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(54) Apparatus and method for detecting fault in glow plug

(57) In method and apparatus for detecting a fault in a glow plug provided in a diesel engine, a possibility of a fault in the glow plug is determined without utilizing a forced change in the state of energization of the glow plug for the purpose of diagnosis, before the presence of a fault in the glow plug is determined by utilizing the forced change in the state of energization of the glow plug. The process of determining the presence of the fault is not executed if it is determined in the process of determining the possibility of the fault that there is no possibility of a fault in the glow plug.

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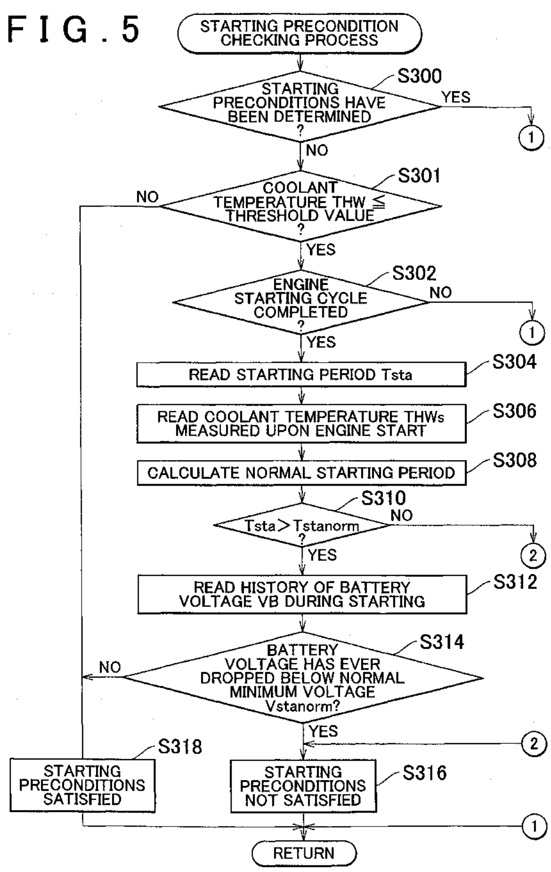

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Description

[0001] The invention relates to method and apparatus for detecting faults in glow plugs provided in diesel engines.

[0002] In order to improve the engine starting performance during start-up of a diesel engine, it has been known to pre-heat the diesel engine by applying current to glow plugs provided in the diesel engine. Such a glow plug includes a heating element that is energized so as to generate heat. When the heating element itself suffers from disconnection or an electric power supply line that leads to the heating element suffers from disconnection or cut-off, a problem arises in the engine starting performance, in particular, during a cold start of the engine. To prevent this problem, it has been proposed to provide a glow-plug disconnection detecting device for detecting faults or abnormalities in the glow plugs. Examples of such detecting devices are disclosed in, for example, Japanese laid-open Patent Publications No. 11-182400, No. 57-26275 and No. 58-113581.

[0003] In the known devices, the presence of a fault, such as disconnection of a glow plug, is determined based on voltage changes resulting from energization of the glow plug during start-up of the engine. However, a fault in the glow plug may not be determined with high accuracy if the fault detection utilizes normal energization control performed on the glow plug, since in some cases the fault determination must be made under a situation in which highly accurate detection is impossible or difficult.

[0004] It is therefore proposed to implement forced energization and deenergization of the glow plug for the purpose of diagnosis, separately from or independently of the normal glow-plug energization control intended for warm-up of the engine, so as to increase a degree of freedom in the timing of implementation of glow-plug fault detection and thus permit highly accurate fault detection or determination under a situation suitable for fault detection.

[0005] Although a fault in the glow plug may be determined with high accuracy if the glow plug is forced to be energized and deenergized for the purpose of diagnosis independently of the normal energization control, a circuit switching mechanism, such as a glow relay, is more frequently switched between ON and OFF because of the diagnostic energization and deenergization. With the number of times of switching thus increased, the durability of the circuit switching mechanism may be reduced.

[0006] It is therefore an object of the invention to provide glow-plug fault detecting method and apparatus which are able to detect or determine a fault in a glow plug with sufficiently high accuracy, without suffering from a reduction in the durability of a circuit switching mechanism for the glow plug.

[0007] To accomplish the above object, there is provided according to a first aspect of the invention a method of detecting a fault in a glow plug provided in a diesel engine, including a process of determining the presence of a fault in the glow plug by utilizing a forced change in a state of energization of the glow plug, characterized in that a process of determining a possibility of a fault in the glow plug without utilizing the forced change in the state of energization of the glow plug is executed prior to the process of determining the presence of the fault, and the process of determining the presence of the fault is not executed if it is determined in the process of determining the possibility of the fault that there is no possibility of a fault in the glow plug.

[0008] A fault in the glow plug is detected with relatively low reliability if the fault detection does not involve the forced change in the state of energization of the glow plug for the purpose of diagnosis, as compared with the case where the fault detection utilizes the forced change in the state of energization of the glow plug. However, a possibility of a fault in the glow plug can be determined with sufficiently high reliability even without using the forced change in the state of energization. According to the above aspect of the invention, the process of determining the possibility of the fault is executed before the presence of the fault is determined by utilizing the forced change in the state of energization of the glow plug, and, if it is determined in the process of determining the possibility of the fault that there is no possibility of a fault in the glow plug, there is no need to execute the process of determining the presence of the fault by utilizing the forced change in the state of energization of the glow plug.

[0009] Accordingly, the process of determining the presence of the fault that assures high reliability in fault detection may be executed only if the fault possibility determination reveals that there is a possibility of a fault in the glow plug, namely, if a determination is made which does not necessarily negate a possibility of the fault. Thus, the number of times the glow plug is forced to be energized or deenergized for the purpose of diagnosis can be reduced. Consequently, otherwise possible reduction of the durability of the circuit switching mechanism can be suppressed while assuring accurate determination of the fault in the glow plug.

[0010] The "forced change" mentioned herein means a process of changing the state of energization of the glow plug for the purpose of detecting a fault in the glow plug. This definition applies in the other portions of the description and claims.

[0011] The above-indicated forced change in the state of energization of the glow plug may be in the form of switching of the glow plug between an energized state and a deenergized state.

[0012] As described above, the forced change in the state of energization may be, in particular, caused by switching of the glow plug between the energized state and the deenergized state. With the forced change thus made, a phenomenon associated with a fault in the glow plug is likely to occur, but at the same time the durability of the circuit switching mechanism tends to be lowered. By employing the fault possibility determination that there is a possibility of a fault as a precondition for execution of the process of determining the presence of the fault, the number of changes in the state of energization of the glow plug can be reduced, and otherwise possible reduction in the durability of the circuit switching mechanism can be suppressed while assuring accurate fault detection.

[0013] In one embodiment of the first aspect of the invention, the possibility of the fault in the glow plug is determined based on an operating state of the diesel engine detected before completion of a starting cycle of the engine while the glow plug is in an energized state.

[0014] If current is applied to the glow plug and the glow plug normally generates heat, electric energy is consumed for generating heat, and the diesel engine can be smoothly started. However, if current is not actually applied to the glow plug even if a command to energize the glow plug is generated, or the amount of current applied to the glow plug is extremely small, no consumption of electric energy for heating of the glow plug takes place, and the engine cannot be started smoothly. In this case, the fault in energization of the glow plug is reflected by the operating state of the engine detected before completion of the engine starting cycle. Thus, the possibility of the fault in the glow plug can be determined based on the engine operating state detected before completion of the starting cycle of the engine.

[0015] In another embodiment of the first aspect of the invention, when it is determined in the process of determining the possibility of the fault that there is a possibility of a fault in the glow plug, and the process of determining the presence of the fault cannot be completed within a period of time set for energization of the glow plug started for start-up of the diesel engine, the process of determining the presence of the fault is not executed.

[0016] With the above arrangement, the process of determining the presence of the fault can be completed within the set time for energization of the glow plug that is started for engine start-up. Thus, normal energization of the glow plug is not prolonged in vain because of the forced change of the state of energization for the purpose of determining the presence of the fault. Accordingly, energy consumption due to the process of determining the presence of the fault in the glow plug can be reduced.

[0017] In a further embodiment of the first aspect of the invention, when it is determined in the process of determining the possibility of the fault that there is a possibility of a fault in the glow plug, the process of determining the presence of the fault is executed provided that the diesel engine is under idle speed control.

[0018] Since the presence of the fault is determined on limited occasions, namely, only during idling of the engine, the determination is less likely to be influenced by other factors, thus assuring further improved accuracy in the determination of the presence of the fault.

[0019] In a still further embodiment of the above aspect of the invention, when it is determined in the process of determining the possibility of the fault that there is a possibility of a fault in the glow plug, the process of determining the presence of the fault is executed provided that a battery voltage is within a reference voltage range.

[0020] If the battery voltage is too low, the load on a power generating mechanism, such as an alternator, may reach 100%. Even if the state of energization of the glow plug is forced to be changed for the purpose of diagnosis in this condition, substantially no change may occur in the load on the diesel engine, and the presence of the fault may not be determined with high accuracy. If the battery voltage is too high, on the other hand, the load on the power generating mechanism is reduced down to 0%. Even if the state of energization of the glow plug is forced to be changed in this condition, substantially no change may occur in the load on the diesel engine, and therefore the presence of the fault may not be determined with high accuracy. In view of these situations, the reference voltage range is provided, and the process of determining the presence of the fault is not executed if the battery voltage is outside the reference range, so as to prevent a reduction of the accuracy in the determination of the presence of the fault.

[0021] In another embodiment of the first aspect of the invention, the presence of the fault in the glow plug is determined based on a change in an operating state of the diesel engine which is caused by the forced change in the state of energization of the glow plug.

[0022] More specifically, the presence of a fault in the glow plug can be determined with high reliability by measuring a change in the operating state of the diesel engine that occurs in response to the forced change in the state of energization of the glow plug. Furthermore, since the process of determining the presence of the fault is executed under a precondition that there is a possibility of a fault in the glow plug, the state of energization of the glow plug is prevented from being changed for the purpose of diagnosis when there is no possibility of the fault. While the forced change in the state of energization of the glow plug may be effected once or may be repeated twice or more, it is preferable to change the state of energization of the glow plug only once or twice.

[0023] In a further embodiment of the first aspect of the invention, the process of determining the presence of the fault comprises (a) a step of causing a first forced change in the state of energization of the glow plug, (b) a step of making a first determination based on a change in the operating state of the diesel engine which is caused by the first forced change, (c) a step of finishing the process of determining the presence of the fault and resuming the state of energization of the glow plug established before the first forced change if the first determination indicates that the glow plug is normal, (d) a step of causing a second forced change in the state of energization of the glow plug so as to bring the glow plug into the state of energization established before the first forced change if the first determination does not indicate that the glow plug is normal, (e) a step of making a second determination based on a change in the operating state of the diesel engine which is caused by the second forced change, (f) a step of finishing the process of determining the presence of the fault if the second determination indicates that the glow plug is faulty, and (g) a step of finishing the process of determining the presence of the fault without making a determination on the fault in the glow plug when the second determination does not indicate that the glow plug is faulty.

[0024] With the above method, the presence of a fault in the glow plug can be determined with high reliability by checking the engine operating state in two steps upon the first forced change and second forced change in the state of energization of the glow plug. Furthermore, the first forced change is cancelled by the second forced change, so that the glow plug can resume the original state of energization when the process of determining the presence of the fault is finished.

