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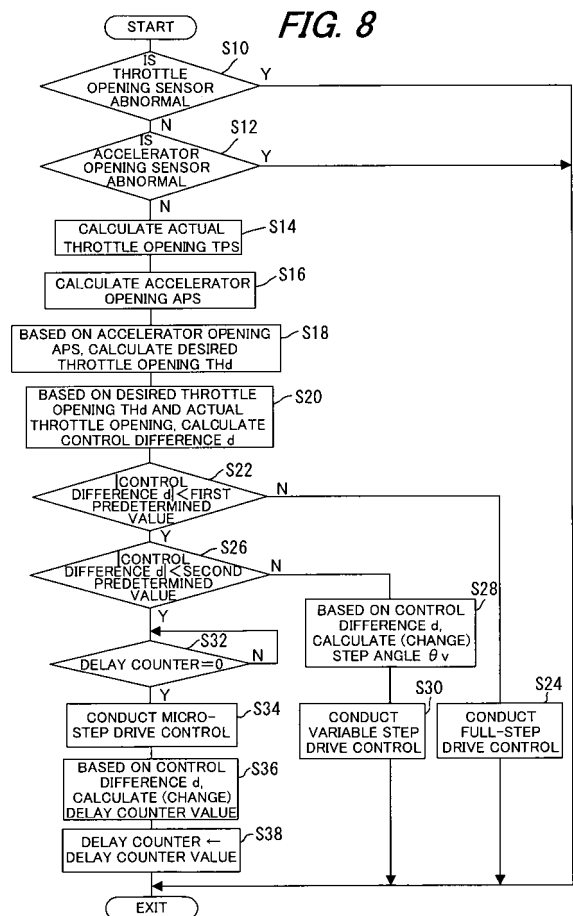
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(54) **Control system for internal combustion engine**

(57) In a system for controlling an internal combustion engine (12) mounted on a vehicle (10) and having an electric motor (44) that drives a throttle valve (24) installed in an intake pipe (22) of the engine and an accelerator (16) installed to be operable by the operator, it is configured to comprise a motor controller that conducts one of a full-step drive control for driving the motor at a full-step angle θ_f , a micro-step drive control for driving the motor at a micro-step angle θ_m which is made by dividing the full-step angle and a variable-step drive control for driving the motor at a step angle θ_v which changes in response to a control difference d between actual throttle opening and desired throttle opening, and controls the operation of the motor so as to decrease the difference (66, S24, S30, S34). With this, it becomes possible to improve response and control accuracy of the throttle valve and also enhances drivability.



Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] This invention relates to a control system for an internal combustion engine, particularly to a control system for an internal combustion engine that controls operation of an electric motor that drives a throttle valve installed in an intake pipe of the engine mounted on a vehicle such as a motorcycle.

Description of the Related Art

[0002] In recent years, so-called Drive-By-Wire control systems for internal combustion engines have been known in which mechanical interconnection between an accelerator and a throttle valve is omitted and the throttle valve is driven by an electric motor. For such a system, there is proposed a technique of improving response and control accuracy of the throttle valve by, for example, Japanese Laid-Open Patent Application No. Hei 9 (1997)-317538. In the prior art, when the throttle valve is in the area where overshoot likely occurs, a rate of change of throttle opening is lowered, while, when it is in the area where the throttle opening is likely delayed in reaching desired throttle opening, the rate of change is raised.

[0003] In a case that the above-mentioned motor is a three-phase brushless DC motor, a control mode utilized should be a full-step drive control that drives the motor with two-phase excitation at the full-step angle or a micro-step drive control that drives the motor with three-phase excitation at the micro-step angle which is made by dividing the full-step angle. The full-step drive control is characterized in that the motor is driven at high speed, resulting in good response, but control accuracy is low. On the other hand, the micro-step drive control is characterized in that the motor is driven at low speed, so response is not as good as the full-step drive control, but control accuracy is ensured.

[0004] Therefore, when the engine is operated under no load such as idling, i.e., control accuracy of the throttle valve is required, the micro-step drive control is conducted and when the engine is in the normal operation under a load, i.e., the good response is required, the full-step drive control is conducted.

[0005] However, although the slight operation of the accelerator by the operator (driver) requires control accuracy even during the normal operation, if the motor is driven with the full-step drive control, desired control accuracy can not be achieved and it disadvantageously lowers drivability.

SUMMARY OF THE INVENTION

[0006] An object of this invention is therefore to over-

come the foregoing drawback by providing a control system for an internal combustion engine that improves response and control accuracy of a throttle valve and also enhances drivability.

5 **[0007]** In order to achieve the object, this invention provides a system for controlling an internal combustion engine mounted on a vehicle and having an electric motor that drives a throttle valve installed in an intake pipe of the engine and an accelerator installed to be operable
10 by the operator, characterized by: a throttle opening detector that detects actual opening of the throttle valve; an accelerator opening detector that detects opening of the accelerator; a desired throttle opening calculator that calculates desired opening of the throttle valve based at
15 least on the detected opening of the accelerator; a throttle opening difference calculator that calculates a difference between the detected actual opening and the calculated desired opening of the throttle valve; and a motor controller that conducts one of a full-step drive control for
20 driving the motor at a full-step angle, a micro-step drive control for driving the motor at a micro-step angle which is made by dividing the full-step angle and a variable-step drive control for driving the motor at a step angle which changes in response to the calculated difference, and controls the operation of the motor so as to decrease
25 the calculated difference.

BRIEF DESCRIPTION OF THE DRAWINGS

30 **[0008]** The above and other objects and advantages of the invention will be more apparent from the following description and drawings in which:

FIG 1 is an overall view schematically showing a control system for an internal combustion engine according to an embodiment of this invention;

FIG. 2 is a cross-sectional view showing an electric motor shown in FIG 1 disposed in a throttle system of the engine;

35 FIG 3 is a circuit diagram schematically showing the configuration of the motor shown in FIG. 1 including a motor drive circuit;

FIG 4 is a set of explanatory views showing, inter alia, signals inputted to base terminals of transistors shown in FIG 3;

FIG 5 is a time chart showing, inter alia, the operation of the motor shown in FIG 3;

FIG. 6 is a set of explanatory views similar to FIG 4 showing, inter alia, signals inputted to the base terminals of the transistors shown in FIG 3;

FIG 7 is a time chart similar to FIG. 5 showing, inter alia, the operation of the motor shown in FIG. 3;

FIG 8 is a flowchart showing the operation of the control system shown in FIG. 1;

55 FIG. 9 is a graph showing the characteristics of a step angle with respect to a control difference, which is used in the processing of the flowchart of FIG 8; and

FIG 10 is a graph showing the characteristics of a delay counter value with respect to the control difference, which is used in the processing of the flow-chart of FIG. 8.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0009] A control system for an internal combustion engine according to a preferred embodiment of the present invention will now be explained with reference to the attached drawings.

[0010] FIG. 1 is an overall view schematically showing a control system for an internal combustion engine according to an embodiment of this invention.

[0011] In FIG 1, reference numeral 10 designates a saddle-seat vehicle, specifically a motorcycle. The motorcycle 10 is mounted with an internal combustion engine 12 and equipped with a handlebar 14 attached to the upper end of a telescopic fork (not shown) of a front wheel and other equipment. The engine 12 is a 4-cycle, single-cylinder, water-cooled gasoline engine having a displacement of 250 cc or thereabout.

[0012] The right end of the handlebar 14 (as viewed by the operator) is equipped with an accelerator 16, precisely an accelerator 16 constituted as a throttle grip to be operable by the operator, and with a front wheel brake lever 20 to be operable by the operator. The front wheel brake lever 20 is mechanically connected to a front wheel brake through a hydraulic cylinder (neither shown). When operated (gripped) by the operator, it operates the front wheel brake to brake the front wheel. The left end of the handlebar 14 is equipped with a grip that the operator can grip and with a clutch lever, but they are neither explained nor illustrated here, since not directly related to the gist of this invention.

[0013] A throttle valve 24 installed in an air intake pipe 22 (partially shown in FIG 1) of the engine 12 regulates the amount of intake air passing through the air intake pipe 22. An injector (not shown) is installed downstream of the throttle valve 24 in the air intake pipe 22 for injecting gasoline fuel into the intake air regulated by the throttle valve 24. The fuel injected by the injector mixes with intake air to form an air-fuel mixture that flows into a combustion chamber 30 when an intake valve 26 opens.

[0014] The air-fuel mixture flowing into the combustion chamber 30 is ignited to burn by a spark discharge from a spark plug 32 supplied with high voltage from an ignition coil (not shown), thereby driving a piston 34 downward in FIG. 1 to rotate a crankshaft 36. When an exhaust valve 40 opens, the exhaust gas produced by the combustion passes through an exhaust pipe, catalyst for removing harmful components of the exhaust gas (neither shown) and the like to be discharged outside the engine 12.

[0015] As shown in FIG. 1, the throttle valve 24 is mechanically separated from the accelerator (throttle grip) 16. Specifically, the throttle valve 24 is connected to an

electric motor (actuator) 44 through a reduction gear mechanism 42 to be driven by the operation of the motor 44. The motor 44 is constituted of a three-phase brushless DC motor having a rotor, stator and the like. The throttle valve 24 is thus operated by a DBW (Drive-By-Wire) system using the motor 44.

