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(54) DRUM WASHING MACHINE

(57) The balance of the laundry sticking to an inner peripheral surface of a drum of a drum washing machine having a drum rotating on a substantially horizontal axis is adjustedbefore spin-drying. A brushless DC motor is adopted for a drum drive motor. The motor current is separated into a d-axis current and a q-axis current to carry out speed control by vector control for controlling these currents independently. Before spin-drying, the rotating speed is increased (S1) up to a speed at which the laundry sticks firmly to the inner peripheral surface of the drum. Then, the machine enters the rotating speed slow-down operation mode (S2) in which the rotating speed is gradually decreased. The balance of the laundry inside the drum is judged to be proper during the speed slow-down, the rotating speed is increased to enter a spin-drying mode (S8). The balance of the laundry inside the drum is judged on the basis of the fluctuation width of the q-axis current.

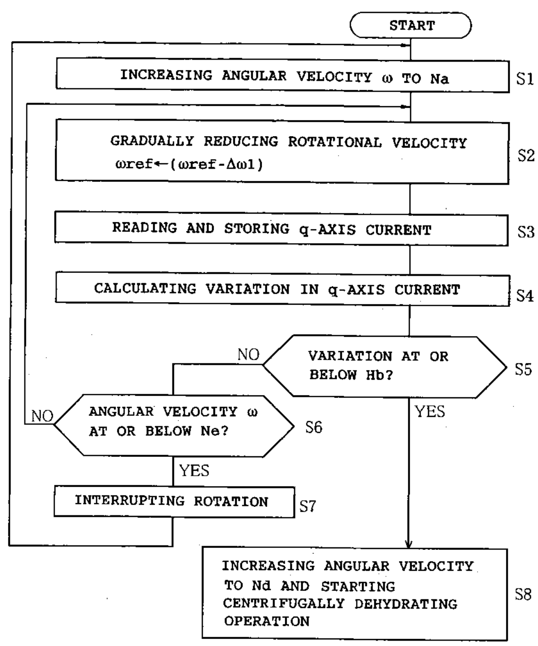

FIG.3

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Description

FIELD OF THE INVENTION

[0001] This invention relates to a drum washing machine provided with a drum rotated about a generally horizontal axis and means for balancing laundry stuck to an inner periphery of the drum prior to a dehydrating or spinning operation.

BACKGROUND ART

[0002] Abnormal oscillation or vibration is sometimes produced in drum washing machines when a centrifugally dehydrating operation is carried out while laundry is stuck to an inner periphery of a drum. There have conventionally been proposed various operation manners for improving uneven distribution of laundry in the drum before start of a high-speed rotation (hereinafter, "balancing operation"). In one of these improving manners, a rotational speed of the drum is gradually reduced so that laundry is balanced. This balancing operation is executed according to a speed curve as shown in FIG. 12, for example. Firstly, a rotational speed of the drum is increased up to a sufficient value (angular velocity Na) at which laundry is stuck to the inner periphery of the drum. Thereafter, the rotational speed is gradually decreased with a small gradient.

[0003] A centrifugal force applied to laundry in a drum being rotated at an angular velocity ω is represented as $Ri \cdot \omega^2$ where Ri is a distance from the rotation center of the drum to laundry. When a rotational axis of the drum is substantially horizontal, part of the laundry in which the value of centrifugal force, $Ri \cdot \omega^2$ is equal to or larger than the gravitational acceleration g remains stuck to the inner peripheral face of the drum, whereas part of the laundry in which the value of centrifugal force, $Ri \cdot \omega^2$ is smaller larger than the gravitational acceleration g is unstuck when arriving near a maximum point, falling down.

[0004] FIG. 10A shows an interior of the drum 101 in the case where the angular velocity ω is equal to the aforesaid angular velocity Na. Since a centrifugal force applied to laundry 102 is equal to or larger than the gravitational acceleration g, the laundry 102 does not fall down even when reaching the maximum point. Suppose now the case where the angular velocity ω is gradually reduced in the above-noted state. A centrifugal force applied to laundry is proportional to the distance from the rotation center of the drum to the laundry. Accordingly, laundry C having a short distance from the rotation center of the drum 101 falls earlier than the laundry 101 stuck to the inner periphery of the drum when the angular velocity ω is decreased to value Nb. Thus, the laundry is dissolved from the unbalanced state and is balanced at angular velocity Nb when all earlier fallen laundry sticks to a part of the inner periphery away from the rotation center and does not fall even when reaching the maximum point.

[0005] When the laundry is balanced at angular velocity Nb as shown in FIG. 12, the angular velocity ω is immediately increased to angular velocity Na or Nc slightly higher than Na. The actual balanced state of laundry is confirmed in a predetermined period of time Ta. When the balanced state is determined to be proper by the confirmation, the angular velocity ω is increased to Nd and the centrifugally dehydrating operation is started. On the other hand, when the balanced state is determined to be improper, the angular velocity ω is once returned to zero and the balancing operation is reexecuted.

[0006] A brushless DC motor is conventionally employed to drive the drum 101. The brushless DC motor is driven by an inverter device in most cases (voltage drive). FIG. 13 shows one of such conventional inverter devices. The inverter device 200 comprises a position detecting section 201, adder 202, PI control section 203, U-V-W conversion section 204, PWM signal forming section 205 and PWM inverter circuit 206. The position detecting section 201 processes two-phase signals from a Hall sensor 208 mounted on an electric motor 207 to detect phase θ and angular velocity ω of a rotor of the motor. The detected angular velocity ω is supplied to the adder 202, which calculates a deviation of the angular velocity ω from a command angular velocity value ωref. The calculated deviation is supplied to the PI control section 203. The PI control section 203 applies a PI operation to the obtained deviation to calculate a voltage command value applied to the motor 207. A result of calculation is supplied to the U-V-W conversion section 204 in the forms of DUTY and PHASE in the case where DC voltage is subsequently pulse-width modulated. The U-V-W conversion section 204 decomposes the supplied voltage command value into three-phase command values, supplying the command values to the PWM signal forming section 205. With reference to phase θ detected by the position detecting section 201, the PWM signal forming section 205 finally generates PWM signals for operating respective switching elements of the PWM inverter circuit 206 driving the respective phase coils of the motor 207. Consequently, the switching elements are turned on and off so that voltages according to the voltage command value are applied to the coils respectively, whereby the rotational speed of the motor 207 is adjusted so as to correspond to the angular velocity command value ωref.

[0007] However, the above-noted conventional control manner has the following problems. As described above, the voltage applied to the motor 207 is proportional to the value obtained by the PI operation of the deviation between the angular velocity ω and the angular velocity command ωref. Thus, the rotational speed control of the motor 207 is carried out by voltage control. Torque developed by the motor 207 is proportional to the magnitude of current flowing into the coils. Even if the voltage proportional to the value obtained by the PI operation is applied to the coils, the current proportional to the aforesaid angular velocity deviation would not be obtained, and accordingly, torque developed is not proportional to the value obtained by the PI operation. Thus, in the case of the voltage control, the follow-up of the angular velocity ω relative to the angular velocity command ωref is low such that the speed control tends to be unstable. Furthermore, the responsiveness of speed control is also low since a period of the feedback control is conventionally several hundreds msec.

[0008] Under the above-described conditions, the angular velocity ω changes as shown by a curve in FIG. 11 when the angular velocity command ωref is reduced with a gentle gradient from the time when the angular velocity ω becomes Na in the aforesaid balancing operation. More specifically, the angular velocity ω is reduced while meandering about a straight line indicative of the angular velocity command ωref.

[0009] The aforesaid balancing operation is caused near the angular velocity at which a centrifugal force acting on the laundry directly stuck to the inner periphery of the drum becomes equal to the gravitational acceleration g (a range from ω1 to ω2). For improvement in the balancing effect, it is desirable that the value of angular velocity ω should be within the range from ω1 to ω2 in which the balancing operation works, for a long period of time. The period of time is increased as shown by period T2 in FIG. 11 when the angular velocity ω is reduced in accordance with the angular velocity command ωref. However, when the angular velocity ω is reduced while meandering as shown in the figure, the time period becomes short as shown by T1 in the figure. Accordingly, a time period in which the balancing operation works becomes short such that balancing is rendered difficult. Furthermore, when the angular velocity ω is reduced while meandering, to determine whether laundry is well balanced becomes difficult and a time period required for the determination is increased.

SUMMARY OF THE INVENTION

[0010] Therefore, an object of the present invention is to provide a drum washing machine in which laundry stuck to the inner periphery of the drum can be balanced prior to the dehydrating operation.

[0011] An electric motor rotating a drum comprises a brushless DC motor including a rotor provided with a permanent magnet. Current flowing into the motor is divided into a d-axis current component parallel to magnetic flux established by the permanent magnet and a q-axis current component perpendicular to the d-axis current component, and the rotational speed of the drum is controlled by a vector control in which the current components are individually controlled so as to correspond with respective command values.

[0012] In order that laundry stuck to the inner periphery of the drum may be balanced, before start of a centrifugally dehydrating operation, a rotational speed of the drum is once increased to a speed at which laundry sticks sufficiently to an inner periphery of the drum. Thereafter, a rotational speed gradually reducing operation starts to gradually reduce the rotational speed. The rotational speed of the drum is increased for proceed to the centrifugally dehydrating operation immediately when it is determined during reduction in the rotational speed that the laundry is balanced in the drum. Rotation of the drum is once stopped and thereafter, the rotational speed of the drum is gradually re-increased when it is not determined that the laundry is balanced in the drum, in spite of a sufficient reduction in the rotational speed of the drum. Such a cycle for the balancing is executed at a predetermined number of times. When it is still not determined that the laundry is balanced in the drum, an alarming operation is carried out and the washing machine is stopped.

[0013] When a variation width of the q-axis current component is reduced to or below a predetermined value, it is determined that the laundry is balanced in the drum.

