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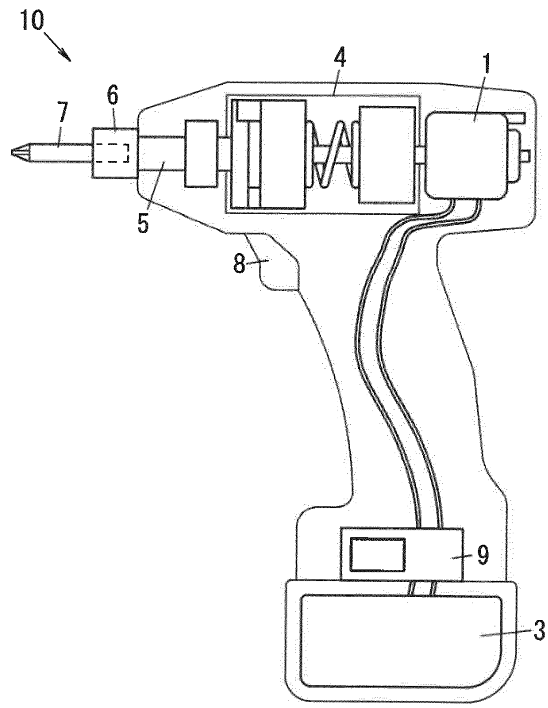
(54) ELECTRIC POWER TOOL

(57) Provided is an electric power tool for controlling a motor such that when the user lets the motor turn at a low velocity, the motor turns slowly and smoothly at the low velocity and that when the user attempts to run the motor at a high velocity, the motor quickly increases its velocity to the high rotational velocity. An electric power tool (10) according to an embodiment includes a motor (1), an operating unit (8), and a control unit (9). The motor (1) is a brushless motor to drive a tip tool (7). The operating unit (8) accepts a command for controlling a manipulated variable (LI, L3) defining the rotational velocity of the motor (1). The control unit (9) applies a voltage with a startup voltage pattern to the motor (1) at a startup time (t1) when the motor (1) has just started up. The control unit (9) controls the rotational velocity of the motor (1) to bring the rotational velocity of the motor (1) into conformity with a target rotational velocity ($\omega 2$, $\omega 4$) of the motor (1) after the motor (1) has started running (from t3 and on). The control unit (9) adjusts, according to the manipulated variable (LI, L3) entered through the operating unit (8) at the startup time (t1) of the motor (1), the startup voltage pattern of the voltage applied to the motor (1) at the startup time (t1) of the motor (1).

FIG. 1



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Description

Technical Field

[0001] The present disclosure generally relates to an electric power tool, and more particularly relates to an electric power tool designed to adjust the rotational velocity of its motor according to a manipulated variable of its operating unit.

Background Art

[0002] JP 2015-122823 A discloses a motor driving controller (as a type of an electric power tool) including: a motor; a trigger (operating unit); and a control means (control unit) for controlling the motor according to the manipulated variable of the trigger. This motor driving controller performs soft startup control to start the motor up with reliability, when the motor has just started turning, and then controls the motor such that the rotational velocity of the motor varies according to the manipulated variable of the trigger, after the motor has started running.

[0003] In the motor driving controller of JP 2015-122823 A, the drive voltage applied to the motor when the motor has just started up is fixed at a low voltage for the soft startup control. Therefore, even if the user attempts to quickly run the motor at a high velocity by pulling the trigger down at a time, the motor driving controller of JP 2015-122823 A is unable to quickly increase the rotational velocity of the motor to his or her desired high rotational velocity.

Summary of Invention

[0004] It is therefore an object of the present disclosure to provide an electric power tool with the ability to control the motor such that when the user lets the motor start up at a low velocity, the motor turns slowly and smoothly at the low velocity and that when the user attempts to run the motor at a high velocity, the motor quickly increases its velocity to the high rotational velocity.

[0005] An electric power tool according to an aspect of the present disclosure includes a motor, an operating unit, and a control unit. The motor is a brushless motor to drive a tip tool. The operating unit accepts a command for controlling a manipulated variable defining a rotational velocity of the motor. The control unit applies a voltage with a startup voltage pattern to the motor at a startup time when the motor has just started up. The control unit controls the rotational velocity of the motor to bring the rotational velocity of the motor into conformity with a target rotational velocity of the motor after the motor has started running. The control unit adjusts, according to the manipulated variable entered through the operating unit at the startup time of the motor, the startup voltage pattern of the voltage applied to the motor at the startup time of the motor.

Brief Description of Drawings

[0006]

FIG. 1 illustrates a schematic configuration for an electric power tool according to an exemplary embodiment;
FIG. 2 illustrates a circuit configuration for the electric power tool;
FIG. 3 is a timing diagram illustrating how the electric power tool performs commutation control;
FIG. 4 is a timing diagram illustrating how the electric power tool operates when its trigger switch is pulled slowly;
FIG. 5 is a timing diagram illustrating how the electric power tool operates when its trigger switch is pulled down at a time; and
FIG. 6 is a timing diagram showing how the duty cycle of an electric power tool according to a second variation changes with time.

Description of Embodiments

[0007] An embodiment of the present disclosure will be described. Note that the embodiment to be described below is only an exemplary one of various embodiments of the present disclosure and should not be construed as limiting. Rather, the exemplary embodiment may be readily modified in various manners depending on a design choice or any other factor without departing from a true spirit and scope of the present disclosure.

(Embodiment)

[0008] An electric power tool 10 according to this embodiment will be described with reference to FIGS. 1-5.

[0009] First, an overview of the electric power tool 10 will be described with reference to FIG. 1. As shown in FIG. 1, the electric power tool 10 is a tool for electrically driving a tip tool 7 by driving the tip tool 7 with the driving force applied from a motor 1. The electric power tool 10 includes the motor 1, a power supply 3, a driving force transmission unit 4, an output shaft 5, a chuck 6, the tip tool 7, a trigger switch (operating unit) 8, and a control unit 9.

[0010] The motor 1 is a drive source for driving the tip tool 7. The motor 1 may be implemented as, for example, a brushless motor with multi-phase (e.g., triphase) stator windings. The power supply 3 is a DC power supply for supplying a current for driving the motor 1 and may be implemented as, for example, a secondary battery, for example. The driving force transmission unit 4 decelerates the output (driving force) of the motor 1 and transmits the decelerated driving force to the output shaft 5. The output shaft 5 is a part to be driven (e.g., in rotation) by the driving force transmitted from the driving force transmission unit 4. The chuck 6 is fixed to the output shaft 5 and is a part to which the tip tool 7 is attached detachably.

The tip tool 7 may be formed in the shape of a driver, a socket, a drill, or any other form according to its intended use. A tip tool 7 is selected from various types of tip tools 7 according to the intended use, and attached to the chuck 6 to allow the user to do any type of machining he or she wants.

[0011] Note that the electric power tool 10 according to this embodiment includes the chuck 6 that makes the tip tool 7 replaceable depending on the intended use, which means that the tip tool 7 is an optional element, not an essential constituent element, for the electric power tool 10. However, the tip tool 7 does not have to be replaceable. Alternatively, the electric power tool 10 may also be designed so as to accept only a particular type of tip tool 7. In that case, the tip tool 7 is one of constituent elements of the electric power tool 10.

[0012] The trigger switch 8 is an operating unit through which a command for controlling a manipulated variable defining the rotational velocity of the motor 1 is entered. The ON/OFF states of the motor 1 are switchable by turning this trigger switch 8. In addition, the rotational velocity per unit time of the output shaft 5 (i.e., the rotational velocity of the motor 1) may also be regulated according to the manipulated variable of the trigger switch 8 (hereinafter simply referred to as a "trigger manipulated variable"). The magnitude of displacement of the trigger switch 8 from its reference position under the operating force corresponds to the manipulated variable. This trigger switch 8 has the manipulated variable transformed by a potentiometer, for example, into a voltage, has the voltage loaded thereto, and then outputs the voltage, as the manipulated variable entered through the trigger switch 8, to the control unit 9.

[0013] The control unit 9 controls the voltage applied from the power supply 3 to the motor 1 in response to the command entered through the trigger switch 8, thereby controlling the rotational velocity of the motor 1. The control unit 9 causes the motor 1 to either start or stop rotating depending on whether or not any command has been entered through the trigger switch 8. In addition, the control unit 9 also controls the rotational velocity of the motor 1 according to the manipulated variable of the trigger switch 8. Controlling the rotational velocity of the motor 1 by operating the trigger switch 8 allows the rotational velocity of the tip tool 7 to be controlled.