[0025] The above-indicated change in the operating state of the diesel engine may be in the form of a change in an engine load.

[0026] When current starts being applied to the glow plug or the amount of current applied to the glow plug is increased in response to the first forced change or the second forced change in the state of energization of the glow plug, the quantity of power generated is increased in accordance with an increase of the speed of battery exhaustion, and the load on the diesel engine is accordingly increased. On the contrary, if current applied to the glow plug is cut off or the amount of current applied to the glow plug is reduced in response to the first forced change or the second forced change, the quantity of power generated is reduced in accordance with a decrease of the speed of battery exhaustion, and the load on the diesel engine is accordingly reduced. When current is not normally applied to the glow plug, therefore, no change in the engine load appears in response to the first forced change or the second forced change in the state of energization of the glow plug. Thus, the presence of a fault in the glow plug can be determined based on a change in the engine load.

[0027] In another example, the above-indicated change in the operating state of the engine may be in the form of a change in a battery voltage.

[0028] When current starts being applied to the glow plug or the amount of current applied to the glow plug is increased in response to the first forced change or the second forced change in the state of energization of the glow plug, the voltage of the battery used for energization of the glow plug drops. On the contrary, if current applied to the glow plug is cut off or the amount of current applied to the glow plug is reduced in response to the first forced change or the second forced change, the battery voltage rises. When current is not normally applied to the glow plug, therefore, no change in the battery voltage appears in response to the first forced change or the second forced change in the state of energization of the glow plug. Thus, the presence of a fault in the glow plug can be determined based on a change in the battery voltage.

[0029] In a further example, the above-indicated change in the operating state of the engine may include a change in a fuel injection quantity and a change in a battery voltage.

[0030] Since both the fuel injection quantity and the battery voltage change in response to the first forced change or the second forced change in the state of energization of the glow plug, the presence of a fault in the glow plug can be determined with improved accuracy by measuring the changes in both of the injection quantity and the battery voltage.

[0031] According to a second aspect of the invention, there is provided an apparatus for detecting a fault in a glow plug provided in a diesel engine, characterized by comprising (a) fault possibility determining means for determining a possibility of a fault in the glow plug based on a phenomenon that occurs without involving a forced change in a state of energization of the glow plug, and (b) fault presence determining means for determining the presence of the fault in the glow plug based on a phenomenon that occurs in response to the forced change in the state of energization of the glow plug when the fault possibility determining means determines that there is a possibility of a fault in the glow plug, wherein the fault presence determining means does not determine the presence of the fault by causing the forced change in the state of energization of the glow plug when the fault possibility determining means determines that there is no possibility of a fault in the glow plug.

[0032] The fault detecting apparatus according to the second aspect of the invention provides similar advantage effects to those provided by the fault detecting method according to the first aspect of the invention.

[0033] The foregoing and/or further objects, features and advantages of the invention will become more apparent from the following description of exemplary embodiments with reference to the accompanying drawings, in which like numerals are used to represent like elements and wherein:

Fig. 1 is a view schematically showing an accumulator injection type diesel engine and its control system that employ glow-plug fault detecting method and apparatus according to a first embodiment of the invention;
Fig. 2 is a view showing an electric power supply system for supplying electric power to a glow plug of the engine of Fig. 1;
Fig. 3 is a flowchart illustrating a part of a fuel injection quantity control routine of the first embodiment:
Fig. 4 is a flowchart illustrating a part of the fuel injection quantity control routine following that of Fig. 3;

Fig. 5 is a flowchart illustrating a starting precondition checking process of the first embodiment;

Fig. 6 is a view explaining a map used for obtaining a normal starting period Tstanorm from a coolant temperature THWs measured upon a start of the engine starting cycle in the starting precondition checking process;

Fig. 7 is a view explaining a map used for obtaining a starting-time normal minimum voltage Vstanorm from the coolant temperature THWs measured upon a start of the engine starting cycle in the starting precondition checking process;

Fig. 8 is a flowchart illustrating a part of a process of checking conditions for execution of glow-plug fault determination according to the first embodiment;

Fig. 9 is flowchart illustrating a part of the process of checking conditions for execution of glow-plug fault determination, which follows that of Fig. 8, according to the first embodiment;

Fig. 10 is a flowchart illustrating a provisional fault determination process according to the first embodiment;

Fig. 11 is a flowchart illustrating a main fault determination process according to the first embodiment;

Fig. 12 is a flowchart illustrating a part of a process of checking conditions for stopping glow-plug fault determination according to the first embodiment;

Fig. 13 is a flowchart illustrating a part of the process of checking conditions for stopping glow-plug fault determination, which follows that of Fig. 12, according to the first embodiment;

Fig. 14 is a time chart showing one example of control according to the first embodiment;

Fig. 15 is a time chart showing another example of control according to the first embodiment;

Fig. 16 is a time chart showing a further example of control according to the first embodiment;

Fig. 17 is a time chart showing a still further example of control according to the first embodiment;

Fig. 18 is a time chart showing another embodiment of control according to the first embodiment;

Fig. 19 is a flowchart illustrating a part of a process of checking conditions for execution of glow-plug fault determination according to a second embodiment of the invention;

Fig. 20 is a flowchart illustrating a provisional fault determination process according to the second embodiment;

Fig. 21 is a flowchart illustrating a main fault determination process according to the second embodiment;

Fig. 22 is a flowchart illustrating a part of a process of checking conditions for stopping glow-plug fault determination according to the second embodiment;

Fig. 23 is a time chart showing one example of control according to the second embodiment;

Fig. 24 is a time chart showing another example of control according to the second embodiment;

Fig. 25 is a time chart showing a further example of control according to the second embodiment; and

Fig. 26 is a time chart showing a still further example of control according to the second embodiment.

[0034] Fig. 1 schematically shows an accumulator injection type diesel engine (or common rail type diesel engine) 2 and a control system for the diesel engine 2, for which glow-plug fault detecting method and apparatus according to a first embodiment of the invention are employed. The accumulator injection type diesel engine 2 as one type of automobile engines is installed on a vehicle.

[0035] The diesel engine 2 includes a plurality of cylinders (i.e., four cylinders in this embodiment, of which only one is shown in Fig. 1) #1, #2, #3, #4, and an injector 4 is provided with respect to each of combustion chambers of the cylinders #1 through #4. Fuel injection from the injector 4 to a corresponding one of the cylinders #1 to #4 of the diesel engine 2 is controlled by controlling the ON/OFF state of a solenoid-operated valve 4a used for fuel injection control with respect to the injector 4.

[0036] The injector 4 is connected to a common rail 6 serving as an accumulator pipe used in common to the four cylinders. While the solenoid-operated valve 4a used for fuel injection control is open, fuel in the common rail is injected through the injector 4 into a corresponding one of the cylinders #1 to #4. A relatively high pressure that is equivalent to a fuel injection pressure is accumulated in the common rail 6. To build up the fuel injection pressure, the common rail 6 is connected to a delivery port 10a of a supply pump 10 via a supply pipe 8. A check valve 8a, which is provided in the supply pipe 8, serves to permit supply of the fuel from the supply pump 10 to the common rail 6, and inhibit reverse flow of the fuel from the common rail 6 to the supply pump 10.

[0037] A fuel tank 12 is connected to the supply pump 10 via a suction port 10b, and a filter 14 is provided in a pipe connecting the fuel tank 12 with the supply pump 10. In operation, the supply pump 10 takes in the fuel from the fuel tank 12 through the filter 14. At the same time, the supply pump 10 raises a fuel pressure to a required high pressure by using a cam (not shown) that moves in synchronism with the rotating diesel engine 2 for reciprocating a plunger, and supplies the highly pressured fuel to the common rail 6.

[0038] A pressure control valve 10c is provided in the vicinity of the delivery port 10a of the supply pump 10. The pressure control valve 10c serves to control the pressure of fuel delivered from the delivery port 10a toward the common rail 6. When the pressure control valve 10c is opened, a redundant portion of the fuel that is not delivered from the delivery port 10a is returned to the fuel tank 12 via a return port 10d provided in the supply pump 10 and a return pipe 16.

[0039] An intake passage 18 and an exhaust passage 20 are connected to a combustion chamber of each of the cylinders #1 to #4 of the diesel engine 2. A throttle valve (not shown) is disposed in the intake passage 18. In operation, the flow rate of the intake air to be introduced into the combustion chamber is controlled by adjusting the opening angle of the throttle valve according to the operating state of the diesel engine 2.

[0040] In addition, a glow plug 22 is disposed in the combustion chamber of each of the cylinders #1 to #4 of the diesel engine 2. The glow plug 22 glows (i.e., heats and turns red) when current is applied to the plug 22 via a glow relay 22a immediately before start-up of the diesel engine 2, and a part of fuel spray is directed at the hot glow plug 22, thereby to promote or aid firing and combustion in the combustion chamber. Thus, the glow plug 22 functions as a start assist device for aiding combustion upon start-up of the engine 2. A fault, such as disconnection, of the glow plug 22 is determined through a process as described later.

[0041] The diesel engine 2 is equipped with various sensors as follows, for detecting operating conditions of the diesel engine 2 in the first embodiment. As shown in Fig. 1, an accelerator stroke sensor 26 for detecting the accelerator pedal position or degree of depression of the accelerator pedal ACCPF is provided in the vicinity of an accelerator pedal 24 as shown in Fig. 1. Also, the diesel engine 2 is provided with a starter 30 for starting the diesel engine 2. The starter 30 includes a starter switch 30a for detecting an operating state of the starter 30. A water temperature sensor 32 for detecting the temperature of a coolant (coolant temperature THW) is mounted in the cylinder block of the diesel engine 2. In addition, an oil temperature sensor 34 for detecting the temperature THO of engine oil is provided in an oil pan (not shown). Also, a fuel temperature sensor 36 for detecting a fuel temperature THF is provided in the return pipe 16, and a fuel pressure sensor 38 for detecting the pressure of fuel in the common rail 6 is provided in the common rail 6. A NE sensor 40 for detecting the engine speed is disposed in the vicinity of a pulser (not shown) provided at a crankshaft (not shown) of the diesel engine 2. In operation, rotation of the crankshaft is transmitted to a camshaft (not shown) for opening and closing an intake valve 18a and an exhaust valve 20a via a timing belt, and the like. The speed of rotation of the camshaft is set to be a half of the speed of rotation of the crankshaft. A cylinder discrimination sensor 42 is disposed in the vicinity of a pulser (not shown) provided at the camshaft. In the first embodiment, the engine speed NE, crank angle CA, and the top dead center (TDC) of the intake stroke of the first cylinder #1 are calculated based on pulse signals transmitted from these sensors 40, 42. A transmission 44 is provided with a shift position sensor 46 for detecting the gear stage or position of the transmission 44. A vehicle speed sensor 48 is provided on the side of the output shaft of the transmission 44, for detecting the vehicle speed SPD based on the speed of rotation of the output shaft. In addition, an air conditioner (not shown) to be driven with power of the diesel engine 2 is provided, and an air-conditioner switch 40 for generating a command to drive the air conditioner is provided.