[0014] The laundry can be stuck uniformly to the inner periphery of the drum by the foregoing balancing operation. Consequently, the washing machine can smoothly proceed to the centrifugally dehydrating operation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] Other objects, features and advantages of the present invention will become clear upon reviewing the following description of embodiments, made with reference to the accompanying drawings, in which:

FIG. 1 is a diagram of a motor drive circuit for a washing machine in accordance with the present invention;

FIG. 2 is a longitudinal section of the washing machine;

FIG. 3 is a flowchart showing the balancing operation in a first embodiment;

FIG. 4 is a waveform chart of the q-axis current in the motor drive circuit of FIG. 1;

FIGS. 5A, 5B and 5C are waveform charts of ac component of the q-axis current as shown in FIG. 4, squared ac component, and squared ac component from which harmonic components have been eliminated respectively;

FIG. 6 is a graph showing an example of angular velocity curve in the balancing operation in the first embodiment;

FIG. 7 is a graph showing another example of angular velocity curve in the balancing operation in the first embodiment;

FIG. 8 is a graph showing an example of angular velocity curve in the balancing operation in a second embodiment;

FIG. 9 is a graph showing another example of angular velocity curve in the balancing operation in the second embodiment;

FIGS. 10A and 10B are diagrams showing the cases where the centrifugal force acting on laundry in the drum and the manners of balancing operation when the angular velocity is large and small respectively;

FIG. 11 is a graph showing changes in the angular velocity of the drum in the prior art;

FIG. 12 is a graph showing an example of angular velocity curve in the balancing operation in the prior art; and

FIG. 13 is a diagram of motor drive circuit in the prior art.

BEST MODE FOR CARRYING OUT THE INVENTION

[0016] Embodiments of the drum washing machine in accordance with the present invention will be described with reference to FIGS. 1 to 11. The invention is applied to a drum washing machine having a drum rotated about a substantially horizontal axis. An overall construction of the washing machine will be described with reference to FIG. 2. The drum washing machine comprises an outer cabinet 1. A door 2 is mounted on a central part of the front of the cabinet 1, which front is shown as a right side in FIG. 2. The door 2 closes and opens an access opening 4 formed in the central front of the cabinet 1. An operation panel 3 is mounted on the cabinet front so as to be located above the door 2. The operation panel 3 includes a number of switches and displays.

[0017] A cylindrical water tub 5 is provided in the cabinet 1 so as to be inclined rearwardly downward. The water tub 5 is elastically supported by a pair of right and left elastic supporting mechanisms 6. A cylindrical drum 7 is provided co-axially in the water tub 5. The drum 7 includes an inner peripheral wall having a number of dehydration holes 8 which also serve as ventilation holes. The drum 7 functions as a wash tub, dehydrating tub and drying tub. The inner peripheral wall of the drum 7 also has a plurality of baffles 9.

[0018] The water tub 5 and drum 7 have fronts formed with openings 10 and 11 through which laundry is put into and taken out of the drum respectively. The opening 10 of the water tub 5 water-tightly communicates with the access opening 4 with bellows 12 provided therebetween. The opening 11 of the drum 7 faces the opening 10 of the water tub 5. A balancing ring 13 is mounted around the opening 11 of the drum 7.

[0019] An electric motor 14 is mounted on a rear of the water tub 5 for rotating the drum 7. The motor 14 is a brushless DC motor of the outer rotor type in which a rotor is disposed around a stator. A stator 15 of the motor 14 is mounted on an outer periphery of a bearing housing 16 further mounted on a central rear of the water tub 5. A rotor 17 of the motor 14 is disposed outside the stator 15 so as to cover it. A centrally mounted rotational shaft 18 is rotatably mounted on bearings 19 further mounted on the bearing housing 16. The rotational shaft 18 includes a front end protruding from the bearing housing 16 and connected to a central rear of the drum 7, whereby the drum 7 is rotated with the rotor 17 of the motor 14 when the rotor is rotated.

[0020] A hot-air generator 24 is provided on a top of the water tub 5. A heat exchanger 25 of the water-cooled type is provided on the rear of the water tub 5. The hot-air generator 24 comprises a hot-air heater 27 provided in a case 26, a fan 29 provided in a casing 28 and a fan motor 31 rotating the fan 29 via a belt transmission mechanism 30. The case 26 communicates with the casing 28. A duct 32 is connected to a front of the case 26. The duct 32 has a distal end which protrudes into a front upper interior of the water tub 5, facing the opening 12 of the drum 7.

[0021] Hot air is generated by the heater 27 and fan 29 and supplied through the duct 32 into the drum 7. The hot air supplied into the drum 7 heats laundry and absorbs water content from the laundry. Air containing the absorbed water content is discharged to the heat exchanger 25 side. An upper interior of the heat exchanger 25 communicates with the interior of the casing 28, whereas a lower interior of the heat exchanger communicates with the interior of the water tub 5. The heat exchanger 25 cools water vapor contained in air passing through the interior thereof when water poured from its upper portion falls down, thereby dehumidifying air. The air passing through the heat exchanger 25 is returned to the hot-air generator 24 to be heated and recirculated.

[0022] A drive circuit for the motor 14 driving the drum 7 will now be described. FIG. 1 is a block diagram showing an example of the drive circuit. A motor drive circuit 40 employs a sensor-less vector control system. The motor drive circuit 40 includes a current control circuit 50, a rotational position estimating circuit 60 for estimating a rotational position of the motor rotor 17, a current command determining circuit 70 and a balanced state determining circuit 80.

[0023] The current control circuit 50 comprises adders 51a and 51b, proportional integral (PI) circuits 52a and 52b, a coordinate transformer 53, a PWM signal forming circuit 54, a PWM inverter circuit 55 and a current detecting circuit 56. The current detecting circuit 56 comprises current detectors 56a and 56b, a three-to-two phase converter 56c and a vector rotator 56d. The rotational position estimating circuit 60 comprises an induced voltage estimating circuit 61, a proportional integral circuit 62 and an integrator 63. The current command determining circuit 70 comprises an adder 71 and a proportional integral circuit 72.

[0024] The current detectors 56a and 56b are connected between the PWM inverter circuit 55 and the motor 14 to detect a three-phase current, Iu, Iv and Iw (Iw is calculated from Iu and Iv). The detected three-phase current is converted by the three-to-two phase converter 56c to a two-phase current $I\alpha$, $I\beta$ equivalent to the three-phase current. The two-phase current $I\alpha$, $I\beta$ is further converted by the vector rotator 56d to current Id, Iq of d-axis and q-axis component. A rotational position estimating value θ which will be described in detail later is used in the conversion operation. In this case, the d-axis and q-axis are rotating coordinate axes in which a direction of magnetic flux established by the permanent magnet of the rotor is a d-axis (magnetic flux axis) and a direction perpendicular to the d-axis is a q-axis (torque axis). As well known, the d-axis current Id is a current component contributing to a magnetic flux generation and the q-axis current Iq is a current component contributing to rotating torque generation.

[0025] Deviations ΔId, ΔIq of the calculated currents Id, Iq from current command values Idr, Iqr are obtained by the adders 51a, 51b respectively. Output voltage command values Vd, Vq are obtained by the proportional plus integral circuits 52a and 52b from the deviations ΔId, ΔIq respectively. The output voltage command values Vd, Vq are converted by the coordinate transformer 53 to values of fixed biaxial coordinate system. Three-phase pulse modulated signals are formed by the PWM signal forming circuit 54 on the basis of the converted values of fixed biaxial coordinate system. The estimated rotational position value θ is also used in the conversion operation by the coordinate transformer 53. A pulse width modulated (PWM) signal is supplied to the PWM inverter circuit 55, whereby voltage is applied to an armature coil of the motor 14. Thus, power is supplied to the motor 14 by the current control circuit 50, and the value of current flowing depends upon the current command values Idr and Iqr.

[0026] A rotational position of the rotor is required for the operation by each of the vector rotator 56d and coordinate converter 53. The rotational position of the rotor is detected by a rotation sensor mounted on the motor 14, for example, an encoder. However, the arrangement of FIG. 1 employs a position sensor-less system estimating a rotational position of the rotor from motor current Id, Iq or the like.

[0027] An induced voltage estimating circuit 61 of the rotational position estimating circuit 60 is supplied with current Id, Iq, d-axis output voltage command value Vd and an estimated angular velocity value ω of the rotor. Furthermore, the induced voltage estimating circuit 61 stores data of inductance Ld, Lq of the armature coil and resistance R, all of which are circuit constants of the motor 14. Using these input values and circuit constants, the induced voltage estimating circuit 61 calculates a d-axis direction estimated value Eds (a d-axis component the inverter device 40 recognizes) of an induced voltage generated in the armature coil by the magnetic flux established by the permanent magnet, by the following equation:

$$Eds=Vd-R\cdot Id-Ld\cdot pId+\omega\cdot Lq\cdot Iq \qquad (1)$$

where p is a differential operator. The obtained estimated induced voltage value Eds is supplied to the proportional plus integral circuit 62, which delivers the following value as an estimated angular velocity value ω:

$$\omega=-G1\cdot Eds - G2\cdot \int Eds\cdot dt \qquad (2)$$

where G1 and G2 are gain constants.

[0028] The estimated rotational position value θ is obtained from the following equation by integrating the aforesaid estimated angular velocity value ω by the integrator 63:

$$\theta=\int \omega\cdot dt \qquad (3)$$

Thus, the estimated angular velocity value ω and the estimated rotational position value θ are determined by the rotational position estimating circuit 60. When the balancing operation calculated from equation (2) is continued by the proportional plus integral circuit 62, the d-axis direction estimated value Eds calculated by equation (1) converges at zero in a short period of time.

[0029] At the time when the d-axis direction estimated value Eds converges at zero, the d-axis recognized (estimated) by the inverter corresponds with the direction of magnetic flux established by the permanent magnet, and the estimated rotational position value θ is equal to an actual rotational position and the estimated angular velocity value ω is equal to an actual angular velocity of the rotor. According to the circuit arrangement of FIG. 1, the rotational position θ and angular velocity ω can be detected without use of any rotational sensor.

