three phase voltages V_{us} , V_{vs} , and V_{ws} , which are sinusoidal commands, from phase θ , δ -axis command voltage $V_{\delta s}$, γ -axis command voltage $V_{\gamma s}$, and sine wave data (sin and cos data) necessary for inverse transformation from the rotating reference frame to the stationary reference frame.

[0037] Formula 2

$$\begin{bmatrix} V_{us} \\ V_{vs} \\ V_{ws} \end{bmatrix} = \sqrt{\frac{2}{3}} \times \begin{bmatrix} \cos\theta & -\sin\theta \\ \cos\left(\theta - \frac{2}{3}\pi\right) & -\sin\left(\theta - \frac{2}{3}\pi\right) \\ \cos\left(\theta - \frac{4}{3}\pi\right) & -\sin\left(\theta - \frac{4}{3}\pi\right) \end{bmatrix} \times \begin{bmatrix} V_{\gamma s} \\ V_{\delta s} \end{bmatrix}$$

[0038] Speed error amplifier 26 receives deviation $\Delta\omega$ between command speed ω_s and speed ω calculated by speed and phase estimation unit 21 and outputs δ -axis command current $I_{\delta s}$ as a result of summation of a proportional component and an integral component.

[0039] From speed ω calculated by speed and phase estimation unit 21 and direct-current voltage V_{dc} input to the inverter circuit, weaker field setting unit 27 calculates γ -axis command current $I_{\gamma s}$ in a negative direction for flux weakening control.

[0040] FIG. 5 is a detailed block diagram of the speed and phase estimation unit for the motor of the washing machine according to the first exemplary embodiment.

[0041] Estimated phase θ is calculated, using parameters of motor 4, namely, resistance value R_a and inductance value L of winding 4a, 4b, or 4c.

[0042] Speed and phase estimation unit 21 includes γ -axis induced voltage calculator 28 and γ -axis induced voltage error amplifier 29.

[0043] Using Formula 3, γ -axis induced voltage calculator 28 calculates γ -axis induced voltage $V_{e\gamma}$ from inductance value L , resistance value R_a , δ -axis current I_{δ} , γ -axis current I_{γ} , γ -axis command voltage $V_{\gamma s}$, and estimated speed ω .

[0044] Formula 3

$$V_{e\gamma} = V_{\gamma s} - (R_a \times I_{\gamma} - \omega \times L \times I_{\delta})$$

[0045] With γ -axis command induced voltage $V_{e\gamma s} = 0$, deviation $\Delta V_{e\gamma}$ from γ -axis command induced voltage $V_{e\gamma s}$ is input to γ -axis induced voltage error amplifier 29.

[0046] γ -axis induced voltage error amplifier 29 outputs estimated speed ω calculated from integral gain $K\omega$. γ -axis induced voltage error amplifier 29 adds estimated speed ω to a value calculated from proportional gain $K\theta$, has an integrator perform time integration, and outputs estimated phase θ .

- 5 **[0047]** It is to be noted, however, that γ -axis induced voltage calculator 28 is not necessarily limited to the use of Formula 3 and may make a calculation using Formula 4 that includes a time differential term.

[0048] Formula 4

$$V_{e\gamma} = V_{\gamma s} - (R_a \times I_{\gamma} + L \times (dI_{\gamma}/dt) - \omega \times L \times I_{\delta})$$

- 10 **[0049]** For inductance L in each of the above formulas, when motor 4 has the characteristic $L_d = L_q$, the same L value is usable. Even when motor 4 has $L_d \neq L_q$, a constant L value ($= L_q$) is usable in the calculation.

- [0050]** FIG. 6A is a vector diagram illustrating estimated coordinates (γ , δ coordinates, that is to say, estimated d , q coordinates) lagging slightly behind (d , q coordinates of motor 4) in the phase estimation for the motor of the washing machine according to the first exemplary embodiment. FIG. 6B is a vector diagram illustrating estimated coordinates (γ , δ coordinates, that is to say, estimated d , q coordinates) traveling slightly faster (than d , q coordinates of motor 4) in the phase estimation for the motor of the washing machine according to the first exemplary embodiment.

- 20 **[0051]** In the vector diagram, γ -axis induced voltage deviation $\Delta V_{e\gamma}$ is a γ -axis component of estimated induced voltage vector $V_e (= \omega \times \Psi_a)$ obtained by subtracting a current drop in R_a and a current drop in ωL from input voltage V_a for motor 4. Since induced voltage vector V_e is always on the q axis, the q axis coincides with the δ axis when estimated phase deviation $\Delta\theta$ (which is positive when the γ , δ coordinates are in a counterclockwise position with respect to the d , q coordinates) is 0. In FIG. 6A, estimated phase deviation $\Delta\theta$ is negative ($\Delta\theta < 0$). In FIG. 6B, estimated phase deviation $\Delta\theta$ is positive ($\Delta\theta > 0$).

- [0052]** In the case of FIG. 6A, γ -axis induced voltage error amplifier 29 increases estimated speed ω and advances θ . In the case of FIG. 6B, γ -axis induced voltage error amplifier 29 decreases estimated speed ω and delays θ . Feedback control is performed thus to bring both γ -axis induced voltage deviation $\Delta V_{e\gamma}$ and estimated phase deviation $\Delta\theta$ to 0. Since the phase estimation is based on the assumption that the motor rotation has

induced voltage V_e , the phase estimation is not systematically stable in a lower speed range that has lower induced voltage as in start-up or a pause. In the lower speed range, open-loop control that does not involve the phase estimation is used.

[0053] With reference to FIGS. 7 to 16 and Tables 1 to 3, a description is provided of clothing quantity detection control in the above configuration of the washing machine according to the first exemplary embodiment.

[0054] FIG. 7 is a flowchart for the clothing quantity detection control in the washing machine according to the first exemplary embodiment.

[0055] At step S100, the clothing quantity detection control starts. At step S101, reverse count n is cleared to 0. At step S102, command rotational speed ω_s for motor 4 is cleared to 0. At step S103, a shift is made to an acceleration control routine (described in detail later) in clothing quantity detection. At step S104, a shift is made to a constant-speed control routine (described in detail later) in the clothing quantity detection. At step S105, a shift is made to a deceleration control routine (described in detail later) in the clothing quantity detection.