[0014] More specifically, when driving the motor 1 in rotation, the control unit 9 applies a drive voltage with a predetermined startup voltage pattern to the motor 1 during an initial startup period from a point in time when the voltage starts to be applied to the motor 1 through a point in time when the motor 1 starts running. Once the motor 1 has started running, the control unit 9 performs velocity control for controlling the drive voltage to be applied to the motor 1 such that while the motor 1 is being driven in rotation (i.e., velocity control period), the rotational velocity of the motor 1 is brought into conformity with the target rotational velocity that has been set in accordance with the trigger manipulated variable.

[0015] As used herein, the term "initial startup period" refers to a period in which the motor 1 does turn, but rotates just intermittently and does not smoothly rotate continuously. The phrase "the motor 1 starts running" means that the motor 1 starts smoothly rotating continuously. The term "startup voltage pattern" refers herein to a voltage pattern to be applied to the motor 1 to start the motor 1 up.

[0016] More specifically, the control unit 9 adjusts the voltage pattern of the drive voltage applied to the motor 1 at the startup time of the motor 1 (i.e., the startup voltage pattern) according to the trigger manipulated variable at the startup time of the motor 1 (i.e., when the voltage starts to be applied to the motor 1). Then, through the initial startup period, the control unit 9 continues to apply, to the motor 1, the startup voltage pattern that has been applied to the motor 1 at the startup time of the motor 1. That is to say, the control unit 9 is configured to select any one of a plurality of startup voltage patterns. The plurality of startup voltage patterns correspond to multiple different drive voltages and also correspond to multiple different trigger manipulated variables. The control unit 9 selects a startup voltage pattern corresponding to the trigger manipulated variable at the startup time of the motor 1 from a plurality of startup voltage patterns, and applies a drive voltage with the startup voltage pattern thus selected to the motor 1 at the startup time of the motor 1. Then, the control unit 9 continues to apply the drive voltage with the startup voltage pattern thus selected to the motor 1 through the initial startup period.

[0017] In this embodiment, the plurality of startup voltage patterns consists of a first voltage pattern and a second voltage pattern. As used herein, the first voltage pattern refers to a voltage pattern in which the trigger manipulated variable at the startup time of the motor 1 is less than a threshold manipulated variable and which has a relatively small drive voltage. On the other hand, the second voltage pattern refers herein to a voltage pattern in which the trigger manipulated variable at the startup time of the motor 1 is equal to or greater than the threshold manipulated variable and which corresponds to a higher drive voltage than the first voltage pattern.

[0018] When finding the trigger manipulated variable at the startup time of the motor 1 less than the threshold manipulated variable, the control unit 9 determines that the user should have pulled the trigger switch 8 slowly. In that case, to allow the motor 1 to turn slowly and smoothly, the control unit 9 applies a drive voltage with the first voltage pattern to the motor 1 at the startup time of the motor 1. This allows, when a command is entered through the trigger switch 8, the user to drive the motor 1 in rotation smoothly (i.e., without generating cocking or overshoot toward the high rotational velocity range) at a low rotational velocity. On the other hand, when finding the trigger manipulated variable at the startup time of the motor 1 equal to or greater than the threshold manipulated variable, the control unit 9 determines that the user should have pulled the trigger switch 8 down at a time.

In that case, to increase the rotational velocity of the motor 1 quickly (i.e., in a relatively short time), the control unit 9 applies a drive voltage with the second voltage pattern to the motor 1 at the startup time of the motor 1. This allows the user to quickly increase, by operating the trigger switch 8, the rotational velocity of motor 1 to his or her desired high rotational velocity.

[0019] In this embodiment, a predetermined time interval is provided between a point in time when a command is entered through the trigger switch 8 and a point in time when the motor 1 starts turning. Thus, when the user pulls the trigger switch 8 slowly, the trigger manipulated variable at the startup time of the motor 1 becomes a relatively small manipulated variable. On the other hand, when the user pulls the trigger switch 8 down at a time, the trigger manipulated variable at the startup time of the motor 1 becomes a relatively large manipulated variable. This allows the control unit 9 to determine, based on the trigger manipulated variable at the startup time of the motor 1, whether the user has pulled the trigger switch 8 slowly or at a time.

[0020] Next, an exemplary circuit configuration for the electric power tool 10 will be described with reference to FIG. 2. As shown in FIG. 2, the electric power tool 10 includes, as a circuit, the motor 1, the power supply 3, the trigger switch 8, and the control unit 9.

[0021] The motor 1 includes a rotor 1a and a stator 1b. The stator 1b includes stator windings U1, V1, and W1 in multiple phases (such as three phases, namely, U, V, and W phases) and a stator core 1c. The three-phase stator windings U1, V1, and W1 are connected together (in a stellar configuration in the example illustrated in FIG. 2). The stator core 1c is an iron core around which the three-phase stator windings U1, V1, and W1 are wound. The rotor 1a includes a permanent magnet with multiple sets (e.g., two sets) of N and S poles. The two sets of N and S poles are arranged alternately so as to interchange each other every 90 degrees in the rotational direction of the rotor 1a. The rotor 1a and the stator 1b face each other along the radius of the rotational axis of the rotor 1a.

[0022] The control unit 9 includes an inverter circuit 15, a driver circuit 18, a position detector circuit 19, and a control circuit 20.

[0023] The inverter circuit 15 generates, in accordance with control voltages H1-H6 applied from the driver circuit 18, three-phase (U1-, V1-, and W1-phase) voltages based on the voltage supplied from the power supply 3, and supplies the three-phase voltages thus generated to the stator windings U1, VI, and W1 of the motor 1, thus driving the motor 1 in rotation.

[0024] The inverter circuit 15 includes six switching elements Q1-Q6. The switching elements Q1-Q6 may be implemented as N-channel MOSFETs, for example. The switching elements Q1-Q6 are connected together to form three-phase bridges. The respective gates of the switching elements Q1-Q6 are connected to the driver circuit 18. The point of connection between the switching elements Q1 and Q2 is connected to the stator winding U1. The point of connection between the switching elements Q3 and Q4 is connected to the stator winding VI. The point of connection between the switching elements Q5 and Q6 is connected to the stator winding W1. The respective sources of the switching elements Q1, Q3, and Q5 are connected to the positive electrode of the power supply 3 through an onward path 22. The respective drains of the switching elements Q2, Q4, and Q6 are connected to the negative electrode of the power supply 3 through a homeward path 23.

[0025] In the following description, the switching elements Q1, Q3, and Q5 connected to the positive electrode of the power supply 3 will be hereinafter referred to as "upper-stage switching elements Q1, Q3, and Q5," while the switching elements Q2, Q4, and Q6 connected to the negative electrode of the power supply 3 will be hereinafter referred to as "lower-stage switching elements Q2, Q4, and Q6." Also, the switching elements Q1 and Q2 connected to the stator winding U1 will be hereinafter referred to as "U1-phase switching elements Q1 and Q2." The switching elements Q3 and Q4 connected to the stator winding VI will be hereinafter referred to as "VI-phase switching elements Q3 and Q4." The switching elements Q5 and Q6 connected to the stator winding W1 will be hereinafter referred to as "W1-phase switching elements Q5 and Q6."

[0026] Under the control (i.e., commutation control) of the control circuit 20, the driver circuit 18 applies control voltages H1-H6 to the respective gates of the switching elements Q1-Q6. Applying these control voltages allows the ON/OFF states of the switching elements Q1-Q6 to be controlled in a predetermined order. This control of their ON/OFF states allows three-phase voltages (drive voltages) to be generated based on the voltage supplied from the power supply 3, and the three-phase voltages thus generated are applied to the motor 1, thereby causing a current based on the three-phase voltages to flow through the stator windings U1, V1, and W1 of the motor 1 to rotate the rotor 1a. That is to say, the motor 1 is driven in rotation.

