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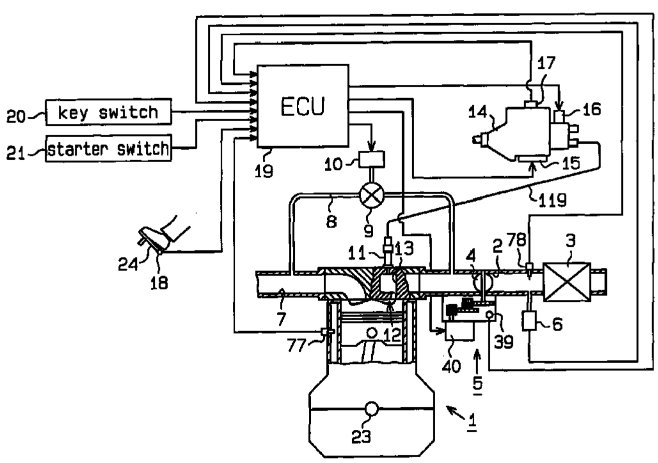
(54) Apparatus and method for driving a valve with a stepping motor

(57) An apparatus for driving a throttle valve (4) with a stepping motor (40) in a diesel engine (1). The apparatus includes a fully open detection switch (39) that is shifted between ON/OFF states by motion of the valve (4) when the valve (39) moves near a fully open position. An ECU (19) initializes a relationship between the driven step number of the stepping motor (40) and the angular position of the throttle valve (4) by setting a reference angle of the stepping motor (40) only when the fully open switch (39) shifts from an OFF state to an ON state, not vice versa. Thus, the reference rotational angle of the stepping motor (40), which corresponds to the fully open position of the throttle valve (4), is located accurately regardless of hysteresis errors that occur when the fully open switch (39) shifts between ON/OFF states. Accordingly, the angular position of the throttle valve (4) is controlled more precisely.

Fig.1



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Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to an apparatus for driving a valve with a stepping motor and a method for controlling the apparatus. More particularly, the present invention pertains to a valve driver for driving a throttle valve of a diesel engine and a method for controlling the driver.

[0002] The power output of a diesel engine is mainly adjusted by controlling the amount of fuel injection. Conventionally, therefore, precise control of the amount of intake air has not been required. However, recent demands for the reduction of exhaust pollutants has led to the incorporation of an exhaust gas recirculation (EGR) apparatus in diesel engines. The EGR apparatus recirculates some of the exhaust gas discharged from engine combustion chambers into an intake manifold, or intake passage. The mixing ratio of the exhaust gas to the intake air that flows through the intake passage is an important factor achieving the cleanest exhaust gas possible without interfering with the operation of the engine. The proper mixing ratio requires fine control of the amount of the intake air.

[0003] Accordingly, a valve drive apparatus enabling fine control of the intake air amount has been proposed. The valve drive apparatus includes a throttle valve, which can be actuated independently from the acceleration pedal, and a stepping motor, which actuates the throttle valve. The stepping motor has an output shaft, the rotational angle of which is controlled accurately by drive pulses, which are input to the motor. The stepping motor is therefore capable of controlling the angular position of the throttle valve with high precision.

[0004] The output shaft of the stepping motor is driven in a stepped manner. Thus, the number of the driven steps, which indicates the rotational angle of the motor, must always correspond to the angular position of the throttle valve to drive the throttle valve with precision. However, when the stepping motor falls out of synchronization with the drive pulses, the steps of the motor do not accurately correspond to the angular position of the throttle valve. This hinders precise control of the throttle valve. In addition, if the stepping motor is de-actuated when the engine is stopped, the stepping motor is required to synchronize its steps with the angular position of the throttle valve when the motor is reactivated. Thus, an initializing process must be carried out to set the proper relationship between the motor steps and the angular position of the throttle valve.

[0005] Japanese Unexamined Patent Publication No. 3-57852 describes such an initializing apparatus. The apparatus includes a switch that shifts between ON/OFF states when the throttle valve passes by a predetermined angular position. The initializing process is executed when the ON/OFF state of the switch changes to set the current step of the stepping motor as a reference step.

[0006] However, a hysteresis error occurs when the ON/OFF state of the switch is shifted. More specifically, the angular position of the throttle valve that is used to set the reference step differs when the switch is turned on from when the switch is turned off. This may result in inaccurate initializing and thus lower reliability. In such cases, precise and stable control of the throttle valve may not be accomplished.

SUMMARY OF THE INVENTION

[0007] Accordingly, it is an objective of the present invention to provide an apparatus for driving a valve with a stepping motor and a method for controlling the apparatus that executes initialization accurately and controls the angular position of the throttle valve in an accurate and stable manner.

[0008] To achieve the above objective, the present invention provides an apparatus for driving a valve with a stepping motor. The stepping motor is driven in a stepped manner. The number of driven steps of the stepping motor normally corresponds to the angular position of the valve. The apparatus includes a switch that is shifted between a first state and a second state by motion of the valve and an initializing means for setting a reference position of the stepping motor based on the state of the switch to establish a relationship between the step number of the stepping motor and the angular position of the valve. The initializing means sets the reference position of the stepping motor only when the switch shifts from the first state to the second state.

[0009] In a further aspect of the present invention, a method for controlling an apparatus that drives a valve with a stepping motor is provided. The stepping motor is driven in a stepped manner. The number of driven steps of the stepping motor normally corresponds to an angular position of the valve. The method includes shifting a switch between a first state and a second state by movement of the valve and setting a reference rotational angle of the stepping motor based on the state of the switch to initialize a relationship between the step number of the stepping motor and the angular position of the valve. The reference rotational angle of the stepping motor is set only when the switch shifts from the first state to the second state.

[0010] Other aspects and advantages of the present invention will become apparent from the following description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The features of the present invention that are believed to be novel are set forth with particularity in the appended claims. The invention, together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings in which:

Fig. 1 is a diagram, partly in cross-section, illustrating a diesel engine incorporating a stepping motor type valve drive apparatus according to a first embodiment of the present invention;

Fig. 2 is a cross-sectional side view showing a throttle valve and the valve drive apparatus;

Fig. 3 is a cross-sectional view taken along line 3-3 in Fig. 2;

Fig. 4 is a partial view showing a driven gear employed in the valve drive apparatus of Fig. 3;

Fig. 5 is a block diagram showing the electric structure of the diesel engine of Fig. 1;

Fig. 6 is a partial cross-sectional view showing the stepping motor of Fig. 2;

Fig. 7 is a cross-sectional side view showing the stepping motor of Fig. 6;

Fig. 8A is a schematic view taken along line 8A-8A in Fig. 7;

Fig. 8B is a schematic view taken along line 8B-8B in Fig. 7;

Fig. 9A is a diagrammatic view illustrating the operation of the stepping motor;

Fig. 9B is a diagrammatic view illustrating the operation of the stepping motor;

Fig. 10 is a table used to describe how voltage is applied to the coils of the stepping motor;

Fig. 11 is a flowchart showing the initializing procedures of the valve drive apparatus of Fig. 1;

Fig. 12 is a flowchart showing the continuation of Fig. 11;

Fig. 13 is a diagram showing the initializing procedures;

Fig. 14 is a timing chart showing the initializing procedures; and

Fig. 15 is a timing chart showing the initializing procedures.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] A throttle valve drive apparatus, which is incorporated in a diesel engine, according to a first embodiment of the present invention will now be described. As shown in Fig. 1, a diesel engine 1 has a plurality of cylinders, each including a combustion chamber 12. Each combustion chamber 12 is connected to an intake passage 2 by way of an intake valve (not shown). An air cleaner 3 for filtering the intake air, a pressure sensor 6 for detecting the intake air pressure (atmospheric pressure), an intake air temperature sensor 78 for detecting the temperature of the intake air, and a throttle valve 4 for adjusting the amount of intake air are arranged from the upstream end of the intake passage 2.

[0013] A drive apparatus 5 for driving the throttle valve 4 includes a stepping motor 40 and a gear train for transmitting movement of the stepping motor 40 to the throttle valve 4. The stepping motor 40 is controlled by an electronic control unit (ECU) 19, which also performs various controls in the diesel engine 1. The drive apparatus 5 further includes a fully open switch 39, which is actuated, or turned on, when the throttle valve 4 is arranged at an angular position that fully opens the intake passage 2.

[0014] Each combustion chamber 12 is connected to an exhaust passage 7 by way of an exhaust valve (not shown). An exhaust gas recirculation (EGR) passage 8 connects the exhaust passage 7 to the intake passage 2 downstream of the throttle valve 4. An EGR valve 9 is arranged in the EGR passage 8. The EGR valve 9 is driven by an actuator 10, which is provided with a diaphragm. The ratio of the EGR amount relative to the amount of intake air drawn into the combustion chambers 12, or the EGR rate, is controlled by adjusting the amount of intake air with the throttle valve 4 and the EGR amount with the EGR valve 9. Thus, appropriate EGR control is always performed regardless of the operating state of the diesel engine 1.

[0015] Each combustion chamber 12 has a precombustion chamber 13. An injection nozzle 11 is provided for each precombustion chamber 13. A fuel injection pump 14 injects fuel into each precombustion chamber 13 through the associated injection nozzle 11. The injection pump 14 is driven by the rotation of a crankshaft 23 to deliver fuel to the injection nozzles 11. Further, the injection pump 14 includes a timer control valve 15 and a spill valve 16 to control the injection timing and amount of the fuel injected from each injection nozzle 11. The timer control valve 15 and the spill valve 16 are controlled by the ECU 19.

[0016] The injection pump 14 has a rotor (not shown) that rotates synchronously with the crankshaft 23. A plurality of projections project from peripheral surface of the rotor. A rotating speed sensor 17, which is an electromagnetic pickup, detects the projections and outputs pulse signals corresponding to the rotating speed of the rotor, or crankshaft 23. The pulse signals output by the speed sensor 17 is converted to signals indicating the speed NE of the diesel engine 1 and then sent to the ECU 19.

[0017] The ECU 19 also receives other types of data and information. For example, the ECU 19 receives atmospheric pressure data from the pressure sensor 6, intake air temperature data from the intake air temperature sensor 78, acceleration pedal depression data (depression amount of an acceleration pedal 24) sent from an acceleration pedal depression sensor 18, ON/OFF information sent from a key switch 20, ON/OFF information sent from a starter switch 21, and coolant temperature data sent from a temperature sensor 77. The key switch 20 is turned to an ON position to start the engine 1 and turned to an OFF position to stop the engine 1. The starter switch 21 is turned on when a starter motor (not shown) for starting the engine 1 is actuated, and turned off when the starter motor is deactuated.

[0018] The drive apparatus for driving the throttle valve 4 will now be described with reference to Figs. 2 to 4. As shown in Fig. 2, the throttle valve 4 is fixed to a valve shaft 26 and supported to pivot integrally with the valve shaft 26. The valve shaft 26 is rotatably supported by a throttle body 25, which is coupled to the intake passage 2. One end of the valve shaft 26 (the upper end as viewed in Fig. 2) is coupled to the throttle body 25 by a return spring 27. The force of the return spring 27 urges the valve shaft 26 to move the throttle valve 4 in a direction opening the intake passage 2.

[0019] The other end of the valve shaft 26 (the lower end as viewed in Fig. 2) extends into a gear box 28, which is coupled to the throttle body 25. A driven gear 29 is secured to the valve shaft end and supported to rotate integrally with the valve shaft 26. A first intermediate gear 36 and a second intermediate gear 37 are formed integrally with each other and rotatably supported in the gear box 28 by a pivot shaft 35. The driven gear 29 meshes with the second intermediate gear 37. The stepping motor 40, which is secured to the gear box 28, has an output shaft 41, which extends into the gear box 28. A drive gear 38 is fixed to the output shaft 41. The drive gear 38 meshes with the first intermediate gear 36. Rotation of the output shaft 41 of the stepper motor 40 is transmitted to the valve shaft 26 by way of the drive gear 38, the first intermediate gear 36, the second intermediate gear 37, and the driven gear 29. Rotation of the valve shaft 26 moves the throttle valve in the opening and closing directions.