[0056] At step S106, reverse count n is incremented by 1. At step S107, a determination is made whether reverse count n is larger than preset count n_s (e.g., 4) for the determination. If reverse count n is larger (YES), a shift is made to step S108. If reverse count n is smaller or equal (NO), a shift is made to step S109. At step S108, a shift is made to a determination output routine (described in detail later) in the clothing quantity detection. At step S109, the rotation is changed from clockwise (CW) to counterclockwise (CCW) or vice versa. Step S110 serves as a transition from "A" in other routines. At step S111, a maximum clothing quantity determination value (indicating, for example, 10 kg) is output. At step S112, the clothing quantity detection control ends.

[0057] FIG. 8 is a flowchart for acceleration control in the clothing quantity detection of the washing machine according to the first exemplary embodiment.

[0058] At step S200, the acceleration control in the clothing quantity detection starts. At step S201, motor acceleration α (e.g., 3000 (r/min)/s) is called. At step S202, command rotational speed ω_s for motor 4 is incremented in accordance with motor acceleration α .

At step S203, a shift is made to a motor speed control routine (described in detail later). At step S204, a determination is made whether command rotational speed ω_s for motor 4 is higher than or equal to maximum command rotational speed $\omega_{\max}$ (e.g., 2160 r/min) for motor 4. If command rotational speed ω_s is higher or equal (YES), a shift is made to step

S205. If command rotational speed ω_s is lower (NO), a shift is made to step S201. At step S205, the acceleration control in the clothing quantity detection ends.

[0059] FIG. 9 is a flowchart for constant-speed control in the clothing quantity detection of the washing machine according to the first exemplary embodiment.

[0060] At step S300, the constant-speed control in the clothing quantity detection starts. At step S301, ON term timer T_{ontm} is cleared to 0.

[0061] At step S302, a determination is made whether reverse count n is 0. If reverse count n is 0 (YES), a shift is made to step S303. If reverse count n is not 0 (NO), a shift is made to step S305. At step S303, cumulative I_q $I_{q_integral}$ is cleared to 0. At step S304, cumulation count $integral_n$ is cleared to 0. At step S305, a shift is made to the motor speed control routine (described in detail later). At step S306, a time (e.g., 1 ms) taken for processing the motor speed control is added to ON term timer T_{ontm} .

[0062] At step S307, a determination is made whether a value of ON term timer T_{ontm} is smaller than cumulation delay T_{delay} (e.g., 0.3 s). If the value is smaller (YES), a shift is made to step S310. If the value is larger or equal (NO), a shift is made to step S308. At step S308, an I_q is added to cumulative I_q $I_{q_integral}$. At step S309, cumulation count $integral_n$ is incremented by 1. At step S310, a determination is made whether the value of ON term timer T_{ontm} is larger than ON term T_{on} . If the value is larger (YES), a shift is made to step S311. If the value is smaller or equal (NO), a shift is made to step S305. At step S311, the constant-speed control in the clothing quantity detection ends.

[0063] FIG. 10 is a flowchart for deceleration control in the clothing quantity detection of the washing machine according to the first exemplary embodiment.

[0064] At step S400, the deceleration control in the clothing quantity detection starts. At step S401, a determination is made whether reverse count n is 0. If reverse count n is 0 (YES), a shift is made to step S402. If reverse count n is not 0 (NO), a shift is made to step S404.

[0065] At step S402, OFF term timer T_{offtm} is cleared to 0. At step S403, cumulative rotation angle $\theta_integral$ is cleared to 0. At step S404, a shift is made to a pause control routine (described in detail later) for the motor speed. At step S405, a determination is made whether motor rotation angle θ (where the term “angle” hereinafter refers to the motor’s electrical angle) is smaller than angle threshold θ_limit . If angle threshold θ_limit is larger (YES), a shift is made to step S406. If motor rotation angle θ is larger or equal (NO), a shift is made to step S407. At step S406, a time (e.g., 1 ms) taken for processing

the motor pause control is added to OFF term timer T_offtm. At step S407, a shift is made to "A" (refer to FIG. 7).

[0066] At step S408, a determination is made whether motor rotational speed ω is lower than minimum rotational speed $\omega_{\min}$ (e.g., 100 r/min) to be detected. If motor rotational speed ω is lower (YES), a shift is made to step S410. If motor rotational speed ω is higher or equal (NO), a shift is made to step S409. At step S409, motor rotation angle θ is added to cumulative rotation angle θ_{integral} . At step S410, a determination is made whether a value of OFF term timer T_offtm is larger than OFF term T_off. If the value is larger (YES), a shift is made to step S411. If the value is smaller or equal (NO), a shift is made to step S404. At step S411, the deceleration control in the clothing quantity detection ends.

[0067] FIG. 11 is a flowchart for determination output in the clothing quantity detection of the washing machine according to the first exemplary embodiment.

[0068] At step S500, the determination output in the clothing quantity detection starts. At step S501, an average I_q is calculated using Formula 5.

[0069] Formula 5

$$I_{q_average} = \frac{I_{q_integral}}{\text{integral_n}}$$

[0070] At step S502, a determination value is output. A detailed description of determination methods is provided with reference to FIGS. 12A and 12B, and Tables 1 to 3. At step S503, the determination output in the clothing quantity detection ends.

[0071] FIG. 12A illustrates a relationship between the average I_q from the determination output in the clothing quantity detection of the washing machine according to the first exemplary embodiment and the clothing quantity determination value. FIG. 12B illustrates a relationship between the cumulative rotation angle from the determination output in the clothing quantity detection of the washing machine according to the first exemplary embodiment and the clothing quantity determination value. Points in each of FIGS. 12A and 12B are evaluation values (in terms of average I_q or cumulative rotation angle) corresponding respectively to clothing quantities (e.g., 2 kg, 4 kg, 6 kg, 8 kg, and 10 kg), and a dashed line is an approximate line connecting these points. As double arrowed lines indicate, thresholds to be used in determining clothing quantity determination values (respectively indicating, for example, 0 to 3 kg, 3 to 5 kg, 5 to 7 kg, 7 to 9 kg, and 9 kg or more) are determined from the evaluation values. For each of the clothing quantities,

evaluation is performed multiple times so that the threshold setting takes into consideration variations in the evaluation value.

[0072] Table 1 shows the clothing quantity determination values that are each determined from the average Iq from the determination output in the clothing quantity detection of the washing machine according to the first exemplary embodiment. Table 2 shows the clothing quantity determination values that are each determined from the cumulative rotation angle from the determination output in the clothing quantity detection of the washing machine according to the first exemplary embodiment. Table 3 shows the clothing quantity determination values that are each determined from the average Iq and the cumulative rotation angle from the determination output in the clothing quantity detection of the washing machine according to the first exemplary embodiment.