[0030] The adder 71 of the current command determining circuit 70 obtains a deviation $\Delta\omega$ between the estimated angular velocity ω and the angular velocity command value ωref supplied from an operation instructing circuit 90 of the washing machine. The obtained deviation $\Delta\omega$ is further processed by the proportional plus integral circuit 72, which supplies output as a q-axis current command value Iqr. The adder 51b obtains a deviation ΔIq between the q-axis current command value Iqr and the detected q-axis current Iq. The deviation ΔIq is adjusted by the proportional plus integral circuit 52b so as to converge at zero. By the adjustment of the proportional plus integral circuits 52b and 72, the estimated angular velocity value ω corresponds to the angular velocity command value ωref, whereupon the motor 14 is rotated at the angular velocity command value ωref designated by the operation instructing circuit 90.

[0031] Since the d-axis current Id does not contribute to the torque development, the current command value Idr is normally set at zero except for the centrifugal dehydrating operation requiring a high speed rotation. The d-axis current Id is controlled by the proportional plus integral circuits 52a so as to become equal to the current command value Idr. The balancing determining circuit 80 will be described in detail later.

[0032] The above-described operational processing is periodically performed by an operator such as DSP (digital signal processor). The operation is carried out in the sequence of the three-to-two phase converter 56c, vector rotator 56d, balanced state determining circuit 80, induced voltage estimating circuit 61, proportional plus integral circuit 62, integration circuit 63, adder 71, proportional plus integral circuit 72, adders 51a and 51b, proportional plus integral circuits 52a and 52b, coordinate transformer 53 and PWM signal forming circuit 54. An operational period is very short, for example, about 128 msec.

[0033] The speed control does not function well in the motor drive circuit 40 of the sensor-less vector control system when the value of angular velocity ω of the motor 14 is too small. Accordingly, when the motor 14 starts in a stationary state, another starting control is carried out until the angular velocity ω is increased to a value at which the angular velocity can be controlled by the sensor-less vector control. The starting control will not be described in detail here since various proposals have been made regarding the starting control. In brief, for example, instead of the output of the coordinate converter 53, the operation instructing circuit 90 may be designed to directly supply two-phase voltage $V\alpha$, $V\beta$ to the PWM signal forming circuit 54, so that the two-phase voltage $V\alpha$, $V\beta$ is gradually increased from zero thereby to increase the rotational speed of the motor 14.

[0034] In the washing machine constructed and arranged as described above and provided with the foregoing motor drive circuit, a balancing operation is carried out in order to improve uneven distribution of laundry stuck on the inner periphery of the drum, prior to a centrifugally dehydrating operation. The balancing operation will be described.

First embodiment of the balancing operation

[0035] A first embodiment of the balancing operation will be described with reference to FIGS. 3 to 7. FIG. 6 shows changes in the rotational speed (angular velocity ω) of the drum 7 in a period from the start of balancing operation to the start of centrifugally dehydrating operation. FIG. 3 is a flowchart showing the balancing operation.

[0036] In the embodiment, the rotational speed of the drum 7 is increased to an angular velocity Na which is sufficient for the laundry to stick to the inner periphery of the drum 7 at an initial stage of the balancing operation (step S1). In this speed increase, the operation instructing circuit 90 delivers angular velocity Na as the angular velocity command value ωref. The starting control is firstly carried out in the course of the speed increase from the stationary state, as noted above.

[0037] The speed gradually reducing operation starts after angular velocity Na has been reached. At step S2 which is executed repeatedly, the angular velocity command value ωref is replaced by a value smaller by $\Delta\omega 1$ than the command value. Simultaneously, whether laundry is balanced in the drum 7 is determined. The determination is based on an amount of variation in the q-axis current Iq. For this purpose, at step S3 which is executed repeatedly, the balanced state determining circuit 80 reads and stores data of the value of q-axis current Iq. Simultaneously, the variation amount of the q-axis current Iq after transition to the speed gradually reducing operation is calculated (step S4) and whether laundry is balanced in the drum 7 is determined (step S5).

[0038] The following describes a ground for the determination as to the balance of laundry on the basis of the variation amount of q-axis current Iq. FIG. 4 shows changes in the q-axis current after start of the speed gradually reducing operation. The q-axis current is shown as a relative value on the axis of ordinates. FIG. 4 shows a waveform in the case where laundry is not balanced at the time the angular velocity Na has been reached. The value of q-axis current varies to a large extent. The reason for the aforesaid variation in the q-axis current will be described. The rotational shaft of the drum 7 is substantially horizontal as described above. Accordingly, the rotational speed of the drum 7 varies depending upon a rotational position thereof when the drum is rotated about the horizontal shaft with laundry not being balanced. In the motor drive circuit 40 of the embodiment, the adder 71 compares the value of angular velocity estimated by the rotational position estimating circuit 60 with the angular velocity command value ωref, thereby calculating a deviation $\Delta\omega$. Accordingly, the deviation $\Delta\omega$ varies depending upon a rotational angle of the drum 7 when laundry is unbalanced in the drum. The proportional integral circuit 72 executes a proportional integral operation for the value of deviation $\Delta\omega$, thereby calculating a q-axis current command value Iqr to be supplied to q-axis so that deviation $\Delta\omega$ becomes zero. Since torque developed by the motor 14 depends upon only the q-axis current Iq, the value obtained by proportionally integrating deviation $\Delta\omega$ is a q-axis current command value Iqr. More specifically, the proportional integral circuit 72 delivers a torque command value to be developed so that deviation $\Delta\omega$ becomes zero, in the form of the q-axis current command value Iqr. The q-axis current Iq detected by the current detecting circuit 56 is supplied to the adder 51b, which calculates deviation ΔIq between the q-axis current Iq and the q-axis current command value Iqr. The deviation ΔIq is supplied to the proportional integral circuit 52b, which then performs a proportional integral operation, thereby obtaining a q-axis voltage command value Vq. The obtained q-axis voltage command value Vq is supplied to the coordinate transformer 53. In other words, the proportional integral circuit 52b calculates the q-axis voltage command value Vq to be applied to the q-axis so that the q-axis current deviation ΔIq becomes zero.

[0039] Thus, when an unbalanced condition of the laundry stuck to the inner periphery of the drum 7 results in the deviation between the angular velocity ω and the angular velocity command value ωref, the q-axis current command value Iqr to render the angular velocity deviation Δω zero is instantaneously obtained and further, the q-axis voltage command value Vq to equalize the q-axis current Iq to the q-axis current command value Iqr is instantaneously obtained. Consequently, the value of the q-axis current Iq is instantaneously adjusted so that the angular velocity deviation Δω becomes zero. The instantaneous adjustment causes the q-axis current Iq to vary to a large extent as shown in FIG. 4. The time period between adjacent peaks of the q-axis current Iq curve corresponds to the time of one turn of the drum 7.

[0040] As described above, when the laundry stuck to the inner periphery of the drum 7 is unbalanced, the q-axis current Iq varies to a large extent during one turn. An amount of variation is reduced when an amount of unbalance is small. Accordingly, a degree of unbalance can be grasped by measuring an amount of variation in the q-axis current Iq during one turn. This is the reason for determining whether laundry is well balanced, on the basis of an extent of variation in the q-axis current Iq.

[0041] The extent of variation in the q-axis current Iq is calculated in the following manner. Firstly, a dc component contained in the q-axis current Iq in FIG. 4 is eliminated and only the ac component is extracted. A dc component changes according to the variation in the angular velocity command value ωref, whereas changes in an ac component results from the angular velocity deviation Δω. FIG. 5A shows the extracted ac component. The variation in the angular velocity command value ωref in one turn is large when the ac component is large. FIG. 5B shows the result obtained by squaring the instantaneous value of ac component. In these operations, when a data amount of instantaneous values of q-axis current Iq is excessively large, data may be thinned out. High-frequency components are eliminated from the result of FIG. 5B, and the result as shown in FIG. 5C is obtained. A curve shown in FIG. 5C represents the magnitude of variation in one turn of q-axis current Iq as shown in FIG. 4. Accordingly, when a height of the curve is compared with a predetermined reference value Hb, whether laundry stuck to the inner periphery of the drum is balanced can be determined.

[0042] At step S5, it is determined whether the variation in the q-axis current is at or below the reference value Hb or whether laundry is balanced. When the variation is not at or below the reference value Hb, the control sequence advances to step S6, where whether the angular velocity is at or below a predetermined value Ne. The value Ne is set so as to be smaller than the angular velocity range from ω1 to ω2 in which only the laundry causing unbalanced condition falls. When the predetermined angular velocity is reached, almost all the laundry in the drum falls at the maximum point. When the value of angular velocity ω is larger than the predetermined value Ne, the control sequence returns to step S2 where the angular velocity ω is further reduced for continuation of rotational speed gradually reducing operation so that whether laundry is balanced is re-determined. When it is determined at step S6 that the value of angular velocity ω is at or below the predetermined value Ne, rotation of the drum is interrupted (step S7) and thereafter, the control sequence returns to step S1 so that the balancing operation is re-executed. The reason for this is that since the angular velocity ω is lower than the angular velocity range from ω1 to ω2 in which the balancing action works, the balancing operation cannot be expected even if it is continued.

[0043] FIG. 7 shows the curve of the angular velocity ω in the case where the steps are re-executed from step S1. FIG. 7 shows a case where it is determined that laundry is balanced, at the time the angular velocity ω becomes Nb during the second rotational speed gradually reducing operation.

[0044] The control sequence advances to step S8 when it is determined at step S5 that the variation in the q-axis current Iq is at or below the reference value Hb. That the q-axis current variation is at or below the reference value Hbmeans that laundry is balanced. Accordingly, the speed command value ωref is increased to an angular velocity Nd so that the centrifugally dehydrating operation is started.