[0042] In the first embodiment, an electronic control unit (ECU) 52 is provided for governing various controls of the diesel engine 2. The ECU 52 performs control processes, such as fuel injection quantity control and glow-plug energization control as described later, for controlling the diesel engine 2, a process of determining a fault or abnormality in glow-plug energization as described later, and so forth. The ECU includes, as a main component, a microcomputer including a central processing unit (CPU), a read-only memory (ROM) that stores in advance various programs, maps, and so forth, a random access memory (RAM) that temporarily stores operation results of the CPU, and a backup RAM that stores operation results, pre-stored data, and so forth. The microcomputer further includes a timer or a counter, an input interface, an output interface, and other components. The accelerator stroke sensor 26, water temperature sensor 32, oil temperature sensor 34, fuel temperature sensor 36, fuel pressure sensor 38 and others are connected to the input interface of the ECU 52 via respective buffers, multiplexers, and A/D converters (not shown). Also, the NE sensor 40, cylinder discrimination sensor 42, vehicle speed sensor 48 and others are connected to the input interface of the ECU 52 via waveform shaping circuits (not shown). Furthermore, the starter switch 30a, shift position sensor 46, air-conditioner switch 50 and others are directly connected to the input interface of the ECU 52. Other than signals from these sensors, the ECU 52 also receives battery voltage VB, control duty DF of an alternator 54, and other parameters, and read values thereof. The CPU reads signals of the above-indicated sensors and switches via the input interface. On the other hand, the solenoid-operated valves 4a, pressure control valve 10c, glow relays 22a and others are connected to the output interface of the ECU 52 via respective drive circuits. The CPU performs calculations based on the input values read via the input interface, and favorably controls the solenoid-operated valves 4a, pressure control valve 10a, glow relays 22a and others via the output interface.

[0043] As shown in Fig. 2 illustrating an electric power supply system of the diesel engine 2, the alternator 54 and an air-conditioner compressor 56 are driven or rotated by the crankshaft 2a of the diesel engine 2 via a belt 2b. A voltage regulator 54a is provided in the alternator 54. The voltage regulator 54a causes the alternator 54 to output a voltage corresponding to a duty signal received from a controller 58 for the alternator 54. The controller 58 detects voltage VB of the battery 60, and performs duty control on the voltage regulator 54a so that the battery 60 is kept in an appropriate charged condition. When the ECU 52 turns on the glow relay 22a, electric power is supplied from the battery 60 and the alternator 54 to the glow plug 22 so that the glow plug 22 can generate heat.

[0044] Next, the fuel injection quantity control routine and the glow-plug energization control routine, which are executed by the ECU 52 in the present embodiment, will be described.

[0045] Fig. 3 and Fig. 4 illustrate the fuel injection quantity control routine. This routine is an interrupt routine that is executed at regular intervals of a fixed crank angle (i.e., executed for each explosion stroke).

[0046] Upon start of the fuel injection quantity control routine, data necessary for control are read into a work region within the RAM of the ECU 52 in step S110. The data may include the engine speed NE detected by the NE sensor 40, the degree of depression of the accelerator pedal ACCPF detected by the accelerator stroke sensor 26, the shift position SFT detected by the shift position sensor 46, and the vehicle speed SPD detected by the vehicle speed sensor 48.

[0047] In the next step S120, a governor injection quantity command value QGOV1 for an engine idling state is calculated from an idling governor injection quantity command value map in which the engine speed NE and the degree of depression of the accelerator pedal ACCPF are used as parameters, based on the engine speed NE and the degree of depression of the accelerator pedal ACCPF. This map, which is empirically determined in advance for the idling state, is stored in the ROM of the ECU 52. Since discrete values are arranged in this map, the governor injection quantity command value QGOV1 is determined through interpolation when no value coincides with map values as parameters. It is to be understood that setting of a map and calculation through interpolation are similarly performed with respect to other maps.

[0048] In the following step S130, a governor injection quantity command value QGOV2 for an engine operating state other than the idling state is calculated from a non-idling governor injection quantity command value map in which the engine speed NE and the degree of depression of the accelerator pedal ACCPF are used as parameters, based on the engine speed NE and the degree of depression of the accelerator pedal ACCPF. Furthermore, an auxiliary governor injection quantity command value QGOV3 that gives an auxiliary characteristic to the non-idling governor injection quantity command value QGOV2 is calculated in step S140 from an auxiliary governor injection quantity command value map using the engine speed NE and the degree of depression of the accelerator pedal ACCPF as parameters, based on the engine speed NE and the degree of depression of the accelerator pedal ACCPF.

[0049] Next, it is determined in step S150 whether the diesel engine 2 is in an operating state other than the idling state. For example, the engine 2 is determined to be in the idling state when the vehicle speed SPD is equal to 0 km/h and the accelerator stroke sensor 26 indicates that the degree of depression of the accelerator pedal ACCPF is equal to 0% after completion of warm-up. If the engine 2 is in the idling state (i.e., when a negative determination is made in step S150), an engine speed deviation NEDL of the actual engine speed NE from a target engine speed NTRG for the idling state is calculated in step S160 as indicated in the following expression (1).

$$\mathrm{NEDL} \leftarrow \mathrm{NTRG} - \mathrm{NE} \tag{1}$$

[0050] Next, an injection quantity correction value QIIDL corresponding to the engine speed deviation NEDL is determined in step S170 from a map using the engine speed deviation NEDL as a parameter. Alternatively, the injection quantity correction value QIIDL may be determined from a function using the engine speed difference NEDL as a parameter.

[0051] Then, an idling injection quantity correction value QII is calculated in step S180 based on the injection quantity correction value QIIDL, according to the following expression (2).

$$\mathrm{QII} \leftarrow \mathrm{QII} \pm \mathrm{QIIDL} \tag{2}$$

[0052] In the above expression (2), QII in the right side represents an idling injection quantity correction value QII determined in the last control cycle, and "± QIIDL" means "+ QIIDL" when NTRG is equal to or greater than NE and "- QIIDL" when NTRG is smaller than NE.

[0053] In step S190 following step S180, a governor injection quantity command value QGOV is calculated according to the following expression (3). If it is determined in step S150 that the engine 2 is in an operating state other than idling (i.e., if an affirmative determination is made in step S150), the control directly proceeds to step S190 for calculating the governor injection quantity command value QGOV.

$$\mathrm{QGOV} \leftarrow \mathrm{MAX}\ (\mathrm{QGOV1} + \mathrm{QII} + \mathrm{QIP},\ \mathrm{MAX}\ (\mathrm{QGOV2},\ \mathrm{QGOV3}) + \mathrm{QIPB}) \tag{3}$$

where QIP is an offset value in the case where the air conditioner, or the like, causes a load during idling, and QIPB is an offset value in the case where the air conditioner, or the like, causes a load when the engine 2 is in an operating state other than idling. MAX ( ) is an operator that selects the maximum value from values in the parentheses.

[0054] Next, it is determined in step S200 whether the vehicle is accelerating or decelerating. This determination is made by, for example, determining whether the governor injection quantity command value QGOV is larger or smaller than a basic injection quantity command value QBASEOL calculated in the last control cycle.

[0055] If the vehicle is accelerating or decelerating (i.e., if an affirmative determination is made in step S200), an operation to restrict an increase or a decrease of the governor injection quantity command value QGOV is performed. This operation aims at preventing shocks that would occur when the governor injection quantity command value QGOV rapidly changes. If the calculation result of step S190 indicates that the governor injection quantity command value QGOV has largely changed from the basic injection quantity command value QBASEOL, the command value QGOV is corrected so as not to cause shocks.

[0056] In the next step S220 (Fig. 4), the governor injection quantity command value QGOV is set as the basic injection quantity command value QBASE. If step S200 determines that the vehicle is not accelerating nor decelerating (namely, if a negative determination is made in step S200), the control directly proceeds to step S220.

[0057] In step S230 following step S220, the final basic injection quantity command value QFINC is calculated by subjecting the basic injection quantity command value QBASE to a guard process to limit the command value QBASE to the maximum injection quantity command value QFULL according to the following expression (4).

$$\text{QFINC} \leftarrow \text{MIN (QBASE, QFULL)} \qquad (4)$$

where MIN( ) is an operator that selects the minimum value from values in the parentheses.

[0058] In the next step S240, a main injection quantity command value QFPL is calculated by subtracting a pilot injection quantity command value QPL from the final basic injection quantity command value QFINC, as indicated in the following expression (5).

$$\text{QFPL} \leftarrow \text{QFINC - QPL} \qquad (5)$$

[0059] Next, a main injection duration TQFPL is calculated in step S250 from a map or a function fq, based on the main injection quantity command value QFPL. Furthermore, a pilot injection duration TQPL is calculated in step S260 from a map or a function fq, based on the pilot injection quantity command value QPL. Then, the basic injection quantity command value QBASE calculated in the current control cycle is set as the last basic injection quantity command value QBASEOL in step S270. In this manner, the fuel injection quantity control routine is once finished.

[0060] In the meantime, the ECU 52 performs the above-mentioned glow-plug energization control process in the following manner. When turn-on of the ignition switch is detected, a command to energize the glow plug 22 is generated, and current is applied from the battery 60 to the glow plug 22, so that the glow plug 22 starts generating heat. Then, a starting cycle of the diesel engine 2 is started upon turn-on of the starter 30. When the starting cycle of the diesel engine 2 is completed, and a certain delay time elapses, energization of the glow plug 22 is stopped. The delay time is set to be shorter as the coolant temperature THW increases.

[0061] Next, operations to detect a fault, such as disconnection, of the glow plug 22 will be described, referring to Fig. 5 and Fig. 8 through Fig. 13.

[0062] Initially, a starting precondition checking process (Fig. 5) will be described. This process is repeatedly executed at certain time intervals after a power supply of the ECU 52 is turned ON. Upon a start of this process, it is determined in step S300 whether starting preconditions as described below have been determined. Since the starting preconditions have not been determined in the initialized state at the time when the power supply is turned ON, a negative determination is made in step S300, and it is determined in step S301 whether the coolant temperature THW detected by the water temperature sensor 32 is equal to or lower than a predetermined water-temperature threshold value. If the coolant temperature THW is larger than the threshold value, a noticeable difference in the engine starting performance does not appear between the case where the glow plug 22 normally generates heat and the case where the glow plug 22 does not generate heat because of, for example, disconnection. Therefore, the process of step S304 through step S314 for checking the starting preconditions cannot be effected with sufficiently high accuracy. In this case, the starting preconditions are determined to be satisfied in step S318, and this process is once finished. Since the starting preconditions are determined in this manner, an affirmative determination is made in step S300 in the next control cycle, and a substantial portion of the starting precondition checking process (Fig. 5) is terminated. With the starting preconditions thus determined to be satisfied, a glow-plug fault determination is executed by effecting forced energization and deenergization of the glow plug 22, namely, applying current to the glow plug 22 and cut off current applied to the glow plug 22 for the purpose of diagnosis.

[0063] When the coolant temperature THW is equal to or lower than the threshold value (i.e., if an affirmative determination is made in step S301), on the other hand, it is determined in step S302 whether the starting cycle of the diesel engine 2 has been completed. If the starting cycle has not been completed (i.e., if a negative determination is made in step S302), the process of Fig. 5 is once finished. Thus, a negative determination is repeatedly made in step S302 until the starting cycle is completed. During this period, the diesel engine 2 is started by cranking, and the engine speed NE is increased by combustion of fuel injected from the injectors 4 until it reaches a speed level that indicates completion of the starting cycle.

[0064] When the engine starting cycle is completed (i.e., when an affirmative determination is made in step S302), a starting period Tsta is read in step S304. The starting period Tsta is a count value obtained by the ECU 52 that counts the period of time from the start of the starting cycle to completion thereof by a process that is separately executed.