[0073] Table 1

Average Iq	Clothing Quantity Determination Value
below 0.2 A	0 to 3 kg
0.2 to 0.5 A	3 to 5 kg
0.5 to 0.9 A	5 to 7 kg
0.9 to 1.4 A	7 to 9 kg
at least 1.4 A	at least 9 kg

[0074] Table 2

Cumulative Rotation Angle	Clothing Quantity Determination Value
at least 112 revs	0 to 3 kg
64 to 112 revs	3 to 5 kg
40 to 64 revs	5 to 7 kg
24 to 40 revs	7 to 9 kg
below 24 revs	at least 9 kg

[0075] Table 3

Average Iq	Cumulative Rotation Angle	Clothing Quantity Determination Value
below 0.5 A	at least 112 revs	0 to 3 kg
	less than 112 revs	3 to 5 kg
0.5 to 0.9 A		5 to 7 kg
0.9 to 1.4 A		7 to 9 kg
at least 1.4 A		at least 9 kg

[0076] As in FIG. 12A, the average Iq is approximately proportional to the clothing quantity determination value. Therefore, the threshold setting is possible in terms of average Iq even for larger clothing quantities. Consequently, the average Iq enables the setting of, for example, the clothing quantity determination values in Table 1.

5 **[0077]** On the other hand, the cumulative rotation angle is nearly in inverse proportion to the clothing quantity determination value as in FIG. 12B. Therefore, for larger clothing quantities, there are narrower variations in the cumulative rotation angle with the thresholds closer together; however, for smaller clothing quantities, there are wider variations in the cumulative rotation angle that facilitate the threshold setting. For that
10 reason, cumulative rotation angle θ_{integral} tends to be better in determining the smaller clothing quantities. The cumulative rotation angle enables the setting of, for example, the clothing quantity determination values in Table 2.

[0078] Table 3 takes advantage of these features. The larger clothing quantity is determined from the average Iq and the smaller clothing quantity is determined from the
15 cumulative rotation angle. In other words, when the average Iq is less than 0.5 A, the clothing quantity determination value indicative of 0 to 3 kg or 3 to 5 kg is determined depending on whether the cumulative rotation angle is at least 112 revs or less than 112 revs. When the average Iq is more than or equal to 0.5 A, the clothing quantity determination value indicative of 5 to 7 kg, 7 to 9 kg, or 9 kg or more is determined
20 depending on whether the average Iq is less than 0.9 A, at least 0.9 A, or at least 1.4 A.

[0079] When the determination output to be performed in the clothing quantity detection is based on Table 1 or 2, the clothing quantity can be easily detected only with a single evaluation value. When, on the other hand, the determination output to be performed in the clothing quantity detection is based on Table 3, the clothing quantity can be accurately
25 detected, taking advantage of the features of evaluation values.

[0080] FIG. 13 is a time chart that is used in detecting the Iq and the rotation angle in the clothing quantity detection of the washing machine according to the first exemplary embodiment.

[0081] Part (a) of FIG. 13 illustrates how the command rotational speed (shown as a dotted line) and the actual rotational speed (shown as a solid line) change over time. Part
30 (b) of FIG. 13 illustrates how the Iq (shown as a solid line) changes over time. There is an ON term that includes a period of the acceleration control and a period of the constant-speed control, and an OFF term that is a period of the deceleration control.

[0082] As illustrated in part (b) of FIG. 13, the I_q cumulation starts after elapse of the cumulation delay in the constant-speed control and ends when the constant-speed control terminates (refer to a shadow area). The average I_q to be used for the determination in the clothing quantity detection is calculated from cumulative $I_{q_integral}$. Since the I_q easily fluctuates due to changes in the rotational speed, the I_q is measured after the cumulation delay here for restrained fluctuation, thus also restraining fluctuation of the average I_q .

[0083] As illustrated in part (a) of FIG. 13, the rotation angle cumulation is performed in the deceleration control until the minimum rotational speed to be detected is reached (refer to a shadow area). Since rotation angles during lower speed rotation where the rotational speed detection is not easy are excluded, the minimum rotational speed to be detected serves as a limit of the rotation angle cumulation to make the cumulative rotation angle more accurate.

[0084] In the drawing, the determination is made after the agitation takes only a single round in one of the directions; however, the average I_q and the cumulative rotation angle are more accurate after an even number of (e.g., four) I_q and rotation angle cumulations through changes in the rotation direction because of a reduced effect of the rotation direction.

[0085] FIG. 14 is a flowchart for the motor speed control in the washing machine according to the first exemplary embodiment.

[0086] At step S600, the motor speed control starts. At step S601, a determination is made whether motor rotational speed ω is higher than command rotational speed ω_s for motor 4. If motor rotational speed ω is higher (YES), a shift is made to step S602. If motor rotational speed ω is lower or equal (NO), a shift is made to step S603. At step S602, δ -axis command current $I_{\delta s}$ is reduced. At step S603, δ -axis command current $I_{\delta s}$ is increased. Speed error amplifier 26 that performs steps S601 to 603 normally performs proportional-integral control that includes an integral element such as averaging when setting δ -axis command current $I_{\delta s}$, because a variable element is significant enough to cause unstable control.

[0087] At step S604, current control timer T_{e_tm} is cleared to 0. At step S605, a shift is made to a current control routine (described in detail later). At step S606, a time (e.g., 0.1 ms) taken for processing the current control is added to current control timer T_{e_tm} . At step S607, a determination is made whether a value of current control timer T_{e_tm} is larger than current control period T_{e_cycle} . If the value is larger (YES), a shift is made to step

S608. If the value is smaller or equal (NO), a shift is made to step S605. At step S608, the motor speed control ends.

[0088] FIG. 15 is a flowchart for the motor pause control in the washing machine according to the first exemplary embodiment. At step S700, the motor pause control starts. At step S701, 0 or a fixed value is substituted for δ -axis command current $I_{\delta s}$. There is a method of using 0 as δ -axis command current $I_{\delta s}$ to cause no torque. There is also a method of using a negative fixed value as δ -axis command current $I_{\delta s}$ to cause brake torque to such a degree that regenerative voltage is not problematic for achieving a shorter braking time period, and a method of using a slightly positive fixed value as δ -axis command current $I_{\delta s}$ to widen a cumulative rotation angle variation with slight driving torque that more reliably effects a pause than, for example, frictional force that acts to decelerate the rotation for facilitating the determination in the clothing quantity detection. An easy-to-use method to be selected depends on the clothing quantity or how the washing machine is configured.