[0045] In the first embodiment, the rotational speed gradually reducing operation is carried out at angular velocity Na for the balancing operation. The control sequence proceeds to the centrifugally dehydrating operation immediately when it is determined that laundry is balanced, in the course of the rotational speed gradually reducing operation.

[0046] In the embodiment, when the angular velocity deviation Δω occurs during one turn of the drum 7, the developed torque is adjusted so that the deviation is instantaneously rendered zero. Accordingly, the angular velocity ω changes without meandering so as to depict a curve substantially corresponding to the straight line of angular velocity command value ωref as shown in FIG. 11. Consequently, a period of time in which the value of angular velocity ω is within the angular velocity range from ω1 to ω2 at which only the laundry resulting in the unbalanced condition falls almost corresponds to the time period T2 in FIG. 11. Since time period T2 is longer than the time period T1 in the prior art, laundry can be balanced in the drum more easily as compared with the prior art construction.

Second embodiment of the balancing operation

[0047] In the foregoing embodiment, the angular velocity ω is firstly increased to Na and thereafter, the first rotational speed gradually reducing operation is carried out for balancing the laundry. In a second embodiment, the balancing operation is executed even in the middle of increasing angular velocity ω to Na. A rotational speed gradually increasing operation is carried out for this purpose. In this case, a speed increase rate at which the angular velocity ω is increased to Na is rendered smaller than one in the first embodiment as shown in

FIG. 8. The angular velocity ω passes through the range from ω1 to ω2 in which the balancing action works. In the case where it is determined that laundry is balanced, when angular velocity ω has reached a middle angular velocity Nb, the angular velocity ω is immediately increased to Nd so that the control sequence proceeds to the centrifugally dehydrating operation.

[0048] The rotational speed gradually reducing operation as performed in the first embodiment is carried out when it is not determined that laundry is balanced, before angular velocity ω reaches Na. When it is determined that laundry is balanced, during the rotational speed gradually reducing operation, the angular velocity ω is immediately increased to Nd so that the control sequence proceeds to the centrifugally dehydrating operation, in the same manner as in the first embodiment. When angular velocity is reduced to Ne but it is not determined that laundry is balanced, rotation of the drum 7 is interrupted and the rotational speed gradually increasing operation is performed as shown in FIG. 9.

[0049] The foregoing rotational speed gradually increasing and reducing operations are repeated such that the laundry is finally balanced in the drum 7. However, it is not preferable that the operations are repeated unlimitedly. Accordingly, when the laundry is unbalanced even after repeat at a predetermined number of times, an alarming operation is carried out and the washing machine is turned off.

Claims

1. A drum washing machine in which a drum is driven by an electric motor so as to be rotated about a substantially horizontal axis, **characterized in that** the motor is controlled so that an amount of speed variation during one turn of the drum is reduced; before start of a centrifugally dehydrating operation, a rotational speed of the drum is once increased to a speed at which laundry sticks sufficiently to an inner periphery of the drum and thereafter gradually reduced; and the rotational speed of the drum is increased for proceed to the centrifugally dehydrating operation immediately when it is determined during reduction in the rotational speed that the laundry is balanced in the drum.

2. A drum washing machine in which a drum is driven by an electric motor so as to be rotated about a substantially horizontal axis, **characterized in that** the motor is controlled so that an amount of speed variation during one turn of the drum is reduced; before start of a centrifugally dehydrating operation, a rotational speed of the drum is once increased to a speed at which laundry sticks sufficiently to an inner periphery of the drum; the rotational speed of the drum is increased for proceed to the centrifugally dehydrating operation immediately when, during the gradual increase in the rotational speed, it is determined that the laundry is balanced in the drum; the rotational speed of the drum is gradually reduced when, during the gradual increase in the rotational speed, it is not determined that the laundry is balanced in the drum; the rotational speed of the drum is increased for proceed to the centrifugally dehydrating operation immediately when, during the gradual reduction in the rotational speed, it is determined that the laundry is balanced in the drum; and rotation of the drum is once stopped and thereafter, the rotational speed of the drum is gradually re-increased when it is not determined that the laundry is balanced in the drum, in spite of a sufficient reduction in the rotational speed of the drum.

3. A drum washing machine according to claim 1 or 2, **characterized in that** the motor comprises a brushless DC motor including a rotor provided with a permanent magnet; current flowing into the motor is divided into a d-axis current component parallel to magnetic flux established by the permanent magnet and a q-axis current component perpendicular to the d-axis current component; and the rotational speed of the drum is controlled by a vector control in which the current components are individually controlled so as to correspond with respective command values.

4. A drum washing machine according to claim 1 or 2, **characterized in that** the motor comprises a brushless DC motor including a rotor provided with a permanent magnet; current flowing into the motor is divided into a d-axis current component estimated by an operation in which a d-axis component estimated value of an induced voltage due to rotation of the permanent magnet is zero and a q-axis current component perpendicular to the d-axis current component; and the rotational speed of the drum is controlled by a sensor-less vector control in which the current components are individually controlled so as to correspond with respective command values.

5. A drum washing machine according to claim 3, **characterized in that** when a variation width of the q-axis current component is reduced to or below a predetermined value, it is determined that the laundry is balanced in the drum.

6. A drum washing machine according to claim 4, **characterized in that** when a variation width of the q-axis current component of the current flowing into the motor is reduced to or below a predetermined value, it is determined that the laundry is balanced in the drum.

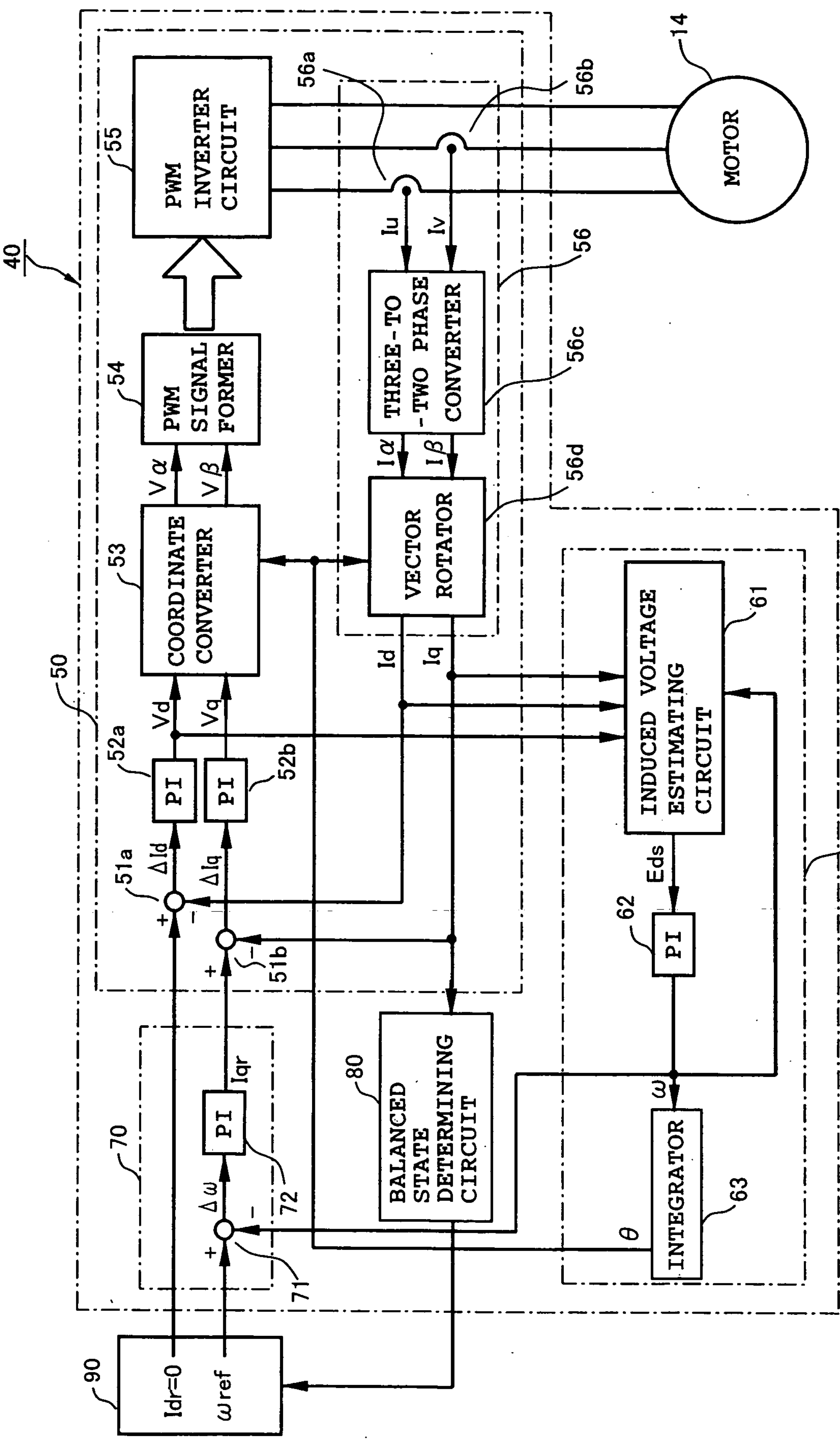

40
50
55
PWM
INVERTER
CIRCUIT
56a
56b
14
MOTOR
Iu
Iv
56
54
PWM
SIGNAL
FORMER
THREE-TO
-TWO PHASE
CONVERTER
56c
Vα
Vβ
Iα
Iβ
56d
53
COORDINATE
CONVERTER
VECTOR
ROTATOR
Id
Iq
61
INDUCED VOLTAGE
ESTIMATING
CIRCUIT
Vd
Vq
52a
PI
PI
52b
51a
ΔId
ΔIq
51b
Eds
62
PI
60
70
Iqr
PI
72
80
BALANCED
STATE
DETERMINING
CIRCUIT
ω
INTEGRATOR
63
θ
Δω
71
90
Idr=0
ωref