[0016] A hall sensor or rotor position sensor 50 having hall elements (explained later) attached near the rotor is provided at the motor 44 and produces an output or signal in response to a position of the rotor. A throttle opening sensor (throttle opening detector) 52 constituted of a potentiometer is provided near the throttle valve 24 and produces an output or signal indicative of the actual opening of the throttle valve 24 (hereinafter called the "actual throttle opening") between around 0 degree and around 90 degrees.

[0017] An accelerator opening sensor (accelerator opening detector) 54 similarly constituted of a potentiometer is provided near the accelerator 16 and produces an output or signal in response to the actual opening of the accelerator 16 (more exactly, the amount of rotation of the throttle grip). The opening of the accelerator 16 is set to a value corresponding to throttle opening near 0 degree as the initial position and to throttle opening near 90 degrees at full rotation.

[0018] An intake air pressure sensor or absolute pressure sensor 56 installed at an appropriate position of the air intake pipe 22 produces an output or signal indicative of the absolute pressure in the air intake pipe 22 (engine load). A coolant temperature sensor 60 attached to a coolant passage (not shown) of the cylinder block of the engine 12 produces an output or signal corresponding to the engine coolant temperature. A crank angle sensor 62 installed near the crankshaft 36 of the engine 12 outputs a pulse signal at a predetermined crank angle.

[0019] The motorcycle 10 is further equipped with an engine controller 64 that controls fuel injection and the like of the engine 12 and a throttle valve controller 66 that controls the operation of the throttle valve 24, precisely, the motor 44. The controllers 64, 66 are connected to a battery 72 through an ignition switch 70 to be supplied with operating power.

[0020] The engine controller 64 comprises a plurality of detection circuits electrically connected to the above-mentioned accelerator opening sensor 54 and the like for detecting sensor outputs and a microprocessor (MPU) 64a that produces an output or signal used for, based on the sensor outputs detected by the detection circuits, controlling the operation of the injector and other outputs.

[0021] As shown in FIG. 1, the output of the accelerator opening sensor 54 is inputted to the MPU 64a through an accelerator opening sensor output detection circuit 64b and is Analog-to-Digital converted. The A/D converted value is transformed using a suitable characteristic curve to obtain a value corresponding to a throttle opening value between about 0 degree and about 90 degrees, specifically to accelerator opening APS (i.e., the accelerator opening APS is calculated or detected).

[0022] The output of the throttle opening sensor 52 is inputted to the MPU 64a through a throttle opening sensor output detection circuit 64c and is Analog-to-Digital converted. The A/D converted value is transformed using a suitable characteristic curve to obtain a value corresponding to a value of the throttle valve 24 between about 0 degree and about 90 degrees, specifically to actual throttle opening TPS (i.e., the actual throttle opening TPS is calculated or detected).

[0023] The MPU 64a is also inputted with the output of the intake air pressure sensor 56 through an intake air pressure sensor output detection circuit 64d and with the output of the coolant temperature sensor 60 through a coolant temperature sensor output detection circuit 64e, and the inputted outputs are Analog-to-Digital converted to be transformed to an intake air pressure PBA and coolant temperature (engine temperature) TW, respectively (i.e., the intake air pressure PBA and coolant temperature TW are calculated). Further, the output of the crank angle sensor 62 is inputted to the MPU 64a through a crank angle sensor output detection circuit 64f and the inputted output is counted to calculate engine speed NE.

[0024] Upon turning-on of the ignition switch 70 by the operator, the battery 72 is connected to a battery voltage detection circuit 64h through a power circuit 64g that supplies operating power to the MPU 64a. The output of the battery voltage detection circuit 64h is also sent to the MPU 64a. Based on the outputs of the battery voltage detection circuit 64h and the like, the MPU64a determines whether the battery 72 is capable of driving the motor 44, e.g., whether the voltage of the battery 72 is equal to or greater than a predetermined value, and when it is discriminated to be capable, outputs an enable signal.

[0025] On the other hand, the throttle valve controller 66 comprises a MPU 66a that produces an output or signal used for controlling the operation of the motor 44 and other outputs based on the outputs of the rotor position sensor 50 and the like. As illustrated, the MPU66a is connected to the MPU 64a of the engine controller 64 to be able to communicate each other through a CAN (Controller Area Network), specifically, connected so as to enable communication of the signals indicative of the calculated accelerator opening APS, actual throttle opening TPS and the like.

[0026] The outputs of the rotor position sensor 50 (i.e., hall sensor outputs of U-phase, V-phase and W-phase) are inputted to the MPU 66a through a rotor position sensor output detection circuit 66b. Based on the output of the rotor position sensor output detection circuit 66b, the accelerator opening APS forwarded from the MPU 64a and the like, the MPU 66a outputs signals (i.e., U-phase, V-phase and W-phase outputs) used for controlling the operation of the motor 44 to the motor drive circuit 66c.

[0027] The throttle valve controller 66 is further equipped with a power circuit 66d that supplies operating power from the battery 72 to the MPU 66a and motor 44 upon turning-on of the ignition switch 70, and a battery voltage detection circuit 66e connected to the power circuit 66d to detect the voltage of the battery 72. The output of the battery voltage detection circuit 66e is sent to the MPU 66a. Based on the inputted output and the like, the MPU 66a determines whether the battery 72 is capable of driving the motor 44, e.g., whether the voltage of the battery 72 is equal to or greater than a predetermined value, and when it is discriminated to be capable, outputs an enable signal.

[0028] The enable signal from the MPU 66a and the above-mentioned enable signal from the MPU 64a are sent to an AND circuit 66f. When the two enable signals are inputted, specifically when it is discriminated in the both MPUs 64a, 66a that the battery 72 is capable of driving the motor 44, the AND circuit 66f outputs a Hi-level signal to close an enable relay 66g and supplies motor drive voltage from the power circuit 66d to the motor drive circuit 66c.

[0029] When supplied with the motor drive voltage from the power circuit 66d, i.e., when the enable relay 66g is closed, based on the outputs of the MPU 66a, the motor drive circuit 66c sends outputs to the coil (U-, V-, W-phases) of the motor 44. The operation of the motor drive circuit 66c will be explained later.

[0030] Next, the explanation on the configuration of the motor 44 and the connection relationship thereof with the throttle valve 24 will be made in detail with reference to FIGs. 2 and 3.

[0031] FIG 2 is a cross-sectional view showing the motor 44 disposed in a throttle system of the engine 12 and FIG 3 is a circuit diagram schematically showing the configuration of the motor 44 including the motor drive circuit 66c.

[0032] In FIG. 2, reference numeral 74 designates the throttle system (throttle body) of the engine 12. The throttle system 74 is installed integrally with the throttle valve 24, motor 44, reduction gear mechanism (i.e., reducer or reduction gear) 42 and other components.

[0033] As mentioned above, the motor 44 is constituted of a three-phase brushless DC motor having the rotor 80, stator 82 and the like. The rotor 80 of substantially cylindrical shape is formed with a plurality of magnetic poles 84 of alternating north-south polarities on the outer periphery of the rotor 80, (i.e., the rotor 80 is magnetized) as can be clearly seen in FIG. 3. The number of pole pairs is six, for example, so the number of magnetic poles of the rotor 80 is twelve ($2 \times 6 = 12$). It should be noted that there are illustrated only four magnetic poles in FIG 3 for simplification of the drawing.

[0034] The output shaft 86 is installed in the center of the rotor 80 and the stator 82 is located to surround the outer periphery of the rotor 80. Specifically, the motor 44 is of inner rotor type in which a rotor is housed in the inside of a stator.

[0035] The stator 82 is equipped with a plurality of, i.e., nine drive coils. In the drawing, there are illustrated only three drive coils for ease of understanding and designated by references 90U, 90V and 90W. The drive coils 90U, 90V, 90W are installed at interval of 120 degrees. The

drive coils 90U, 90V, 90W include three phases of U-phase, V-phase and W-phase and coils constituting the respective phases are connected to each other in a manner of the star (Y) connection. In FIG. 3, the ends of the drive coils 90U, 90V, 90W are provided with circles (designated by references U, U', V, V', W, W'), and they are used for schematically expressing directions of current flow in the explanation below.

[0036] Three hall elements HU, HV, HW are installed near the outer periphery of the rotor 80 and arranged at interval of 120 degrees. The hall elements HU, HV, HW each produces a signal corresponding to a polar character (N-pole or S-pole) of the magnetic pole 84 formed on the rotor 80, i.e., produces a Hi-level signal when the N-pole passes and a Lo-level signal when the S-pole passes.

[0037] The stator 82 (precisely, the drive coils 90U, 90V, 90W) is connected to the motor drive circuit 66c. The motor drive circuit 66c is equipped with six NPN transistors Tr1 to Tr6 that are three-phase bridge-connected to each other. Specifically, the collector terminals of the transistors Tr1, Tr2, Tr3 on the upper side are connected to the power circuit 66d and the emitter terminals thereof are connected to the collector terminals of the associated transistors Tr4, Tr5, Tr6 on the lower side.