[0089] Thereafter, steps that are the same as steps S604 to S608 of the motor speed control in FIG. 14 are performed. At step S702, current control timer T_{e_tm} is cleared to 0. At step S703, a shift is made to the current control routine (described in detail later). At step S704, a time (e.g., 0.1 ms) taken for processing the current control is added to current control timer T_{e_tm} . At step S705, a determination is made whether a value of current control timer T_{e_tm} is larger than current control period T_{e_cycle} . If the value is larger (YES), a shift is made to step S706. If the value is smaller or equal (NO), a shift is made to step S703. At step S706, the motor pause control ends.

[0090] FIG. 16 is a flowchart for motor current control in the washing machine according to the first exemplary embodiment.

[0091] At step S800, the motor current control starts. At step S801, current detection unit 18 detects phase currents I_u , I_v , and I_w . At step S802, a determination is made whether any one of phase currents I_u , I_v , and I_w is smaller than phase current threshold I_limit . If phase current I_u , I_v , or I_w is smaller (YES), a shift is made to step S803. If phase current I_u , I_v , or I_w is larger or equal (NO), a shift is made to step S804.

[0092] At step S803, three-phase to two-phase converter 22 calculates δ -axis current I_{δ} , using Formula 1. At step S804, a shift is made to "A" (refer to FIG. 7). At step S805, a determination is made whether δ -axis current I_{δ} is larger than δ -axis command current $I_{\delta s}$. If δ -axis current I_{δ} is larger (YES), a shift is made to step S806. If δ -axis current I_{δ} is

smaller or equal (NO), a shift is made to step S807. At step S806, δ -axis command voltage $V_{\delta s}$ is reduced. At step S807, δ -axis command voltage $V_{\delta s}$ is increased.

[0093] I_{δ} error amplifier 23 that performs steps S805 to S807 normally performs proportional-integral control that includes an integral element such as averaging when

5 setting δ -axis command voltage $V_{\delta s}$, because a variable element is significant enough to cause unstable control.

[0094] Thereafter, as in the case of the δ axis, the voltage calculation involving steps S808 to S811 is performed for the γ -axis. At step S808, three-phase to two-phase converter 22 calculates γ -axis current I_{γ} , using Formula 1. At step S809, a determination is

10 made whether γ -axis current I_{γ} is larger than γ -axis command current $I_{\gamma s}$. If γ -axis current I_{γ} is larger (YES), a shift is made to step S810. If γ -axis current I_{γ} is smaller or equal (NO), a shift is made to step S811. At step S810, γ -axis command voltage $V_{\gamma s}$ is reduced.

At step S811, γ -axis command voltage $V_{\gamma s}$ is increased. I_{γ} error amplifier 24 that performs steps S809 to S811 normally performs proportional-integral control that includes an

15 integral element such as averaging when setting γ -axis command voltage $V_{\gamma s}$, because a variable element is significant enough to cause unstable control.

[0095] At step S812, two-phase to three-phase converter 25 calculates application voltages V_{us} , V_{vs} , and V_{ws} , using Formula 2. At step S813, the voltage application to motor 4 is effected via PWM control unit 19 and inverter circuit 17. At step S814, the

20 motor current control ends.

[0096] SECOND EXEMPLARY EMBODIMENT

Although a washing machine according to the second exemplary embodiment has the same configuration as that of the first exemplary embodiment, its clothing quantity detection control includes a different control detail and is described with reference to

25 FIGS. 17 and 18. A change is made to the I_q cumulation condition (step S307 of FIG. 9) in the constant-speed control of the clothing quantity detection according to the first exemplary embodiment.

[0097] FIG. 17 is a flowchart for constant-speed control in clothing quantity detection of the washing machine according to the second exemplary embodiment. Step S307 of FIG.

30 9 changes to step S307a.

[0098] At step S307a, which is different, a determination is made whether a difference between motor rotational speed ω and command rotational speed ω_s for motor 4 has settled completely to be smaller than convergence speed $\omega_converge$ (e.g., 10 r/min). If the

difference is greater or has not settled completely (NO), a shift is made to step S310. If the difference has settled completely to be smaller (YES), a shift is made to step S308.

[0099] FIG. 18 is a time chart that is used in detecting an Iq in the clothing quantity detection of the washing machine according to the second exemplary embodiment.

5 **[0100]** Part (a) of FIG. 18 illustrates how the command rotational speed (shown as a dotted line) and the actual rotational speed (shown as a solid line) change over time. Part (b) of FIG. 18 illustrates how the Iq (shown as a solid line) changes over time. There is an ON term that includes a period of acceleration control and a period of the constant-speed control, and an OFF term that is a period of deceleration control.

10 **[0101]** As illustrated in part (a) of FIG. 18, the constant-speed control has a threshold range (refer to a shadow area) between the command rotational speed + the convergence speed and the command rotational speed - the convergence speed. The complete settlement is determined by determining whether an inflection point of the actual rotational speed has settled in the threshold range. Five left-side inflection points (x) of the actual
15 rotational speed are not in the threshold range; however, the sixth inflection point (o) is in the threshold range, so that this is where Iq measurement and Iq cumulation start.

[0102] Because of the settlement in the threshold range, the rotational speed shows less fluctuation. Since the Iq is measured while the rotational speed shows less fluctuation, the Iq also shows less fluctuation, and average Iq fluctuation is restrained.

20 **[0103]** The second exemplary embodiment is otherwise similar to the first exemplary embodiment.

[0104] Effects and others

As described above, a washing machine according to the first exemplary embodiment and a washing machine according to the second exemplary embodiment each
25 include an impeller rotatable in a washing and spin-drying tub, an electric motor including a permanent magnet and a winding, a power supply circuit that supplies a current to the electric motor, and a current detection unit that detects a current in the electric motor. Each of these washing machines further includes a transmission mechanism that transmits torque of the electric motor to the impeller, a rotational speed control unit that controls the
30 electric motor to obtain a specified rotational speed, and a control unit that performs a set of controls on the electric motor a predetermined number of times, the set of controls including at least one of acceleration control, constant-speed control, and pause control which are performed one after another in sequence, the set of controls being performed alternately for clockwise rotation and counterclockwise rotation of the impeller. The

control unit includes a clothing quantity detection unit that detects a quantity of laundry from an average current value in a period of the constant-speed control or a rotation angle in a period of the pause control.