[0065] Next, a starting coolant temperature THWs measured at the time of a start of the engine starting cycle is read in step S306. The starting coolant temperature THWs is a coolant temperature THW that was detected at the time of the start of the engine starting cycle and stored in a memory by a process separately executed by the ECU 52.

[0066] Next, a normal starting period Tstanorm (corresponding to the reference starting period) is calculated in step S308. The normal starting period Tstanorm is the upper limit of the starting period that is expected when the glow plug 22 normally generates heat, or represents an allowable range over the upper limit. Since the normal starting period Tstanorm changes depending upon the coolant temperature THWs measured upon engine start, the normal starting period Tstanorm is calculated based on the coolant temperature THWs with reference to, for example, a map of Fig. 6 that is stored in the ROM of the ECU 52.

[0067] Subsequently, it is determined in step S310 whether the actual starting period Tsta is longer than the normal starting period Tstanorm. If Tsta is equal to or shorter than Tstanorm (i.e., if a negative determination is made in step S310), it means that the glow plug 22 normally generates heat so as to smoothly start the diesel engine 2. In this case, the starting preconditions are determined to be not satisfied in step S316 so that the fault determination process including forced energization and deenergization of the glow plug 22 as described later is not carried out. Then, the process of Fig. 5 is once finished. With the starting preconditions thus determined to be not satisfied, an affirmative determination is made in step S300 in the next control cycle, and the substantial starting precondition checking process (Fig. 5) is finished. Thus, the engine operating state in which the starting preconditions are set to be not satisfied means that there is no possibility of a fault in glow-plug energization.

[0068] If the actual starting period Tsta is longer than the normal starting period Tstanorm (i.e., if an affirmative determination is made in step S310), the history of the battery voltage VB during starting is read in step S312. During starting of the engine 2, namely, during a period from start of the engine starting cycle to completion thereof, the battery voltage VB is detected by a process that is separately executed by the ECU 52. Through this process, the history of the battery voltage VB is stored in a memory, which history indicates whether the battery voltage VB has ever been lower than the starting-time normal minimum voltage Vstanorm (corresponding to the reference voltage) calculated based on the starting-time coolant temperature THWs with reference to, for example, a map shown in Fig. 7. The starting-time normal minimum voltage Vstanorm indicates the smallest degree of a voltage drop of the battery that is expected when the glow plug 22 is normally energized to generate heat, or indicates an allowable range over the minimum voltage drop.

[0069] On the basis of the history of the battery voltage VB, it is determined in step S314 whether the battery voltage VB has ever dropped below the starting-time normal minimum voltage Vstanorm during starting of the engine 2. If the battery voltage VB dropped below the normal minimum voltage Vstanorm (i.e., if an affirmative determination is made in step S314), it means that the glow plug 22 normally generates heat, and the starting period Tsta, which is longer than Tstanorm, is considered to be caused by another factor that is different from a fault in glow-plug energization.

[0070] If an affirmative determination is made in step S314, therefore, the starting preconditions are determined to be not satisfied in step S316 as described above, and the process of Fig. 5 is once finished. With the starting preconditions thus determined, an affirmative determination is made in step S300 in the next control cycle, and the substantial starting precondition checking process of Fig. 5 is finished. The engine operating state in which the starting preconditions are determined to be not satisfied means that there is no possibility of a fault in glow-plug energization.

[0071] If the battery voltage VB has never dropped below the starting-time normal minimum voltage Vstanorm during starting (i.e., if a negative determination is made in step S314), the starting preconditions are determined to be satisfied in step S318, and the process of Fig. 5 is once finished. With the starting preconditions thus determined, an affirmative determination is made in step S300 in the next control cycle, and the substantial starting precondition checking process of Fig. 5 is finished.

[0072] The engine operating state in which the starting preconditions are determined to be satisfied means that there is a possibility of a fault in glow-plug energization though an affirmative determination may be made in step S310 and a negative determination may be made in step S314 for a reason other than a fault in the glow plug 22.

[0073] Next, a process of checking conditions for execution of glow-plug fault determination will be described with reference to Fig. 8 and Fig. 9. Namely, the process of Figs. 8 and 9 is executed to check conditions for execution of a provisional fault determination process (Fig. 10) and a main fault determination process (Fig. 11) as described later. The process of Fig. 8 and Fig. 9 is repeatedly executed at certain time intervals. Upon a start of this process, it is determined in step S400 whether the starting preconditions have been determined by the starting precondition checking process (Fig. 5). If the starting preconditions are not determined to be satisfied or not satisfied (namely, if a negative determination is made in step S400), the process of Figs. 8 and 9 is once finished.

[0074] If the starting preconditions are determined to be satisfied or not satisfied in the starting precondition checking process of Fig. 5 (i.e., if an affirmative determination is made in step S400), it is determined in step S402 whether execution of glow-plug fault determination has been permitted. Since execution of the glow-plug fault determination is not permitted in the initialized state at the time of turn-on of the power supply, a negative determination is made in step S402. In this case, the control proceeds to step S404.

[0075] In step S404, it is determined whether sensors used for determination are normally operating. More specifically, it is determined whether any fault or abnormality is observed in any of the water temperature sensor 32, vehicle speed sensor 48 and other sensors from which information is needed so as to determine whether the glow-plug fault determination process is permitted to be executed. The determination whether the sensors are normally operating may be made by using data obtained, for example, by a sensor failure detecting process that is separately executed by the ECU 52.

[0076] If any fault is detected in one or more of the above sensors (i.e., if a negative determination is made in step S404), the process of Figs. 8 and 9 is once finished. Since accurate glow-plug fault determination cannot be effected as long as a fault is found in any one or more of the above sensors, the control does not proceed to step S426 to permit execution of the glow-plug fault determination process.

[0077] If all of the sensors are normal (i.e., if an affirmative determination is made in step S404), it is then determined in step S406 whether a coolant temperature THW detected by the water temperature sensor 32 is within a predetermined reference temperature range (e.g., a range of 0 °C to 20°C). The reference temperature range is set in accordance with the type of the diesel engine. More specifically, the reference temperature range is set to a range suitable for fault detection, in which the engine operating state apparently differs between the case where the glow plug 22 normally generates heat during idling and the case where the glow plug 22 is not able to generate sufficient heat. Namely, when the coolant temperature THW is below the lowest temperature in the reference temperature range, the vehicle operator is able to detect a fault in glow plug energization by himself/herself since faulty glow-plug energization and insufficient heat generated by the glow plug 22 make it difficult for the engine 2 to be started. In addition, when the coolant temperature THW is excessively low, combustion in the idling state after the start of the engine is unstable, and a fault in the glow-plug energization cannot be detected with high accuracy, even if the engine 2 can be started due to normal heat generation by the glow plug 22. When the coolant temperature THW is higher than the highest temperature in the reference temperature range, the engine is smoothly operated even if the glow plug 2 fails to heat sufficient heat. In this case, therefore, a fault in glow-plug energization cannot be detected with high accuracy.

[0078] If the coolant temperature THW is not within the reference temperature range (i.e., if a negative determination is made in step S406), the process of Figs. 8 and 9 is once finished.

[0079] If the coolant temperature THW is within the reference temperature range (i.e., if an affirmative determination is made in step S406), it is then determined in step S408 whether the degree of depression of the accelerator pedal ACCPF detected by the accelerator stroke sensor 26 is equal to 0%, namely, whether the accelerator pedal 24 is completely released. If the accelerator pedal 24 is not released, namely, is depressed by some degree (i.e., if a negative determination is made in step S408), which means that the vehicle is not in the idling state, the fuel injection quantity is not stable, and a fault in glow-plug energization cannot be detected with sufficiently high accuracy in the fault determination process as described later. In this case, therefore, the process of Figs. 8 and 9 is finished.

[0080] If the accelerator pedal 24 is completely released (i.e., if an affirmative determination is made in step S408), it is determined in step S410 whether the vehicle speed detected by the vehicle speed sensor 48 is equal to 0 km/h. If the vehicle speed is not equal to 0 km/h (i.e., if a negative determination is made in step S410), namely, if the vehicle is running, the vehicle is not in the idling state, and the fuel injection quantity is not stable. Therefore, a fault in glow-plug energization cannot be detected with sufficiently high accuracy in the fault determination process as described later. In this case, therefore, the process of Figs. 8 and 9 is finished.

[0081] If the vehicle speed is equal to 0 km/h (i.e., if an affirmative determination is made in step S410), it is determined in step S412 whether the battery voltage VB is within a predetermined reference voltage range. The reference voltage range is set in accordance with the type of the diesel engine. More specifically, the reference voltage range is set to a range in which the engine operating state, in particular, the fuel injection quantity, apparently differs between the case where current is normally applied to the glow plug 22 and the case where no current is applied to the glow plug 22. If the battery voltage VB is lower than the lowest voltage in the reference voltage range, the load on the alternator 54 reaches 100%. In this condition, substantially no change in the engine load may occur even if the glow plug 22 is switched between the energized state and the deenergized state, and therefore any fault in glow-plug energization cannot be detected with high accuracy. If the battery voltage VB is higher than the highest voltage in the reference voltage range, the load on the alternator 54 is almost equal to 0%. In this condition, substantially no change in the engine load may occur even if the glow plug 22 is switched between the energized state and the deenergized state, and therefore any fault in glow-plug energization cannot be detected with high accuracy.

[0082] If the battery voltage VB is not within the reference voltage range (i.e., if a negative determination is made in step S412), the process of Figs. 8 and 9 is once finished.

[0083] If the battery voltage VB is within the reference voltage range (i.e., if an affirmative determination is made in step S412), it is determined in step S414 whether a deviation (|NE - NTRG|) of the engine speed NE detected by the NE sensor 40 from the target idle speed NTRG set by the ECU 52 is within a predetermined reference deviation range. The reference deviation range is set in accordance with the type of the diesel engine, and is defined as a range in which the fuel injection quantity does not largely change under the idle speed control. This step makes it possible to clearly determine a difference in the fuel injection quantity by switching the glow plug 22 between the energized state and the deenergized state in the fault determination process as described later.

[0084] If the deviation (|NE - NTRG|) is not within the reference deviation range (i.e., if a negative determination is made in step S414), the process of Figs. 8 and 9 is once terminated.

[0085] If the deviation (|NE - NTRG|) is within the reference deviation range (i.e., if an affirmative determination is made in step S414), it is determined in step S416 (Fig. 9) whether an engine stabilization time has passed after completion of the engine starting cycle. In this connection, the fuel injection quantity is likely to be unstable immediately after completion of the engine starting cycle. Therefore, the engine stabilization time, which is the time it takes until the fuel injection quantity is supposed to be stabilized, is set so that a difference in the fuel injection quantity due to switching of the glow plug 22 between the energized state and the deenergized state can be determined with high certainty. Since it takes a longer time to stabilize the engine with a reduction in the coolant temperature, the engine stabilization time may be set with reference to a map, or the like so that the engine stabilization time increases as the coolant temperature THW decreases.

[0086] If the engine stabilization time has not passed after completion of the starting cycle (i.e., if a negative determination (NO) is made in step S416), the process of Figs. 8 and 9 is once finished to ensure a stand-by time until the fuel injection quantity becomes stable.