[0020] As shown in Fig. 3, a lever 32, which has two arms 32a and 32b, is pivotally coupled to the valve shaft 26. The lever 32 is connected to the driven gear 29 by a relief spring 31. The relief spring 31 urges the lever 32 in a counterclockwise direction, as viewed in Fig. 3, with respect to the driven gear 29. The arm 32b is bent toward the driven gear 29. The distal end of the arm 32b engages with a groove 30 formed in the driven gear 29. The lever 32 is pivotal relative to the driven gear 29 within a range defined by the opposing walls of the groove 30. The distal end of the arm 32b normally abuts against one wall of the groove 30 due to the counterclockwise urging force of the relief spring 31, as shown in Fig. 4. The driven gear 29 and the lever 32 are rotated integrally in this state.

[0021] As shown in Fig. 3, the fully open switch 39 is arranged in the gear box 28. The distal end of the other arm 32a has a pressing portion 33, which abuts against the fully open switch 39. The pressing portion 33 abuts against the fully open switch 39 and turns on the switch 39 when the throttle valve 4 is located at a fully open position, at which the intake passage 2 is fully opened by the throttle valve 4. In the present embodiment, the throttle valve 4 can further be rotated in the opening direction from the fully open position. The fully open position refers to the angular position of the throttle valve 4 at which the opened area of the intake passage 2 is maximum. The throttle valve 4 is permitted to move further in the opening direction from the fully open position until it abuts against a stopper (not shown). The angular position of the throttle valve 4 when in contact with the stopper defines the maximum angular position of the throttle valve 4.

[0022] A fully closed stopper (not shown) is arranged in the gear box 28. The lever 32 abuts against the fully closed stopper when the throttle valve 4 is located at a fully closed position, at which the intake passage 2 is completely closed by the throttle valve 4. This restricts further rotation of the lever 32 in the closing direction of the throttle valve 4. The fully closed position refers to the angular position of the throttle valve 4 at which the opened area of the intake passage 2 is minimum, or null. However, the driven gear 29 can further be rotated in the closing direction even if the throttle valve 4 is located at the fully closed position. When the driven gear 29 is further rotated in the closing direction from the state at which the further rotation of the lever 32 is restricted, the relief spring 31 urges the driven gear 29 in the opening direction of the throttle valve 4.

[0023] The electric structure of the diesel engine 1 will now be described with reference to the block diagram of Fig. 5. The ECU 19 has a read only memory (ROM) 61, which stores control programs such as that used for fuel injection control, fuel injection timing control, EGR control, and intake air amount control. The ROM 61 also stores functional data for computing values corresponding to various conditions. The ECU 19 further includes a central processing unit (CPU) 60, a random access memory (RAM) 62, and a backup RAM 63. The CPU 60 executes computations based on the programs stored in the ROM 61. The RAM 62 temporarily stores the computation results provided by the CPU 60 and the data input by various sensors. The backup RAM 63 stores necessary data when the supply of power to the ECU 19 is cut off. A bus 64 connects the CPU 60, the ROM 61, the RAM 62, and the backup RAM 63 to one another and to an input interface 66 and an output interface 67.

[0024] The signals sent from the pressure sensor 6, the acceleration pedal depression sensor 18, the coolant temperature sensor 77, and the intake air temperature sensor 78 are temporarily stored in associated buffers 69. The signals stored in each buffer 69 are sequentially selected by a multiplexer 68 based on commands from the CPU 60, converted to digital signals by an analog to digital (A/D) converter 65, and then sent to the input interface 66. The pulse signals from the engine speed sensor 17 are binarized by a waveform shaping circuit 71 and then sent to the input interface 66. The ON/OFF signals from the key switch 20, the starter switch 21, and the fully open switch 39 are sent to the input interface 66.

[0025] Command signals from the CPU 60 are sent to drivers 72, 73, 74, and 75 through the output interface 67. Based on the command signals from the CPU 60, the drivers 72-75 drive the stepping motor 40, the actuator 10, the timer control valve 15, and the spill valve 16, respectively.

[0026] The stepping motor 40 will now be described in detail with reference to Figs. 6 to 10. As shown in Figs. 6 and 7, the stepping motor 40 has a rotor 42, which rotates integrally with the output shaft 41, and two stator cups, namely an A-phase stator cup 44 and a B-phase stator cup 45, which surround the rotor 42. The rotor 42 houses a permanent magnet 43 at its peripheral portion. The permanent magnet 43 has N poles and S poles alternately arranged at predetermined angular intervals in the angular direction as shown in Figs. 8A and 8B.

[0027] As shown in Figs. 6 and 7, the A-phase stator cup 44 and the B-phase stator cup 45 are cylindrical. The rotor 42 is located in the hollow portion of the stator cups 44, 45. Two coils, an AP-phase coil 46 and an AN-phase coil 47, are provided around the rotor 42 in the A-phase stator cup 44. Likewise, two coils, a BP-phase coil 48 and a BN-phase coil 49, are provided around the rotor 42 in the B-phase stator cup 45. The coils 46-49 are wound in the same direction.

[0028] The A-phase stator cup 44 has a plurality of upper teeth 50 and a plurality of lower teeth 51 arranged around the rotor 42. As shown in Fig. 8A, the upper teeth 50 and lower teeth 51 are alternately arranged at angular intervals that are the same as those between the alternately arranged N and S poles of the permanent magnet 43. Likewise, the B-phase stator cup 45 has a plurality of upper teeth 52 and a plurality of lower teeth 53 arranged around the rotor 42. As shown in Fig. 8B, the upper teeth 52 and lower teeth 53 are alternately arranged at angular intervals that are the same as those between the alternately arranged N and S poles of the permanent magnet 43. The teeth 50,51 of the A-phase stator cup 44 are offset by a half teeth interval from the corresponding teeth 52, 53 of the B-phase stator cup 45. The upper teeth 50, 53 and the lower teeth 51, 53 are excited when voltage is applied to the coils 46-49.

[0029] The electric structure of the stepping motor 40 and the driver 72 for driving the stepping motor 40 will now be discussed with reference to Figs. 9A and 9B. Figs. 9A and 9B schematically illustrate the rotor 42 and the stator cups 44 and 45 of the stepping motor 40 in a planar development. The electric structure is also schematically shown in Figs. 9A and 9B to facilitate description of the functions of the driver 72.

[0030] Voltage, provided by a DC power supply 58, is applied to the AP-phase coil 46 and the AN-phase coil 47 in the A-phase stator cup 44. The driver 72 has an AP-phase coil switch 54 and an AN-phase coil switch 55 to permit or stop the application of voltages to the coils 46 and 47, respectively. When the coil switches 54, 55 are turned on, voltage is applied to the associated coils 46, 47, thereby exciting the upper teeth 50 and the lower teeth 51. As described above, the coils 46, 47 are wound in the same direction. However, the currents fed to the coils 46, 47 flow in opposite directions, as shown in Figs. 9A and 9B. Therefore, the polarities of the upper teeth 50 and the lower teeth 51 when a voltage is applied to the AP-phase coil 46 are opposite to those when a voltage is applied to the AN-phase coil 47. More specifically, the application of voltage to the AP-phase coil 46 excites the upper teeth 50 to N polarity and the lower teeth 51 to S polarity, as shown in Fig. 9A. The application of a voltage to the AN-phase coil 47 excites the upper teeth 50 to S polarity and the lower teeth 51 to N polarity, as shown in Fig. 9B.

[0031] The B-phase stator cup 45 has an electric structure similar to that of the A-phase stator cup 44. The shifting of a BP-phase coil switch 56 and a BN-phase coil switch 57 between ON/OFF states selectively permits or stops the application of voltages to the associated coils 48, 49. The application of voltage to the BP-phase coil 48 excites the upper teeth 52 to N polarity and the lower teeth 53 to S polarity. Although not shown in Figs. 9A and 9B, the application of voltage to the BE-phase coil 49 excites the upper teeth 52 to S polarity and the lower teeth 53 to N polarity.

[0032] The operation of the stepping motor 40, which is driven by the driver 72, will now be described with reference to Figs. 9A, 9B, and 10. The driver 72 applies voltage to the coils 46-49 of the stepping motor 40 in the modes illustrated in Fig. 10. As shown in the table of Fig. 10, the driver 72 has eight excitation phase modes ("0" to "7"). The driver 72 switches its excitation phase mode to rotate the stepping motor 40. As shown in the table, in the odd number excitation phase modes "1", "3", "5", and "7", the driver 72 applies voltages to one of the two coils 46, 47 in the A-phase stator cup 44 and to one of the two coils 48, 49 in the B-phase stator cup 45. In the even number excitation phase modes "0", "2", "4", and "6", the driver 72 applies a voltage to just one of the four coils 46-49.

[0033] Fig. 9A shows the state of the driver 72 and the stepping motor 40 when the excitation phase mode of the driver 72 is set at "1", as illustrated in Fig. 10. As shown in Fig. 9A, when the excitation phase mode is set at "1", the driver 72 closes the AP-phase coil switch 54 and the BP-phase coil switch 56 to apply voltage to the AP-phase coil 46 and the BP-phase coil 48, respectively. In the A-phase stator cup 44, the application of voltage to the AP-phase coil 46 excites the upper teeth 50 to N polarity and the lower teeth 51 to S polarity. In the B-phase stator cup 45, the application of voltage to the BP-phase coil 48 excites the upper teeth 52 to N polarity and the lower teeth 53 to S polarity.

[0034] In this state, each S pole of the permanent magnet 43 housed in the rotor 42 is attracted by the corresponding pair of adjacent N-polarized upper teeth 50, 52 in the respective A-phase and B-phase stator cups 44, 45 and drawn to an intermediate position between the pair of upper teeth 50, 52. Likewise, each N pole of the permanent magnet 43 is attracted by the corresponding pair of adjacent S-polarized lower teeth 51, 53 in the respective A-phase and B-phase stator cups 44, 45 and drawn to an intermediate position between the pair of lower teeth 51, 53. The rotor 42 is thus rotated such that the S poles of the permanent magnet 43 are drawn to intermediate positions between the corresponding pair of adjacent upper teeth 50, 52, while the N poles of the permanent magnet 43 are drawn to intermediate positions between the corresponding pair of adjacent lower teeth 51, 53.

[0035] Afterward, if the excitation phase mode is changed to "3" from "1", the driver 72 applies voltages to the AN-phase coil 47 and the BP-phase coil 48, as shown in Fig. 10. In excitation phase mode "3", as shown in Fig. 9B, the upper teeth 50 of the A-phase stator cup 44 are excited to S polarity and the lower teeth 51 to N polarity. The upper teeth 52 of the B-phase stator cup 45 are excited to N polarity and the lower teeth 53 to S polarity. Therefore, each S pole of the permanent magnet 43 is drawn to an intermediate position between the corresponding pair of adjacent N-polarized lower teeth 51 and upper teeth 52. Each N pole of the permanent magnet 43 is drawn to an intermediate position between the corresponding pair of adjacent S-polarized upper teeth 50 and lower teeth 53.

[0036] When the excitation phase mode changes to "3" from "1", the rotor 42 is rotated rightward, as viewed in Figs. 9A and 9B, by half the interval of the adjoining poles of the permanent magnet 43. In the present embodiment, when the rotor 42 and output shaft 41 of the motor 40 are rotated rightward, as viewed in Figs. 9A and 9B, the throttle valve 4 is driven in the closing direction. When the rotor 42 and drive shaft 41 are rotated leftward, as viewed in Figs. 9A and 9B, the throttle valve 4 is driven in the opening direction.