[0105] Since either the average current value in the constant-speed control period or the rotation angle in the pause control period is measured in this configuration, the clothing quantity is easily detectable.

[0106] The clothing quantity detection unit may detect a quantity of laundry from both an average current value in a period of the constant-speed control and a rotation angle in a period of the pause control.

[0107] With this configuration, smaller clothing quantities are detectable from the rotation angle that varies greatly, and larger clothing quantities are detectable from the average current value that varies the same way for the larger clothing quantities and the smaller clothing quantities. Therefore, the clothing quantity is accurately detectable.

[0108] The clothing quantity detection unit may detect a quantity of laundry from an average current value between elapse of a predetermined time period that follows a shift to a period of the constant-speed control and termination of the period of the constant-speed control.

[0109] This configuration enables restrained fluctuation of the average current value after each measurement, thus enabling the clothing quantity detection to be easy and accurate.

[0110] The clothing quantity detection unit may detect a quantity of laundry from an average current value between elapse of a predetermined time period that follows complete settlement of a difference between a target rotational speed and an actual rotational speed in a predetermined value range in a period of the constant-speed control and termination of the period of the constant-speed control.

[0111] This configuration enables the calculation of the average current value after the fluctuation of the rotational speed that causes the fluctuation of the average current value after each measurement is restrained. Therefore, the clothing quantity detection is enabled to be accurate.

[0112] The clothing quantity detection unit may detect a quantity of laundry from a rotation angle while torque is set at zero or a constant value in a period of the pause control.

[0113] In this configuration, the constant torque is sustained in the pause control period and thus enables fluctuation of the rotation angle due to torque fluctuation to be restrained. Therefore, the clothing quantity detection is enabled to be easy and accurate. Moreover,

sensorless detection of the rotation angle is enabled by inertia rotation in which PWM output is not brought to a complete stop.

[0114] A quantity of laundry may be detected from a rotation angle from when a period of the pause control starts until an actual rotational speed reaches a specified rotational speed.

[0115] In this configuration, rotation angle cumulation is performed only in a higher speed rotation range that enables the rotational speed detection to be accurate. Therefore, the clothing quantity detection is enabled to be accurate.

[0116] The control unit may terminate clothing quantity detection and determine that a quantity of laundry is maximum when a current in the electric motor is larger than or equal to a predetermined value or when a rotation angle is smaller than a predetermined value.

[0117] This configuration enables the determination of the larger or largest clothing quantity with no need to perform the entire clothing quantity detection sequence and thus enables a time- and energy-saving clothing quantity detection sequence.

[0118] OTHER EXEMPLARY EMBODIMENTS

Each of the first and second exemplary embodiments has been described above as being illustrative of the technique of the present disclosure. However, the above techniques are not restrictive of the present disclosure.

[0119] Exemplary embodiments below are given as other illustrations.

[0120] The washing machine used as an example in the description of each of the first and second exemplary embodiments is the top-loading type that uses speed reducer and clutch 6 for connection to pulsator 1 or washing and spin-drying tub 2, with motor pulley 31 and impeller pulley 32 connected by belt 5; however, even with a direct drive washing machine that has a washing and spin-drying tub coaxial with a motor, a clothing quantity is easily and accurately detectable.

[0121] The washing machine used as the example in the description of each of the first and second exemplary embodiments is the top-loading type that uses the pulsator; however, even with a top-loading washing machine that uses an agitator, a clothing quantity is easily and accurately detectable.

[0122] THIRD EXEMPLARY EMBODIMENT

A description is hereinafter provided of water flow review control in a washing machine according to the third exemplary embodiment.

[0123] The washing machine according to the third exemplary embodiment has the same configuration as the washing machine according to the first exemplary embodiment that is

illustrated in FIGS. 1 to 6B and thus has the same reference characters, which will not be described.

[0124] The water flow review control in the configuration of the washing machine according to the third exemplary embodiment is described with reference to FIGS. 19 to 27.

[0125] FIG. 19 is a flowchart for the water flow review control in the washing machine according to the third exemplary embodiment.

[0126] At step S1100, the water flow review control starts. At step S1101, reverse count n is cleared to 0. At step S1102, command rotational speed ω_s for motor 4 is cleared to 0. At step S1103, a shift is made to an acceleration control routine (described in detail later) in a water flow review. At step S1104, a shift is made to a constant-speed control routine (described in detail later) in the water flow review. At step S1105, a shift is made to a deceleration control routine (described in detail later) in the water flow review. At step S1106, reverse count n is incremented by 1. At step S1107, a determination is made whether reverse count n is larger than preset count n_s (e.g., 22) for the determination. If reverse count n is larger (YES), a shift is made to step S1108. If reverse count n is smaller or equal (NO), a shift is made to step S1109. At step S1108, a shift is made to a determination output routine (described in detail later) in the water flow review control. At step S1109, the rotation is changed from CW to CCW or vice versa. Step S1110 serves as a transition from "B" in another routine. At step S1111, a maximum determination value (indicating, for example, a weakest water flow) is output in the water flow review control. At step S1112, the water flow review control ends.

[0127] FIG. 20 is a flowchart for acceleration control in the water flow review of the washing machine according to the third exemplary embodiment.

[0128] At step S1200, the acceleration control in the water flow review starts. At step S1201, motor acceleration α (e.g., 3000 (r/min)/s) is called. At step S1202, command rotational speed ω_s for motor 4 is incremented in accordance with motor acceleration α . At step S1203, a shift is made to a motor speed control routine (described in detail later). At step S1204, a determination is made whether command rotational speed ω_s for motor 4 is higher than or equal to maximum command rotational speed ω_{max} (e.g., 2160 r/min) for motor 4. If command rotational speed ω_s is higher or equal (YES), a shift is made to step S1205. If command rotational speed ω_s is lower (NO), a shift is made to step S1201. At step S1205, the acceleration control in the water flow review ends.

[0129] FIG. 21 is a flowchart for constant-speed control in the water flow review of the washing machine according to the third exemplary embodiment.

[0130] At step S1300, the constant-speed control in the water flow review starts. At step S1301, ON term timer T_{ontm} is cleared to 0. At step S1302, a shift is made to the motor speed control routine (described in detail later). At step S1303, a time (e.g., 1 ms) taken for processing the motor speed control is added to ON term timer T_{ontm} . At step S1304, a determination is made whether a value of ON term timer T_{ontm} is larger than ON term T_{on} . If the value is larger (YES), a shift is made to step S1305. If the value is smaller or equal (NO), a shift is made to step 302. At step S1305, the constant-speed control in the water flow review ends.