[0087] When the engine stabilization time has passed (i.e., when an affirmative determination is made in step S416), it is determined in step S418 whether the remaining glow-plug energization time in which the glow-plug energization control process as described above is executed is equal to or longer than a predetermined period of time (which will be called "required time for fault determination") that permits execution of the fault determination process. The required time for fault determination means time required for performing two fault determination processes (of Fig. 10 and Fig. 11) as described later, in which the glow plug 22 is forced to deenergized for detection of a change in the engine operating state, and is forced to be energized for detection of a change in the engine operating state.

[0088] If the remaining glow-plug energization time is shorter than the required time for fault determination at the time of execution of step S418 (i.e., if a negative determination is made in step S418), the process of Fig. 8 and Fig. 9 is finished. In this case, the fault determination processes of Fig. 10 and Fig. 11 as described later will not be carried out in the current trip of the vehicle.

[0089] If the remaining glow-plug energization time is equal to or longer than the required time for fault determination (i.e., if an affirmative determination is made in step S418), on the other hand, it is determined in step S420 whether glow-plug energization switching control for switching the glow plug 22 between the energized state and the deenergized state for the purpose of diagnosis has ever been executed in the fault determination processes of Fig. 10 and Fig. 11 during the current trip. Thus, the fault determination processes of Figs. 10 and 11 are permitted only once during one trip, so that switching of the glow relay 22a is minimized, thereby to avoid or suppress a reduction in the durability of the glow relay 22a.

[0090] If the fault determination processes of Figs. 10 and 11 have been executed in the current trip (i.e., if an affirmative determination is made in step S420), the fault determination processes of Figs. 10 and 11 are not executed again in the current trip, and the process of Fig. 8 and Fig. 9 is terminated.

[0091] Next, it is determined in step S422 whether the starting preconditions are satisfied in the starting precondition checking process (Fig. 5). If the starting preconditions are not satisfied (i.e., if a negative determination is made in step S422), it is determined in step S424 whether the main fault determination stored by the ECU 52 in the last or other previous trip has already been made affirmative. If the main fault determination was not made affirmative in the last trip (i.e., if a negative determination is made in step S424), the present process is terminated.

[0092] If the main fault determination was affirmative in the last or other previous trip (i.e., if an affirmative determination is made in step S424), the main fault determination is returned to be negative in step S425, and execution of glow-plug fault determination is permitted in step S426.

[0093] If the starting preconditions are satisfied (i.e., if an affirmative determination is made in step S422), the normality determination is made negative in step S423, and execution of the glow-plug fault determination is permitted in step S426. Namely, when an affirmative determination is made in step S422, there is a possibility of a fault in glow-plug energization in the starting precondition checking process (Fig. 5) as described above ("NO" in step S314), or determination on a possibility of a fault was impossible ("NO" is step S301). In these cases, therefore, the presence of a fault is determined by executing the fault determination processes of Fig. 10, Fig. 11 as described later.

[0094] When an affirmative determination is made in step S424, there is a possibility that repair has already been completed after it was determined in the last or other previous trip that a fault is present in glow-plug energization. Thus, even if it is determined in step S316 that there is no possibility of a fault in glow-plug energization in the starting precondition checking process (Fig. 5), the fault determination processes of Fig. 10 and Fig. 11 as described later are executed so as to provide information as to whether the glow plug 22 has been brought into a normal state by repair.

[0095] Next, the fault determination processes of Fig. 10 and Fig. 11 in which the glow plug 22 is switched between the energized state and the deenergized state will be described. Fig. 10 illustrates a provisional fault determination process, and Fig. 11 illustrates a main fault determination process. These processes are repeatedly executed at regular time intervals.

[0096] Once the provisional fault determination process (Fig. 10) is started, it is determined in step S500 whether execution of glow-plug fault determination is permitted in step S426 of the process of Fig. 8 and Fig. 9 for checking conditions for executing glow-plug fault determination as described above. If the glow-plug fault determination is not permitted (i.e., if a negative determination is made in step S500), the process of Fig. 10 is finished, and no substantial fault determination process is performed.

[0097] If execution of glow-plug fault determination is permitted (i.e., if an affirmative determination is made in step S500), it is then determined in step S502 whether this is the first cycle since execution of glow-plug fault determination was permitted. If this is the first cycle (i.e., if an affirmative determination is made in step S502), the target idle speed NTRG obtained at this time is stored in the memory as a target idle speed NTold immediately before deenergization of the glow plug 22 in step S504. This target idle speed NTold is used for determining the presence of a change in the target idle speed NTRG in a process of Fig. 12 for checking conditions for stopping glow-plug fault determination as described later.

[0098] In the next step S506, the current final basic injection quantity command value QFINC (obtained in step S230 of Fig. 4) is stored in the memory as a final basic injection quantity command value Qold1 immediately before deen-ergization of the glow plug 22. Then, the current battery voltage VB is stored in the memory as a battery voltage VBold immediately before deenergization of the glow plug 22 in step S508.

[0099] In the next step S510, energization of the glow plug 22 that has continued from turn-on of the ignition switch to the current point of time is forced to be stopped. Namely, the glow plug 22 is forced to be deenergized for the purpose of diagnosis. As a result, electric energy that has been supplied to the glow plug 22 disappears, and the amount of consumption of electric energy as a whole is significantly reduced. Therefore, the load on the diesel engine 2 is reduced in accordance with the reduction of the electric energy consumption. In the idle speed control executed as a part of the fuel injection quantity control process (of Fig. 3 and Fig. 4), therefore, the final basic injection quantity command value QFINC is reduced so as to maintain the same target idle speed NTRG. Also, the battery voltage VB rises in response to the stop of energization of the glow plug 22, namely, cut-off of current that has been applied to the glow plug 22

[0100] Subsequently, a change in the final basic injection quantity command value QFINC under idle speed control and a change in the battery voltage VB are determined so as to determine whether the load on the diesel engine 2 has been normally reduced.

[0101] Initially, it is determined in step S512 whether the condition that satisfies the following expression (6) has continued for a period of time required for determining a reduction in the engine load.

$$\mathrm{Qold1} - \mathrm{QFINC} \geq \mathrm{dQ1} \qquad (6)$$

where dQ1 is reduction judgment value, which is set in advance through experiments, and represents the minimum value of the amount of reduction of the fuel injection quantity that corresponds to the above-mentioned reduction of the electric energy consumption.

[0102] If the above expression (6) is not satisfied or if the condition that satisfies the expression (6) has not continued for the required time (i.e., if a negative determination is made in step S512), it is determined in step S514 whether the condition that satisfies the following expression (7) has continued for a period of time required for determining an increase in the battery voltage VB.

$$\mathrm{VB} - \mathrm{VBold1} \geq \mathrm{dV1} \qquad (7)$$

where dV1 is increase judgment value, which is set in advance through experiments, and represents the minimum value of the amount of increase of the battery voltage VB that would occur at the time of deenergization of the glow plug 22.

[0103] If the above expression (7) is not satisfied or if the condition that satisfies the expression (7) has not continued for the required time (i.e., if a negative determination is made in step S514), it is determined in step S516 whether the condition that satisfies the following expression (8) has continued for a period of time required for determining no change in the engine load.

$$Qold1 - QFINC < dQ1 \qquad (8)$$

This expression (8) represents a condition that the above-indicated expression (6) is not satisfied.

[0104] If the above expression (8) is not satisfied or if the condition that satisfies the expression (8) has not continued for the required time (i.e., if a negative determination is made in step S516), the process of Fig. 10 is once finished.

[0105] If the condition that satisfies the above expression (6) has continued for the time required for determining a reduction in the engine load (i.e., if an affirmative determination is made in step S512), or if the condition that satisfies the above expression (7) has continued for the time required for determining an increase in the battery voltage VB (i.e., if an affirmative determination is made in step S514), normality determination is made affirmative in step S518. Namely, glow-plug energization is determined to be normal. When an affirmative determination is made in step S512 or step S514, it indicates that the glow plug 22 had been normally energized before the glow-plug energization was forced to be stopped in step S510, and energization of the glow plug 22 was stopped (i.e., the glow plug 22 was deenergized) as commanded by the ECU 52 in step S510. In this case, information that normality determination is affirmative is stored in the backup RAM of the ECU 52. Thus, the process of Fig. 10 is finished. If normality determination is affirmative, energization of the glow plug 22 is resumed (i.e., current is applied to the glow plug 22 again) and the main fault determination process (Fig. 11) is not executed, in a process (Fig. 12 and Fig. 13) of checking conditions for stopping glow-plug fault determination.

[0106] If negative determinations are made in both step S512 and step S514, and the condition that satisfies the above expression (8) has continued for the time required for determining no change in the engine load (i.e., if an affirmative determination is made in step S516), provisional fault determination is made affirmative in step S520. This situation indicates that the glow plug 22 had not been normally energized before energization of the glow plug 22 was forced to be stopped in step S510, or glow-plug energization was not stopped as commanded by the ECU 52 in step S510. In this case, therefore, information that provisional fault determination is affirmative (i.e., glow-plug energization is provisionally determined to be faulty) is stored in the backup RAM of the ECU 52. Thus, the process of Fig. 10 is finished. With the provisional fault determination being affirmative, the provisional fault determination process (Fig. 11) is stopped and a substantial process of the main fault determination process (Fig. 11) is executed in the process (Fig. 12 and Fig. 13) of checking conditions for stopping glow-plug fault determination.

[0107] The main fault determination process (Fig. 11) will be now explained. This process is repeatedly executed at regular time intervals. Once the process of Fig. 11 is started, it is determined in step S600 whether the provisional fault determination is affirmative (namely, the glow-plug energization is provisionally determined to be faulty). Since the provisional fault determination is kept negative as set by initialization until the provisional fault determination is made affirmative in the provisional fault determination process (Fig. 10), a negative determination is made in step S600, and the process of Fig. 11 is once finished without performing any substantial portion of the process.

[0108] On the contrary, if the provisional fault determination is made affirmative in the provisional fault determination process (Fig. 10) as described above (i.e., if an affirmative determination is made in step S600), it is determined in step S601 whether a predetermined stand-by time has passed since the forced deenergization of the glow plug 22 in step S510 of the provisional fault determination process (Fig. 10). The stand-by time is set in advance for preventing switching of the glow relay 22a between ON and OFF in a short time, thereby preventing a reduction of the durability of the glow relay 22a. The stand-by time may be set to, for example, 100 msec though it depends on the type of the glow relay 22a and the amount of current that flows through the glow relay 22a.

[0109] If the stand-by time has not passed (i.e., if a negative determination is made in step S601), the process of Fig. 11 is once finished, and the substantial portion of the main fault determination process is not started.

[0110] If the stand-by time has passed (i.e., if an affirmative determination is made in step S601), it is determined in step S602 whether this step is executed for the first time after an affirmative determination is made in step S601. If step S602 is executed for the first time (i.e., if an affirmative determination is made in step S602), the final basic injection quantity command value QFINC obtained at this time is stored in the memory as a final basic injection quantity command value Qold2 immediately before energization of the glow plug 22 in step S604. Then, the current battery voltage VB is stored in the memory as a battery voltage VBold2 immediately before energization of the glow plug 22 in step S606.

[0111] In step S608 following step S606, the glow plug 22 that has been deenergized is forced to be energized for the purpose of diagnosis. Namely, current starts being applied to the glow plug 22 again, and the amount of consumption of electrical energy is greatly increased. As a result, the load on the diesel engine 2 is increased in accordance with the increase in the electrical energy consumption. In the idle speed control executed as a part of the fuel injection quantity control process (Fig. 3 and Fig. 4), therefore, the final basic fuel quantity command value QFINC is increased so as to maintain the same target idle speed NTRG. Furthermore, the battery voltage VB drops due to the start of energization of the glow plug 22.