[0027] Under the control (velocity control) of the control circuit 20, the driver circuit 18 applies, as control voltages H1, H3, and H5, pulse-width modulated (PWM) control voltages to the respective gates of the upper-stage switching elements Q1, Q3, and Q5. Also, under the control of the control circuit 20, the driver circuit 18 applies, as control voltages H2, H4, and H6, non-pulse-width modulated rectangular-wave control voltages to the respective gates of the lower-stage switching elements Q2, Q4, and Q6. The driver circuit 18 adjusts the duty cycle of the PWM control voltages applied to the upper-stage switching elements Q1, Q3, and Q5, thereby controlling the amount of electricity supplied to the motor 1 and controlling the rotational velocity of the motor 1. As used herein, the "duty cycle" is the ratio of the pulse width of a control voltage (operating time) to one pulse cycle (total elapsed time) thereof.

[0028] Alternatively, non-PWM rectangular-wave control voltages may be applied as control voltages H1, H3, and H5 to the respective gates of the upper-stage switching elements Q1, Q3, and Q5. Also, PWM control voltages may also be applied as control voltages H2, H4, and H6 to the respective gates of the lower-stage switching elements Q2, Q4, and Q6.

[0029] The position detector circuit 19 detects the rotational position of the rotor 1a of the motor 1. The position detector circuit 19 includes a plurality of (e.g., three) Hall elements 19a, 19b, and 19c, which may be implemented as Hall ICs (integrated circuits). The Hall elements 19a, 19b, and 19c are arranged in the vicinity of the rotor 1a. The Hall elements 19a, 19b, and 19c are arranged every 60 degrees in the direction of rotation so as to face the permanent magnet. The Hall elements 19a, 19b, and 19c detect the magnetic force applied by the permanent magnet by electromagnetic coupling method, thereby detecting the rotational position of the rotor 1a.

[0030] The control circuit 20 may be implemented as a microcomputer, and may include a central processing unit (CPU), a read-only memory (ROM), a random access memory (RAM), and other components. The ROM serves as a storage unit for storing a processing program and control data. The RAM serves as storage for temporarily retaining data.

[0031] The control circuit 20 controls the driver circuit 18 based on the result of detection by the position detector circuit 19 and the manipulated variable entered through the trigger switch 8 (i.e., the trigger manipulated variable). The control circuit 20 performs commutation control for driving the motor 1 in rotation and velocity control for controlling the rotational velocity of the motor 1. In performing the commutation control, the control circuit 20 controls the control voltages H1-H6 to be applied to the respective gates of the switching elements Q1-Q6 such that in accordance with the result of detection by the position detector circuit 19, a current based on the three-phase voltages as described above flows through the stator windings U1, V1, and W1 to rotate the rotor 1a. This causes the motor 1 to be driven in rotation. On the other hand, in performing the velocity control, the control circuit 20 adjusts, according to the trigger manipulated variable, the duty cycle of the control voltages H1, H3, and H5 applied to the respective gates of the upper-stage switching elements Q1, Q3, and Q5. This allows the rotational velocity of the motor 1 to be controlled in accordance with the trigger manipulated variable.

[0032] The period for which the control circuit 20 performs the velocity control is made up of the initial startup period and the velocity control period. The initial startup period is the period from a point in time when the motor 1 starts turning to a point in time when the motor 1 starts running as described above. The velocity control period is a period following the initial startup period (i.e., a period on and after the point in time when the motor 1 starts running) as described above, and is a period in which the motor 1 rotates smoothly and continuously.

[0033] In the initial startup period, the control circuit 20 adjusts the duty cycle of the control voltages to be applied to the respective gates of the upper-stage switching elements Q1, Q3, and Q5 at the startup time of the motor 1 (hereinafter referred to as "startup duty cycle") according to the trigger manipulated variable at the startup time of the motor 1. This causes the voltage pattern of the drive voltage applied to the motor 1 at the startup time of the motor 1 (i.e., the startup voltage pattern) to vary according to the trigger manipulated variable at the startup time of the motor 1. Then, during the initial startup period, the control circuit 20 applies control voltages with the startup duty cycle thus adjusted to the respective gates of the upper-stage switching elements Q1, Q3, and Q5.

[0034] That is to say, the control circuit 20 has a plurality of startup duty cycles. The plurality of startup duty cycles are stored in a predetermined storage unit provided for the control circuit 20. The plurality of startup duty cycles correspond one to one to multiple different trigger manipulated variables and also correspond one to one to the plurality of startup voltage patterns. The control circuit 20 selects one duty cycle, corresponding to the trigger manipulated variable at the startup time of the motor 1, out of the plurality of startup duty cycles. Then, the control circuit 20 applies a control voltage with the selected duty cycle to the respective gates of the upper-stage switching elements Q1, Q3, and Q5 to which the voltage is applied at the startup time of the motor 1. Then, the control circuit 20 continues to apply the control voltage with the selected startup duty cycle to the respective gates of the upper-stage switching elements Q1, Q3, and Q5 to which the voltage is applied during the initial startup period.

[0035] Note that the startup voltage pattern refers herein to the drive voltage that the switching elements Q1, Q3, and Q5 subjected to the PWM control at the startup duty cycle apply to the motor 1. Thus, the startup voltage pattern also has the same PWM modulated waveform as the startup duty cycle. Also, the startup voltage pattern is formed based on the startup duty cycle. Thus, the control circuit 20 having a plurality of startup duty cycles is equivalent to the control circuit 20 having a plurality of startup voltage patterns.

[0036] In the velocity control period, the control circuit 20 sets the target rotational velocity of the motor 1 based on the trigger manipulated variable, and controls the duty cycle of the control voltages applied to the respective switching elements Q1-Q6 such that the rotational velocity of the motor 1 is brought into conformity with the target rotational velocity.

[0037] FIG. 3 is a timing diagram showing how the control unit 9 operates.

[0038] In FIG. 3, the upper three graphs show the respective waveforms of position detection signals Sa, Sb, and Sc output from the Hall elements 19a, 19b, and 19c, and induced voltages Va, Vb, and Vc generated on the stator windings U1, V1, and W1, respectively. The lower six graphs in FIG. 3 show the respective waveforms of the control voltages H1-H6 applied from the driver circuit 18 to the switching elements Q1-Q6, respectively.

[0039] The respective Hall elements 19a, 19b, and 19c detect the magnetic force applied from the permanent magnet of the rotor 1a rotating and output position detection signals Sa, Sb, and Sc with signal values of one or zero. In this embodiment, the rotor 1 a includes a four-pole permanent magnet with two sets of N and S poles, and therefore, the signal values of the position detection signals output from the respective Hall elements 19a, 19b, and 19c change into either one or zero every time the rotor 1a rotates 90 degrees. The timings at which the signal values of the respective position detection signals output from the respective Hall elements 19a, 19b, and 19c change shift from each other by 30 degrees. The signal values of the position detection signals Sa, Sb, and Sc of the respective Hall elements 19a, 19b, and 19c switch at the zero-crossing points of the induced voltages Va, Vb, and Vc. As used herein, the zero-crossing points refer to points in time when the induced voltages Va, Vb, and Vc cross zero.

[0040] The position detector circuit 19 detects, at the signal value switching timings of the position detection signals Sa, Sb, and Sc, the rotational position of the rotor 1a every time the rotational angle changes by 30 degrees. FIG. 3 illustrates how the signal values of the position detection signals Sa, Sb, and Sc change every time the rotational angle changes by 30 degrees.

[0041] In accordance with the position detection signals Sa, Sb, and Sc supplied from the position detector circuit 19, the control circuit 20 has the control voltages H1-H6 to be applied to the switching elements Q1-Q6 changed via the driver circuit 18 every time the rotational angle of the rotor 1a changes by 30 degrees.

[0042] In the example illustrated in FIG. 3, suppose a situation where the motor 1 starts turning at a point in time T0 and starts running at a point in time T2. In that case, the point in time T0 defines a startup time for the motor 1 and the point in time T2 defines a running start time for the motor 1. That is to say, the period from the point in time T0 through the point in time T2 defines the initial startup period and the period from the point in time T2 on defines the velocity control period. The control circuit 20 starts performing commutation control on the switching elements Q1-Q6 from the point in time T0. In that case, in the period from the point in time T0 through the point in time T2 (i.e., in the initial startup period), the control circuit 20 makes the driver circuit 18 apply a control voltage (e.g., H5 in the example illustrated in FIG. 3) with the startup duty cycle corresponding to the trigger manipulated variable at the startup time (T0) of the motor 1, out of a plurality of startup duty cycles, to an upper-stage switching element (such as Q5) to be subjected to the PWM control.