[0037] Accordingly, the driver 72 switches the excitation phase mode to rotate the output shaft 41 of the stepping motor 40 and thereby rotate the throttle valve 4. When the excitation phase mode is shifted in a descending order, the throttle valve 4 is rotated in the opening direction. When the excitation phase mode is shifted in an ascending order, the throttle valve 4 is rotated in the closing direction.

[0038] In the present embodiment, the stepping motor 40 is controlled by two kinds of excitation systems referred to as "1-2 phase excitation system" and "2 phase excitation system". In the 1-2 phase excitation system, the excitation phase modes "0" to "7" are performed one after another, specifically, in the sequence of "0" to "1" to "2" and so forth or in the reverse sequence of "2" to "1" to "0" and so forth. Therefore, in the 1-2 phase excitation system, the mode where only one coil is excited and the mode where two coils are simultaneously excited are alternated, as illustrated in Fig. 10. In the 2 phase excitation system, every other excitation phase mode is selected.
Specifically, the excitation phase mode is changed in the sequence of "1" to "3" to "5" and so forth or in the reverse sequence of "5" to "3" to "1" and so forth. Thus, in the 2 phase excitation system, only the modes in which two coils are simultaneously excited are performed.

[0039] In the 1-2 phase excitation system, the driven angular interval of the rotor 42 for each shifting of the excitation phase mode is smaller. The angular position of the throttle valve 4 is thus finely controlled. In the 2 phase excitation system, the driven angular interval of the rotor 42 for each shifting of the excitation phase mode is greater. This increases the moving speed of the throttle valve 4. The two excitation systems are selectively used in accordance with the current circumstances to improve both the precision and the response of the throttle valve 4 when controlling its angular position.

[0040] In the present embodiment, a step is defined as the motor's rotational angle for each shifting of the excitation phase mode when using the 1-2 phase excitation system. Therefore, when the 2 phase excitation system is used, each shifting of the excitation phase mode rotates the motor 40 by two steps.

[0041] The method of driving the throttle valve with the stepping motor 40 under normal conditions will now be discussed. The angular position of the throttle valve 4 corresponds to the angular position of the stepping motor 40, which is determined by the number of steps carried out by the stepping motor 40. The ECU 19 controls the angle of the throttle valve 4 based on the step number performed by the stepping motor 40.

[0042] The ECU 19 first judges the operating state of the engine 1 based on the detection signals sent from various sensors. The ECU 19 then computes a target step number LSTRG, which corresponds to the target angular position of the throttle valve 4, in accordance with the engine operating state. The rotational angle of the stepping motor 40 corresponding to the fully open position of the throttle valve 4 or its vicinity is set as a reference rotational angle. Furthermore, the step number of the motor 40 when arranged at the reference rotational angle is referred to as a reference step number and set at "0". The target step number LSTRG is indicated by the number of steps from the reference step number. The target step number LSTRG becomes larger as the target angular position, or angle, of the throttle valve 4 becomes smaller. That is, the target step number LSTRG becomes larger as the target area of the intake passage 2 opened by the throttle vale 4 becomes smaller.

[0043] The target step number LSTRG is corrected in accordance with parameters that include the coolant temperature detected by the coolant temperature sensor 77, the intake air temperature detected by the intake air temperature sensor 78, and the atmospheric pressure detected by the pressure sensor 6. This guarantees the intake of the appropriate amount of air corresponding to the operating state of the engine 1.

[0044] The ECU 19 actuates the stepping motor 40 based on the difference between the target step number LSTRG and the current and actual step number LSACT. In the same manner as the target step number LSTRG, the actual step number LSACT is indicated by the number of steps from the reference step number. Furthermore, the actual step number LSACT becomes larger as the actual angle of the throttle valve 4 (i.e., the area opened by the throttle valve 4) becomes smaller.

[0045] When the actual step number LSACT is smaller than the target step number LSTRG, that is, when the actual angle of the throttle valve 4 is greater than its target angle (target angular position), the ECU 19 shifts the excitation phase mode in an ascending manner such that the stepping motor 40 actuates the throttle valve 4 in the closing direction. When the actual step number LSACT is greater than the target step number LSTRG, that is, when the actual angle of the throttle valve 4 is smaller than the target angle, the ECU 19 shifts the excitation phase mode in a descending manner such that the stepping motor 40 actuates the throttle valve 4 in the opening direction.
Accordingly, the stepping motor 40 is controlled to match the actual step number LSACT with the target step number LSTRG. When the actual angle of the throttle valve 4 coincides with the target angle, the amount of intake air optimally corresponds with the operating state of the engine 1.

[0046] If the difference between the actual step number LSACT and the target step number LSTRG is only one step, the motor 40 needs to be driven by only one step. In this case, the 1-2 phase excitation system is used to drive the stepping motor 40. Otherwise, the 2 phase excitation system is used to drive the stepping motor 40 two steps at a time.

[0047] A command value LSTP, which is the sum of the actual step number LSACT and a predetermined offset value, is used when controlling the stepping motor 40. The command value LSTP is actually expressed by a binary number, which includes a plurality of digits. The lower three digits indicate the value of the excitation phase mode corresponding to the current actual step number LSACT. With reference to Figs. 10 and 13, the rotational angle of the stepping motor 40 corresponding to excitation phase mode "3" when the throttle valve 4 is in the vicinity of the fully opened position is set as the reference rotational angle. The step number of the stepping motor 40 when located at the reference rotational angle is set to "0" as the reference step number. Furthermore, the offset value is set to "3". Thus, if the stepping motor 40 is driven by six steps from the reference rotational angle in the direction closing the throttle valve 4, the actual step number becomes "6". In this case, the command value LSTP is "9", which is the sum of the actual step number LSACT "6" and the offset value "3". The lower three digits of the binary number representing "9" are "001", which would correspond to "1" if used in decimal form. In other words, the value of "1" indicates the value of the excitation phase mode corresponding to the current, actual step number LSACT "6".

[0048] If the stepping motor 40 goes out of synchronization or if the stepping motor 40 is de-actuated when the engine 1 is stopped, correspondence between the step number of the stepping motor 40 and the angular position of the throttle valve 4 is lost. In such cases, if the conditions described below are satisfied, an initializing routine is executed to initialize and synchronize the relationship between the step number of the motor 40 and the angular position of the throttle valve 4.

[0049] The initializing process will now be described with reference to Figs. 11 to 15. A flowchart showing the initializing procedures executed by the ECU 19 is illustrated in Figs. 11 and 12. The initializing routine is executed when conditions (1) to (4), which are listed below, are all satisfied.

(1) The key switch 20 is turned on.
(2) The starter switch 21 is turned off.
(3) The engine speed NE is in the range of 500 to 2,000rpm.
(4) Initialization has not yet been carried out after starting the engine 1.

[0050] While the starter motor is being actuated to crank the engine 1, the supply of voltage fed to electric devices, such as the stepping motor 40 and its driver 72, is unstable. The initializing process may thus not be performed normally when the starter switch 21 is turned on. Furthermore, if the engine speed NE exceeds 2000rpm, the vibrations of the diesel engine 1 become strong. This may vibrate the fully open switch 39 when shifting between ON/OFF states and interfere with normal initialization. Accordingly, a single initializing routine is executed when the engine speed NE stabilizes, the vibrations are small, and cranking of the engine 1 has been completed.

[0051] After completing the execution of the initializing routine and when there is a possibility that the stepping motor 40 may have gone out of synchronization during operation of the engine 1, the initializing routine is executed once more if all four conditions (1) to (4) are satisfied. For example, if the fully open switch 39 is unactuated, or off, during normal control of the stepping motor 40 despite the actual step number LSACT being equal to or lower than a value that corresponds with the fully open position of the throttle valve 4, there is a possibility that the stepping motor 40 may be out of synchronization. There is also a possibility that the stepping motor 40 may be out of synchronization if the fully opened switch 39 is on despite the actual step number LSACT being greater than a value that corresponds with the fully open position of the throttle valve 4. In such cases, the initializing routine is performed again.

[0052] When starting the initializing routine, the reference step number is not yet set. Therefore, the stepping motor 40 cannot be controlled in the normal manner, that is, by using the command value LSTP, since the actual step number LSACT of the stepping motor 40 has not yet been confirmed. Accordingly, as shown in Fig. 13, the stepping motor 40 is controlled based on a mode value LSOF that represents one of the excitation phase modes "0" to "7". The mode value LSOF corresponds to the lower three digits of the command value LSTP. In other words, the mode value LSOF is set at one of the eight values of "0" to "7". During the execution of the initializing routine, the ECU 19 commands the driver 72 to control the stepping motor 40 in accordance with the excitation phase mode indicated by the mode value LSOF. The ECU 19 sets the initial value of the mode value LSOF at "1" when executing the initializing routine and drives the stepping motor 40 two steps at a time, or by double steps, with the 2 phase excitation system. The ECU 19 also counts the driven step numbers of the stepping motor 40 as a counter value C.

[0053] When entering the initializing routine, the ECU 19 first performs step S100, which is illustrated in Fig. 11, to judge whether or not the fully open switch 39 is on. If the fully open switch 39 is on, the throttle valve 4 is located between the fully open position and the maximum open position. In this case, the ECU 19 proceeds to step S101.

[0054] At step S101, the ECU 19 resets the counter value C to "0". The ECU 19 then proceeds to step S102 and drives the stepping motor 40 by double steps to move the throttle valve 4 in the closing direction. More specifically, the ECU 19 adds "2" to the current mode value LSOF so that the driver 72 shifts the excitation phase mode accordingly and drives the stepping motor 40 by double steps. The value of "2" is added to the mode value LSOF to shift the excitation phase mode sequentially from "1" to "3" to "5" to "7" to "1" and so forth. At step S103, the ECU 19 counts the driven number of steps by adding "2" to the counter value C in an incremental manner.

[0055] At step S104, the ECU 19 judges whether or not the fully open switch 39 is off. If the fully open switch 39 is off, the angle of the throttle valve 4 is smaller than that of the fully open position. In this case, the ECU 19 proceeds to step S106. If the fully open switch 39 is still on, the ECU 19 proceeds to step S105.

[0056] At step S105, the ECU 19 determines whether or not the counter value C is equal to or greater than a predetermined first judgement value k1. If the counter value C is smaller than the first judgement value k1, the ECU 19 returns to step S102 and drives the throttle valve 4 by double steps until the fully open switch 39 is turned off. This procedure is illustrated in Fig. 14. If the counter value C is equal to or greater than the first judgement value k1, the ECU 19 determines that there is an abnormality and proceeds to step S118. At step S118, the ECU 19 raises an abnormality flag and then terminates subsequent processing.

[0057] The first judgement value k1 is set at a value that is slightly greater than the number of stepping motor steps required to move the throttle valve 4 from the maximum open position to the fully open position. In other words, the hysteresis error that occurs when the fully open switch 39 shifts between ON/OFF states and the assembly margins that are tolerated when installing the stopper (not shown) for restricting the maximum open position are taken into consideration.

[0058] If the throttle valve 4 is functioning normally, the fully open switch 39 is turned off when the throttle valve 4 is driven in the closing direction from the maximum open position by the number of steps corresponding to the first judgement value k1. Thus, the drive system of the throttle valve 4 is deemed to have an abnormality if the fully open switch 39 does not shift to an OFF state from an ON state when the throttle valve 4 is driven in the closing direction by the number of steps corresponding to the first judgement value k1. Abnormalities include malfunctions of the throttle valve 4, the fully open switch 39, and the drive apparatus 5, which includes the stepping motor 40. If the occurrence of such an abnormality raises the abnormality flag in step S118, for example, the current excitation mode may be fixed to lock the throttle valve 4 at its current angular position.

[0059] If the fully open switch 39 is turned off in step S104, the ECU 19 proceeds to step S106 and resets the counter value C to "0" again. The ECU 19 then proceeds to step S107 and drives the stepping motor 40 by two steps to move the throttle valve 4 in the opening direction. In this case, the ECU 19 subtracts "2" from the current mode value LSOF so that the driver 72 shifts the excitation phase mode and drives the stepping motor 40 by two steps. The value of "2" is subtracted from the mode value LSOF to shift the excitation phase mode sequentially from "7" to "5" to "3" to "1" to "7" and so forth. At step S108, the ECU 19 counts the driven number of steps by adding "2" to the counter value C in an incremental manner.