[0112] Subsequently, a change in the final basic injection quantity command value QFINC under idle speed control and a change in the battery voltage VB are determined so as to determine whether the load on the diesel engine 2 has been normally increased.

[0113] Initially, it is determined in step S610 whether the condition that satisfies the following expression (9) has continued for a period of time required for determining an increase in the engine load.

$$QFINC - Qold2 \geq dQ2 \qquad (9)$$

where dQ2 is increase judgment value, which is set in advance through experiments, and represents the minimum value of the amount of increase of the fuel injection quantity that corresponds to the above-mentioned increase of the electric energy consumption.

[0114] If the above expression (9) is not satisfied or if the condition that satisfies the expression (9) has not continued for the required time (i.e., if a negative determination is made in step S610), it is determined in step S612 whether the condition that satisfies the following expression (10) has continued for a period of time required for determining a drop of the battery voltage VB.

$$VBold2 - VB \geq dV2 \qquad (10)$$

where dV2 is drop judgment value, which is set in advance through experiments, and represents the minimum value of the amount of drop of the battery voltage VB that would occurs at the time of energization of the glow plug 22.

[0115] If the above expression (10) is not satisfied or if the condition that satisfies the expression (10) has not continued for the required time (i.e., if a negative determination is made in step S612), it is determined in step S614 whether the condition that satisfies the following expression (11) has continued for a period of time required for determining no change in the engine load.

$$QFINC - Qold2 < dQ2 \qquad (11)$$

This expression (11) represents a condition that the above-indicated expression (9) is not satisfied.

[0116] If the above expression (11) is not satisfied or if the condition that satisfies the expression (11) has not continued for the required time (i.e., if a negative determination is made in step S614), the process of Fig. 11 is once finished.

[0117] If the condition that satisfies the above expression (9) has continued for the time required for determining an increase in the engine load (i.e., if an affirmative determination is made in step S610) or if the condition that satisfies the above expression (10) has continued for the time required for determining a drop of the battery voltage VB (i.e., if an affirmative determination is made in step S612), provisional fault determination is made negative in step S616. Namely, glow-plug energization is provisionally determined to be normal. When an affirmative determination is made in step S610 or step S612, it indicates that the glow plug 22 had certainly been in the deenergized state before the forced energization of the glow plug 22 in step S608, and the glow plug 22 was energized again as commanded by the ECU 52 in step S608. This situation indicates that the forced deenergization of the glow plug 22 (in step S510 of Fig. 10) was not clearly detected for some reason in the provisional fault determination process (Fig. 10) even though the glow plug 22 was actually deenergized for the purpose of diagnosis. In the main fault determination process (Fig. 11), however, it was confirmed that the glow plug 22 functions normally.

[0118] In the above case, therefore, the provisional fault determination is made negative, and this information is stored in the backup ROM of the ECU 52. Then, the process of Fig. 11 is once finished. In the following control cycle, a negative determination is made in step S600 since the provisional fault determination is negative, and therefore the substantial portion of the main fault determination process (Fig. 11) is not executed. Since energization of the glow plug 22 is resumed in this case, current applied to the glow plug 22 is cut off after the glow-plug energization continues for the remaining part of the glow-plug energization time set in the glow-plug energization control process started upon turn-on of the ignition switch.

[0119] If negative determinations are made in both step S610 and step S612, and the condition that satisfies the above expression (11) has continued for the time required for determining no change in the engine load (i.e., if an affirmative determination is made in step S614), main fault determination is made affirmative in step S618. This situation indicates that glow-plug energization is determined to be faulty in the provisional fault determination process (Fig. 10), and is also determined to be faulty in the main fault determination process (Fig. 11). In this case, glow-plug energization is determined with high certainty to be faulty, and information that main fault determination is affirmative is stored in the backup RAM of the ECU 52. Thus, the process of Fig. 11 is finished. With the main fault determination being affirmative, the main fault determination process (Fig. 11) is stopped in the process (Fig. 12 and Fig. 13) of checking conditions for stopping glow-plug fault determination.

[0120] The process (Fig. 12 and Fig. 13) of checking conditions for stopping glow-plug fault determination will be now explained. This process is repeatedly executed at regular intervals, for stopping the provisional fault determination process (Fig. 10) and the main fault determination process (Fig. 11).

[0121] Upon start of the process of Figs. 12 and 13, it is determined in step S700 whether execution of glow-plug fault determination is permitted in step S426 of the process (Figs. 8 and 9) of checking conditions for executing glow-plug fault determination. If execution of glow-plug fault determination is not permitted (i.e., if a negative determination is made in step S700), the present process is finished, and a substantial portion of this process is not performed.

[0122] If execution of glow-plug fault determination is permitted (i.e., if an affirmative determination is made in step S700), the same operations as those of step S404 through step S412 of the process (Figs. 8 and 9) of checking conditions for execution of glow-plug fault determination are performed in step S702 through step S710. More specifically, it is determined in step S702 whether the sensors used for determination are normal. If the sensors are normally operating (i.e., if an affirmative determination is made in step S702), it is determined in step S704 whether the coolant temperature THW is within the reference temperature range. If the coolant temperature THW is within the reference temperature range (i.e., if an affirmative determination is made in step S704), it is determined in step S706 whether the degree of depression of the accelerator pedal ACCPF is equal to zero (namely, the accelerator pedal 24 is released). If the accelerator pedal depression ACCPF is equal to zero (i.e., if an affirmative determination is made in step S706), it is determined in step S708 whether the vehicle speed is equal to 0 km/h. If the vehicle speed is equal to 0 km/h (i.e., if an affirmative determination is made in step S708), it is determined in step S710 whether the battery voltage VB is within the reference voltage range.

[0123] If the battery voltage VB is within the reference voltage range (i.e., if an affirmative determination is made in step S710), it is determined in step S712 whether there is any change in the target idle speed NTRG under idle speed control during execution of the provisional fault determination process (Fig. 10) and the main fault determination process (Fig. 11). This determination is made by comparing the current target idle speed NTRG with the target idle speed NTold immediately before deenergization of the glow plug 22, which speed NTold is stored in step S504 of the provisional fault determination process (Fig. 10).

[0124] While a variation arises in the final basic injection quantity command value QFINC if the target idle speed NTRG changes, it is difficult to distinguish this variation from a variation in the injection quantity due to switching of the glow plug 22 between the energized state and the deenergized state. Accordingly, the determination in step S712 is made so as to avoid erroneous determinations in the provisional fault determination process (Fig. 10) and the main fault determination process (Fig. 11).

[0125] If there is no change in the target idle speed NTRG (i.e., if a negative determination is made in step S712), it is determined in step S714 whether both the normality determination and the main fault determination are negative. If the normality determination and the main fault determination are both negative (if an affirmative determination is made in step S714), it is then determined in step S716 whether there is a change in any of switches of various devices that use the battery 60 as a power supply. These switches may include the air-conditioner switch 50, an electric heater switch, a tail lamp switch, a defogger switch, a brake signal switch, and so forth. If there is a change in any of these switches, variations arise in the battery voltage VB and the final basic injection quantity command value QFINC. It is difficult to distinguish these variations from variations in the battery voltage VB and the command value QFINC due to switching of the glow plug 22 between the energized state and the deenergized state. Thus, the determination in step S716 is made so as to avoid erroneous determinations in the provisional fault determination process (Fig. 10) and the main fault determination process (Fig. 11).

[0126] If there is no change in the switches (i.e., if a negative determination is made in step S716), it is then determined in step S718 whether the provisional fault determination is negative (i.e., glow-plug energization is provisionally determined to be faulty). Here, if the normality determination is negative and the provisional fault determination is negative during execution of the provisional fault determination process (Fig. 10) (i.e., if an affirmative determination is made in step S718, the process of Figs. 12 and 13 is once terminated.

[0127] If a negative determination is made in any of steps S702 - S710 and step S714 or an affirmative determination is made in step S712 or step S716, the provisional fault determination is made negative in step S720. In this case, a negative determination is made in step S600 in the main fault determination process (Fig. 11), and a substantial portion of this process is not performed.

[0128] In step S722 following step S720, forced energization process is executed, namely, the glow plug 22 is forced to be energized, after a stand-by time has passed since the glow plug 22 was switched from the energized state to the deenergized state in step S510 of the provisional fault determination process (Fig. 10). The stand-by time is provided for preventing or suppressing a reduction in the durability of the glow relay 22a, and is set to be the same as the stand-by time as explained above with respect to step S601 of the main fault determination process (Fig. 11).

[0129] In the forced energization process as described above, the glow plug 22 is immediately energized if the stand-by time has already passed at a point of time when step S722 is executed. If the stand-by time has not passed at the time of execution of step S722, on the other hand, the glow plug 22 is energized after a lapse of the stand-by time. If the glow plug 22 was already forced to be energized for the purpose of diagnosis in step S608 of the main fault determination process (Fig. 11), the glow plug 22 is kept in the energized state.

[0130] In step S724 following step S722, execution of glow fault determination is not permitted, and the process of Fig. 12 and Fig. 13 is once finished.

[0131] In the next control cycle, since permission of execution of glow-plug fault determination is cancelled, a negative determination is made in step S700 in the process (Figs. 12 and 13) of checking conditions for stopping glow-plug fault determination, and a substantial portion of this process is not performed. Similarly, a negative determination is made in step S500 during execution of the provisional fault determination process (Fig. 10), and a substantial portion of this process is not performed.

[0132] It is to be noted that a negative determination is made in step S714 when the normality determination is made affirmative in step S518 of the provisional fault determination process (Fig. 10), or the main fault determination is made affirmative in step S618 of the main fault determination process (Fig. 11).

[0133] If the provisional fault determination is made affirmative in step S520 of the provisional fault determination process (Fig. 10), and a negative determination is made in step S718, execution of the provisional fault determination process (Fig. 10) is stopped in step S726.

[0134] Examples of the control process according to the present embodiment as described above are illustrated in Fig. 14 through Fig. 18.

[0135] Fig. 14 illustrates the case where the starting preconditions are determined to be not satisfied. When the ignition switch is turned ON at time t0, current is immediately applied to the glow plug 22. At time t1, an indicator lamp indicates permission of starting of the diesel engine 2 to the vehicle operator, and the operator immediately turns on the starter 30, whereby the engine starting cycle is initiated. After the engine speed NE increases up to a speed level that indicates completion of the engine starting cycle, the ECU 52 determines completion of the engine starting cycle at time t2. The actual starting period Tsta (period between t1 and t2) obtained at this time is equal to or shorter than the normal starting period Tstanorm. In the example of Fig. 14, the battery voltage VB drops to be lower than the normal minimum voltage Vstanorm during starting.

[0136] After completion of the engine starting cycle, therefore, a negative determination is made in step S310 of the starting precondition checking process (Fig. 5), and the preconditions are determined to be not satisfied in step S316. Accordingly, neither the provisional fault determination process (Fig. 10) nor the main fault determination process (Fig. 11) is executed, and current is kept applied to the glow plug 22 for normal glow-plug energization. If the energization time set under normal glow-plug energization control expires at time t3, energization of the glow plug 22 is stopped, namely, current that has been applied to the glow plug 22 is cut off. With the process as described above, the information that the starting preconditions are not satisfied, the main fault determination is negative, and the normality determination is negative is recorded in the memory of the ECU 52 as internal diagnosis information.