[0038] The drive coil 90U is connected to an energizing path between the emitter terminal of the transistor Tr1 and the collector terminal of the transistor Tr4. Similarly, the drive coil 90W is connected to an energizing path between the transistor Tr2 and the transistor Tr5, and the drive coil 90V is connected to an energizing path between the transistor Tr3 and the transistor Tr6. The emitter terminals of the transistors Tr4, Tr5, Tr6 are connected to the power circuit 66d. The base terminals of the transistors Tr1 to Tr6 are connected to a control circuit (not shown) that outputs On/Off signals to change current flow to the drive coils 90U, 90V, 90W. As shown in FIG. 3, the base terminals of the upper-side transistors Tr1 to Tr3 are assigned by references "UU," "UW" and "UV," and those of the lower-side transistors Tr4 to Tr6 by references "LU," "LV" and "LV."

[0039] The control (control mode) of the operation of the motor 44 by the motor drive circuit 66c configured as stated above will be explained with reference to FIG. 4 onward. The control modes of the motor 44 according to this embodiment include a full-step drive control for driving the motor 44 with two-phase excitation at the full-step angle, a micro-step drive control for driving the motor 44 with three-phase excitation at the micro-step angle which is a value obtained by dividing the full-step angle and a variable-step drive control for driving the motor 44 with three-phase excitation at a step angle which changes in response to a difference between the actual throttle opening and desired throttle opening.

[0040] First, the full-step drive control is explained. FIG. 4 is a set of explanatory views showing signals inputted to the base terminals of the transistors Tr1 to Tr6, directions of current flowing through the drive coils 90U,

90V, 90W and the like during the full-step drive control. FIG. 4A shows a case of clockwise rotation of the rotor 80 in the drawing and FIG 4B shows a case of counterclockwise rotation thereof. FIG 5 is a time chart showing the operation of the motor 44, transistors Tr1 to Tr6 and the like in the case of FIG 4A, i.e., when the rotor 80 is rotated clockwise. In FIG. 5, there are illustrated only two magnetic poles (S-pole, N-pole) for ease of understanding.

[0041] As shown in FIG 4A and time points t_{11} to t_{12} of FIG. 5, when the base terminals (LW, UV) are inputted with On signals to conduct the transistors Tr5 and Tr3, current flows from the drive coil 90V (V-phase) to drive coil 90W (W-phase) to excite the drive coils 90V, 90W. At that time, the current of the drive coil 90V flows rearward in the drawing on the V side and flows forward or frontward on the V' side. On the other hand, the current of the drive coil 90W flows forward on the W side and flows rearward on the W' side. As a result, the magnetic field is generated in the drive coils 90V, 90W, thereby rotating the rotor 80 clockwise as shown in FIG. 5.

[0042] When making the rotor 80 further rotate clockwise, as shown in time points t_{12} to t_{13} or the like of FIG 5, the base terminals (UU, LW) are inputted with On signals to conduct the transistors Tr1 and Tr5, current flows from the drive coil 90U to drive coil 90W to excite the drive coils 90U, 90W. At that time, the current of the drive coil 90U flows rearward in the drawing on the U side and flows forward on the U' side. On the other hand, the current of the drive coil 90W flows forward on the W side and flows rearward on the W' side. As a result, the magnetic field is generated in the drive coils 90U, 90W, thereby rotating the rotor 80 clockwise further.

[0043] Similarly, as shown in FIG. 4A and time points t_{13} to t_{17} or the like of FIG 5, signals inputted to the base terminals UU, UW, UV, LU, LW, LV of the transistors are controlled to control the clockwise rotation of the rotor 80. In the foregoing, the explanation is made only on the clockwise rotation of the rotor 80 and the explanation on the counterclockwise rotation is omitted because the characteristics thereof are exactly the contrary of the clockwise rotation.

[0044] Thus the full-step drive control is so-called two-phase excitation drive control in which current flows from the drive coil 90V to drive coil 90W or from the drive coil 90U to drive coil 90W, i.e., among the U-phase, V-phase and W-phase constituted by the drive coils 90U, 90V and 90W, two phases are excited.

[0045] A rotation angle (full-step angle; advance angle) θ_f of the motor 44 at the time of conducting the full-step drive control will be explained. The full-step angle θ_f is defined based on resolution of the rotor 80 and that of the stator 82. Specifically, since, as mentioned above, the number of magnetic poles of the rotor 80 is twelve (six pairs) and that of the stator 82 is nine, resolutions thereof are calculated in accordance with the following equations.

Resolution of the rotor: $360 [\text{degree}] / 12 [\text{pole}] = 30 [\text{degree}]$
 Resolution of the stator: $360 [\text{degree}] / 9 [\text{pole}] = 40 [\text{degree}]$

[0046] Here, [degree] in the above equations is a unit of mechanical angle.

[0047] Accordingly, the rotation angle (full-step angle) θ_f of the motor 44 at the time the full-step drive control is conducted is calculated as follows.

$$\theta_f = 40 - 30 = 10 [\text{degree}]$$

[0048] Next, among the three control modes of the motor 44 according to this embodiment, the micro-step drive control and variable-step drive control are explained with reference to FIG. 6 onward.

[0049] FIG 6 is a set of explanatory views similar to FIG. 4, but showing signals inputted to the base terminals of the transistors Tr1 to Tr6, directions of current flowing through the drive coils 90U, 90V, 90W and the like during the micro-step drive control or variable-step drive control. FIG 6A shows a case of clockwise rotation of the rotor 80 in the drawing and FIG. 6B shows a case of counterclockwise rotation thereof. FIG. 7 is a time chart similar to FIG 5, but showing the operation of the motor 44, transistors Tr1 to Tr6 and the like in the case of FIG 6A, i.e., when the rotor 80 is rotated clockwise.

[0050] As shown in FIG 6A and time points t_{21} to t_{22} of FIG 7, when the base terminals (UU, UV, LW) are inputted with On signals to conduct the transistors Tr1, Tr3 and Tr5, current flows from the drive coils 90U, 90V to drive coil 90W to excite the drive coils 90U, 90V, 90W. At this time, the current of the drive coil 90U flows rearward in the drawing on the U side and flows forward on the U' side. The current of the drive coil 90V flows rearward on the V side and flows forward on the V' side. The current of the drive coil 90W flows forward on the W side and flows rearward on the W' side. As a result, the magnetic field is generated in the drive coils 90U, 90V, 90W, thereby rotating the rotor 80 clockwise as shown in FIG. 7.

[0051] When making the rotor 80 further rotate clockwise, as shown in time points t_{22} to t_{33} or the like, the base terminals (UU, LW, LV) are inputted with On signals to conduct the transistors Tr1, Tr5 and Tr6, current flows from the drive coil 90U to drive coils 90V, 90W to excite the drive coils 90U, 90V, 90W. At this time, the current of the drive coil 90U flows rearward in the drawing on the U side and flows forward on the U' side. The current of the drive coil 90V flows forward on the V side and flows rearward on the V' side. The current of the drive coil 90W flows forward on the W side and flows rearward on the W' side. As a result, the magnetic field is generated in the drive coils 90U, 90V, 90W, thereby rotating the rotor 80 clockwise further.

[0052] Similarly, as shown in FIG. 6A and time points

t_{23} to t_{27} or the like of FIG. 7, signals inputted to the base terminals UU, UV, LU, LW, LV of the transistors are controlled to control the clockwise rotation of the rotor 80. In the foregoing, the explanation is made only on the clockwise rotation of the rotor 80 and the explanation on the counterclockwise rotation is omitted because the characteristics thereof are exactly the contrary of the clockwise rotation.

[0053] Thus, while the above-mentioned full-step drive control is the two-phase excitation drive control, the micro-step drive control and variable-step drive control are so-called three-phase excitation drive control in which current flows from the drive coils 90U, 90V to drive coil 90W for example, i.e., all of the U-phase, V-phase and W-phase constituted by the drive coils 90U, 90V and 90W are excited. In these two control modes, energizations of the drive coils 90U, 90V, 90W are PWM-controlled separately or independently to regulate a rotation angle of the rotor 80.

[0054] The explanation will be made on a difference between the micro-step drive control and variable-step drive control, i.e., between rotation angles (advance angles) depending on a conducted control mode. When the micro-step drive control is conducted, the rotation angle (micro-step angle, i.e., interval of the minimum angle at which the rotor 80 can stop) θ_m of the motor 44 is a value obtained by dividing the full-step angle θ_f , e.g., is to be 2 degrees obtained by dividing the full-step angle (10 [degree]) into five.

[0055] The rotation angle (step angle) θ_v in the variable-step drive control is set to a value greater than the micro-step angle θ_m (2 [degree]) and smaller than the full-step angle θ_f (10 [degree]), i.e., a value between 2 to 10 degrees. Calculation (change) of the step-angle θ_v during the variable-step drive control will be explained later.

[0056] The explanation of FIG. 2 is resumed. The stator 82 of the motor 44 is fastened to the throttle system 74. The rotor 80 is rotatably supported by the throttle system 74 through the output shaft 86 and also connected to a shaft 92 of the throttle valve 24 through the output shaft 86 and reducer 42. Specifically, rotation of the rotor 80 causes the shaft 92 to rotate, thereby opening and closing the throttle valve 24.