[0060] At step S109, the ECU 19 judges whether or not the fully open switch 39 has been turned on. If the fully open switch 39 has been turned on, the throttle valve 4 is in the fully open position. In this case, the ECU 19 proceeds to step S111. If the fully open switch 39 is off, the ECU 19 proceeds to step S110.

[0061] At step S110, the ECU 19 determines whether or not the counter value C is equal to or greater than a predetermined second judgement value k2. If the counter value C is smaller than the second judgement value k2, the ECU 19 returns to step S107 and drives the throttle valve 4 by double steps until the fully open switch 39 is turned on. This procedure is illustrated in Fig. 14. If the counter value C is equal to or greater than the second judgement value k2, the ECU 19 determines that there is an abnormality and proceeds to step S118.

[0062] The second judgement value k2 is set by taking into consideration the hysteresis error that occurs when the fully open switch 39 shifts between ON/OFF states. As shown in Fig. 13, the angle of the throttle valve 4 (i.e., the area opened by the throttle valve 4) when the fully open switch 39 shifts from an ON state to an OFF state is normally smaller than that when the fully open switch 39 shifts from an OFF state to an ON state. Thus, the second judgement value k2 is set at a value that is slightly greater than the number of motor steps required to move the throttle valve 4 by an angle corresponding to the hysteresis error.

[0063] Under normal conditions, the fully open switch 39 should be turned on in step 109 before the counter value C becomes equal to or greater than the second judgement value k2 in step S110. Therefore, if the counter value C becomes equal to or greater than the second judgement value k2 in step S110 before the fully open switch 39 is turned on in step S109, an abnormality is deemed to have occurred in the drive system of the throttle valve 4.

[0064] If it is determined that the fully open switch 39 is turned on in step S109, the ECU 19 proceeds to step S111 and sets the reference step number. The procedures for setting the reference step number will now be described with reference to Fig. 13. The period from when the mode value LSOF (i.e., the excitation phase mode) indicates "1" to when the mode value LSOF indicates "1" again is defined as a single control cycle in the initializing routine. In other words, the stepping motor 40 is driven by eight steps during a single control cycle. When it is determined that the fully open switch 39 has shifted from an ON state to an OFF state in step S109, the ECU 19 selects the control cycle that includes the current mode value LSOF. The angular position of the stepping motor 40 at which the mode value LSOF is equal to a specific value ("3" in Fig. 13) during the selected cycle is set as the reference position. The step number of the stepping motor 40 at the reference position becomes the reference step number and is set as "0".

[0065] The value obtained by subtracting the specific value "3" from the mode value LSOF corresponding to when the fully open switch 39 shifts from an OFF state to an ON state is stored as a deviation D in the RAM 62. The deviation D represents the actual step number LSACT of the stepping motor 40 when the fully open switch 39 is shifted from an OFF state to an ON state, that is, when the throttle valve 4 is fully open.

[0066] For example, in Fig. 13, the mode value LSOF indicates "5" when the fully open switch 39 is shifted from an OFF state to an ON state. Thus, in the control cycle that includes this "5", the step number of the stepping motor 40 when the mode value LSOF is equal to the specific value of "3" is set at "0" as the reference step number. In this state, the deviation D is "2". The actual step number LSACT of the stepping motor 40 when the throttle valve 4 is in the fully open position is confirmed based on the deviation D. Therefore, the employment of the deviation D guarantees location of the fully open position when necessary, such as when confirming whether the stepping motor 40 has gone out of synchronization.

[0067] The step number of the stepping motor 40 is set at "0" as the reference step number when the mode value LSOF is equal to the predetermined value of "3" regardless of whether the mode value LSOF corresponding to when the fully open switch 39 shifts from an OFF state to an ON state is a value other than "5" (i.e., "7", "3", "1"), as long as the same control cycle is being executed. If the mode value LSOF is "7", "3", or "1" when the fully open switch 39 shifts from an OFF state to an ON state, the deviation D is "4", "0", and "-2", respectively.

[0068] If the fully open switch 39 is confirmed to be OFF in step S100, the ECU 19 determines that the angle of the throttle valve 4 is smaller than that of the fully open position In this case, the ECU 19 proceeds to step S112, which is illustrated in Fig. 12.

[0069] At step S112, the ECU 19 resets the counter value C to "0". The ECU 19 then proceeds to step S113 and drives the throttle valve 4 in the opening direction by two steps. At step S114, the ECU 19 adds "2" to the counter value C in an incremental manner.

[0070] At step S115, the ECU 19 judges whether or not the fully open switch 39 has been turned on. If so, the throttle valve 4 is in the fully open position. In this case, the ECU 19 proceeds to step S111 and sets the reference step number as described above. If the fully open switch 39 is still off, the ECU 19 proceeds to step S116.

[0071] At step S116, the ECU 19 judges whether or not the counter value C is equal to or greater than a predetermined third judgement value k3. If the counter value C is smaller than the third judgement value, the ECU 19 returns to step S113 and drives the throttle valve 4 in the opening direction by double steps until the fully open switch 39 is turned on. This procedure is illustrated in Fig. 15. If the counter value C is equal to or greater than the third judgement value k3, the ECU 19 deems that an abnormality has occurred and proceeds to step S118, which is illustrated in Fig. 11.

[0072] The third judgement value k3 is set at a value indicating the number of steps included in the moving range of the throttle valve 4. In other words, the number of steps required for the stepping motor 40 to drive the throttle valve 4 from the minimum open position to the maximum open position is set as the third judgement value k3. Under normal conditions, the fully open switch 39 should be turned on in step S115 before the counter value C becomes equal to or greater than the third judgement value k3 in step S116. Therefore, an abnormality is deemed to have occurred in the drive system of the throttle valve 4 if the counter value C reaches the third judgement value k3 in step S116 before the fully open switch 39 is turned on in step S115.

[0073] Accordingly, the reference step position is set only when the fully open switch 39 changes to an ON state from an OFF state regardless of the angular position of the throttle valve 4 when starting the initializing process. Therefore, the reference rotational angle of the stepping motor 40 that corresponds to the fully open position of the throttle valve 4 is located accurately to set the reference step number with precision regardless of hysteresis errors that may take place when the fully open switch 39 shifts between ON/OFF states. This accurately matches the step number of the stepping motor 40 with the angular position of the throttle valve 4 and thus controls the angular position of the throttle valve 4 with high precision.

[0074] The relationship between the ON/OFF state of the fully open switch 39 and the driven number of steps of the throttle valve 4 is monitored during the initializing routine. This leads to the detection of abnormalities in the drive system of the throttle valve 4. When an abnormality is confirmed, the angle of the throttle valve 4 is locked. Therefore, since the throttle valve 4 is not driven when an abnormality occurs, the application of undesirable loads to the drive system of the throttle valve 4 is prevented.

[0075] The diesel engine 1 must be supplied with a sufficient amount of intake air immediately after starting the engine 1 to stabilize the operating state of the engine 1.

Accordingly, the reference step number is set when the throttle valve 4 reaches the fully open position. This guarantees a sufficient amount of air intake and starts the engine 1 in a satisfactory manner.

[0076] It should be apparent to those skilled in the art that the present invention may be embodied in many other specific forms without departing from the spirit or scope of the invention. For example, the present invention may be embodied in the forms described below.

[0077] The shifting of the fully open switch 39 between ON/OFF states need not take place when the throttle valve 4 is arranged at the fully open position, as in the preferred and illustrated embodiment. The shifting may take place when the throttle valve 4 is located at other angular positions.

[0078] Furthermore, instead of setting the reference step number when the fully open switch 39 shifts from an OFF state to an ON state, the reference step number may be set when the fully open switch 39 is shifted from an ON state to an OFF state.

[0079] The application of the present invention is not limited to the throttle valve 4. The present invention may be applied to other types of valves that are driven by a stepping motor, such as an EGR valve. Additionally, the application of the present invention is not limited to diesel engines. The present invention may also be applied to other types of engines, such as gasoline engines.

[0080] Therefore, the present examples and embodiments are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may be modified within the scope and equivalence of the appended claims.

[0081] An apparatus for driving a throttle valve (4) with a stepping motor (40) in a diesel engine (1). The apparatus includes a fully open detection switch (39) that is shifted between ON/OFF states by motion of the valve (4) when the valve (39) moves near a fully open position. An ECU (19) initializes a relationship between the driven step number of the stepping motor (40) and the angular position of the throttle valve (4) by setting a reference angle of the stepping motor (40) only when the fully open switch (39) shifts from an OFF state to an ON state, not vice versa. Thus, the reference rotational angle of the stepping motor (40), which corresponds to the fully open position of the throttle valve (4), is located accurately regardless of hysteresis errors that occur when the fully open switch (39) shifts between ON/OFF states. Accordingly, the angular position of the throttle valve (4) is controlled more precisely.

Claims

1. An apparatus for driving a valve (4) with a stepping motor (40), wherein the stepping motor (40) is driven in a stepped manner, the number of driven steps of the stepping motor (40) normally corresponding to the angular position of the valve (4), wherein the apparatus includes a switch (39) that is shifted between a first state and a second state by motion of the valve (4) and an initializing means for setting a reference position of the stepping motor (40) based on the state of the switch (39) to establish a relationship between the step number of the stepping motor (40) and the angular position of the valve (4), the apparatus being characterized in that:

   the initializing means sets the reference position of the stepping motor (40) only when the switch (39) shifts from the first state to the second state.

2. The apparatus according to claim 1, characterized in that if the switch (39) is in the second state prior

to an initialization, the initializing means first causes the switch (39) to shift from the second state to the first state and then causes the switch (39) to shift from the first state to the second state for setting the reference position.

3. The apparatus according to claim 2, characterized in that the initializing means (19) monitors the relationship between the state of the switch (39) and the driven step number of the stepping motor (40), wherein the initializing means (19) controls the stepping motor (40) to lock the valve (4) at its current angular position upon detection of an abnormality.

4. The apparatus according to any one of claims 1 to 3, characterized in that the stepping motor (40) is driven by sequentially performing excitation phase modes of a control cycle, wherein the initializing means (19) selects a control cycle that includes an excitation phase mode that corresponds to the shifting of the switch (39) from the first state to the second state, and wherein the initializing means (19) sets the rotational angle of the stepping motor (40) that corresponds to a predetermined excitation phase mode in the selected control cycle as the reference position.

5. The apparatus according to any one of claims 1 to 4, characterized in that the valve includes a throttle valve (4) arranged in an intake passage (2) of an engine (1), and wherein the state of the switch (39) changes when the throttle valve (4) is located at or in the vicinity of a position where the throttle valve (4) fully opens the intake passage (2).

6. The apparatus according to claim 5, characterized in that the initializing means (19) performs an initialization only when the speed of the engine (1) is within a predetermined range.

7. The apparatus according to any one of claims 1 to 6, characterized in that the switch (39) is unactuated when in the first state and actuated when in the second state.

8. A method for controlling an apparatus that drives a valve with a stepping motor (40), wherein the stepping motor (40) is driven in a stepped manner, the number of driven steps of the stepping motor (40) normally corresponding to an angular position of the valve (4), wherein the method includes shifting a switch (39) between a first state and a second state by movement of the valve (4) and setting a reference rotational angle of the stepping motor (40) based on the state of the switch (39) to initialize a relationship between the step number of the stepping motor (40) and the angular position of the valve (4), the method being characterized in that:

the reference rotational angle of the stepping motor (40) is set only when the switch (39) shifts from the first state to the second state.