[0043] Then, in the period from the point in time T2 on (i.e., in the velocity control period), the motor 1 starts rotating smoothly and continuously. This allows the control circuit 20 to detect the rotational velocity of the motor 1 appropriately based on the position detection signals Sa, Sb, and Sc of the position detector circuit 19. Thus, the control circuit 20 makes the driver circuit 18 perform velocity control on the switching elements Q1-Q6 such that the rotational velocity of the motor 1 is brought into conformity with the target rotational velocity. That is to say, the control circuit 20 sets the target rotational velocity of the motor 1 based on the trigger manipulated variable. Then, the control circuit 20 makes the driver circuit 18 control the duty cycle of the control voltages H1, H3, and H5 to be applied to the upper-stage switching elements Q1, Q3, and Q5 to be subjected to the PWM control such that the rotational velocity of the motor 1 is brought into conformity with the target rotational velocity. In the example illustrated in FIG. 3, in the period from the point in time T2 to the point in time T4, the control circuit 20 makes the driver circuit 18 control the duty cycle of the control voltage H3 to be applied to the switching element Q3 such that the rotational velocity of the motor 1 is brought into conformity with the target rotational velocity. Subsequently, in the period from the point in time T4 to the point in time T6, the control circuit 20 makes the driver circuit 18 control the duty cycle of the control voltage H1 to be applied to the switching element Q1 such that the rotational velocity of the motor 1 is brought into conformity with the target rotational velocity.

[0044] Next, it will be described in further detail with reference to FIGS. 4 and 5 how the control unit 9 operates.

[0045] In FIGS. 4 and 5, the upper graph shows how the trigger manipulated variable changes with time. In FIGS. 4 and 5, the middle graph shows how the duty cycle of the control voltages H1, H3, and H5 to be applied to the switching elements Q1, Q3, and Q5, respectively, changes with time. In FIGS. 4 and 5, the lower graph shows how the rotational velocity of the motor 1 changes with time.

[0046] In the following description, regarding the control of the switching elements Q1-Q6, only the control of the switching elements Q1, Q3, and Q5 subjected to the PWM control will be described.

[0047] First, it will be described with reference to FIG. 4 how the control unit 9 operates when the user pulls the trigger switch 8 slowly. The trigger manipulated variable in a situation where the user slowly pulls the trigger switch 8 may slowly increase monotonically from the point in time (t0) when the trigger switch 8 starts to be operated to a point in time t2, and then stays constant trigger manipulated variable L2 from the time t2 on.

[0048] The control circuit 20 sets the target rotational velocity of the motor 1 according to the trigger manipulated variable. The target rotational velocity of the motor 1 may be proportional to the trigger manipulated variable, for example.

[0049] In the following description of this operation, at a point in time t1 when a certain amount of time has passed since the point in time t0 when a command started to be entered through the trigger switch 8, the control circuit 20 is supposed to start up the motor 1. Thereafter, at a point in time t3, the motor 1 is supposed to start running. In that case, the point in time t1 defines the turning start time (startup time) for the motor 1, and the point in time t3 defines the running start time for the motor 1. Therefore, the period from the point in time t1 to the point in time t3 defines the initial startup period and the period from the point in time t3 on defines the velocity control period.

[0050] At the point in time t1, the control circuit 20 selects a duty cycle DT1 corresponding to the trigger manipulated variable L1 at the startup time t1 of the motor 1 from a plurality of startup duty cycles. This duty cycle DT1 is a relatively small duty cycle because the trigger manipulated variable L1 at the startup time of the motor 1 (i.e., at the point in time tl) is relatively small. Then, the control circuit 20 starts applying a control voltage with the startup duty cycle DT1 selected at the startup time of the motor 1 (i.e., at the point in time T1) to the switching elements Q1, Q3, and Q5 to be subjected to the PWM control. Then, the control circuit 20 continues to apply the control voltage with the startup duty cycle DT1 to the respective gates of the switching elements Q1, Q3, and Q5 to be subjected to the PWM control until the motor 1 starts running.

[0051] Next, once the motor 1 starts running at the point in time t3, the control circuit 20 increases, at a constant rate, the duty cycle of the control voltages H1, H3, and H5 to be applied to the switching elements Q1, Q3, and Q5 to be subjected to the PWM control to a duty cycle DT2 such that the rotational velocity of the motor 1 approaches the target rotational velocity ω2. Note that the target rotational velocity ω2 corresponds to the manipulated variable L2. Thereafter, when the rotational velocity of the motor 1 reaches the target rotational velocity ω2 at the point in time t4, the control circuit 20 starts maintaining the duty cycle at DT2. This allows the rotational velocity of the motor 1 to be maintained at the rotational velocity ω2.

[0052] In this case, the startup duty cycle DT1 for use in the initial startup period is a relatively small duty cycle. This allows, when the motor 1 starts turning, the motor 1 to be driven in rotation at a low rotational velocity without causing cocking or overshoot toward a higher rotational velocity.

[0053] Next, it will be described with reference to FIG. 5 how the control unit 9 operates in a situation where the user pulls the trigger switch 8 down at a time. In the upper, middle, and lower portions of FIG. 5, the solid-line graph indicates the results obtained for the electric power tool 10 according to this embodiment. In the middle and lower portions of FIG. 5, the dotted line graphs G1 and G2 indicate the results obtained for an electric power tool as a comparative example.

[0054] In the electric power tool 10 according to this embodiment, the trigger manipulated variable in a situation where the user pulls the trigger switch 8 down at a time may steeply increase monotonically from the point in time when the trigger switch 8 starts to be operated (i.e., the point in time t0) to a point in time t2a and then stays a constant trigger manipulated variable L4 from the point in time t2a on.

[0055] The control circuit 20 sets the target rotational velocity of the motor 1 according to the trigger manipulated variable. The target rotational velocity of the motor 1 may be proportional to the trigger manipulated variable, for example.

[0056] In the following description of this operation, at a point in time t1 when a certain amount of time has passed since the point in time t0 when a command started to be entered through the trigger switch 8, the control circuit 20 is supposed to start up the motor 1. Thereafter, at a point in time t3a, the motor 1 is supposed to start running. In that case, the point in time t1 defines the turning start time (startup time) for the motor 1, and the point in time t3a defines the running start time for the motor 1. Therefore, the period from the point in time t1 to the point in time t3a defines the initial startup period and the period from the point in time t3a on defines the velocity control period.

[0057] At the point in time t1, the control circuit 20 selects a duty cycle DT3 corresponding to the trigger manipulated variable L3 at the startup time t1 of the motor 1 from a plurality of startup duty cycles. This duty cycle DT3 is larger than the startup duty cycle DT1 shown in FIG. 4 because the trigger manipulated variable L3 at the startup time for the motor 1 (i.e., at the point in time tl) is larger than the trigger manipulated variable L2 shown in FIG. 4. Then, the control circuit 20 starts applying a control voltage with the startup duty cycle DT3 selected at the startup time for the motor 1 (i.e., at the point in time t1) to the switching elements Q1, Q3, and Q5 to be subjected to the PWM control. Then, the control circuit 20 continues to apply the control voltage with the startup duty cycle DT3 to the respective gates of the switching elements Q1, Q3, and Q5 to be subjected to the PWM control until the motor 1 starts running.

[0058] Next, once the motor 1 starts running at the point in time t3a, the control circuit 20 increases, at a constant rate, the duty cycle of the control voltages H1, H3, and H5 to be applied to the switching elements Q1, Q3, and Q5 to be subjected to the PWM control to a duty cycle DT4 such that the rotational velocity of the motor 1 approaches the target rotational velocity ω4. Note that the target rotational velocity ω4 corresponds to the trigger manipulated variable L4. Thereafter, when the rotational velocity of the motor 1 reaches the target rotational velocity ω4 at the point in time t4a, the control circuit 20 starts maintaining the duty cycle at DT4. This allows the rotational velocity of the motor 1 to be maintained at the rotational velocity ω4.