[0131] FIG. 22 is a flowchart for deceleration control in the water flow review of the washing machine according to the third exemplary embodiment.

[0132] At step S1400, the deceleration control in the water flow review starts. At step S1401, a determination is made whether reverse count n is 0. If reverse count n is 0 (YES), a shift is made to step S1402. If reverse count n is not 0 (NO), a shift is made to step S1404. At step S1402, OFF term timer T_{offtm} is cleared to 0. At step S1403, cumulative rotation angle $\theta_{integral}$ is cleared to 0. At step S1404, a shift is made to a pause control routine (described in detail later) for the motor speed. At step S1405, a determination is made whether angle threshold θ_{limit} (where the term “angle” hereinafter refers to the motor’s electrical angle) is larger than motor rotation angle θ . If angle threshold θ_{limit} is larger (YES), a shift is made to step S1406. If angle threshold θ_{limit} is smaller or equal (NO), a shift is made to step S1407. At step S1406, a time (e.g., 1 ms) taken for processing the motor pause control is added to OFF term timer T_{offtm} . At step S1407, a shift is made to “B” (refer to FIG. 19).

[0133] At step S1408, a determination is made whether motor rotational speed ω is lower than minimum rotational speed ω_{min} (e.g., 100 r/min) to be detected. If motor rotational speed ω is lower (YES), a shift is made to step S1410. If motor rotational speed ω is higher or equal (NO), a shift is made to step S1409. At step S1409, motor rotation angle θ is added to cumulative rotation angle $\theta_{integral}$. At step S1410, a determination is made whether a value of OFF term timer T_{offtm} is larger than OFF term T_{off} . If the value is larger (YES), a shift is made to step S1411. If the value is smaller or equal (NO), a shift is made to step S1404. At step S1411, the deceleration control in the water flow review ends.

[0134] FIG. 23 illustrates a relationship between the cumulative rotation angle from determination output in the water flow review control of the washing machine according to the third exemplary embodiment and the water flow to be determined in the water flow review control.

[0135] Points in FIG. 23 are evaluation values (in terms of cumulative rotation angle) corresponding respectively to water flows (e.g., the weakest water flow, a weaker water flow, and a standard water flow) at a constant water level, and a dashed line is an approximate line connecting these points. As double arrowed lines indicate, thresholds to be used in determining water flow determination values (respectively indicating, for example, the weakest water flow, the weaker water flow, and the standard water flow at the water level of 65 L) are determined from the evaluation values. For each of the water flows, evaluation is performed multiple times so that the threshold setting takes into consideration variations in the evaluation value.

[0136] Table 4 shows the water flows that are each determined from the cumulative rotation angle from the determination output in the water flow review control of the washing machine according to the third exemplary embodiment.

[0137] Table 4

Cumulative Rotation Angle	Water Flow to be Determined
at least 130 revs	Weakest Water Flow
75 to 130 revs	Weaker Water Flow
below 75 revs	Standard Water Flow

[0138] As in FIG. 23, the cumulative rotation angle is nearly in inverse proportion to the water flow determination value from the water flow review control. Therefore, for the standard water flow at the constant water level, there is a narrower variation in the cumulative rotation angle with the thresholds closer together; however, for the weaker water flow, there is a wider variation in the cumulative rotation angle that facilitates the threshold setting. Therefore, the cumulative rotation angle enables the setting of, for example, the water flow determination values in Table 4 in the water flow review control.

[0139] Table 5 shows examples of respective terms of the water flows to be determined. For example, the term of the standard water flow is 1.4 s ON/1.0 s OFF, the term of the weaker water flow is 1.0 s ON/1.2 s OFF, and the term of the weakest water flow is 0.5 s ON/1.2 s OFF.

[0140] Table 5

Water Flow to be Determined	Term of Water Flow (Example)
Weakest Water Flow	0.5 s ON/1.2 s OFF
Weaker Water Flow	1.0 s ON/1.2 s OFF
Standard Water Flow	1.4 s ON/1.0 s OFF

[0141] FIG. 24 is a time chart that is used in detecting the rotation angle in the water flow review control of the washing machine according to the third exemplary embodiment.

[0142] This drawing illustrates how the command rotational speed (shown as a dotted

5 line) and the actual rotational speed (shown as a solid line) change over time. There is an ON term that includes a period of the acceleration control and a period of the constant-speed control, and an OFF term that is a period of the deceleration control.

[0143] The rotation angle cumulation is performed in the deceleration control until the minimum rotational speed to be detected is reached (refer to a shadow area). Since

10 rotation angles during lower speed rotation where the rotational speed detection is not easy are excluded, the minimum rotational speed to be detected serves as a limit of the rotation angle cumulation to make the cumulative rotation angle more accurate.

[0144] In the drawing, the determination is made after the agitation takes only a single round in one of the directions; however, the average cumulative rotation angle is more

15 accurate after an even number of (e.g., twenty-two) rotation angle cumulations through changes in the rotation direction because of a reduced effect of the rotation direction.

[0145] FIG. 25 is a flowchart for the motor speed control in the washing machine according to the third exemplary embodiment.

[0146] At step S1500, the motor speed control starts. At step S1501, a determination is

20 made whether motor rotational speed ω is higher than command rotational speed ω_s for motor 4. If motor rotational speed ω is higher (YES), a shift is made to step S1502. If

motor rotational speed ω is lower or equal (NO), a shift is made to step S1503. At step S1502, δ -axis command current $I_{\delta s}$ is reduced. At step S1503, δ -axis command current

$I_{\delta s}$ is increased. Speed error amplifier 26 that performs steps S1501 to 1503 normally

25 performs proportional-integral control that includes an integral element such as averaging when setting δ -axis command current $I_{\delta s}$, because a variable element is significant enough to cause unstable control.

[0147] At step S1504, current control timer T_{e_tm} is cleared to 0. At step S1505, a shift is made to a current control routine (described in detail later). At step S1506, a time (e.g.,

30 0.1 ms) taken for processing the current control is added to current control timer T_{e_tm} .

At step S1507, a determination is made whether a value of current control timer Te_{tm} is larger than current control period Te_{cycle} . If the value is larger (YES), a shift is made to step S1508. If the value is smaller or equal (NO), a shift is made to step S1505. At step S1508, the motor speed control ends.