[0057] Reduction ratio of the reducer 42 is set to 20. As mentioned above, since the full-step angle θ_f of the motor 44 is 10 [degree] during the full-step drive control, the throttle system 74 according to this embodiment can regulate the throttle opening in units of 0.5 [degree] (10 [degree] / 20). Since the micro-step angle θ_m of the motor 44 is 2 [degree] during the micro-step drive control, the throttle system 74 can regulate the throttle opening in units of 0.1 [degree] (2 [degree] / 20). Since the step angle θ_v is 2 to 10 [degree] during the variable-step drive control, the throttle system 74 can regulate the throttle opening in units of 0.1 to 0.5 [degree].

[0058] FIG 8 is a flowchart showing the operation of the control system according to this embodiment. The

illustrated program is executed in the throttle valve controller 66 or the like at every predetermined interval, e.g., 10msec.

[0059] In S10, it is determined whether the throttle opening sensor 52 is abnormal. This determination is made based on the output of the throttle opening sensor output detection circuit 64c and the like. When the result in S10 is YES, the remaining steps are skipped and when the result is NO, the program proceeds to S12, in which it is determined whether the accelerator opening sensor 54 is abnormal. This determination is made based on the output of the accelerator opening sensor output detection circuit 64b and the like. When the result in S12 is YES, the remaining steps are skipped and when the result is NO, the program proceeds to S 14.

[0060] In S 14, the output of the throttle opening sensor 52 is detected to calculate the actual throttle opening TPS. The program proceeds to S16, in which the output of the accelerator opening sensor 54 is detected and based thereon, the accelerator opening APS is calculated, and to S 18, in which based on the calculated accelerator opening APS, desired throttle opening THd is calculated.

[0061] The program proceeds to S20, in which the actual throttle opening TPS is subtracted from the desired throttle opening THd to obtain a difference, i.e., a control difference d [degree], to S22, in which it is determined whether an absolute value of the control difference d is less than a first predetermined value dref1. The first predetermined value dref1 is set to a value indicating that the desired throttle opening THd and the actual throttle opening TPS are not close (i.e., there is a relatively large difference therebetween), specifically 1 [degree].

[0062] When the result in S22 is NO, i.e., the absolute value of the control difference d is equal to or greater than the first predetermined value dref1, in other words, a difference between the desired throttle opening THd and actual throttle opening TPS is relatively large and the throttle valve is required with good response more than control accuracy, the program proceeds to S24, in which the full-step drive control (two-phase excitation drive control) is selected to be conducted. Specifically, the operation of the motor 44 is controlled by driving the motor 44 at the full-step angle θ_f to decrease the control difference d. Since the rotation angle (full-step angle θ_f) of the motor 44 is 10 [degree], i.e., relatively large, the motor 44 can be rotated at high speed, thereby enabling to open and close the throttle valve 24 at high speed.

[0063] On the other hand, when the result in S22 is YES, the program proceeds to S26, in which it is determined whether the absolute value of the control difference d is less than a second predetermined value dref2. The second predetermined value dref2 is set to a value smaller than the first predetermined value dref1, specifically 0.2 [degree].

[0064] When the result in S26 is NO, i.e., the absolute value of the control difference d is equal to or greater than the second predetermined value dref2 and less than

the first predetermined value dref1, in other words, a difference between the desired throttle opening THd and actual throttle opening TPS is a little large and the throttle valve is required with both response and control accuracy to some extent, the program proceeds to S28, in which the step angle θ_v of the variable-step drive control is calculated, specifically the step angle (drive step amount) θ_v is calculated or changed to correspond to the control difference d.

[0065] More specifically, the step angle θ_v is calculated or changed by retrieving the characteristic curve (mapped data) shown in FIG 9 using the control difference d. As shown in FIG. 9, the step angle θ_v is set to a value proportional to the absolute value of the control difference d, i.e., a value that increases with increasing absolute value of the control difference d.

[0066] The program proceeds to S30, the variable-step drive control (three-phase excitation drive control) is selected to be conducted. Specifically, the operation of the motor 44 is controlled by driving the motor 44 at the step angle θ_v to decrease the control difference d. Since the rotation angle of the motor 44 is the step angle θ_v that changes in response to the control difference d, the motor 44 can be operated at speed corresponding to the control difference d, i.e., at speed that satisfies both of response and control accuracy to some extent, thereby enabling to open and close the throttle valve 24 at appropriate speed.

[0067] When the result in S26 is YES, i.e., the desired throttle opening THd and actual throttle opening TPS are close (there is a slight difference therebetween) and the throttle valve is required with control accuracy more than good response, the program proceeds to S32, in which it is determined whether a delay counter (explained later) has reached zero. When the result in S32 is NO, this determination process is repeated and when the result is YES, the program proceeds to S34, in which the micro-step drive control (three-phase excitation drive control) is conducted. Specifically, the operation of the motor 44 is controlled by driving the motor 44 at the micro-step angle θ_m to decrease the control difference d. Since the rotation angle (micro-step angle θ_m) of the motor 44 is 2 [degree], i.e., relatively small, the motor 44 can be rotated at low speed, thereby enabling to open and close the throttle valve 24 at low speed to achieve the desired throttle opening THd.

[0068] The program proceeds to S36, in which a delay counter value set in the delay counter (down counter (the initial value is zero)) is calculated or changed. Specifically, the delay counter value is calculated or changed by retrieving the characteristic curve (mapped data) shown in FIG. 10 using the control difference d. As shown in FIG. 10, the delay counter value is set to a value inversely proportional to the absolute value of the control difference d, i.e., a value that increases with decreasing absolute value of the control difference d.

[0069] Then in S38, the delay counter value changed in S36 is set in the delay counter, time measurement is

started and the program is terminated once. Owing to the processing of S36 and S38, the result in S32 should be NO in subsequent program loops and the processing of S34 is not executed, i.e., the micro-step drive control is not conducted. Thus when the micro-step drive control is selected, the micro-step drive control is not conducted before the delay counter reaches zero, in other words, is conducted every time when the delay counter reaches zero, i.e., at every predetermined time period.

[0070] As stated in the foregoing, the foregoing embodiment of this invention is configured to have a system for (and method of) controlling an internal combustion engine (12) mounted on a vehicle (10) and having an electric motor (44) that drives a throttle valve (24) installed in an intake pipe (22) of the engine and an accelerator (16) installed to be operable by the operator, characterized by: a throttle opening detector that detects actual opening of the throttle valve (throttle opening sensor 52, engine controller 64, S14), an accelerator opening detector that detects opening of the accelerator (accelerator opening sensor 54, engine controller 64, S16); a desired throttle opening calculator that calculates desired opening of the throttle valve (24) based at least on the detected opening of the accelerator (throttle valve controller 66, S18); a throttle opening difference calculator that calculates a difference (control difference d) between the detected actual opening and the calculated desired opening of the throttle valve (throttle valve controller 66, S20); and a motor controller that conducts one of a full-step drive control for driving the motor (44) at a full-step angle θ_f , a micro-step drive control for driving the motor (44) at a micro-step angle θ_m which is made by dividing the full-step angle and a variable-step drive control for driving the motor (44) at a step angle θ_v which changes in response to the calculated difference, and controls the operation of the motor (44) so as to decrease the calculated difference (throttle valve controller 66, S24, S30, S34).

[0071] With this, it becomes possible to improve response and control accuracy of the throttle valve 24 and also enhances drivability. Specifically, the motor 44 is controlled by using, in addition to the full-step drive control with good response and the micro-step drive control with good control accuracy, the variable-step drive control in which the step angle θ_v is variable and response and control accuracy are ensured to some extent. For instance, when the accelerator 16 is slightly operated by the operator, the micro-step drive control is conducted, when the accelerator 16 is quickly opened, the full-step drive control is conducted, and when the micro-step drive control and full-step drive control are switched, the variable-step drive control is conducted. Therefore, one from among the three control modes can be selected to be conducted in response to the operating condition, thereby enabling to improve response and control accuracy of the throttle valve 24 and also enhances drivability.

[0072] The system further includes a control selector that selects one of the full-step drive control, the micro-

step drive control and the variable-step drive control based on the calculated difference (throttle valve controller 66, S22, S26).

[0073] With this, it becomes possible to select a control mode corresponding to a difference between the actual throttle opening TPS and desired throttle opening THd, i.e., a control mode suitable for the operating condition at the moment, thereby enabling to further improve response and control accuracy of the throttle valve 24 and also further enhances drivability.

[0074] In the system, the motor controller conducts the micro-step drive control at every predetermined time interval when the micro-step drive control is selected (throttle valve controller 66, S32, S34).

[0075] With this, in the operating condition where the micro-step drive control is selected, i.e., control accuracy is required, it becomes possible to operate the motor 44 at low speed, in other words, so that the throttle valve 24 gradually reaches the desired throttle opening THd, thereby enabling to still further improve control accuracy.

[0076] In the system, the predetermined time interval (delay counter value) changes in response to the calculated difference (throttle valve controller 66, S36).