Fig.1

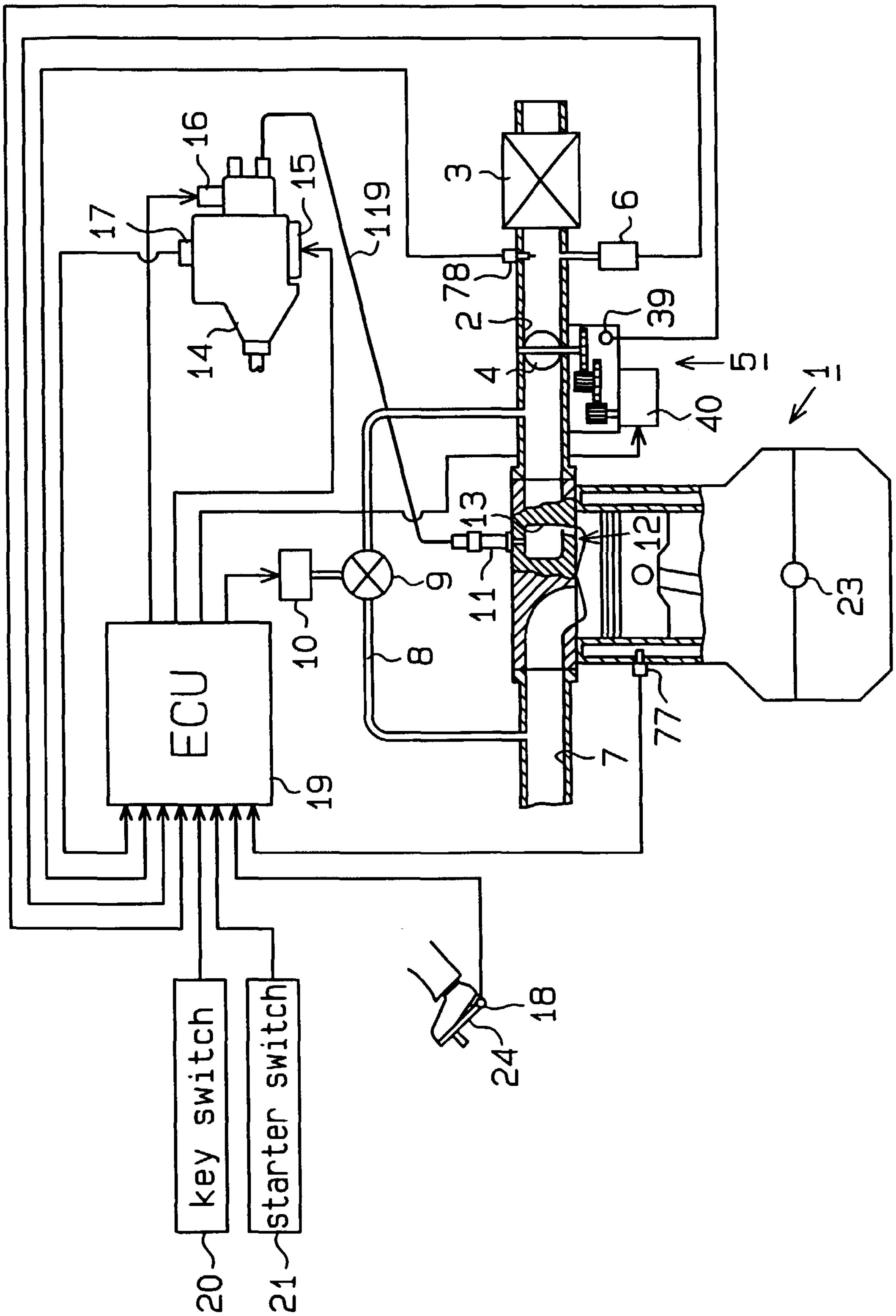

ECU
key switch
starter switch
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
23
24
39
40
77
78
119