[0059] In this operation, the startup duty cycle DT3 for use in the initial startup period is a relatively high duty cycle (i.e., a duty cycle higher than the startup duty cycle DT1). Therefore, the rotational velocity ω3 during the initial startup period is a relatively high rotational velocity (i.e., a rotational velocity higher than the rotational velocity ω1). This allows the duty cycle of the control voltages H1, H3, and H3 to be applied to the switching elements Q1, Q3, and Q5 to be increased quickly (i.e., in a relatively short time) from the startup duty cycle DT3 to the duty cycle DT4. This enables the rotational velocity of the motor 1 to be quickly increased from the rotational velocity ω3 to the rotational velocity ω4. Consequently, this allows, when the user pulls the trigger switch 8 down at a time, the rotational velocity of the motor 1 to be quickly increased to a high rotational velocity ω4 that the user wants.

[0060] On the other hand, as indicated by the dotted-line graphs G1 and G2 in FIG. 5, in an electric power tool as a comparative example (i.e., a known electric power tool), the startup duty cycle for use in the initial startup period (as indicated by the middle graph G1 in FIG. 5) is a constant duty cycle (such as DT1) irrespective of the trigger manipulated variable. Thus, even if the user pulls the trigger switch 8 down at a time, the startup duty cycle for use in the initial startup period also remains DT1. Therefore, if the duty cycle for use in the velocity control period is increased at a constant rate to the duty cycle DT4 on and after the point in time t3a when the motor starts running, then duty cycle reaches DT4 at a point in time t5. That is to say, the point in time t5 when DT4 is reached in the electric power tool as a comparative example is later than the point in time t4a when DT4 is reached in the electric power tool 10 according to this embodiment. Consequently, in the electric power tool as a comparative example, even if the user pulls the trigger switch 8 down at a time, the point in time t5 when the rotational velocity of the motor (as indicated by the lower graph G2 in FIG. 5) reaches the rotational velocity ω4 desirable for the user is still later than the point in time t4a in the case of the electric power tool 10 according to this embodiment.

(Variations)

[0061] Next, variations of the embodiment described above will be enumerated. Note that the embodiment described above is only an exemplary one of various embodiments of the present disclosure and should not be construed as limiting. Rather, the exemplary embodiment may be readily modified in various manners depending on a design choice or any other factor without departing from a true spirit and scope of the present disclosure. Variations to be described below may be adopted in combination as appropriate. In the following description of variations, any constituent element, having the same function as a counterpart of the exemplary embodiment described above, will be designated by the same reference numeral as that counterpart's, and a detailed description thereof will be omitted herein. Thus, the following description will be focused on only differences between the exemplary embodiment described above and the variations.

(First variation)

[0062] In the exemplary embodiment described above, the control unit 9 adjusts, according to the trigger manipulated variable at the startup time of the motor 1, the startup voltage pattern to be applied to the motor 1 that has just started turning. However, this is only an example and should not be construed as limiting. Alternatively, the control unit 9 may also adjust the startup voltage pattern according to the target rotational velocity of the motor 1 that has just started turning. Note that the target rotational velocity of the motor 1 may be set by the control unit 9 according to the trigger manipulated variable. For example, the greater the trigger manipulated variable is, the higher the target rotational velocity of the motor 1 may be set to be. The smaller the trigger manipulated variable is, the lower the target rotational velocity of the motor 1 may be set to be. That is why even if the startup voltage pattern to be applied to the motor 1 that has just started turning is adjusted according to the target rotational velocity of the motor 1 at the startup time of the motor 1, the same advantages as those of the exemplary embodiment described above are also achievable.

(Second variation)

[0063] In the embodiment described above, the startup voltage pattern to be applied to the motor 1 during the initial startup period is constant. That is to say, the startup duty cycle of the control voltages to be applied to the respective gates of the switching elements Q1, Q3, and Q5 subjected to the PWM control during the initial startup period is constant. However, this is only an example and should not be construed as limiting. Alternatively, the startup voltage pattern may be changed in the middle of the initial startup period. That is to say, the startup duty cycle may be changed in the middle of the initial startup period.

[0064] For example, suppose a situation where the motor 1 will not rotate at all at the startup duty cycle of the drive voltage applied to the motor 1 at the startup time of the motor 1. In that case, as shown in FIG. 6, the startup duty cycle may be increased stepwise by a constant percentage every time a predetermined amount of time passes since the startup time t1 of the motor 1 as shown in FIG. 6. In the example illustrated in FIG. 6, the startup duty cycle during the initial startup period is DT3 at the startup time t1 of the motor 1, and is increased to DT3a (> DT3) at a time t3, which is later by a predetermined amount of time than the time t1. In the example illustrated in FIG. 6, the startup duty cycle is increased stepwise. However, this is only an example and should not be construed as limiting. Alternatively, the startup duty cycle may be decreased stepwise.

[0065] According to this variation, changing the startup voltage pattern in the middle of the initial startup period allows the drive voltage to be applied to the motor 1 that has just started turning to be regulated to an appropriate voltage for the motor 1 to start rotating.

(Third variation)

[0066] In the second variation described above, when the startup voltage pattern is changed in the middle of the initial startup period, the startup voltage pattern may be adjusted according to the trigger manipulated variable. That is to say, when changed in the middle of the initial startup period, the startup duty cycle may be adjusted according to the trigger manipulated variable. For example, when the trigger switch 8 is pulled down at a time to cause a steep increase in the trigger manipulated variable, the startup duty cycle may be changed into a larger duty cycle more quickly during the initial startup period. Alternatively, when the trigger switch 8 is pulled slowly to cause a gentle increase in the trigger manipulated variable, the startup duty cycle may be changed into a larger duty cycle more gently during the initial startup period. This variation allows the startup voltage pattern to be adjusted according to the trigger manipulated variable after the motor 1 has started turning.

(Resume)

[0067] An electric power tool (10) according to a first aspect includes a motor (1), an operating unit (8), and a control unit (9). The motor (1) is a brushless motor to drive a tip tool (7). The operating unit (8) accepts a command for controlling a manipulated variable defining a rotational velocity of the motor (1). The control unit (9) applies a voltage with a startup voltage pattern to the motor (1) at a startup time (t1) when the motor (1) has just started up. The control unit (9) controls the rotational velocity of the motor (1) to bring the rotational velocity of the motor (1) into conformity with a target rotational velocity (ω2, ω4) of the motor (1) after the motor (1) has started running (from t3 and on). The control unit (9) adjusts, according to the manipulated variable (LI, L3) entered through the operating unit (8) at the startup time (t1) of the motor (1), the startup voltage pattern of the voltage applied to the motor (1) at the startup time (t1) of the motor (1).

[0068] This configuration allows the user to adjust, according to the manipulated variable (LI, L3) at the startup time (t1) of the motor (1), the startup voltage pattern of the voltage applied to the motor (1) at the startup time (t1) of the motor (1). This allows, when the user lets the motor (1) turn at a low velocity by pulling the operating unit (8) slowly, the rotational velocity of the motor (1) to be controlled at a low velocity so that the motor (1) rotates smoothly and slowly without causing cocking or sudden overshoot to a high rotational velocity on and after the time (t3) when the motor (1) starts running. On the other hand, this also allows, when the user attempts to run the motor (1) at a high velocity by pulling the operating unit (8) down at a time, the rotational velocity of the motor (1) to quickly increase and reach the user's desired high rotational velocity (ω4).

[0069] In an electric power tool (10) according to a second aspect, which may be implemented in conjunction with the first aspect, the control unit (9) sets the target rotational velocity (ω1-ω4) based on the manipulated variable (L1-L4) of the operating unit (8) and also adjusts, according to a setting of the target rotational velocity (ω1, ω3) that has been selected at the startup time (t1) of the motor (1), the startup voltage pattern of the voltage applied to the motor (1) at the startup time (t1) of the motor (1).

[0070] This configuration allows the startup voltage pattern to be adjusted according to the target rotational velocity (ω1, ω3) of the motor (1).

[0071] In an electric power tool (10) according to a third aspect, which may be implemented in conjunction with the first or second aspect, the control unit (9) changes the startup voltage pattern in the middle of an initial startup period that begins at the startup time (t1) of the motor (1) and ends at a time (t3, t3a) when the motor (1) starts running.

[0072] This configuration allows the drive voltage applied to the motor (1) after the motor (1) has started up (from t1 and on) to be regulated toward a voltage suitable for the motor (1) to start running by changing the startup voltage pattern in the middle of the initial startup period.

[0073] In an electric power tool (10) according to a fourth aspect, which may be implemented in conjunction with the third aspect, the control unit (9) adjusts, in the middle of the initial startup period, the startup voltage pattern according to a manipulated variable entered through the operating unit (8).