[0148] FIG. 26 is a flowchart for the motor pause control in the washing machine according to the third exemplary embodiment.

[0149] At step S1600, the motor pause control starts. At step S1601, 0 or a fixed value is substituted for δ -axis command current $I\delta_s$. There is a method of using 0 as δ -axis command current $I\delta_s$ to cause no torque. There is also a method of using a negative fixed value as δ -axis command current $I\delta_s$ to cause brake torque to such a degree that regenerative voltage is not problematic for achieving a shorter braking time period, and a method of using a slightly positive fixed value as δ -axis command current $I\delta_s$ to widen a cumulative rotation angle variation with slight driving torque that more reliably effects a pause than, for example, frictional force that acts to decelerate the rotation for facilitating the determination in water splashing detection. An easy-to-use method to be selected depends on the clothing quantity or how the washing machine is configured.

[0150] Thereafter, steps that are the same as steps S1504 to S1508 of the motor speed control are performed. At step S1602, current control timer Te_{tm} is cleared to 0. At step S1603, a shift is made to the current control routine (described in detail later). At step S1604, a time (e.g., 0.1 ms) taken for processing the current control is added to current control timer Te_{tm} . At step S1605, a determination is made whether a value of current control timer Te_{tm} is larger than current control period Te_{cycle} . If the value is larger (YES), a shift is made to step S1606. If the value is smaller or equal (NO), a shift is made to step S1603. At step S1606, the motor pause control ends.

[0151] FIG. 27 is a flowchart for motor current control in the washing machine according to the third exemplary embodiment.

[0152] At step S1700, the motor current control starts. At step S1701, current detection unit 18 detects phase currents I_u , I_v , and I_w . At step S1702, three-phase to two-phase converter 22 calculates δ -axis current $I\delta$, using Formula 1. At step S1703, a determination is made whether δ -axis current $I\delta$ is larger than δ -axis command current $I\delta_s$. If δ -axis current $I\delta$ is larger (YES), a shift is made to step S1704. If δ -axis current $I\delta$ is smaller or equal (NO), a shift is made to step S1705. At step S1704, δ -axis command voltage $V\delta_s$ is reduced. At step S1705, δ -axis command voltage $V\delta_s$ is increased.

[0153] Id error amplifier 23 that performs steps S1703 to S1705 normally performs proportional-integral control that includes an integral element such as averaging when setting δ -axis command voltage $V_{\delta s}$, because a variable element is significant enough to cause unstable control.

- 5 **[0154]** Thereafter, as in the case of the δ axis, the voltage calculation involving steps S1706 to S1709 is performed for the γ -axis. At step S1706, three-phase to two-phase converter 22 calculates γ -axis current I_{γ} , using Formula 1. At step S1707, a determination is made whether γ -axis current I_{γ} is larger than γ -axis command current $I_{\gamma s}$. If γ -axis current I_{γ} is larger (YES), a shift is made to step S1708. If γ -axis current I_{γ} is smaller or
10 equal, a shift is made to step S1709. At step S1708, γ -axis command voltage $V_{\gamma s}$ is reduced. At step S1709, γ -axis command voltage $V_{\gamma s}$ is increased. I_{γ} error amplifier 24 that performs steps S1707 to S1709 normally performs proportional-integral control that includes an integral element such as averaging when setting γ -axis command voltage $V_{\gamma s}$, because a variable element is significant enough to cause unstable control.
- 15 **[0155]** At step S1710, two-phase to three-phase converter 25 calculates application voltages V_{us} , V_{vs} , and V_{ws} , using Formula 2. At step S1711, the voltage application to motor 4 is effected via PWM control unit 19 and inverter circuit 17. At step S1712, the motor current control ends.

[0156] Effects and others

- 20 As described above, a washing machine according to the present exemplary embodiment includes an impeller rotatable in a washing and spin-drying tub, an electric motor including a permanent magnet and a winding, a power supply circuit that supplies a current to the electric motor, and a current detection unit that detects a current in the electric motor. The washing machines further includes a transmission mechanism that
25 transmits torque of the electric motor to the impeller, a rotational speed control unit that controls the electric motor to obtain a specified rotational speed, and a control unit that performs a set of controls on the electric motor a predetermined number of times, the set of controls including at least one of acceleration control, constant-speed control, and pause control which are performed one after another in sequence, the set of controls being
30 performed alternately for clockwise rotation and counterclockwise rotation of the impeller. During washing, the control unit performs water flow review control based on a rotation angle in a period of the pause control.

[0157] With this configuration, washing water splashing is predicted when the rotation angle increases, and a water flow is adjusted or controlled to prevent the water splashing. The washing water splashing is prevented this way, and washing performance is secured.

[0158] A water flow during washing may be changed on the basis of a rotation angle from when a shift to a period of the pause control in the water flow review control is made until an actual rotational speed reaches a specified rotational speed.

[0159] This configuration enables detection of the rotation angle in a medium to high speed range and not in a low speed range where rotation angle errors easily occur, thus enabling the rotation angle detection to be accurate.

[0160] A water flow during washing may be changed on the basis of a rotation angle from when a period of the pause control in the water flow review control starts until a predetermined time period elapses.

[0161] With this configuration, the rotation angle is detected in a medium to high speed range before a low speed range where rotation angle errors easily occur is reached, thus enabling the rotation angle detection to be easy and accurate.

[0162] A water flow during washing may be changed on the basis of a rotation angle while torque is set at zero or a constant value in a period of the pause control in the water flow review control.

[0163] In this configuration, the constant torque is sustained in the pause control period and thus enables fluctuation of the rotation angle due to torque fluctuation to be restrained. Therefore, the water flow review control is enabled to be accurate. Moreover, sensorless detection of the rotation angle is enabled by inertia rotation in which PWM output is not brought to a complete stop.

[0164] The control unit may terminate detection of a water flow to be changed and effects a weaker water flow thereafter when a rotation angle is greater than or equal to a predetermined value in the water flow review control.

[0165] Before the detection of the water flow to be changed is completed, washing water splashing is predicted, and the weaker water flow is effected in this configuration.

Therefore, time-saving detection of the water flow to be changed and associated energy-saving operation are implementable.

[0166] OTHER EXEMPLARY EMBODIMENTS

The third exemplary embodiment has been described above as being illustrative of the technique of the present disclosure. However, the above technique is not restrictive of the present disclosure.

[0167] Exemplary embodiments below are given as other illustrations.