FIG.1

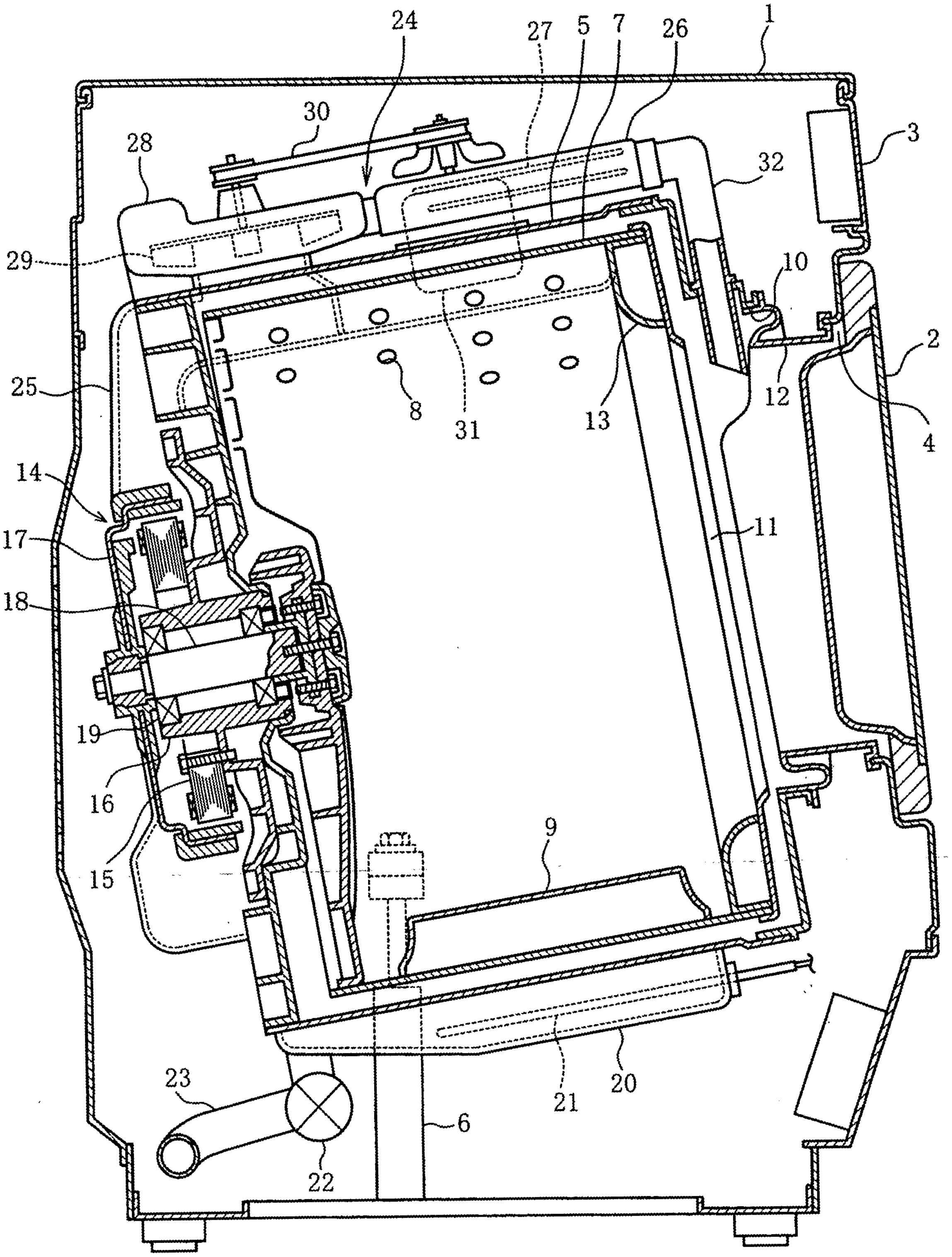

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32

FIG.2

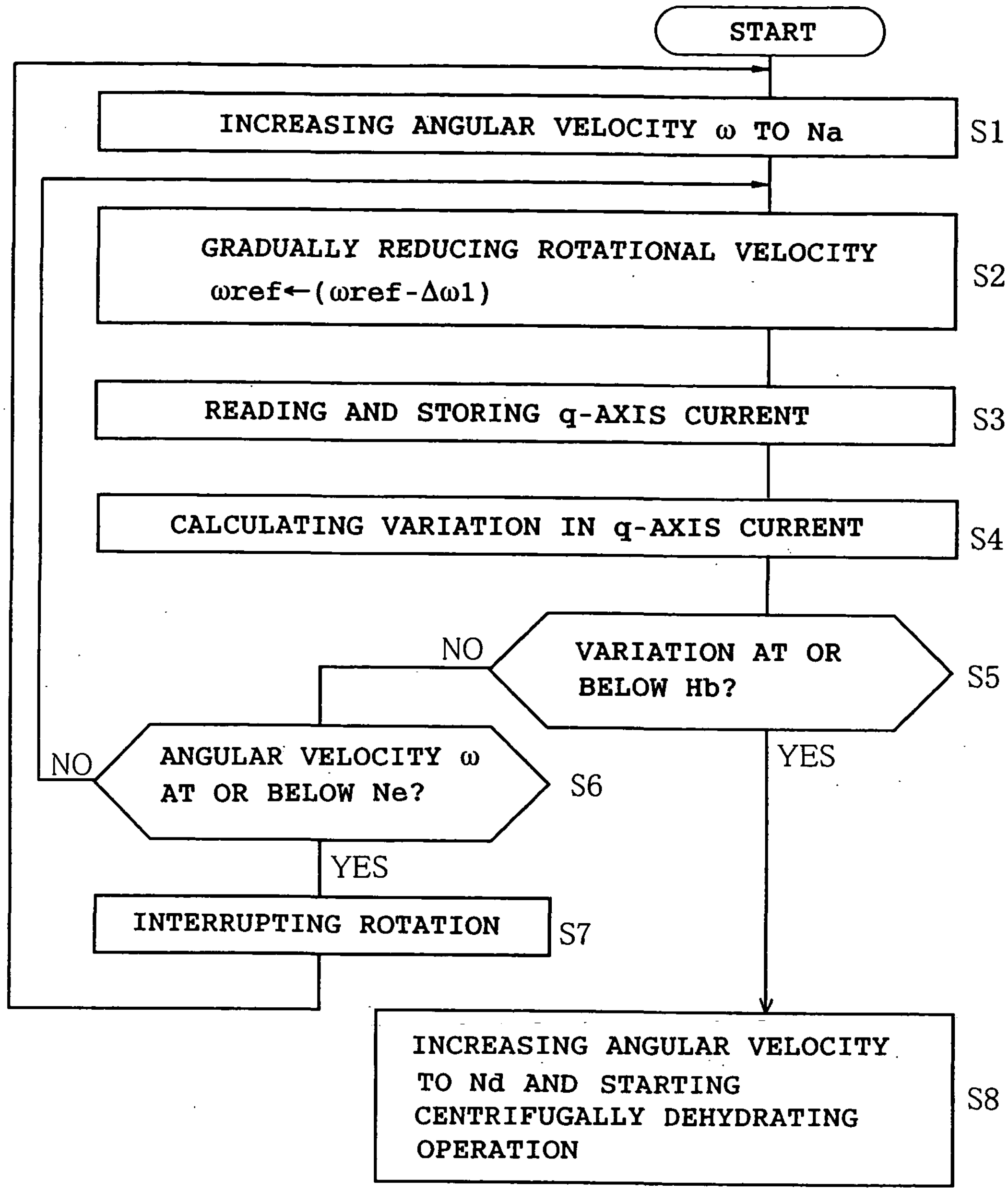

START
INCREASING ANGULAR VELOCITY ω TO Na
S1
GRADUALLY REDUCING ROTATIONAL VELOCITY
ωref←(ωref-Δω1)
S2
READING AND STORING q-AXIS CURRENT
S3
CALCULATING VARIATION IN q-AXIS CURRENT
S4
VARIATION AT OR BELOW Hb?
S5
NO
YES
ANGULAR VELOCITY ω AT OR BELOW Ne?
S6
NO
YES
INTERRUPTING ROTATION
S7
INCREASING ANGULAR VELOCITY TO Nd AND STARTING CENTRIFUGALLY DEHYDRATING OPERATION
S8