[0074] This configuration allows the startup voltage pattern to be adjusted according to a manipulated variable entered through the operating unit (8) after the motor (1) has started up (from t1 and on). This allows, when the user attempts to run the motor (1) at a high rotational velocity by pulling the operating unit (8) down at a time, the voltage with the startup voltage pattern to be increased according to a manipulated variable entered through the operating unit (8). Thus, the rotational velocity of the motor (1) is able to reach the user's desired high rotational velocity (ω4) quickly by accelerating the time (t3a) when the motor (1) starts running.

[0075] In an electric power tool (10) according to a fifth aspect, which may be implemented in conjunction with any one of the first to fourth aspects, the control unit (9) has a plurality of startup voltage patterns corresponding to multiple different manipulated variables. The control unit (9) selects, from the plurality of startup voltage patterns, a startup voltage pattern corresponding to the manipulated variable (LI, L3) at the startup time (t1) of the motor (1), and applies a voltage with the selected startup voltage pattern to the motor (1) at the startup time (t1) of the motor (1).

[0076] This configuration allows the startup voltage pattern to be adjusted according to the manipulated variable by simple processing.

Reference Signs List

[0077]

1	Motor
7	Tip Tool
8	Operating Unit
9	Control Unit
10	Electric Power Tool
L1-L4	Manipulated Variable
t1	Startup Time for Motor
t3, t3a	Running Start Time for Motor
ω1-ω4	Target Rotational Velocity

Claims

1. An electric power tool (10) comprising:

   a motor (1) of a brushless type configured to drive a tip tool (7);
   an operating unit (8) configured to accept a command for controlling a manipulated variable defining a rotational velocity of the motor (1); and
   a control unit (9) configured to apply a voltage with a startup voltage pattern to the motor (1) at a startup time (t1) when the motor (1) has just started up and to control the rotational velocity of the motor (1) to bring the rotational velocity of the motor (1) into conformity with a target rotational velocity (ω2, ω4) of the motor (1) after the motor (1) has started running,
   the control unit (9) being configured to adjust, according to the manipulated variable entered through the operating unit (8) at the startup time (t1) of the motor (1), the startup voltage pattern of the voltage applied to the motor (1) at the startup time (t1) of the motor (1).

2. The electric power tool (10) of claim 1, wherein the control unit (9) is configured to set the target rotational velocity (ω1-ω4) based on the manipulated variable (L1-L4) and also configured to adjust, according to a setting of the target rotational velocity (ω1, ω3) that has been selected at the startup time (t1) of the motor (1), the startup voltage pattern of the voltage applied to the motor (1) at the startup time (t1) of the motor (1).

3. The electric power tool (10) of claim 1 or 2, wherein the control unit (9) is configured to change the startup voltage pattern in the middle of an initial startup period that begins at the startup time (t1) of the motor (1) and ends at a time (t3, t3a) when the motor (1) starts running.

4. The electric power tool (10) of claim 3, wherein the control unit (9) is configured to adjust the startup voltage pattern according to a manipulated variable entered through the operating unit (8) in the middle of the initial startup period.

5. The electric power tool (10) of any one of claims 1 to 4, wherein
   the control unit (9) has a plurality of startup voltage patterns corresponding to multiple different manipulated variables, and
   the control unit (9) is configured to select, from the plurality of startup voltage patterns, a startup voltage pattern corresponding to the manipulated variable at the startup time (t1) of the motor (1), and apply a voltage with the selected startup voltage pattern to the motor (1) at the startup time (t1) of the motor (1).

FIG. 1

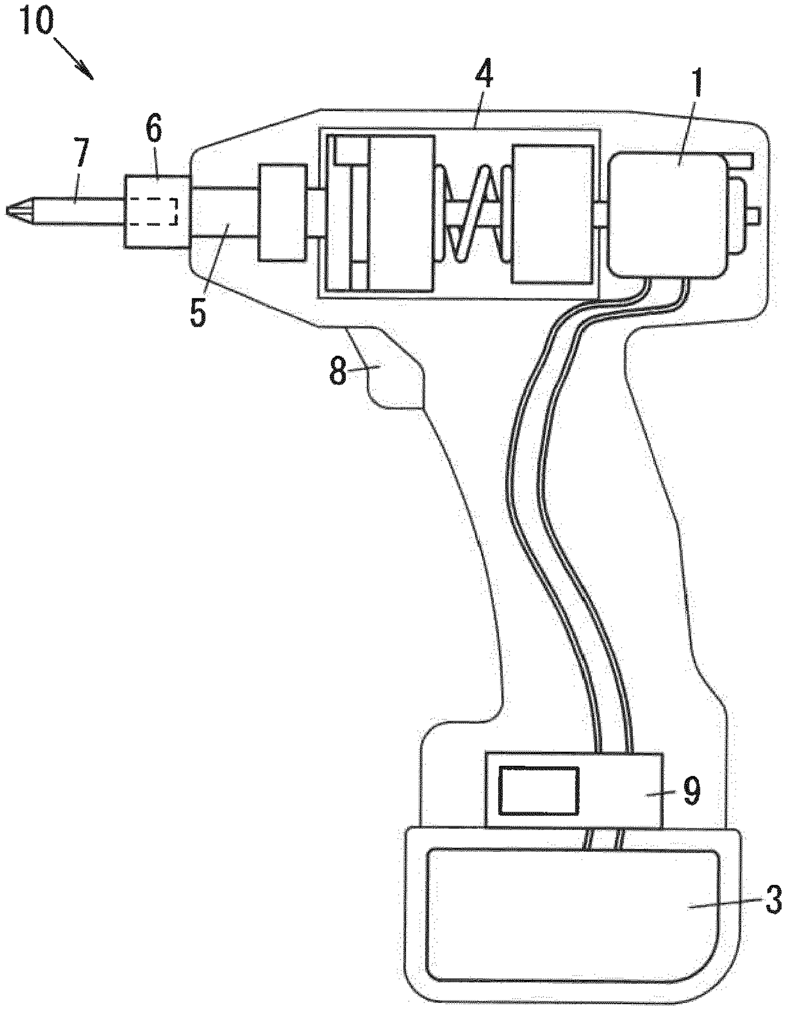
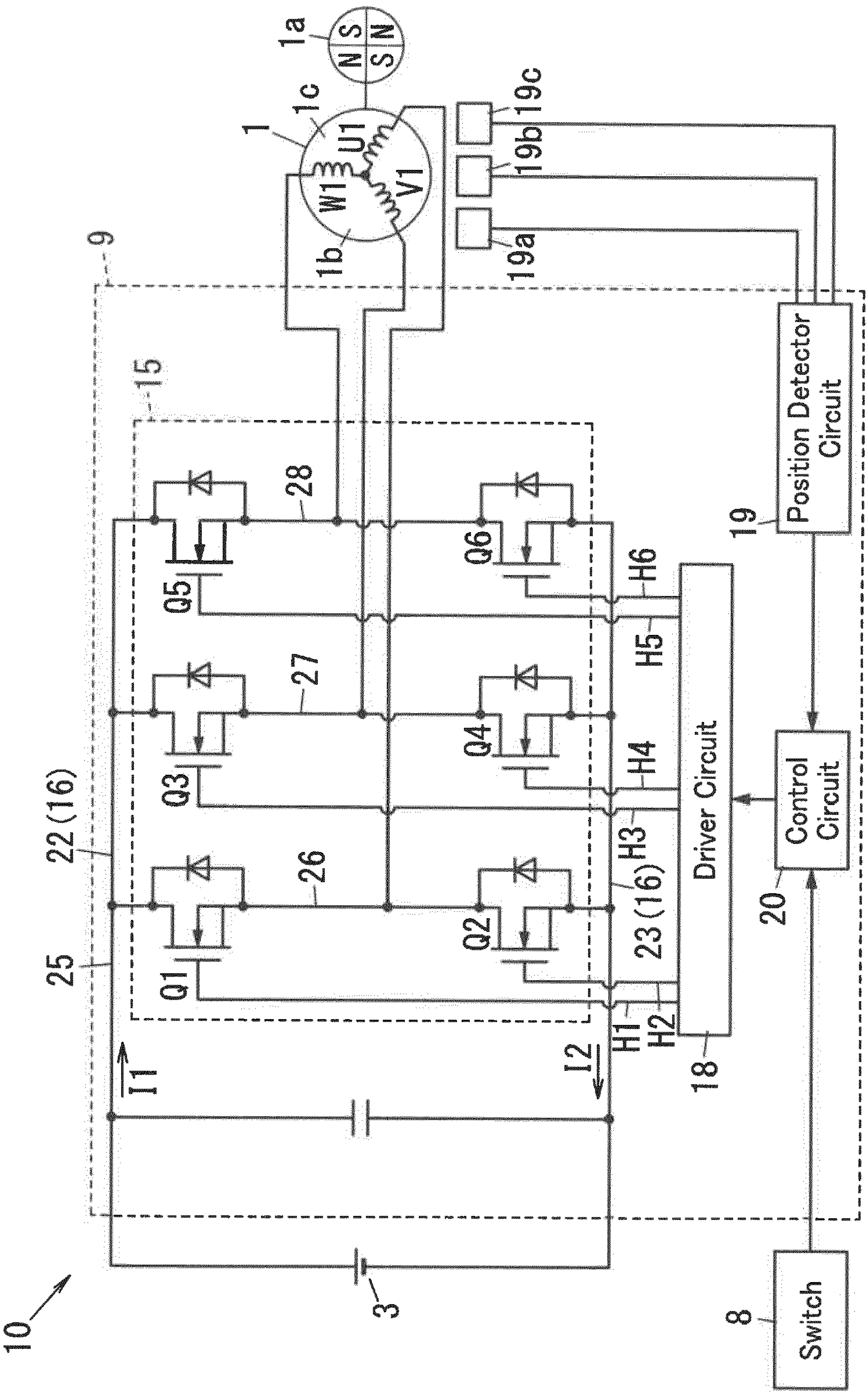