[0137] Fig. 15 illustrates the case where no current flows through the glow plug 22 because of disconnection even if a command to energize the glow plug 22 is generated. Initially, the ignition switch is turned ON at time t10, and the starter 30 starts driving of the engine 2 at time t11 in response to a signal to permit starting, which is followed by completion of the engine starting cycle at time t12. In this case, the actual starting period Tsta is longer than the normal starting period Tstanorm, and the battery voltage VB has never dropped to be lower than the starting-time normal minimum voltage Vstanorm. Therefore, an affirmative determination is made in step S310 and a negative determination is made in step S314 in the starting precondition checking process (Fig. 5), and the starting preconditions are determined to be satisfied in step S318. As a result, the process (Fig. 8 and Fig. 9) of checking conditions for execution of glow-plug fault determination is executed. If execution of glow-plug fault determination is permitted in step S426, the provisional fault determination process (Fig. 10) is executed at time t13 so that the glow plug 22 is forced to be deenergized. In the example of Fig. 15, neither the fuel injection quantity nor the battery voltage changes immediately after cut-off of current to the glow plug 22, even after a stand-by time for determination. Therefore, an affirmative determination is made in step S516, and the provisional fault determination is made affirmative in step S520 at time t14 in Fig. 15. As a result, the provisional fault determination process (Fig. 10) is stopped in step S726 of the process (Fig. 12 and Fig. 13) of checking conditions for stopping glow-plug fault determination, and instead the substantive main fault determination process (Fig. 11) is started so that the glow plug 22 is forced to be energized in step S608. In the example of Fig. 15, neither the fuel injection quantity nor the battery voltage changes immediately after forced energization of the glow plug 22, even after a stand-by time for determination. Therefore, an affirmative determination is obtained in step S614, and the main fault determination is made affirmative in step S618 at time t15 in Fig. 15. Then, a negative determination is made in step S714 in the process (Figs. 12 and 13) of checking conditions for stopping glow-plug fault determination, and the provisional fault determination is made negative in step S720, whereby execution of glow-plug fault determination is not permitted in step S724. Since the glow plug 22 has been forced to be energized, the energized state of the glow plug 22 is maintained in step S722.

[0138] Subsequently, when the energization time set in normal glow-plug energization control expires (t16), current applied to the glow plug 22 is cut off. With the process as described above, the information that the starting preconditions are satisfied, the main fault determination is affirmative, and the normality determination is negative is recorded in the memory of the ECU 52.

[0139] Fig. 16 illustrates the case where energization of the glow plug 22 is determined to be normal in the provisional fault determination process (Fig. 10). Initially, the ignition switch is turned ON at time t20, and the starter 30 starts driving of the engine 2 at time t21 in response to a signal to permit starting, which is followed by completion of the engine starting cycle at time t22. In this case, the actual starting period Tsta is longer than the normal starting period Tstanorm, and the battery voltage VB has never dropped to be lower than the starting-time normal minimum voltage Vstanorm. Therefore, an affirmative determination is made in step S310 and a negative determination is made in step S314 in the starting precondition checking process (Fig. 5), and the starting preconditions are determined to be satisfied in step S318. As a result, the process (Fig. 8 and Fig. 9) of checking conditions for execution of glow-plug fault determination is executed. If execution of glow-plug fault determination is permitted in step S426, the provisional fault determination process (Fig. 10) is executed at time t23, and the glow plug 22 is forced to be deenergized. In the example of Fig. 16, the battery voltage VB is immediately increased by an amount larger than the increase judgment value dV1, and an affirmative determination is made in step S514. Also, the fuel injection quantity is reduced by an amount larger than the reduction judgment value dQ1.

[0140] In the above case, the normality determination is made affirmative in step S518 at time t24 in Fig. 16. Accordingly, the provisional fault determination is kept being negative in step S720, and execution of glow-plug fault determination is not permitted in step S724, so that the provisional fault determination process (Fig. 10) is stopped. Furthermore, in step S722, energization of the glow plug 22 is resumed at time t25 after a lapse of the stand-by time measured from the forced deenergization of the glow plug 22 in step S510. Thus, the main fault determination process (Fig. 11) is not executed. Subsequently, glow-plug energization is terminated when the energization time set in normal glow-plug energization control expires at time t26. With the process as described above, information that the starting preconditions are satisfied, the main fault determination is negative, and the normality determination is affirmative is recorded in the memory of the ECU 52.

[0141] Fig. 17 illustrates the case where sufficiently large changes do not occur in the fuel injection quantity and the battery voltage when the glow plug 22 is forced to be deenergized in the provisional fault determination process (Fig. 10), and sufficiently large changes occur in the fuel injection quantity and the battery voltage for the first time when the glow plug 22 is forced to be energized in the main fault determination process (Fig. 11). The control proceeds from time t30 to t34 in the same manner in which the control proceeds from time t10 to t14 as explained above with reference to Fig. 15. In the main fault determination process (Fig. 11) started at time t34, the glow plug 22 is forced to be energized in step S608. In the example of Fig. 17, the fuel injection quantity is first increased by an amount larger than the increase judgment value dQ2 (i.e., an affirmative determination is made in step S610), and therefore the provisional fault determination is made negative in step S616 at time t35. After the energization time set in normal glow-plug energization control expires at time t36, the glow plug 22 is deenergized, namely, current applied to the glow plug 22 is cut off. With the process as described above, information that the starting preconditions are satisfied, the main fault determination is negative, and the normality determination is negative is recorded in the memory of the ECU 52. It is to be noted that execution of glow-plug fault determination is not permitted in step S724 at an appropriate time, for example, when the accelerator pedal 24 is depressed (i.e., when a negative determination is made in step S706).

[0142] Fig. 18 illustrates the case where a fault in the glow-plug energization was found in the last or other previous trip, and the engine 2 is started immediately after repair is completed. The control proceeds from time t40 to t42 in the same manner in which the control proceeds from time t0 to t2 as explained above with respect to Fig. 14. Since normal energization of the glow plug 22 is performed, a negative determination is made in step S310 or an affirmative determination is made in step S314, so that the starting preconditions are determined to be not satisfied in step S316.

[0143] If affirmative determinations are made in all of steps S400 through S420 except for steps S402 and S420 and negative determinations are made in steps S402 and S420 in the process (Figs. 8 and 9) of checking conditions for executing glow-plug fault determination, it is then determined in step S422 whether the starting preconditions are satisfied in step S422. At this time, since the starting preconditions are not satisfied assuming that there is no possibility of a fault in the glow plug 22, a negative determination is made in step S422, and it is determined in step S424 whether the main fault determination has already been affirmative. Here, since the main fault determination has already been affirmative (i.e., an affirmative determination is made in step S424), the main fault determination is returned to be negative in step S425, and execution of glow-plug fault determination is permitted in step S426. Thus, the substantial provisional fault determination process (Fig. 10) is started.

[0144] In the provisional fault determination process (Fig. 10), the glow plug 22 is forced to be deenergized. At this time, since the glow plug 22 is normally deenergized, the battery voltage VB is immediately increased by an amount larger than the increase judgment value dV1, and an affirmative determination is made in step S514 at time t44. Also, the fuel injection quantity is reduced by an amount larger than the reduction judgment value dQ1.

[0145] In the above case, the normality determination is made affirmative in step S518. Accordingly, a negative determination is made in step S714, and the provisional fault determination is kept being negative in step S720. Also, execution of glow-plug fault determination is not permitted in step S724, and the provisional fault determination process (Fig. 10) is stopped. Furthermore, the glow plug 22 is forced to be energized again at time t45 through the process of step S722, after a lapse of the stand-by time as measured from the forced deenergization of the glow plug 22 in step S510.

[0146] Subsequently, when the energization time set in normal glow-plug energization control expires at time t46, the glow-plug energization is terminated. With the process as described above, information that the starting preconditions are not satisfied, the main fault determination is negative, and the normality determination is positive is stored in the memory of the ECU 52.

[0147] In the glow-plug fault detecting apparatus and method as described above, the starting precondition checking process (Fig. 5) corresponds to fault possibility determining means, and the process (Figs. 8 and 9) of checking conditions for execution of glow-plug fault determination, the provisional fault determination process (Fig. 10), the main fault determination process (Fig. 11) and the process (Figs. 12 and 13) of checking conditions for stopping glow-plug fault determination correspond to fault presence determining means. Also, the process of calculating the starting period Tsta by counting a period of time from the start of the engine starting cycle to completion thereof and the process of detecting the history of the battery voltage VB for a period from the start of the engine starting cycle to completion thereof correspond to means for detecting an engine state before completion of the engine starting cycle. The process (Figs. 8 and 9) of checking conditions for executing glow-plug fault determination and the provisional fault determination process (Fig. 10) correspond to the first fault determining means, and the main fault determination process (Fig. 11) and the process (Figs. 12 and 13) of checking conditions for stopping glow-plug fault determination correspond to the second fault determining means.

[0148] The first embodiment of the invention as described above yields the following effects.

(1) In the starting precondition checking process (Fig. 5), a fault of the glow plug 22 is detected based on the length of the starting period Tsta or the history of the battery voltage VB during starting without relaying on forced energization and deenergization of the glow plug 22. The fault detection through this process exhibits lower certainty or reliability as compared with the case where a fault is detected through forced energization and deenergization of the glow plug 22 for the purpose of diagnosis. This is because the starting period Tsta may be prolonged or the battery voltage VB may not be lowered for other reasons even if current is normally applied to the glow plug 22.

However, if the starting period Tsta is sufficiently short or the battery voltage VB is sufficiently lowered during energization of the glow plug 22 for warm-up of the engine 2, no possibility of a fault in glow-plug energization can be determined with high reliability even if the energized state of the glow plug 22 is not forced to be changed for diagnostic purposes. Accordingly, if it is determined that there is no possibility of a fault through the starting precondition checking process (Fig. 5) executed before the provisional fault determination process (Fig. 10) and the main fault determination process (Fig. 11), there is no need to execute the provisional fault determination process (Fig. 10) and the main fault determination process (Fig. 11). If it is not determined in the starting precondition checking process (Fig. 5) that there is no possibility of a fault in the glow plug 22, namely, if it is determined that there is a possibility of a fault, the provisional fault determination process (Fig. 10) and the main fault determination process (Fig. 11) in which the glow plug 22 is forced to be energized or deenergized for diagnostic purposes are executed. Thus, the number of times the energized state of the glow plug 22 is changed by driving the glow relay 22a can be reduced.

Thus, a fault in glow-plug energization can be detected with sufficiently high accuracy by monitoring changes in the fuel injection quantity and changes in the battery voltage immediately after forced energization or deenergization of the glow plug 22 in the case where it is determined that there is a possibility of a fault in glow-plug energization. Furthermore, the number of switching of the glow plug 22 between the energized state and the deenergized state can be reduced, and the therefore otherwise possible deterioration of the durability of the glow relay 22a can be suppressed.

(2) If glow-plug energization is normally performed, the engine starting cycle is completed early, and the starting period Tsta turns out to be short. If glow-plug energization is not normally performed, to the contrary, the starting period Tsta is increased. In the starting precondition checking process (Fig. 5), therefore, it is determined that there is no possibility of a fault in the glow plug 22 if the starting period Tsta is equal to or shorter than the normal starting period Tstanorm. On the contrary, if the starting period Tsta is longer than the normal starting period Tstanorm, a possibility of a fault in the glow plug 22 cannot be negated though the long starting period may be caused by another reason.