FIG.3

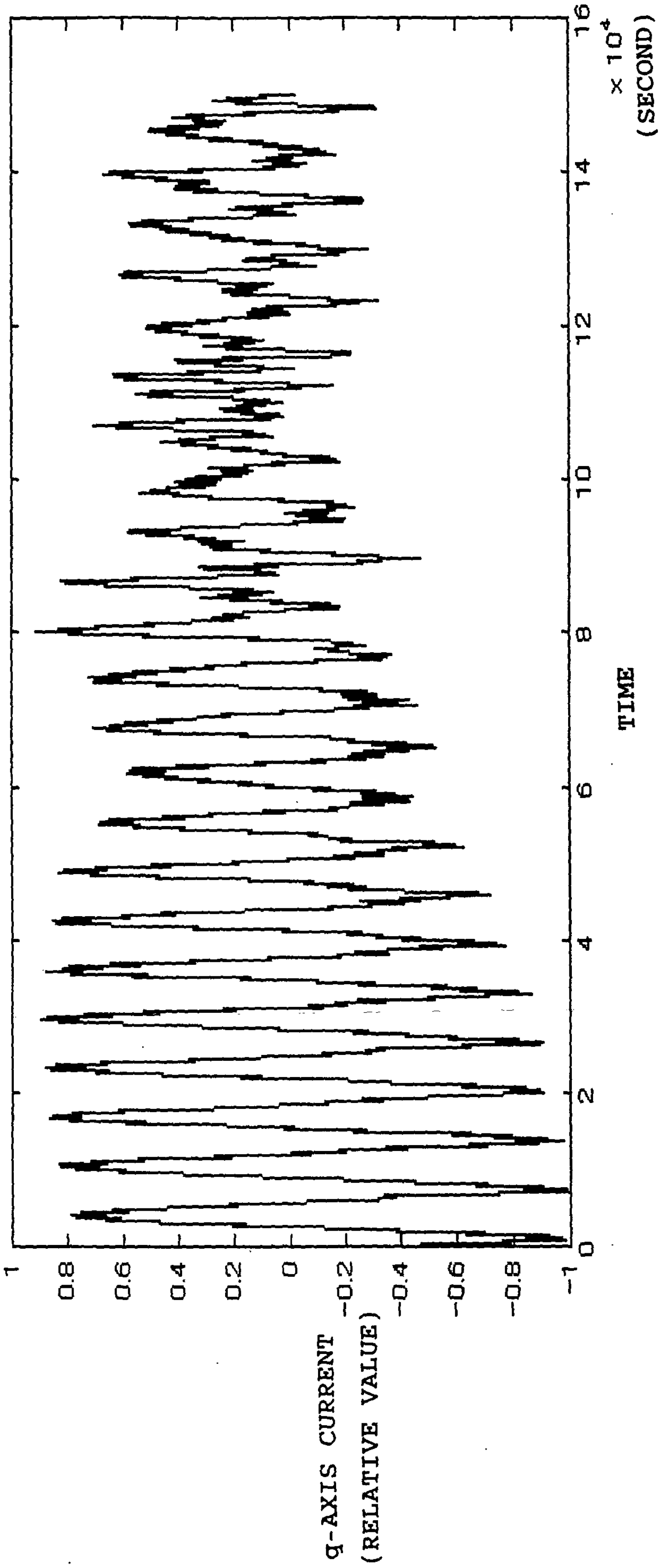

q-AXIS CURRENT
(RELATIVE VALUE)
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
0
2
4
6
8
10
12
14
16
TIME
× 10⁴
(SECOND)

FIG. 4

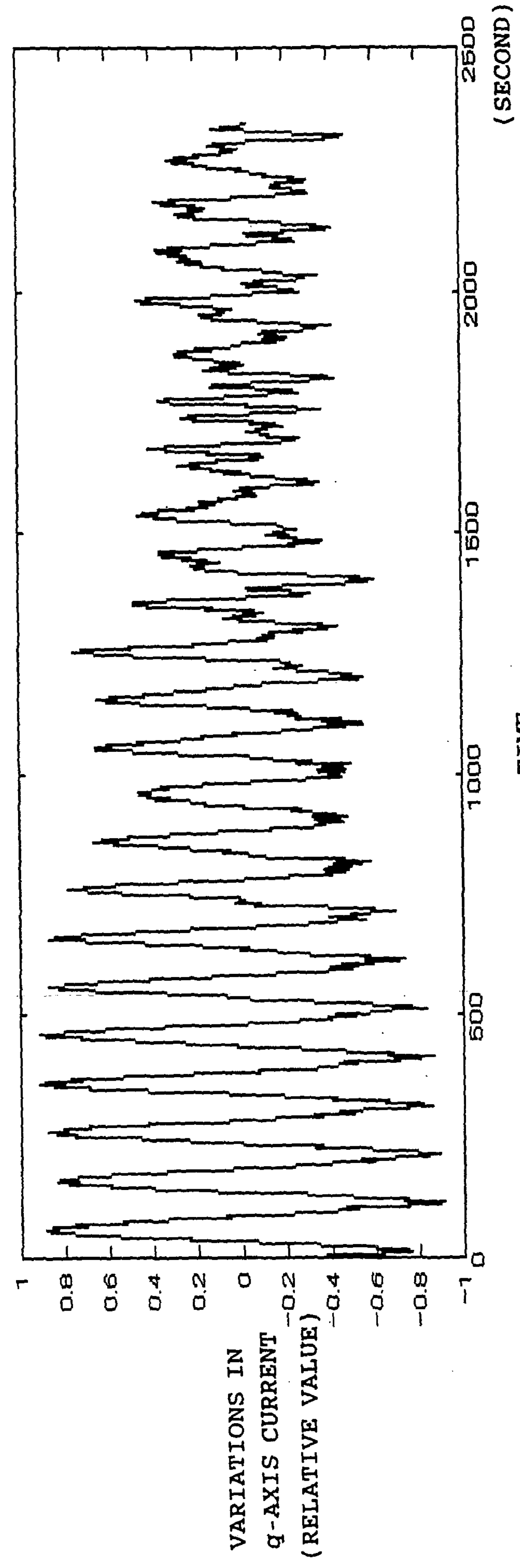

VARIATIONS IN
q-AXIS CURRENT
(RELATIVE VALUE)
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
0
500
1000
1500
2000
2500
(SECOND)
TIME

FIG.5A

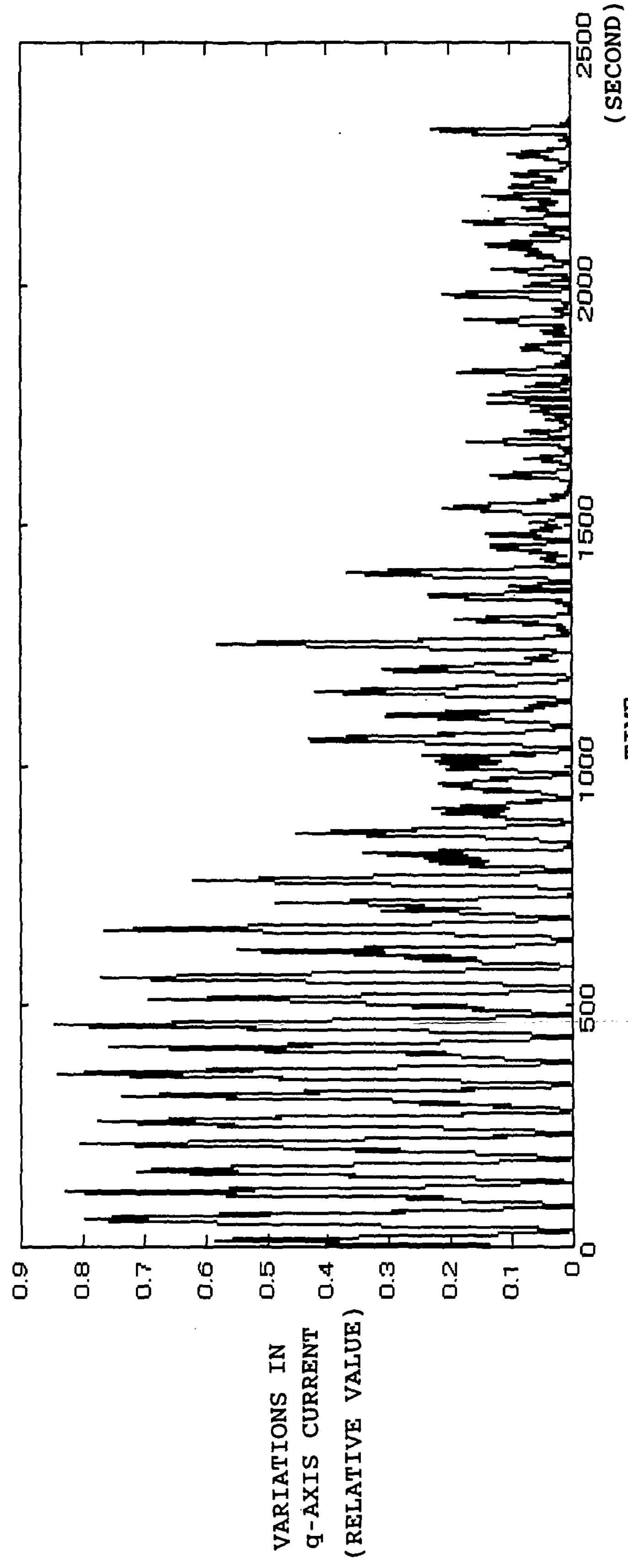

VARIATIONS IN
q-AXIS CURRENT
(RELATIVE VALUE)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
500
1000
1500
2000
2500
(SECOND)
TIME