FIG. 2



Position Detector Circuit
Control Circuit
Driver Circuit
Switch
N
S
U1
V1
W1
Q1
Q2
Q3
Q4
Q5
Q6
H1
H2
H3
H4
H5
H6
I1
I2
1
1a
1b
1c
3
8
9
10
15
18
19
19a
19b
19c
20
22 (16)
23 (16)
25
26
27
28

FIG. 3

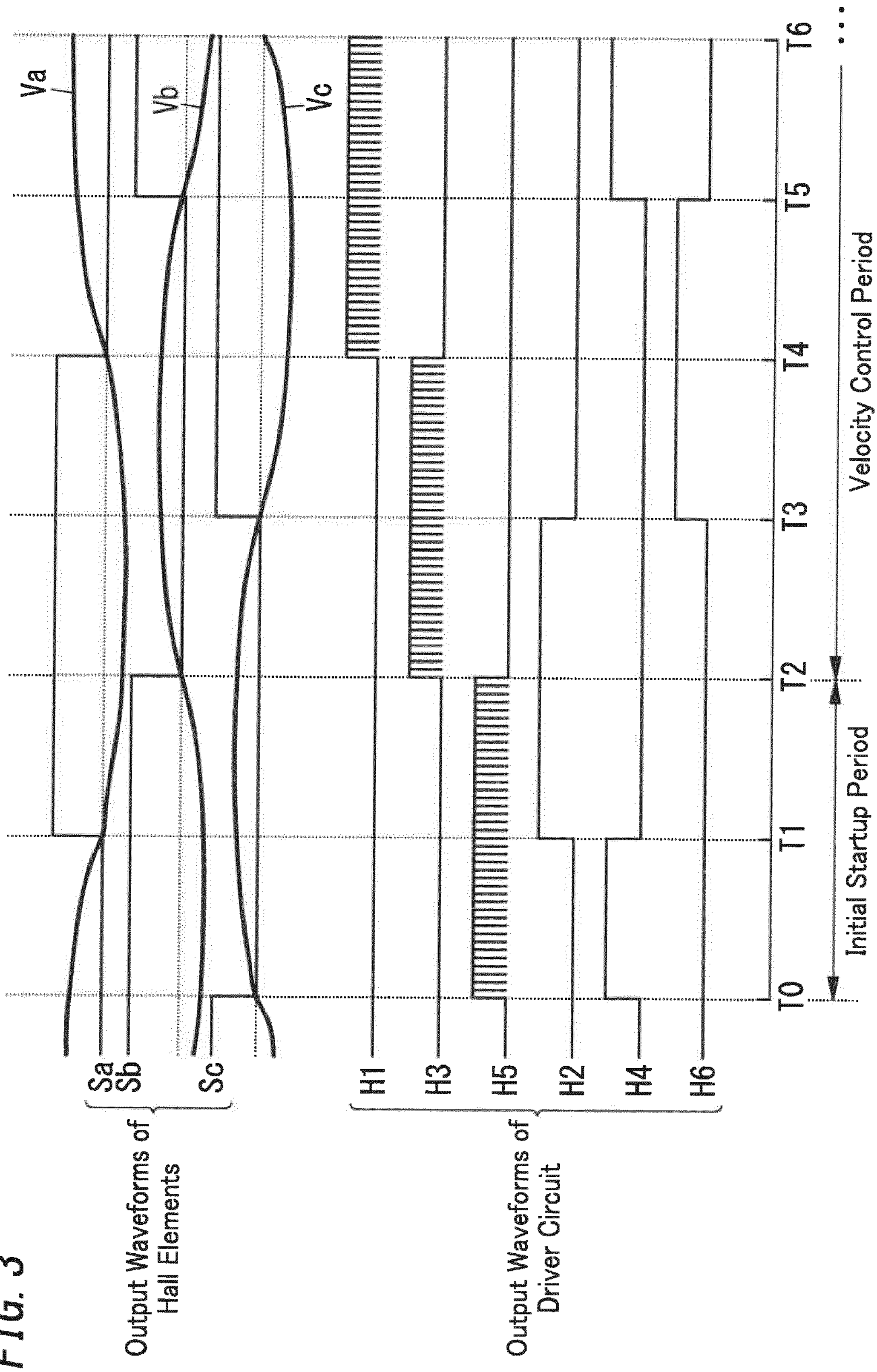

Va
Vb
Vc
Output Waveforms of Hall Elements
Sa
Sb
Sc
Output Waveforms of Driver Circuit
H1
H3
H5
H2
H4
H6
T0
T1
T2
T3
T4
T5
T6
Initial Startup Period
Velocity Control Period