[0077] With this, it becomes possible to elongate the predetermined time period, i.e., increase the delay counter value, more specifically increase a time span of conducting the micro-step drive control, as the difference decreases, so as to drive the motor 44 at further low speed, thereby reliably achieving the foregoing effects.

[0078] It should be noted that, although the desired throttle opening THd is calculated based on the accelerator opening APS, it can be calculated based on, in addition to the accelerator opening APS, engine speed NE or the like. In that sense, in Claim 1, it is described as "a desired throttle opening calculator that calculates desired throttle opening of the throttle valve based at least on the detected accelerator opening."

[0079] It should also be noted that the motorcycle 10 is used as an example of a saddle-seat vehicle on which the engine 12 is mounted, but it is not limited thereto and can be another type of saddle-seat vehicle such as a scooter, ATV (All Terrain Vehicle) or the like, a seat or saddle of which the operator straddles, or any other type of vehicle.

[0080] It should further be noted that, although the displacement of the engine 12, the number of magnetic poles of the rotor 80, rotation angles θ_f , θ_m , θ_v of the motor 44 and the like are indicated with specific values, they are only examples and not limited thereto.

Claims

1. A system for controlling an internal combustion engine (12) mounted on a vehicle (10) and having an electric motor (44) that drives a throttle valve (24) installed in an intake pipe (22) of the engine and an accelerator (16) installed to be operable by the op-

erator, **characterized by:**

- a throttle opening detector that detects actual opening of the throttle valve (52, 64, S 14);
 an accelerator opening detector that detects opening of the accelerator (54, 64, S16);
 a desired throttle opening calculator that calculates desired opening of the throttle valve based at least on the detected opening of the accelerator (66, S 18);
 a throttle opening difference calculator that calculates a difference between the detected actual opening and the calculated desired opening of the throttle valve (66, S20); and
 a motor controller that conducts one of a full-step drive control for driving the motor at a full-step angle θ_f , a micro-step drive control for driving the motor at a micro-step angle θ_m which is made by dividing the full-step angle and a variable-step drive control for driving the motor at a step angle θ_v which changes in response to the calculated difference, and controls the operation of the motor so as to decrease the calculated difference (66, S24, S30, S34).
2. The system according to claim 1, further including:
 a control selector that selects one of the full-step drive control, the micro-step drive control and the variable-step drive control based on the calculated difference (66, S22, S26).
3. The system according to claim 1 or 2, wherein the motor controller conducts the micro-step drive control at every predetermined time interval when the micro-step drive control is selected (66, S32, S34).
4. The system according to claim 3, wherein the predetermined time interval changes in response to the calculated difference (66, S36).
5. A method of controlling an internal combustion engine (12) mounted on a vehicle (10) and having an electric motor (44) that drives a throttle valve (24) installed in an intake pipe (22) of the engine and an accelerator (16) installed to be operable by the operator, **characterized by:**
 detecting actual opening of the throttle valve (52, 64, S 14);
 detecting opening of the accelerator (54, 64, S16);
 calculating desired opening of the throttle valve based at least on the detected opening of the accelerator (66, S 18);
 calculating a difference between the detected actual opening and the calculated desired opening of the throttle valve (66, S20); and

conducting one of a full-step drive control for driving the motor at a full-step angle θ_f , a micro-step drive control for driving the motor at a micro-step angle θ_m which is made by dividing the full-step angle and a variable-step drive control for driving the motor at a step angle θ_v which changes in response to the calculated difference, and controlling the operation of the motor so as to decrease the calculated difference (66, S24, S30, S34).

6. The method according to claim 5, further including the step of:
 selecting one of the full-step drive control, the micro-step drive control and the variable-step drive control based on the calculated difference (66, S22, S26).
7. The method according to claim 5 or 6, wherein the step of control conducting conducts the micro-step drive control at every predetermined time interval when the micro-step drive control is selected (66, S32, S34).
8. The method according to claim 7, wherein the predetermined time interval changes in response to the calculated difference (66, S36).