Fig.2

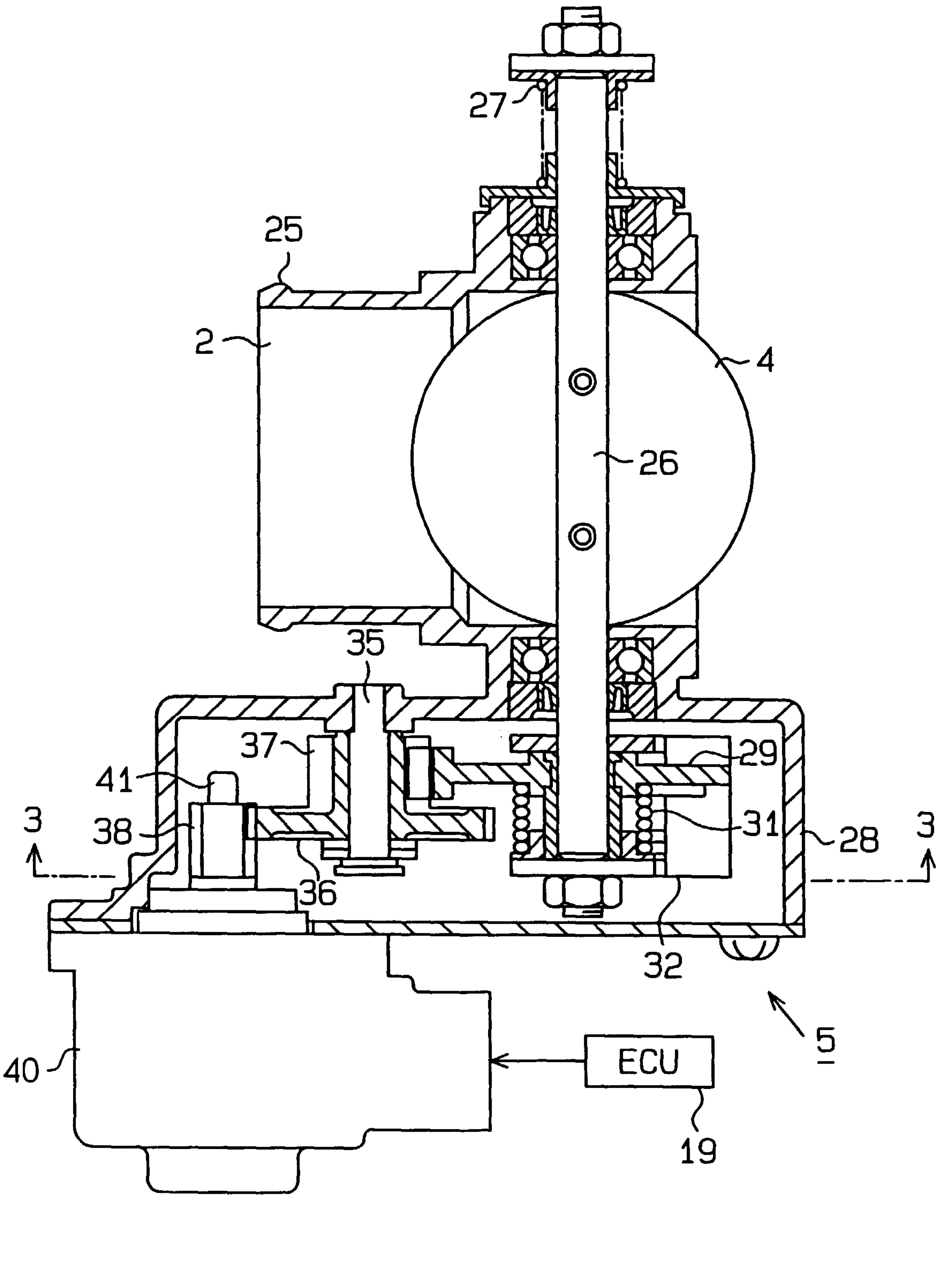


Fig.3

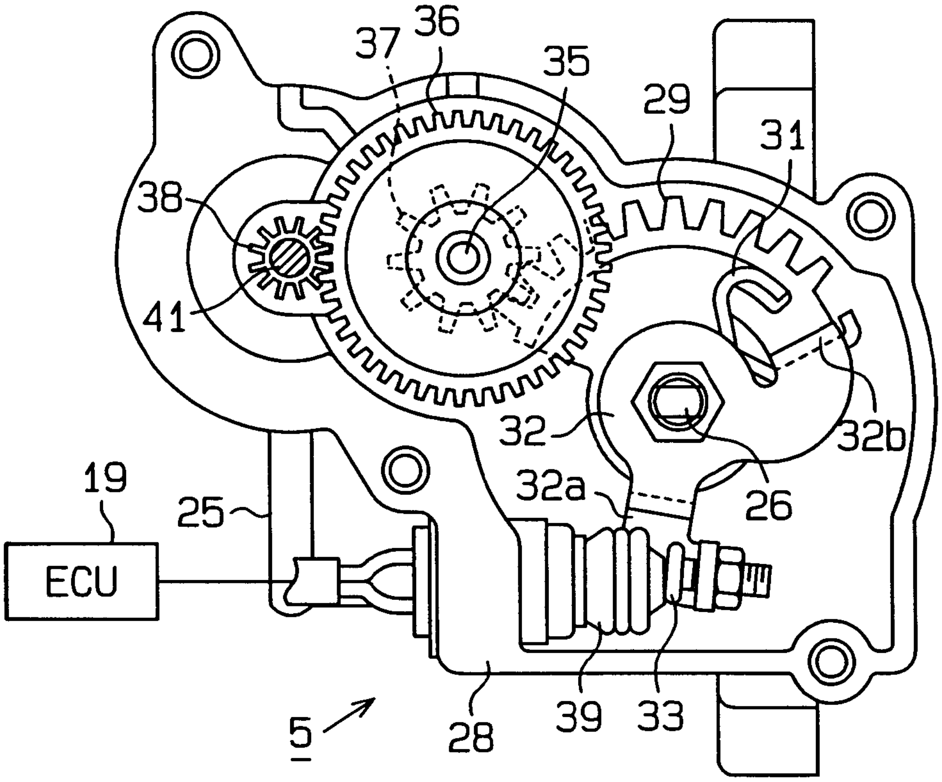

37
36
35
29
31
38
41
32
32b
26
32a
19
25
ECU
5
28
39
33

Fig.4

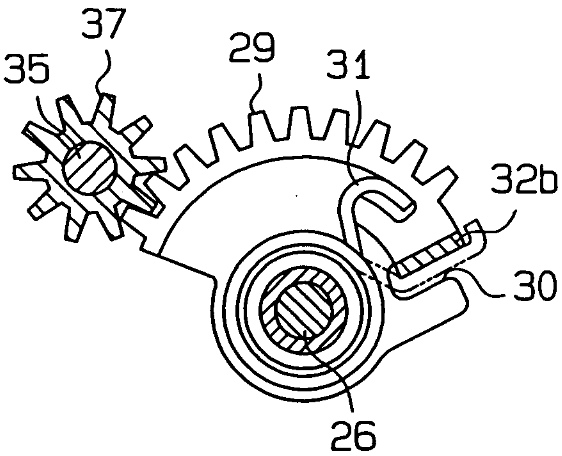

37
35
29
31
32b
30
26

Fig.5

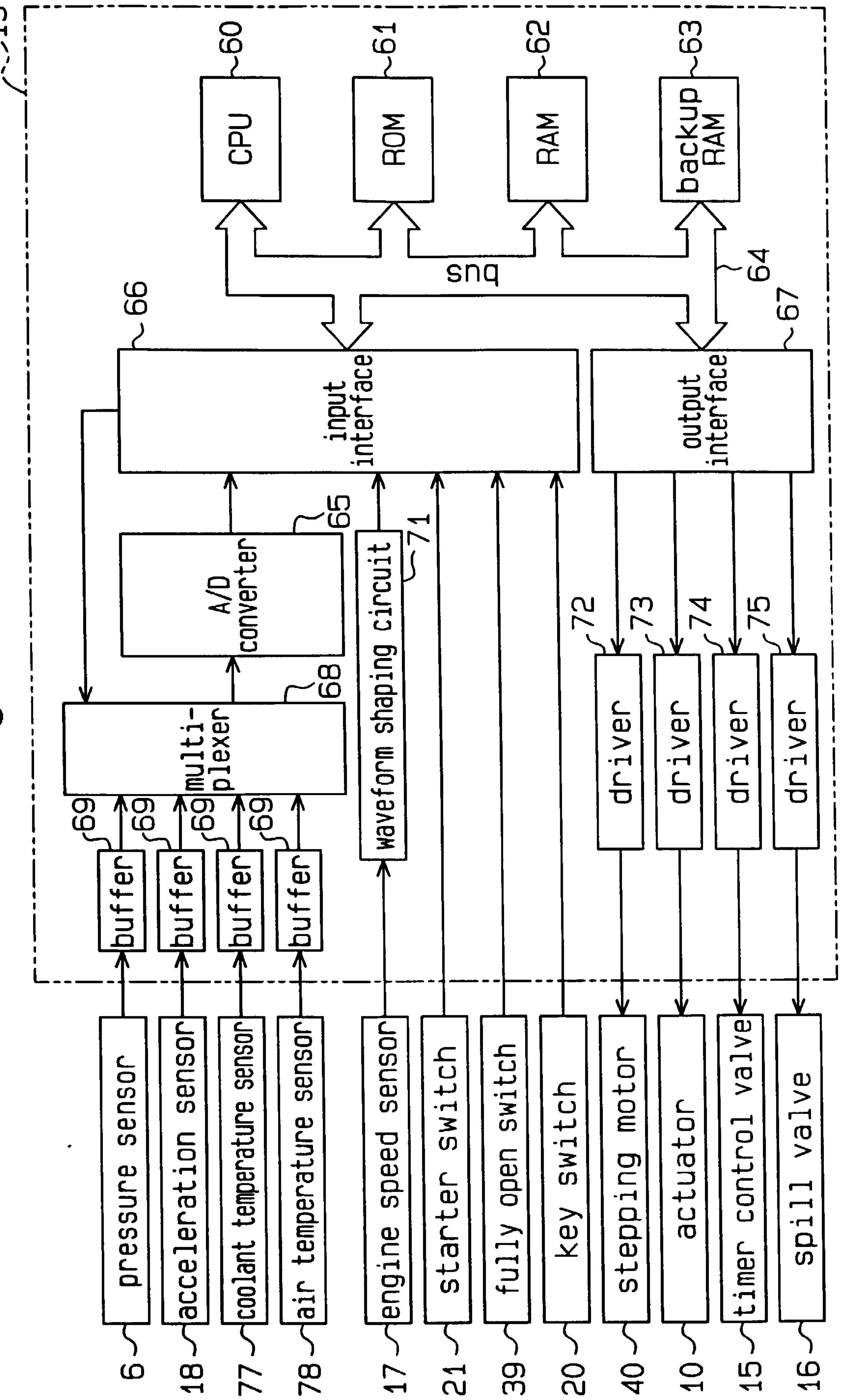

19
CPU
60
ROM
61
RAM
62
backup RAM
63
bus
64
66
input interface
67
output interface
65
A/D converter
71
waveform shaping circuit
68
multi-plexer
69
buffer
buffer
buffer
buffer
72
73
74
75
driver
driver
driver
driver
pressure sensor
6
acceleration sensor
18
coolant temperature sensor
77
air temperature sensor
78
engine speed sensor
17
starter switch
21
fully open switch
39
key switch
20
stepping motor
40
actuator
10
timer control valve
15
spill valve
16