FIG.5B

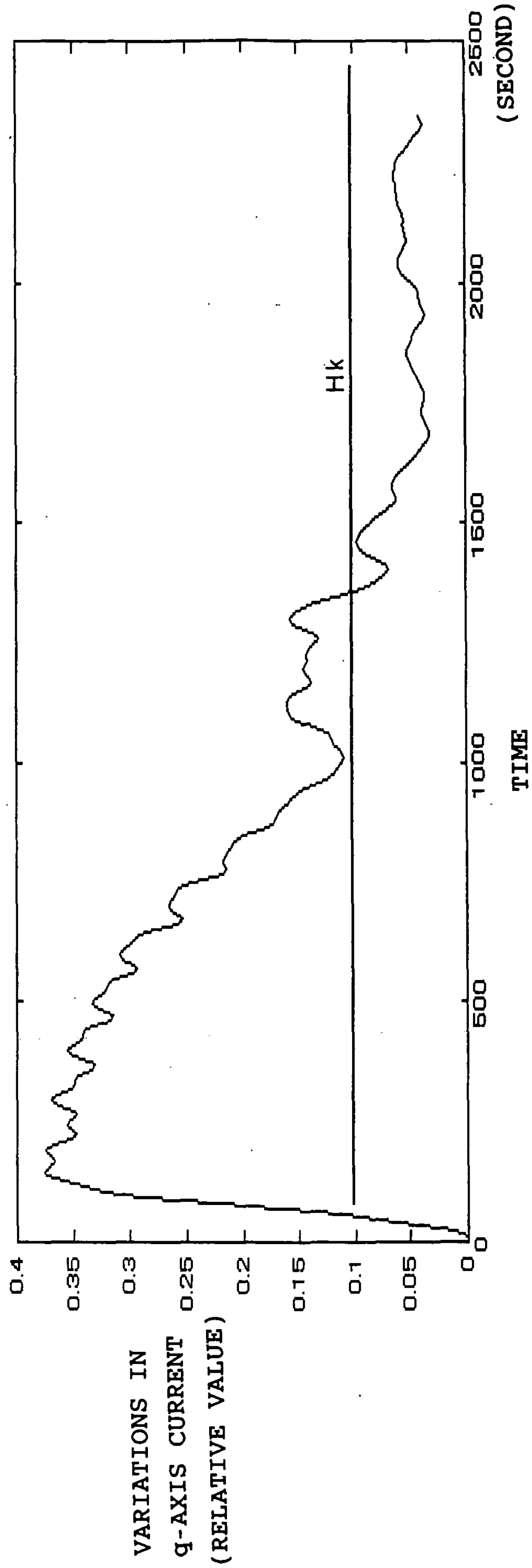
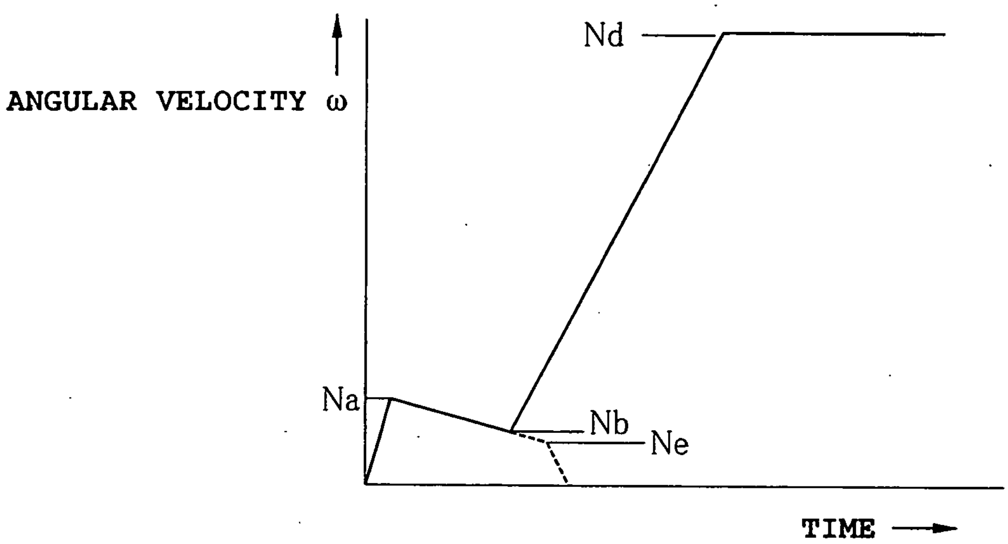
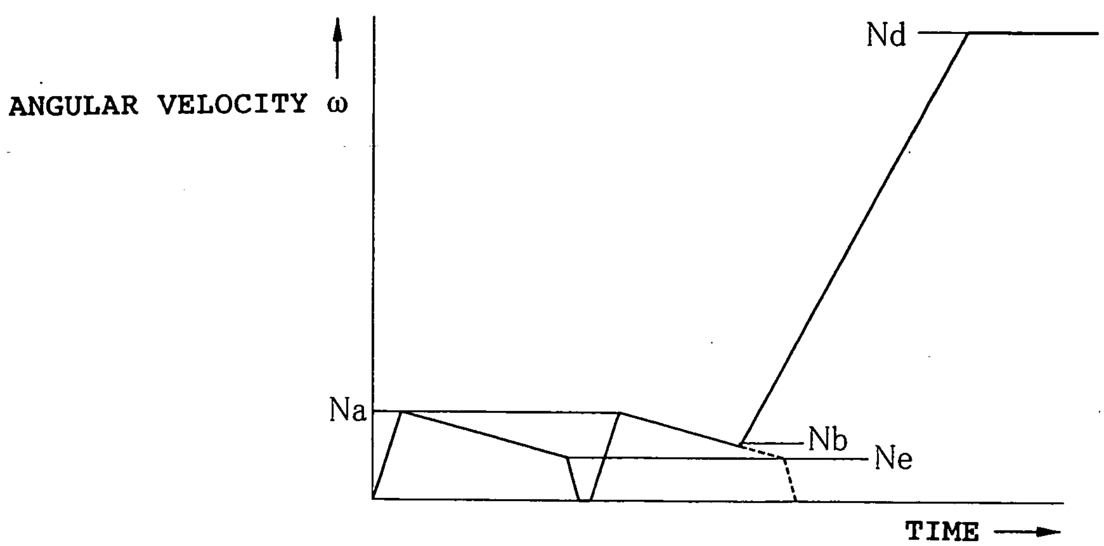

VARIATIONS IN
q-AXIS CURRENT
(RELATIVE VALUE)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Hk
0
500
1000
1500
2000
2500
TIME
(SECOND)