[0168] The washing machine used as an example in the description of the third exemplary embodiment is the top-loading type that uses speed reducer and clutch 6 for connection to pulsator 1 or washing and spin-drying tub 2, with motor pulley 31 and

5 impeller pulley 32 connected by belt 5; however, even with a direct drive washing machine that has a washing and spin-drying tub coaxial with a motor, easy and accurate water flow review control is enabled.

[0169] The washing machine used as the example in the description of the third exemplary embodiment is the top-loading type that uses the pulsator; however, even with a
10 top-loading washing machine that uses an agitator, washing performance is secured by controlling the normal water flow to a degree that no water splashing occurs, and the water splashing is prevented by making the water flow weaker.

INDUSTRIAL APPLICABILITY

15 **[0170]** The present disclosure enables easy and accurate detection of a clothing quantity even without position sensors. Specifically, the present disclosure is applicable to any top-loading washing machine that uses a pulsator, and any top-loading washing machine that uses an agitator.

[0171] Moreover, the present disclosure secures washing performance through control of
20 a normal water flow to such a degree that no water splashing occurs even without position sensors, and prevents the water splashing by making the water flow weaker. Specifically, application to any top-loading washing machine that uses a pulsator and any top-loading washing machine that uses an agitator is possible.

25 REFERENCE MARKS IN THE DRAWINGS

- [0172]** 1: pulsator (impeller)
2: washing and spin-drying tub
3: water receiving tub
4: motor (electric motor)
30 4a: winding
4b: winding
4c: winding
4d: permanent magnet (rotor)
5: belt (transmission mechanism)

	6: speed reducer and clutch (transmission mechanism)
	7: geared motor
	8: brake belt
	9: outer frame of washing machine
5	10: panel portion
	11: lid
	12: display unit
	13: control device
	14: water supply valve
10	15: drain valve
	16: rectifier circuit
	17: inverter circuit (power supply circuit)
	18: current detection unit
	19: PWM control unit
15	20: control unit
	21: speed and phase estimation unit
	22: three-phase to two-phase converter
	23: $I\delta$ error amplifier
	24: $I\gamma$ error amplifier
20	25: two-phase to three-phase converter
	26: speed error amplifier
	27: weaker field setting unit
	28: γ -axis induced voltage calculator
	29: γ -axis induced voltage error amplifier
25	31: motor pulley (transmission mechanism)
	32: impeller pulley (transmission mechanism)

CLAIMS

1. A washing machine comprising:
 - an impeller rotatable in a washing and spin-drying tub;
 - an electric motor including a permanent magnet and a winding;
 - a power supply circuit that supplies a current to the electric motor;
 - a current detection unit that detects a current in the electric motor;
 - a transmission mechanism that transmits torque of the electric motor to the impeller;
 - a rotational speed control unit that controls the electric motor to obtain a specified rotational speed; and
 - a control unit that performs a set of controls on the electric motor a predetermined number of times, the set of controls including at least one of acceleration control, constant-speed control, and pause control which are performed one after another in sequence, the set of controls being performed alternately for clockwise rotation and counterclockwise rotation of the impeller, wherein
 - the control unit includes a clothing quantity detection unit that detects a quantity of laundry from an average current value in a period of the constant-speed control or a rotation angle in a period of the pause control.
2. The washing machine according to claim 1, wherein the clothing quantity detection unit detects a quantity of laundry from both an average current value in a period of the constant-speed control and a rotation angle in a period of the pause control.
3. The washing machine according to claim 1 or 2, wherein the clothing quantity detection unit detects a quantity of laundry from an average current value between elapse of a predetermined time period that follows a shift to a period of the constant-speed control and termination of a period of the constant-speed control.
4. The washing machine according to claim 1 or 2, wherein the clothing quantity detection unit detects a quantity of laundry from an average current value between elapse of a predetermined time period that follows complete settlement of a difference between a target rotational speed and an actual rotational speed in a predetermined value range in a

period of the constant-speed control and termination of a period of the constant-speed control.

5. The washing machine according to claim 1 or 2, wherein the clothing quantity detection unit detects a quantity of laundry from a rotation angle while torque is set at zero or a constant value in a period of the pause control.

6. The washing machine according to claim 1 or 2, wherein the clothing quantity detection unit detects a quantity of laundry from a rotation angle from when a period of the pause control starts until an actual rotational speed reaches a specified rotational speed.

7. The washing machine according to claim 5, wherein the clothing quantity detection unit detects a quantity of laundry from a rotation angle from when a period of the pause control starts until an actual rotational speed reaches a specified rotational speed.

8. The washing machine according to claim 1 or 2, wherein the control unit terminates clothing quantity detection and determines that a quantity of laundry is maximum when a current in the electric motor is larger than or equal to a predetermined value or when a rotation angle is smaller than a predetermined value.

9. A washing machine comprising:
an impeller rotatable in a washing and spin-drying tub;
an electric motor including a permanent magnet and a winding;
a power supply circuit that supplies a current to the electric motor;
a current detection unit that detects a current in the electric motor;
a transmission mechanism that transmits torque of the electric motor to the impeller;
a rotational speed control unit that controls the electric motor to obtain a specified rotational speed; and

a control unit that performs a set of controls on the electric motor a predetermined number of times, the set of controls including at least one of acceleration control, constant-speed control, and pause control which are performed one after another in sequence, the set of controls being performed alternately for clockwise rotation and counterclockwise rotation of the impeller, wherein

during washing, the control unit performs water flow review control based on a rotation angle in a period of the pause control.

10. The washing machine according to claim 9, wherein the control unit changes a water flow during washing on a basis of a rotation angle from when a shift to a period of the pause control in the water flow review control is made until an actual rotational speed reaches a specified rotational speed.

11. The washing machine according to claim 9, wherein the control unit changes a water flow during washing on a basis of a rotation angle from when a period of the pause control in the water flow review control starts until a predetermined time period elapses.

12. The washing machine according to any one of claims 9 to 11, wherein the control unit changes a water flow during washing on a basis of a rotation angle while torque is set at zero or a constant value in a period of the pause control in the water flow review control.

13. The washing machine according to any one of claims 9 to 11, wherein the control unit terminates a review of a water flow to be changed and effects a weaker water flow when a rotation angle is greater than or equal to a predetermined value in the water flow review control.

14. The washing machine according to claim 12, wherein the control unit terminates a review of a water flow to be changed and effects a weaker water flow when a rotation angle is greater than or equal to a predetermined value in the water flow review control.