Fig.6

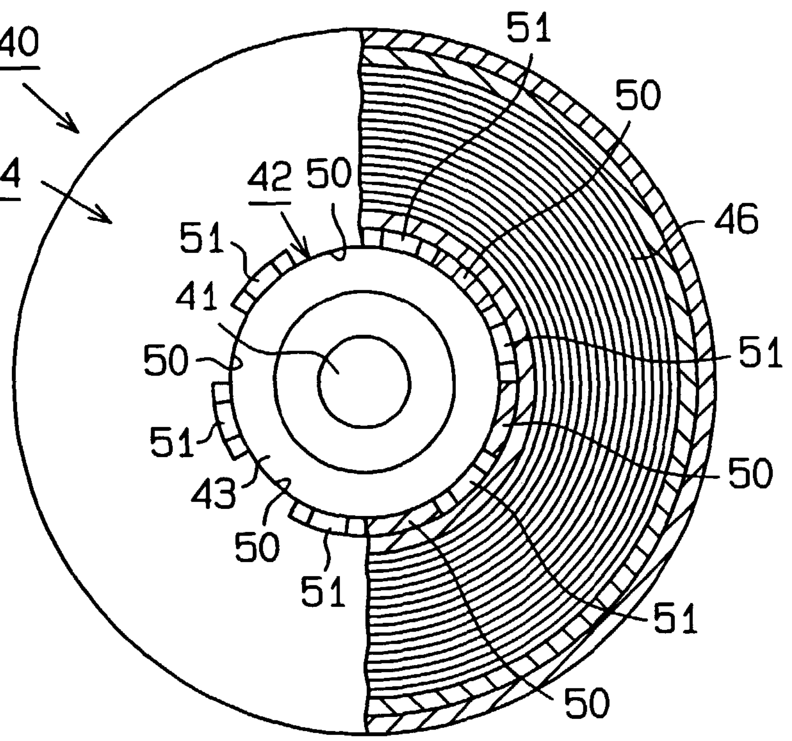

40
44
42
50
51
41
50
51
43
50
51
51
50
46
51
50
51
50

Fig.7

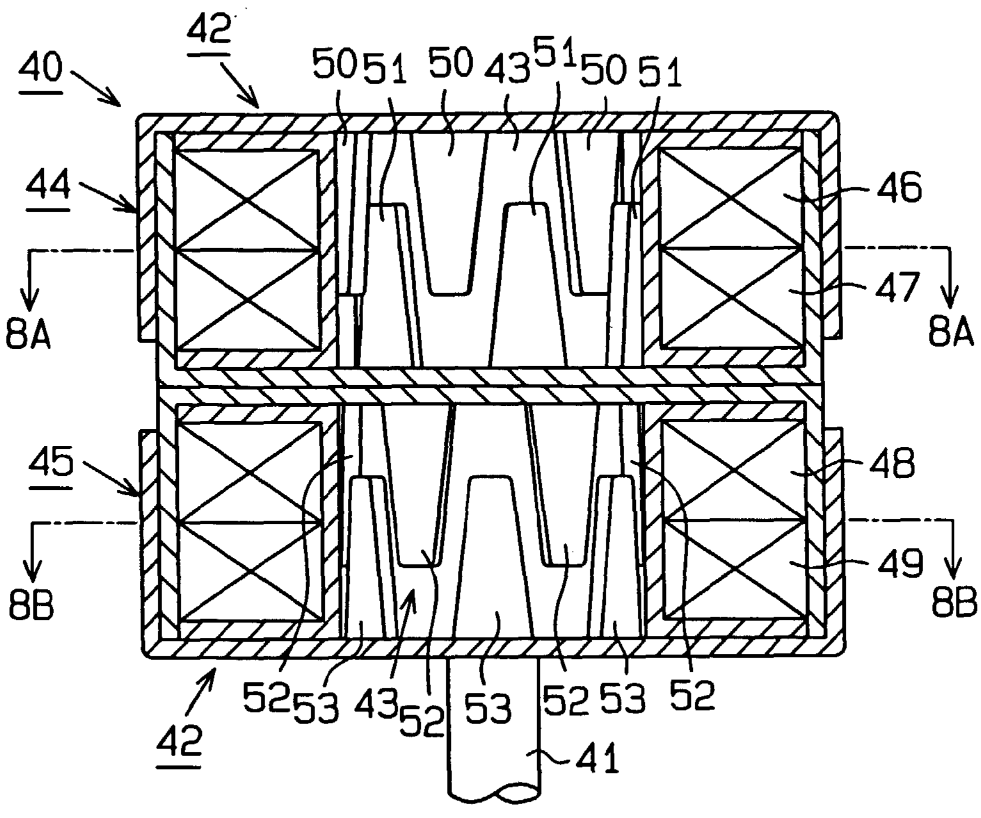

42
40
50
51
50
43
51
50
51
44
46
47
8A
8A
45
48
49
8B
8B
52
53
43
52
53
52
53
52
42
41

Fig.8A

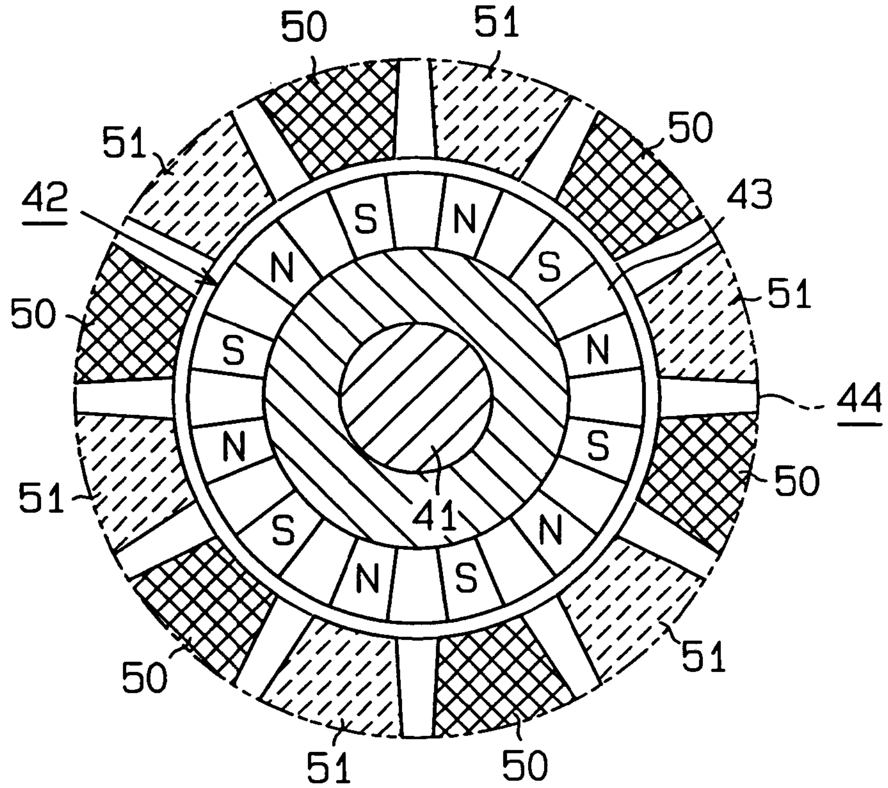

50
51
50
51
42
43
51
50
44
50
51
41
50
51
51
50
S
N
N
S
S
N
N
S
S
N
N
S

Fig.8B

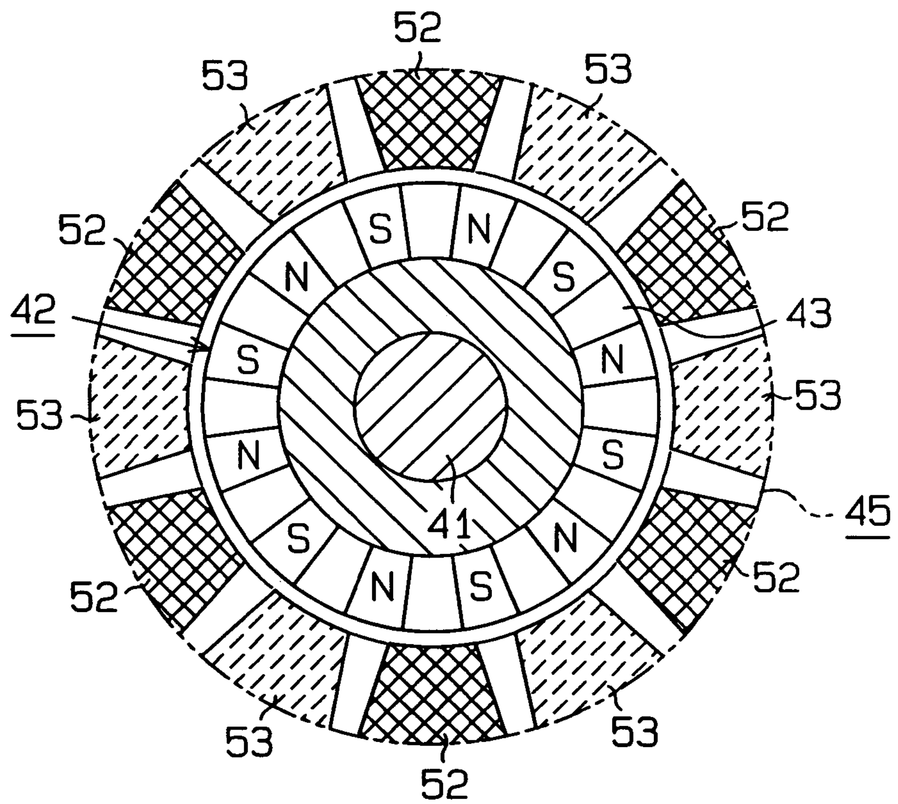
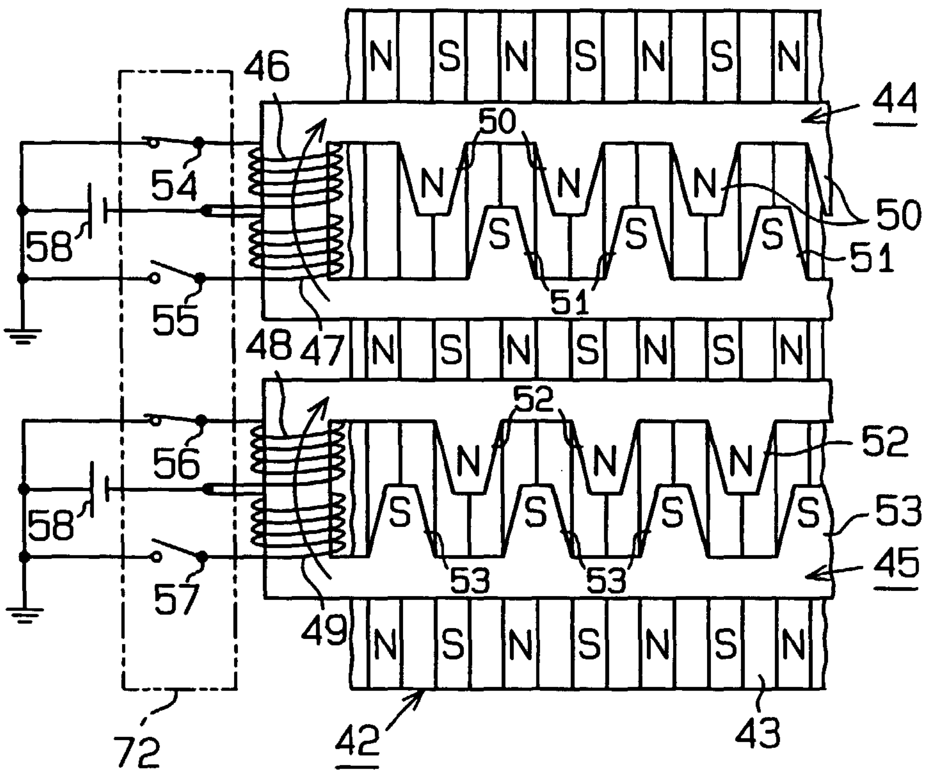

52
53
53
52
52
42
43
53
53
45
41
52
52
53
53
52
S
N
N
S
S
N
N
S
S
N
N
S

Fig.9A


N
S
N
S
N
S
N
46
44
50
54
N
N
N
50
58
S
S
S
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55
51
48
47
N
S
N
S
N
S
N
52
56
N
N
N
52
58
S
S
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S
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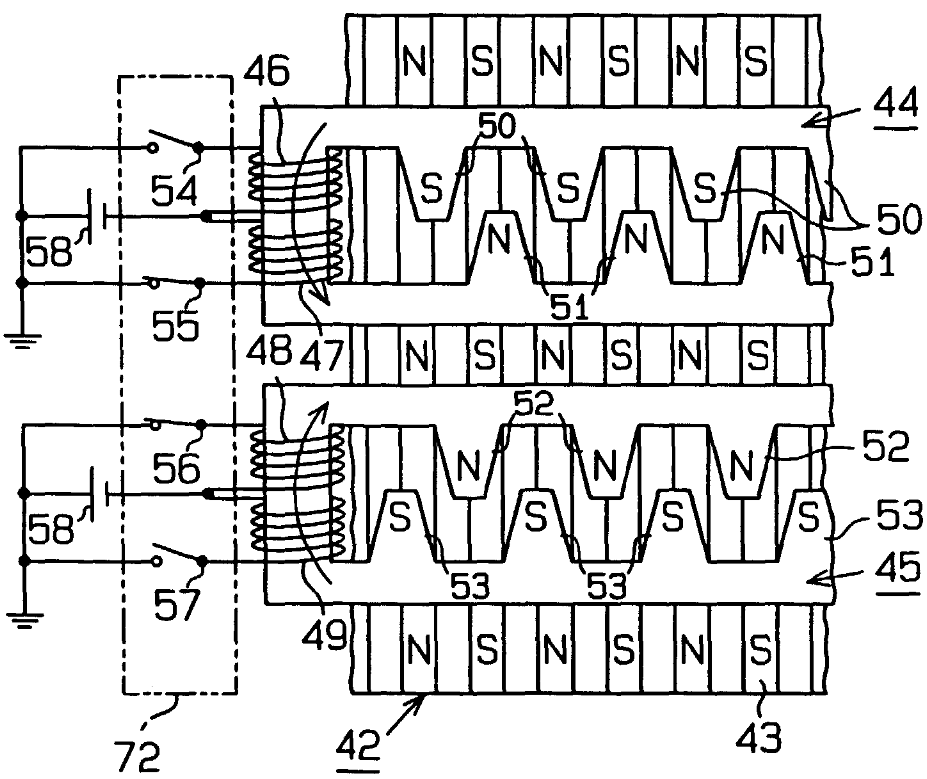
72
42
43

Fig.9B


N
S
N
S
N
S
46
44
50
54
S
S
S
50
58
N
N
N
51
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51
48
47
N
S
N
S
N
S
52
56
N
N
N
52
58
S
S
S
S
53
57
53
53
45
49
N
S
N
S
N
S
72
42
43

Fig.10

	excitation phase mode (lower 3bits of LSTP)							
	0	1	2	3	4	5	6	7
AP-phase coil 46	on	on	off	off	off	off	off	on
BP-phase coil 48	off	on	on	on	off	off	off	off
AN-phase coil 47	off	off	off	on	on	on	off	off
BN-phase coil 49	off	off	off	off	off	on	on	on

Fig.11

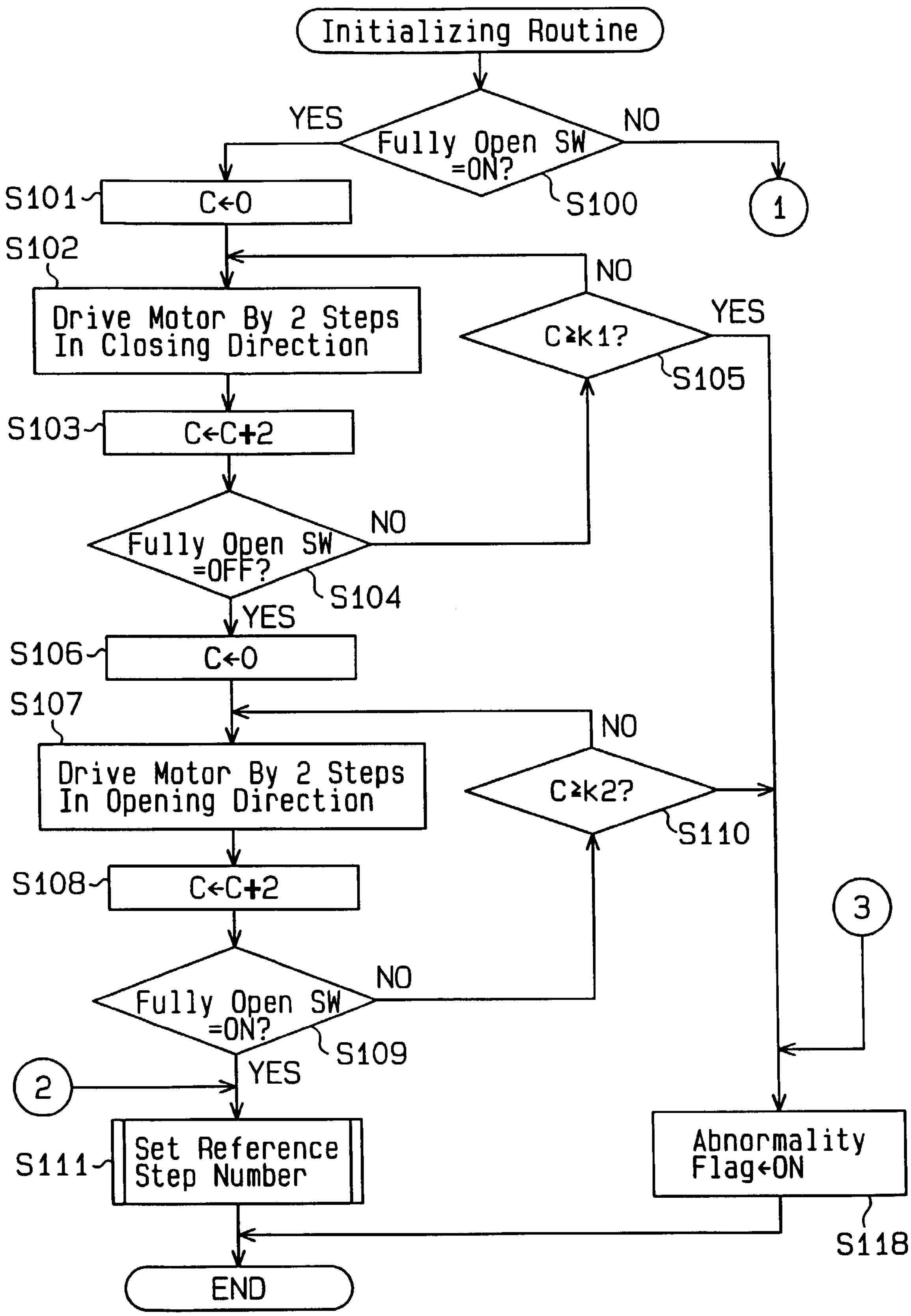

Initializing Routine
Fully Open SW =ON?
S100
YES
NO
1
S101
C←0
S102
Drive Motor By 2 Steps In Closing Direction
S103
C←C+2
Fully Open SW =OFF?
S104
NO
YES
C≥k1?
S105
NO
YES
S106
C←0
S107
Drive Motor By 2 Steps In Opening Direction
S108
C←C+2
Fully Open SW =ON?
S109
NO
YES
C≥k2?
S110
NO
3
2
S111
Set Reference Step Number
Abnormality Flag←ON
S118
END