FIG. 1

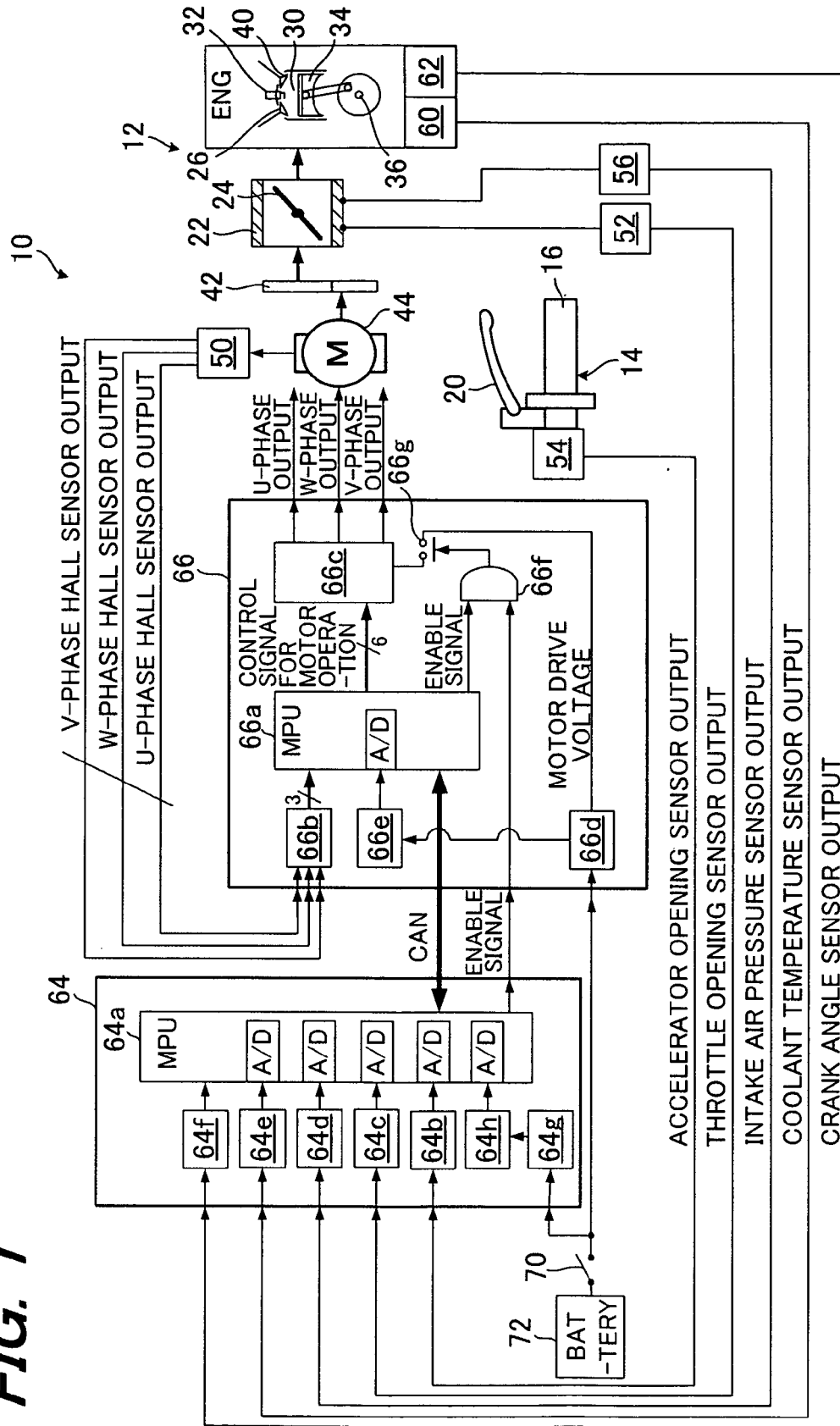


FIG. 2

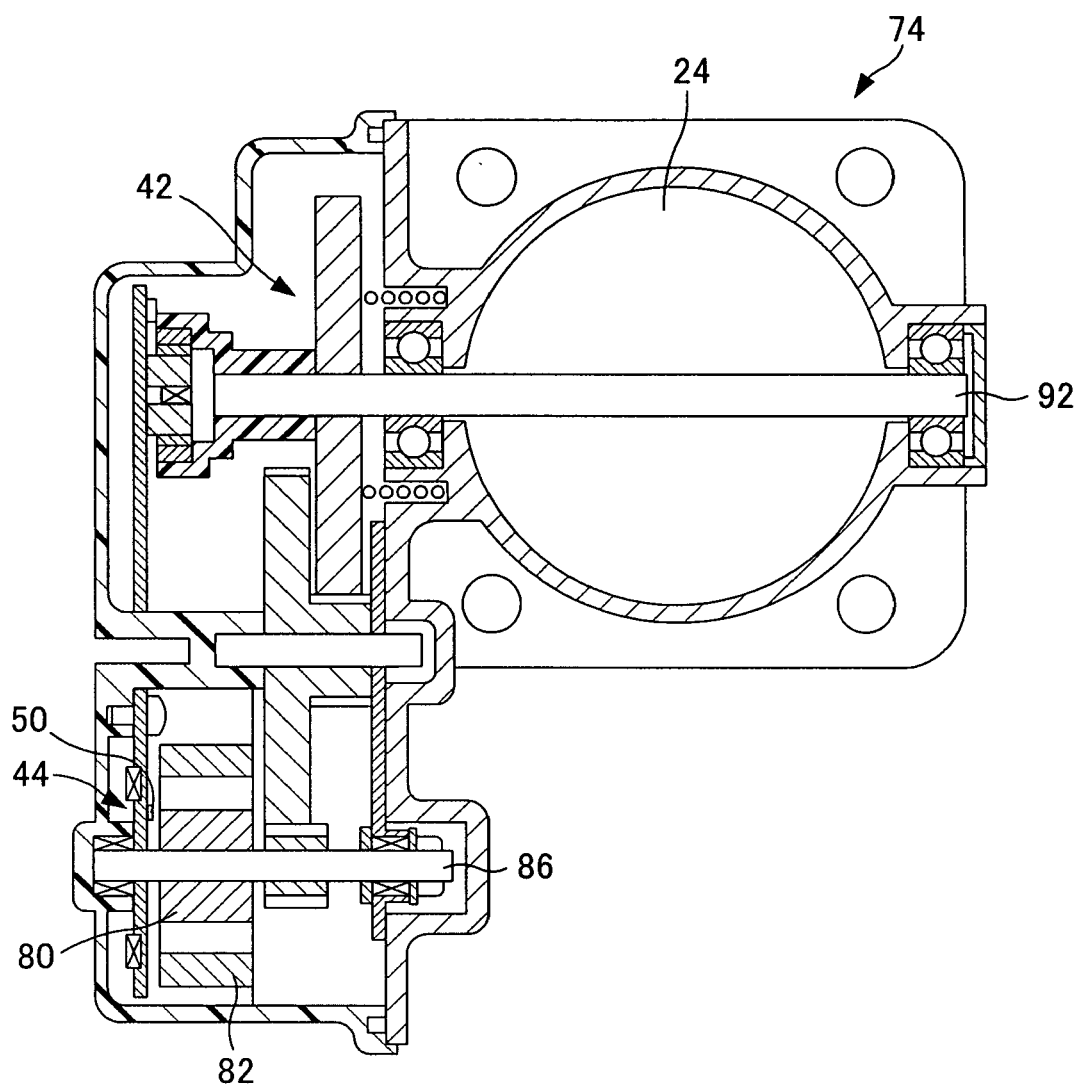
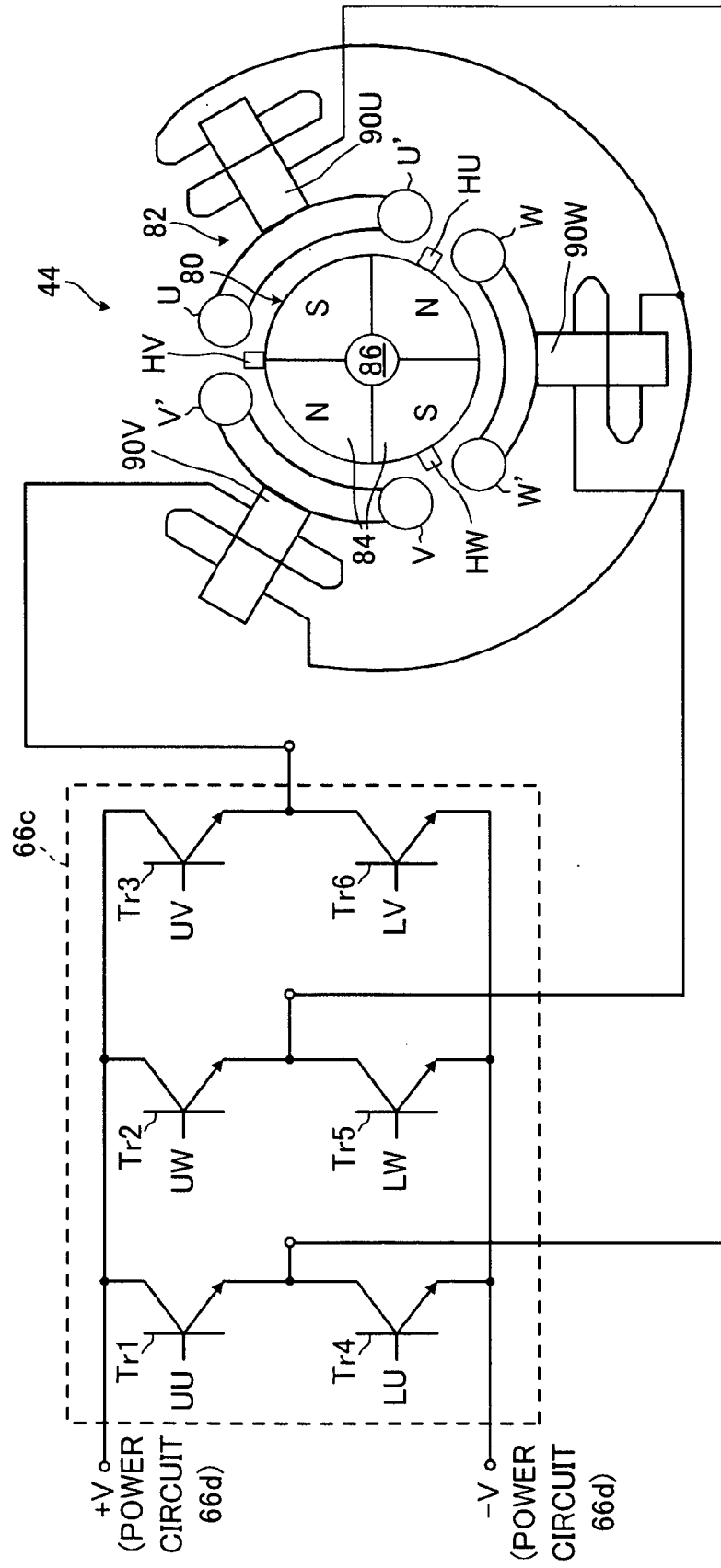