FIG.5C



ANGULAR VELOCITY ω
Nd
Na
Nb
Ne
TIME

FIG.6



ANGULAR VELOCITY ω
Nd
Na
Nb
Ne
TIME

FIG.7

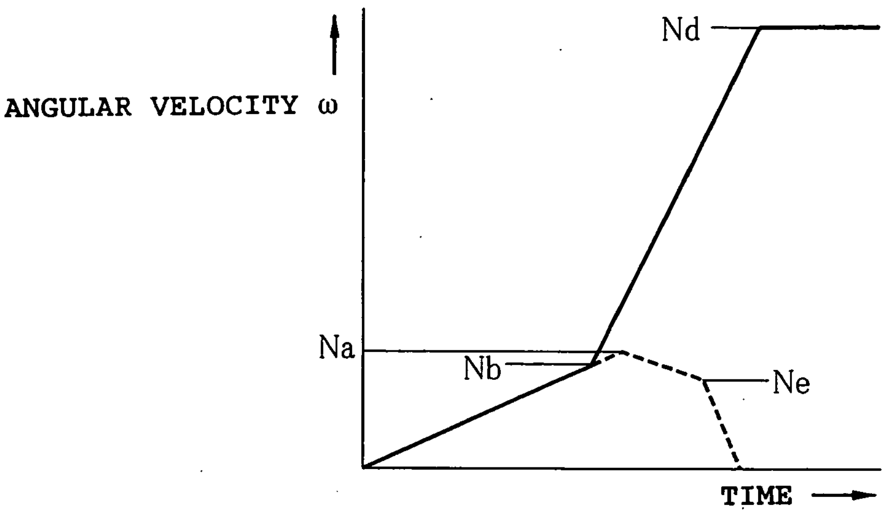

ANGULAR VELOCITY ω
Nd
Na
Nb
Ne
TIME

FIG.8

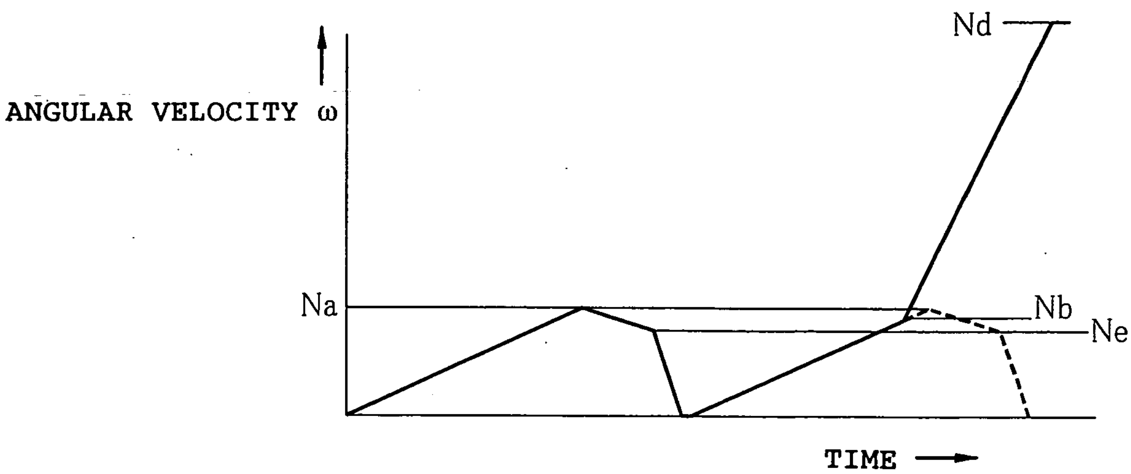

ANGULAR VELOCITY ω
Nd
Na
Nb
Ne
TIME

FIG.9

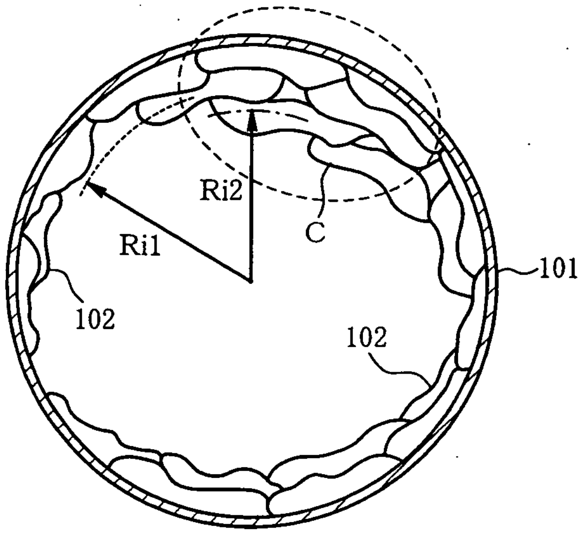


FIG.10A

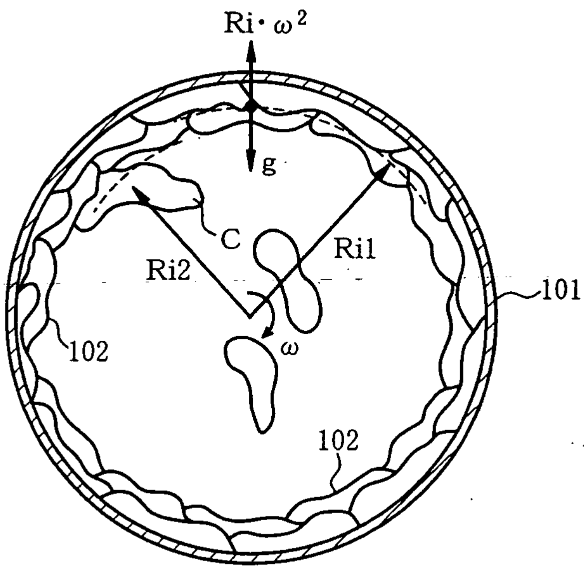


FIG.10B

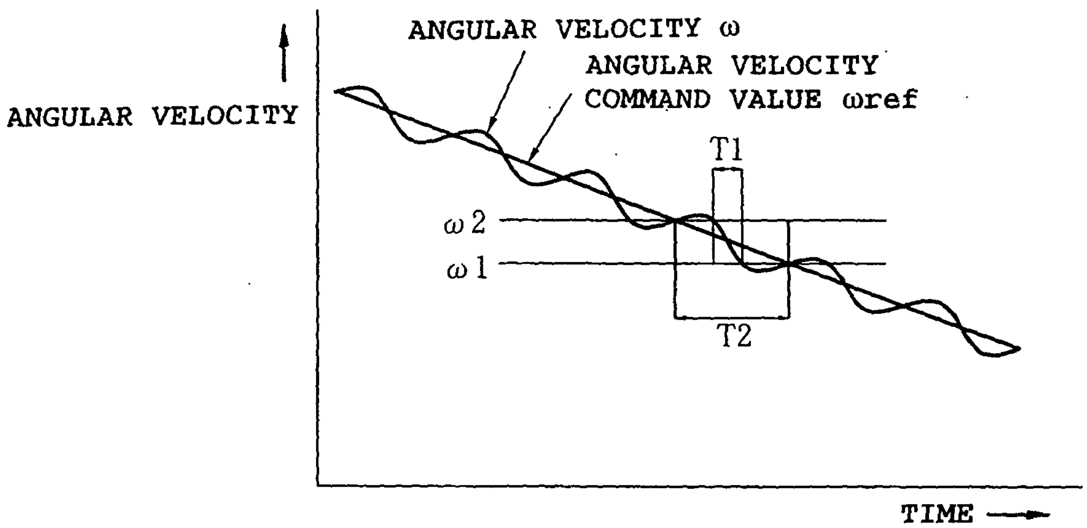


FIG.11 PRIOR ART

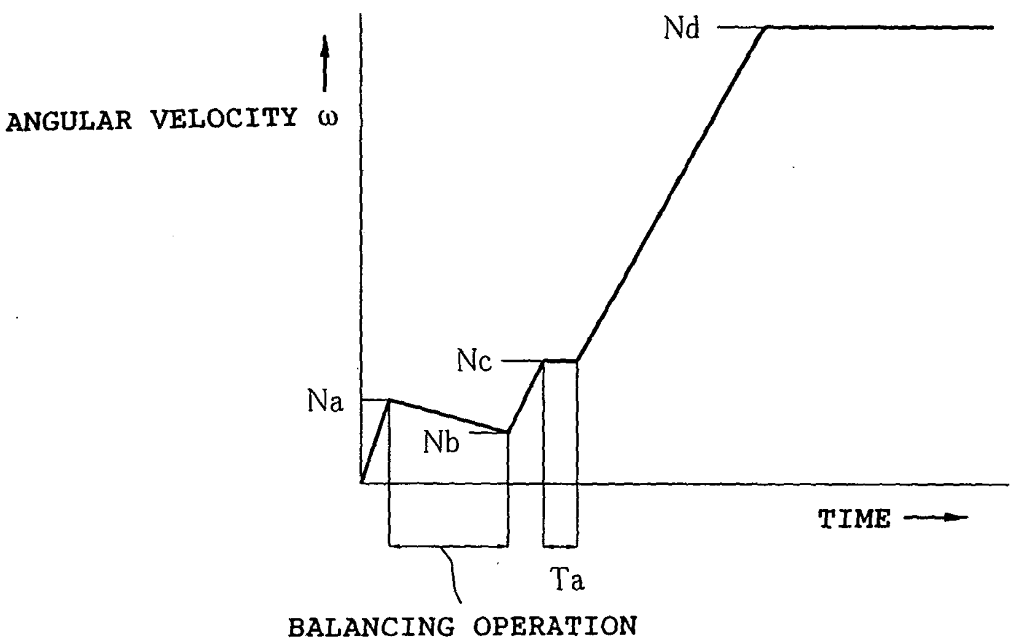


FIG.12 PRIOR ART

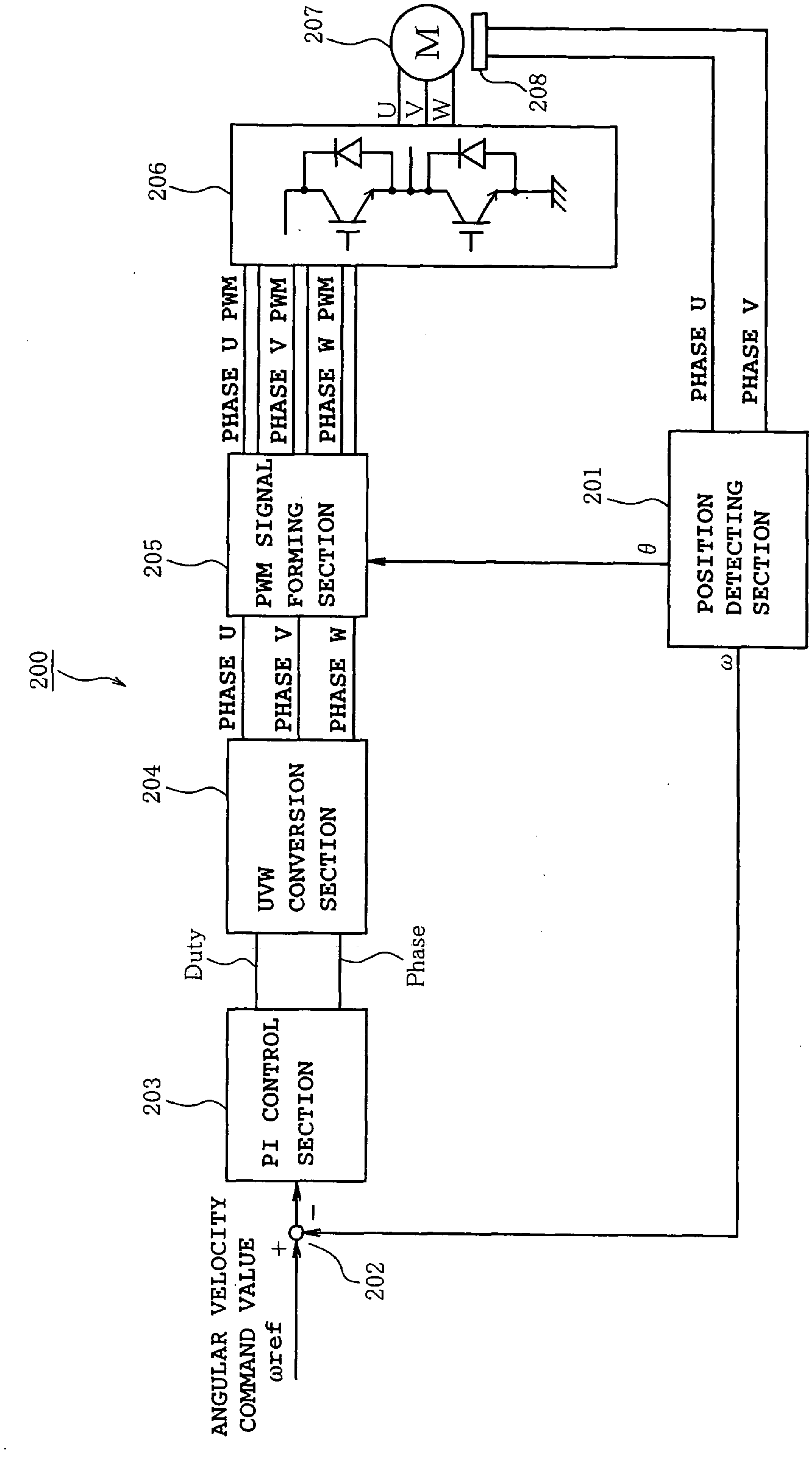


FIG.13 PRIOR ART

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP03/09215

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl^7 D06F33/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl^7 D06F1/00-51/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2003
Kokai Jitsuyo Shinan Koho	1971-2003	Toroku Jitsuyo Shinan Koho	1994-2003

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	JP 47-038114 B1 (Hitachi, Ltd.), 26 September, 1972 (26.09.72),	
X	Full text; Fig. 3	1,2
Y	Full text; Fig. 3 (Family: none)	3-6
	JP 8-266788 A (Sanyo Electric Co., Ltd.), 15 October, 1996 (15.10.96),	
X	Full text; Fig. 5	1,2
Y	Full text; Fig. 5 (Family: none)	3-6
Y	JP 2001-46780 A (Hitachi, Ltd.), 20 February, 2001 (20.02.01), Par. Nos. [0098] to [0099]; Fig. 10 & CN 1283719 A	3,4

☒ Further documents are listed in the continuati on of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 20 August, 2003 (20.08.03)	Date of mailing of the international search report 02 September, 2003 (02.09.03)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 1998)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP03/09215

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0903845 A2 (Matsushita Electric Industrial Co., Ltd.), 24 March, 1999 (24.03.99), Full text; all drawings & JP 11-319367 A & US 6163912 A	3,4
Y	JP 2001-310097 A (Yaskawa Electric Corp.), 06 November, 2001 (06.11.01), Par. No. [0010]; all drawings (Family: none)	5,6

Form PCT/ISA/210 (continuation of second sheet) (July 1998)