Fig.12

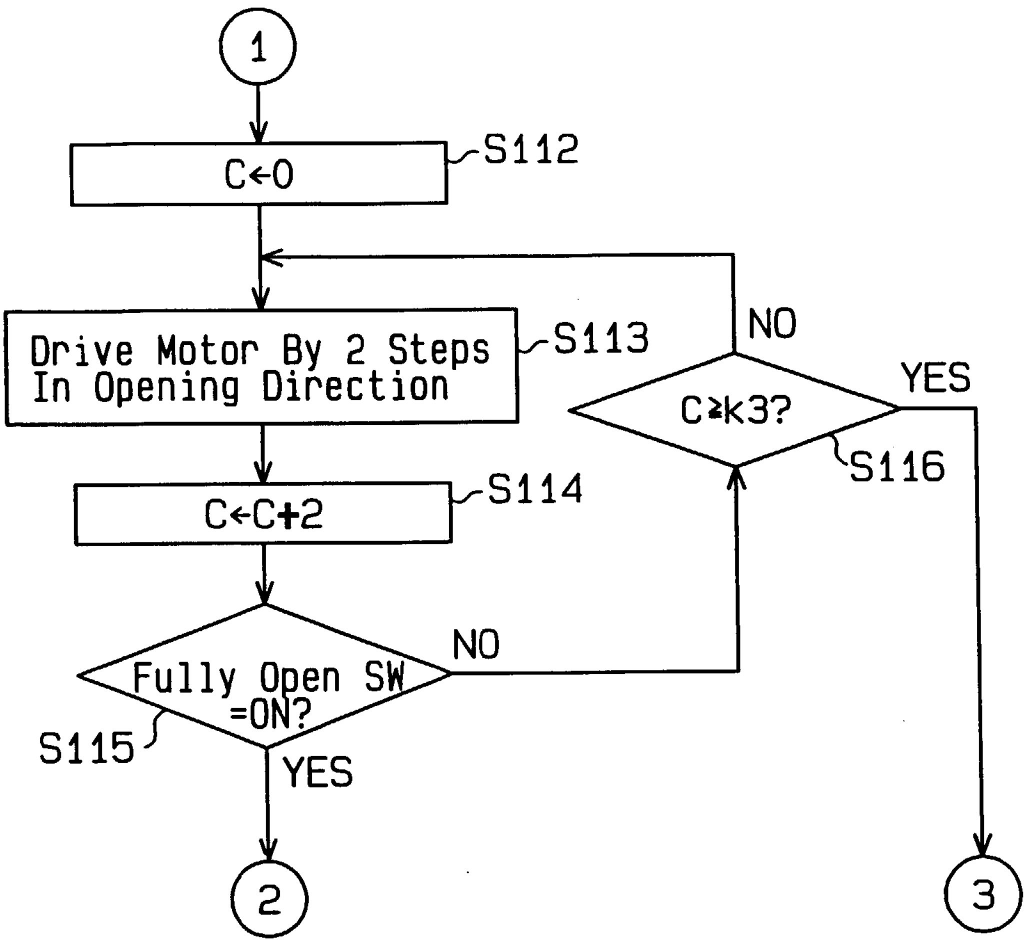
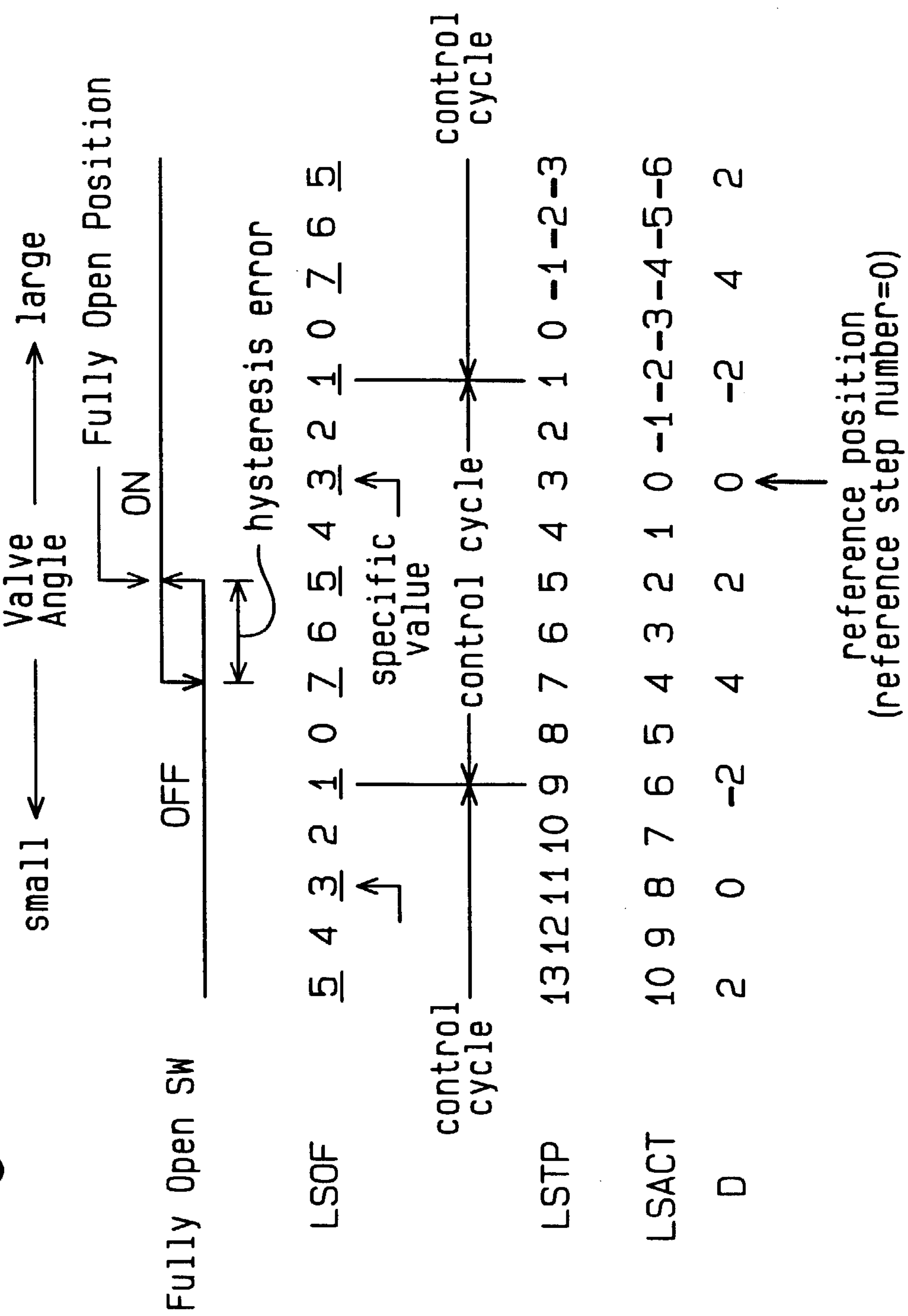

1
C←0
S112
Drive Motor By 2 Steps
In Opening Direction
S113
C←C+2
S114
Fully Open SW
=ON?
S115
NO
YES
C≥k3?
S116
NO
YES
2
3

Fig.13



small
Valve Angle
large
Fully Open SW
OFF
ON
Fully Open Position
hysteresis error
specific value
LSOF
5 4 3 2 1 0 7 6 5 4 3 2 1 0 7 6 5
control cycle
control cycle
control cycle
LSTP
13 12 11 10 9 8 7 6 5 4 3 2 1 0 -1 -2 -3
LSACT
10 9 8 7 6 5 4 3 2 1 0 -1 -2 -3 -4 -5 -6
D
2 0 -2 4 2 0 -2 4 2
reference position
(reference step number=0)

Fig.14

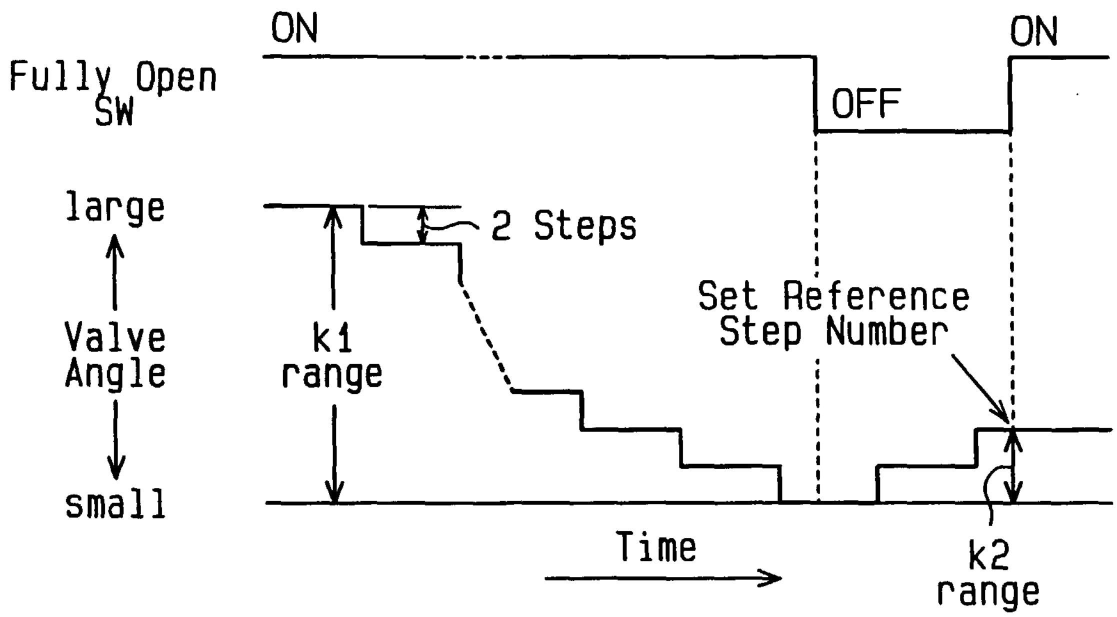
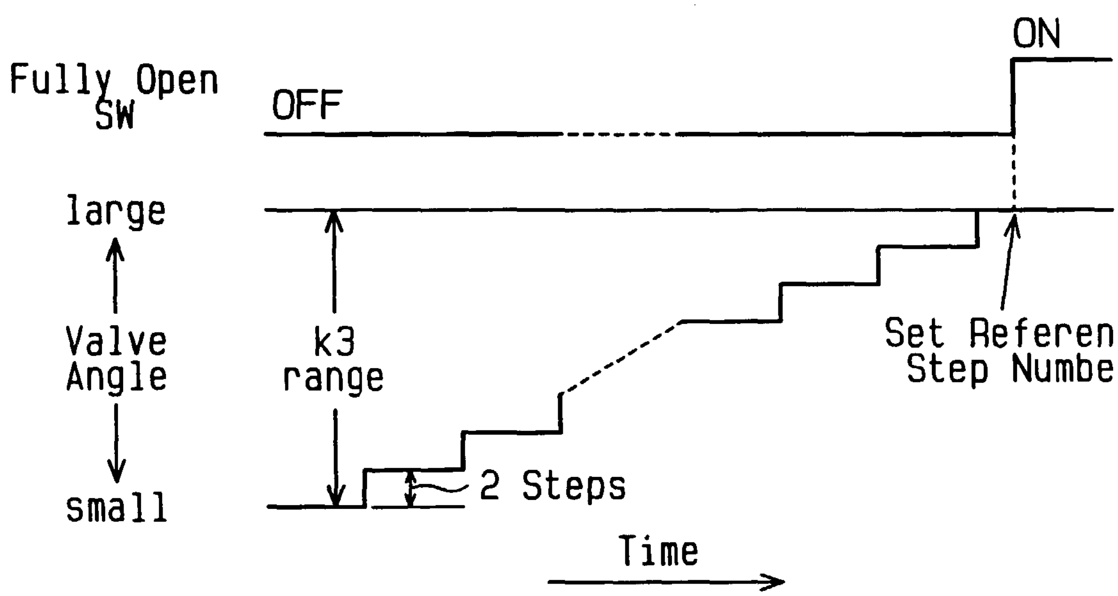

Fully Open SW
ON
OFF
ON
large
Valve Angle
small
2 Steps
k1 range
Set Reference Step Number
Time
k2 range

Fig.15


Fully Open SW
OFF
ON
large
Valve Angle
small
k3 range
Set Reference Step Number
2 Steps
Time