FIG. 3



CLOCKWISE ROTATION

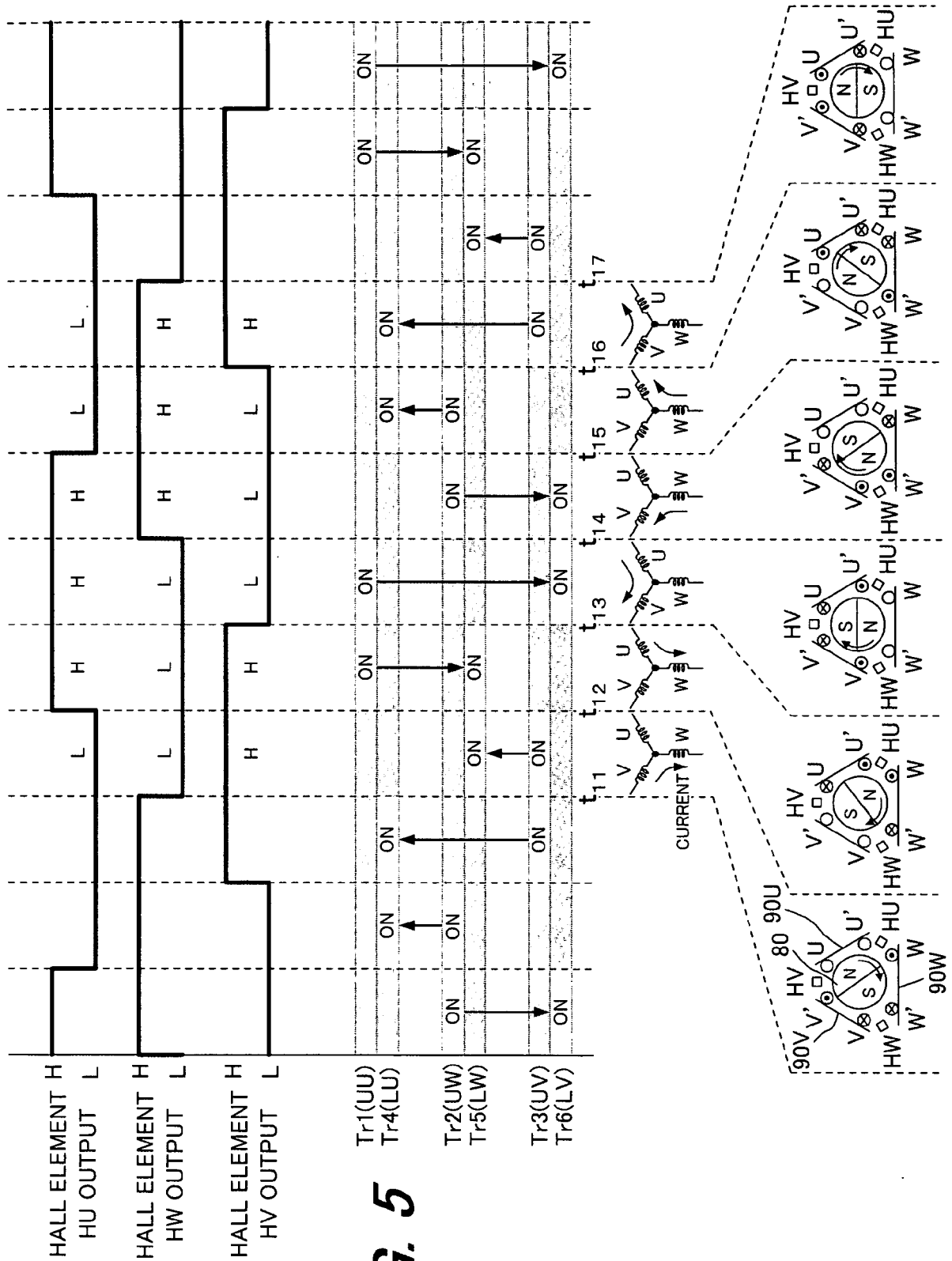
FIG. 4A

HALL ELEMENT OUTPUT			U			W			V			EXCITATION PATTERN			CURRENT DIRECTION		
HU	HW	HV	UU	LU	Tr1	UW	LW	UV	LV	Tr6	Tr3	V → W			U	U'	W
			Tr1	Tr4	Tr5	Tr2	Tr5	Tr3	Tr6						U	U'	W
L	L	H	OFF	OFF	ON	OFF	ON	ON	OFF	OFF	OFF	○	○	○	○	○	○
H	L	H	ON	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF	○	○	○	○	○	○
H	L	L	ON	OFF	OFF	OFF	OFF	OFF	ON	ON	OFF	○	○	○	○	○	○
H	H	L	OFF	OFF	OFF	ON	OFF	OFF	ON	ON	OFF	○	○	○	○	○	○
L	H	L	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF	OFF	○	○	○	○	○	○
L	H	H	OFF	ON	OFF	OFF	OFF	ON	OFF	OFF	OFF	○	○	○	○	○	○

COUNTERCLOCKWISE ROTATION

FIG. 4B

HALL ELEMENT OUTPUT			U			W			V			EXCITATION PATTERN			CURRENT DIRECTION		
HU	HW	HV	UU	LU	Tr1	UW	LW	UV	LV	Tr6	Tr3	W → V			U	U'	W
			Tr1	Tr4	Tr5	Tr2	Tr5	Tr3	Tr6						U	U'	W
L	L	H	OFF	OFF	ON	ON	OFF	OFF	ON	ON	OFF	○	○	○	○	○	○
H	L	H	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF	OFF	○	○	○	○	○	○
H	L	L	OFF	ON	OFF	OFF	OFF	ON	OFF	OFF	OFF	○	○	○	○	○	○
H	H	L	OFF	OFF	OFF	OFF	ON	ON	OFF	OFF	OFF	○	○	○	○	○	○
L	H	L	ON	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF	○	○	○	○	○	○
L	H	H	ON	OFF	OFF	OFF	OFF	OFF	ON	ON	OFF	○	○	○	○	○	○



CLOCKWISE ROTATION

HALL ELEMENT OUTPUT				U			W			V			EXCITATION PATTERN			CURRENT DIRECTION					
HU	HW	HV		UU	LU	Tr1	UW	LW	Tr5	UV	LV	Tr6				U	U'	W	W'	V	V'
H	L	H	→	ON	OFF	ON	OFF	ON	ON	ON	OFF	OFF	VU→W			⊗	⊙	⊗	⊙	⊗	⊙
H	L	L	→	ON	OFF	ON	OFF	ON	ON	OFF	ON	ON	U→VW			⊗	⊙	⊗	⊙	⊗	⊙
H	H	L	→	ON	OFF	ON	ON	OFF	OFF	OFF	ON	ON	UW→V			⊗	⊙	⊗	⊙	⊗	⊙
L	H	L	→	OFF	ON	ON	ON	OFF	OFF	OFF	ON	ON	W→UV			⊙	⊗	⊙	⊗	⊙	⊗
L	H	H	→	OFF	ON	ON	ON	OFF	OFF	ON	OFF	ON	WV→U			⊙	⊗	⊙	⊗	⊙	⊗
L	L	H	→	OFF	ON	ON	OFF	ON	ON	ON	OFF	OFF	V→WU			⊙	⊗	⊙	⊗	⊙	⊗
H	L	L	→	OFF	ON	ON	OFF	ON	ON	ON	OFF	OFF				⊙	⊗	⊙	⊗	⊙	⊗

FIG. 6A

COUNTERCLOCKWISE ROTATION

HALL ELEMENT OUTPUT				U			W			V			EXCITATION PATTERN			CURRENT DIRECTION					
HU	HW	HV		UU	LU	Tr1	UW	LW	Tr5	UV	LV	Tr6				U	U'	W	W'	V	V'
H	L	H	←	ON	OFF	ON	OFF	ON	ON	ON	OFF	OFF	VU→W			⊙	⊗	⊙	⊗	⊙	⊗
H	L	L	←	ON	OFF	ON	OFF	ON	ON	OFF	ON	ON	U→VW			⊙	⊗	⊙	⊗	⊙	⊗
H	H	L	←	ON	OFF	ON	ON	OFF	OFF	OFF	ON	ON	UW→V			⊙	⊗	⊙	⊗	⊙	⊗
L	H	L	←	OFF	ON	ON	ON	OFF	OFF	OFF	ON	ON	W→UV			⊙	⊗	⊙	⊗	⊙	⊗
L	H	H	←	OFF	ON	ON	ON	OFF	OFF	ON	OFF	ON	WV→U			⊙	⊗	⊙	⊗	⊙	⊗
L	L	H	←	OFF	ON	ON	OFF	ON	ON	ON	OFF	OFF	V→WU			⊙	⊗	⊙	⊗	⊙	⊗
H	L	L	←	OFF	ON	ON	OFF	ON	ON	ON	OFF	OFF				⊙	⊗	⊙	⊗	⊙	⊗