FIG. 4

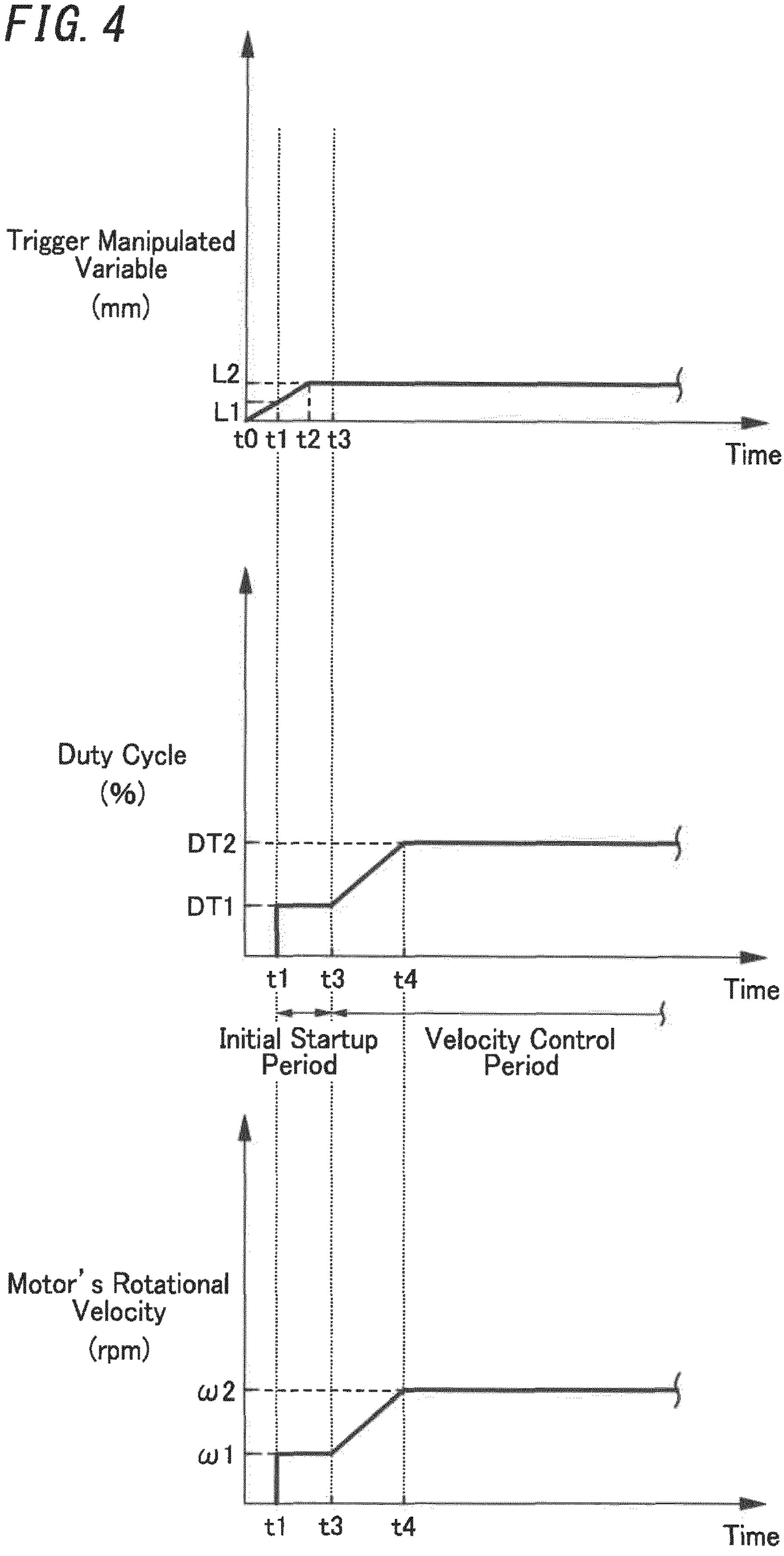

Trigger Manipulated Variable (mm)
L2
L1
t0 t1 t2 t3
Time
Duty Cycle (%)
DT2
DT1
t1 t3 t4
Time
Initial Startup Period
Velocity Control Period
Motor's Rotational Velocity (rpm)
ω2
ω1
t1 t3 t4
Time

FIG. 5

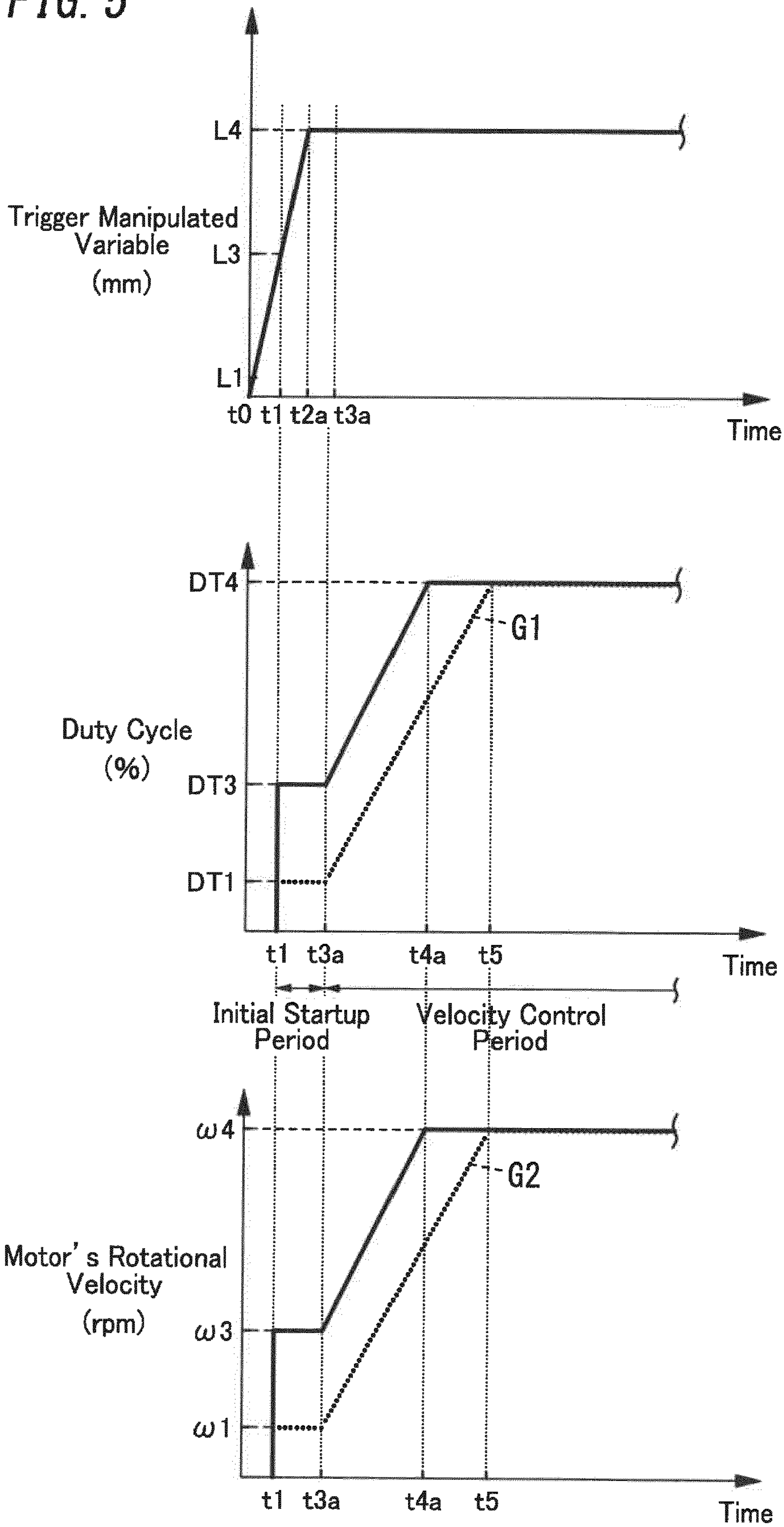
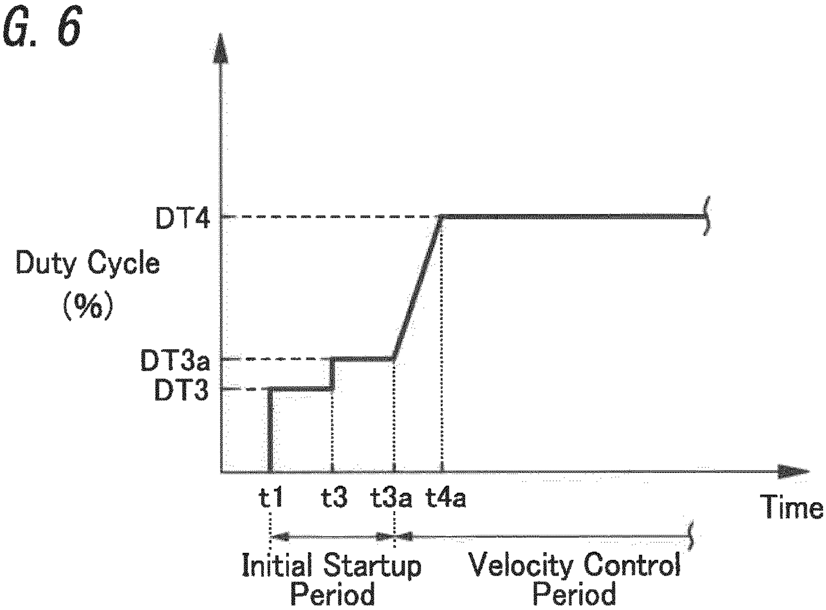

L4
Trigger Manipulated Variable (mm)
L3
L1
t0 t1 t2a t3a
Time
DT4
G1
Duty Cycle (%)
DT3
DT1
t1 t3a t4a t5
Time
Initial Startup Period
Velocity Control Period
ω4
G2
Motor's Rotational Velocity (rpm)
ω3
ω1
t1 t3a t4a t5
Time

FIG. 6


DT4
Duty Cycle
(%)
DT3a
DT3
t1
t3
t3a
t4a
Time
Initial Startup Period
Velocity Control Period

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EUROPEAN SEARCH REPORT

Application Number
EP 20 16 6759

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B25B
B25H

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
The Hague	1 September 2020	Adam, Emmanuel

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