FIG. 6B

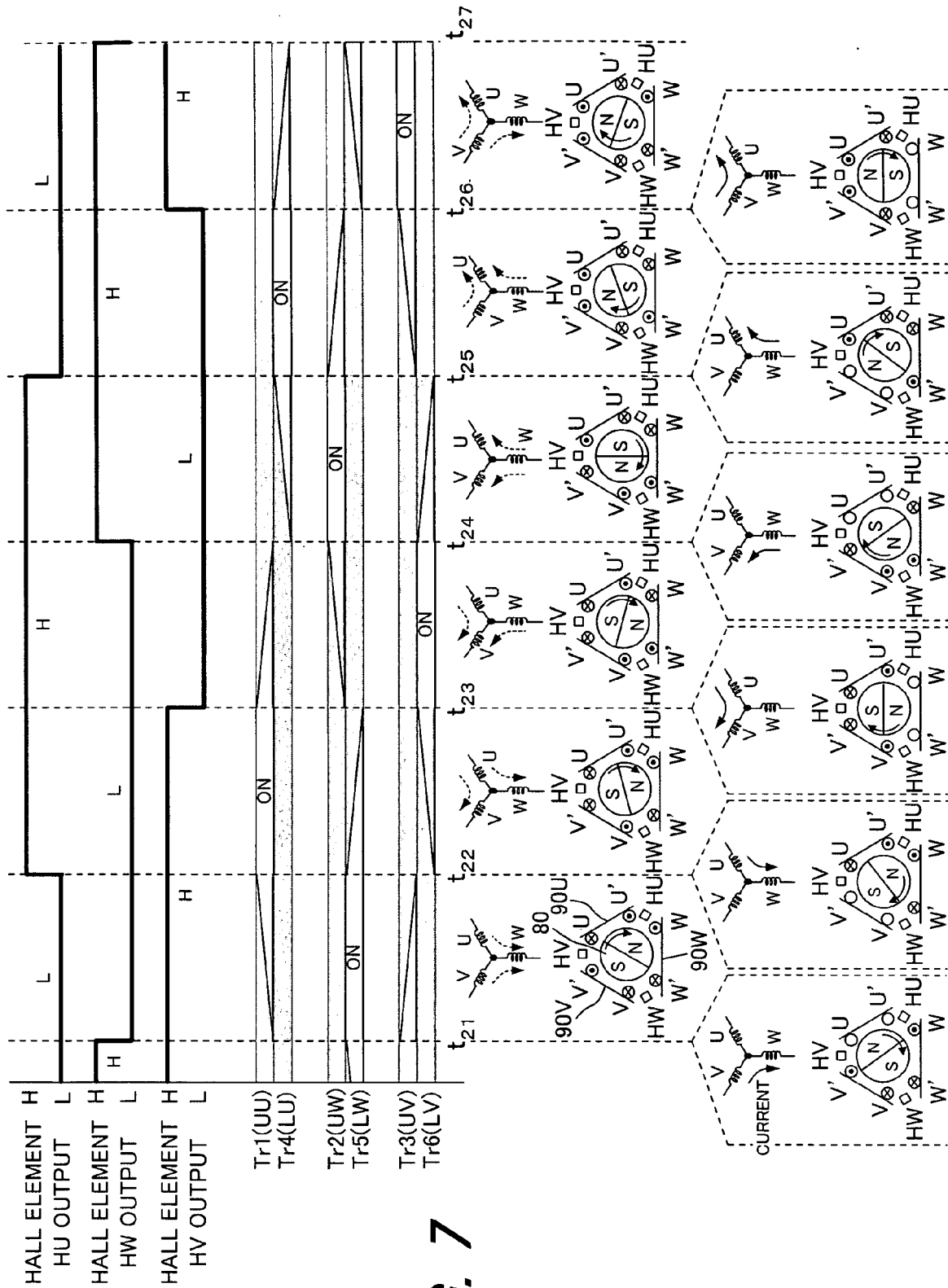


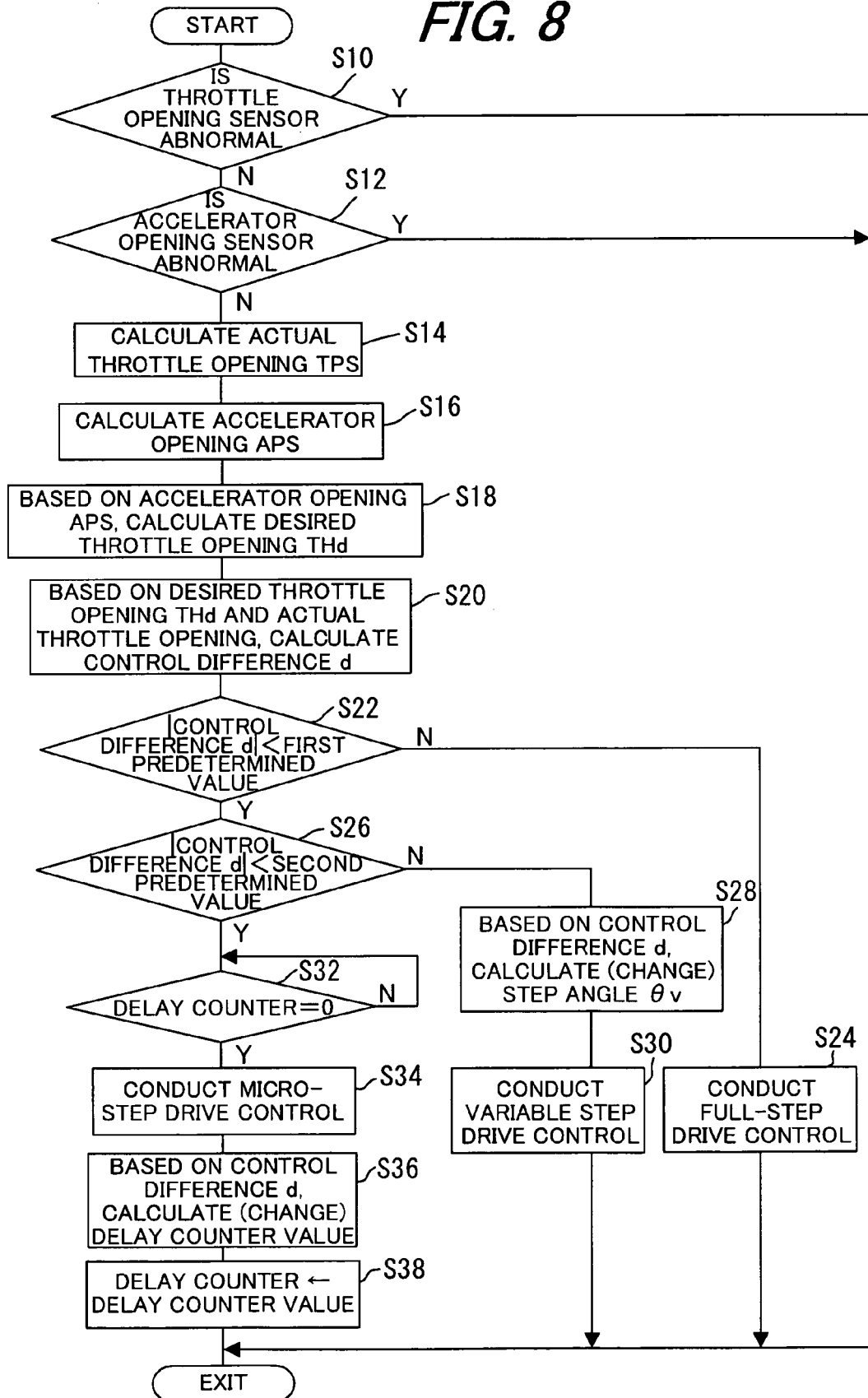
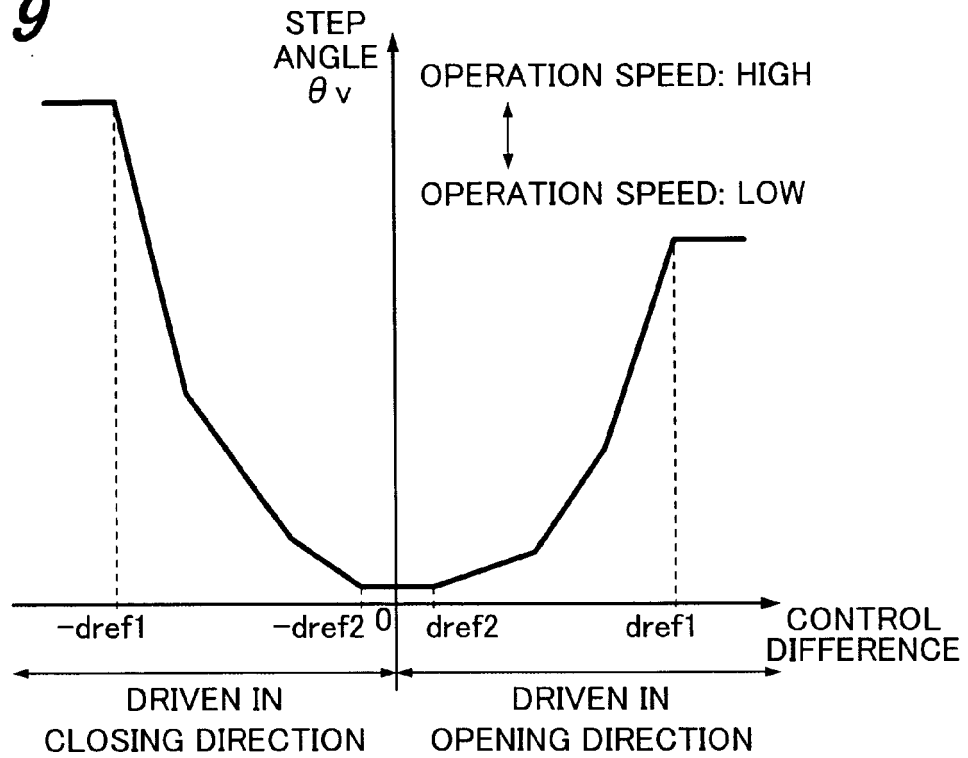
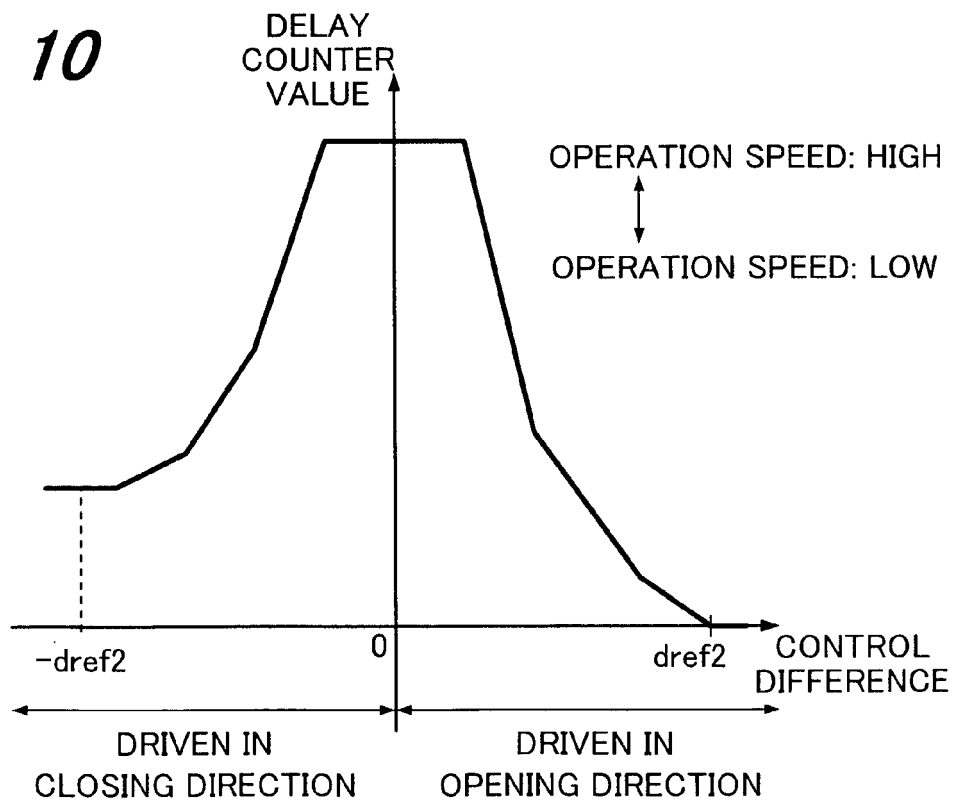
FIG. 8

FIG. 9**FIG. 10**

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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