If glow-plug energization is normally performed, the battery voltage VB drops off at a time prior to completion of the engine starting cycle. On the other hand, if no current is applied to the glow plug 22 or the amount of current applied to the glow plug 22 is excessively small, the battery voltage VB does not drop or hardly drops. In the starting precondition checking process (Fig. 5), therefore, it is determined that there is no possibility of a fault in the glow plug 22 if the battery voltage VB has ever dropped below the starting-time normal minimum voltage Vstanorm before completion of the engine starting cycle. On the contrary, if there is no history of a drop of the battery voltage VB below the starting-time normal minimum voltage Vstanorm before completion of the starting cycle, a possibility of a fault in the glow plug 22 cannot be negated or denied though the absence of the voltage drop may be caused by another reason.

Accordingly, if the starting period Tsta is longer than the normal starting period Tstanorm and there is no history of a drop of the battery voltage VB below the starting-time normal minimum voltage Vstanorm before completion of the engine starting cycle, it is determined that there is a possibility of a fault in the glow plug 22.

Thus, in the starting precondition checking process (Fig. 5), the possibility of a fault in the glow plug 22 can be easily determined even if the glow plug 22 is not forced to be energized or deenergized for the purpose of diagnosis. Furthermore, the normal starting period Tstanorm and the starting-time normal minimum voltage Vstanorm are set based on the coolant temperature THWs measured at the beginning of the engine starting cycle, and therefore the possibility of a fault can be determined with relatively high certainty or reliability.

(3) In the process (Figs. 8 and 9) of checking conditions for executing glow-plug fault determination, execution of glow-plug fault determination is permitted only if the remaining portion of the glow-plug energization time set in the normal glow-plug energization control is long enough to execute the provisional fault determination process (Fig. 10) and the main fault determination process (Fig. 11) (i.e., if an affirmative determination is made in step S418).

In the provisional fault determination process (Fig. 10) and the main fault determination process (Fig. 11), therefore, determination of the presence of a fault accompanied by forced changes of the energized state of the glow plug 22 can be completed within the time set for normal glow-plug energization. Thus, the glow-plug energization control is not prolonged in vain due to the forced changes of the energized state of the glow plug 22 for the purpose of diagnosis, and energy consumption for determination of the presence of a fault can be reduced.

The forced changes of the energized state of the glow plug 22 are effected during normal glow-plug energization in the provisional fault determination process (Fig. 10) and the main fault determination process (Fig. 11). Since the process (Figs. 8 and 9) of checking conditions for executing glow-plug fault determination allows the energized state of the glow plug 22 to be forced to be changed only after the engine operating state becomes stable, no problem arises in the stability of the engine operation after starting thereof.

(4) With the provisional fault determination process (Fig. 10) and the main fault determination process (Fig. 11) as described above, a fault in glow-plug energization can be detected with high reliability in two steps or stages, namely, through energization and deenergization of the glow plug 22 for diagnostic purposes. Furthermore, by switching the glow plug 22 from the energized state to the deenergized state and from the deenergized state to the energized state in the two steps, the glow plug 22 can be returned to the energized state, thus causing no problem in the stability of the operation of the diesel engine 2.

(5) If energization and deenergization of the glow plug 22 are carried out at short time intervals, namely, if the glow relay 22a is switched off and on at short intervals, the durability of the glow relay 22a may be reduced. In step S601 of the main fault determination process (Fig. 11), therefore, the forced energization of the glow plug 22 is not executed until the stand-by time set for protecting the glow relay 22a passes from a point of time when the glow plug 22 is forced to be deenergized in step S510 of the provisional fault determination process (Fig. 10). Thus, otherwise possible reduction of the durability of the glow relay 22a can be prevented.

(6) In the process (Figs. 8 and 9) of checking conditions for executing glow-plug fault determination, even if it is apparently determined that there is no possibility of a fault in glow-plug energization (i.e., a negative determination is made in step S422), execution of glow-plug fault determination is permitted in step S426 provided that the main fault determination was already made affirmative in the last or other previous trip (i.e., an affirmative determination is made in step S424).

[0149] With the above arrangement, the provisional fault determination process (Fig. 10) can be executed and the main fault determination process (Fig. 11) can be further executed in some cases after repair is done with respect to the previously detected fault, so that internal information relating to diagnosis, for example, can be updated to reflect normal glow-plug energization after the repair.

[0150] Next, a second embodiment of the invention will be described. In this embodiment, while the glow plug 22 is energized under normal glow-plug energization control performed upon a start of the engine, only the starting precondition checking process (Fig. 5) is executed, and the starting preconditions are determined to be satisfied or not satisfied. Then, after completion of the energization of the glow plug 22 for warm-up of the engine 2, the glow plug 22 is energized or deenergized for the purpose of determining the presence of a fault, only in the case where the starting preconditions are satisfied or in the case where the main fault determination has already been affirmative.

[0151] In the second embodiment, a process as shown in Fig. 19 is executed which replaces a part of the process of checking conditions for executing glow-plug fault determination as shown in Fig. 9 of the first embodiment. Also, a provisional fault determination process as shown in Fig. 20 and a main fault determination process as shown in Fig. 21 are executed in place of the provisional fault determination process (Fig. 10) and the main fault determination process (Fig. 11). Furthermore, a process as shown in Fig. 22 is executed which replaces a part of the process of checking conditions for stopping glow-plug fault determination as shown in Fig. 13. With regard to the other construction and processes, the second embodiment is substantially identical with the first embodiment.

[0152] Referring first to Fig. 19, it is determined in step S417, as a condition for permitting execution of glow-plug fault determination, whether a stand-by time has passed after the normal glow-plug energization period expires. This step S417 replaces step S416 and step S418 of Fig. 9.

[0153] Thus, execution of glow-plug fault determination is not permitted (in step S426) unless the normal glow-plug energization period expires. Thus, neither deenergization nor energization of the glow plug 22 for a diagnostic purpose is carried out during normal glow-plug energization for warm-up of the engine.

[0154] If affirmative determinations are made in step S400 and steps S404 through S417 and negative determinations are made in step S402 and step S420 after the normal glow-plug energization period expires, it is determined in step S422 whether the starting preconditions are satisfied. If the starting preconditions set in the starting precondition checking process (Fig. 5) are not satisfied (i.e., if a negative determination is made in step S422), it is determined in step S424 whether the main fault determination has already been affirmative. If the main fault determination is negative (i.e., if a negative determination is made in step S424), the present process is terminated. Thus, the forced energization and deenergization of the glow plug 22 for the purpose of diagnosis are not carried out in the same trip. In this case, the control proceeds in the same manner as shown in the time chart of Fig. 14 as explained above with respect to the first embodiment.

[0155] The case where the starting preconditions are determined to be satisfied in the starting precondition checking process (Fig. 5) will be now described. In this case, the forced deenergization and energization of the glow plug 22 are not carried out within the normal glow-plug energization period. For example, as shown in the time chart of Fig. 23, the ignition switch is turned on at time t50, and the starter 30 is allowed to start driving the diesel engine 2 at time t51, followed by completion of the engine starting cycle at time t52. In this particular case, the actual starting period Tsta is longer than the normal starting period Tstanorm, and the battery voltage VB has never dropped below the starting-time normal minimum voltage Vstanorm. Accordingly, an affirmative determination is made in step S310 and a negative determination is made in step S314 in the starting precondition checking process (Fig. 5), and the preconditions are determined to be satisfied in step S318. However, the provisional fault determination process (Fig. 20) is not immediately started but waits until the normal glow-plug energization period expires.

[0156] If affirmative determinations are made in step S400 and steps S404 through S417 and negative determinations are made in step S402 and step S420 in the process (Fig. 8 and Fig. 19) after the normal glow-plug energization period expires, it is determined in step S422 whether the starting preconditions are satisfied. In this particular case, since the starting preconditions are satisfied (i.e., an affirmative determination is made in step S422), the normality determination is made negative in step S423, and execution of glow-plug fault determination is permitted in step S426 at time t54. As a result, the provisional fault determination process (Fig. 20) is started, and affirmative determinations are made in step S800 and step S802. After execution of steps S804 through step S808, the glow plug 22 is forced to be energized in step S810. It will be understood that step S800 through step S808 are substantially identical with step S500 through step S508 of the provisional fault determination process (Fig. 10) of the first embodiment.

[0157] Subsequently, it is determined in step S812 whether the condition that satisfies the following expression (12) has continued for a period of time required for determining an increase of the engine load.

$$QFINC - Qold3 \geq dQ3 \tag{12}$$

where dQ3 is increase judgment value, which is set in advance through experiments, and is defined as the minimum value of the amount of increase of the fuel injection quantity that corresponds to an increase of the consumption of electric energy caused by the energization of the glow plug 22.

[0158] If the above expression (12) is not satisfied or if the condition that satisfies the above expression (12) has not continued for the time required for determining the increase of the engine load (i.e., if a negative determination is made in step S812), it is then determined in step S814 whether the condition that satisfies the following expression (13) has continued for a period of time required for determining a drop of the battery voltage VB.

$$VBold3 - VB \geq dV3 \tag{13}$$

where dV3 is drop judgment value, which is set in advance through experiments, and represents the minimum value of the drop of the battery voltage VB that occurs in response to the energization of the glow plug 22.

[0159] If the above expression (13) is not satisfied or if the condition that satisfies the above expression (13) has not continued for the time required for determining the drop of the battery drop (i.e., if a negative determination is made in step S814), it is determined in step S816 whether the condition that satisfies the following expression (14) has continued for a period of time required for determining no change of the engine load.

$$QFINC - Qold3 < dQ3 \qquad (14)$$

This expression (14) represents a state in which the above-indicated expression (12) is not satisfied.

[0160] If the above expression (14) is not satisfied or if the condition that satisfies the above expression (14) for the time required for determining no change of the engine load (i.e., if a negative determination is made in step S816), the process of Fig. 20 is once terminated.

[0161] As shown in the time chart of Fig. 23, if the condition that satisfies the above expression (14) has continued for the time required for determining no change of the engine load (if an affirmative determination is made in step S816) at time t55 before affirmative determinations are made in step S812 and step S814, the provisional fault determination is made affirmative in step S820. This indicates that the glow plug 22 had been in the energized state though it should have been in the deenergized state before the glow plug 22 was energized for the purpose of diagnosis in step S810, or the glow plug 22 was not energized as commanded by the ECU 52 in step S810. In this case, information that the provisional fault determination is positive is stored in the backup RAM of the ECU 52, and the process of Fig. 20 is once terminated).

[0162] With the provisional fault determination thus made positive, the provisional fault determination process (Fig. 20) is stopped in step S726 in the process (Figs. 12, 22) of checking conditions for stopping glow-plug fault determination, and the substantial main fault determination process (Fig. 21) starts being executed (i.e., an affirmative determination is made in step S900).

[0163] After execution of step S900 through step S906 in the main fault determination process (Fig. 21), the glow plug 22 is forced to be deenergized for the purpose of diagnosis in step S908. It will be understood that the contents of step S900 through step S906 are substantially identical with those of step S600 through step S606 of the main fault determination process (Fig. 11) through the glow plug 22 is energized rather than deenergized in the process of Fig. 11.

[0164] Next, a change in the final basic injection quantity command value QFINC under idle speed control and a change in the battery voltage VB are determined in order to determine whether the load on the diesel engine 2 has normally reduced due to deenergization of the glow plug 22.

[0165] Initially, it is determined in step S910 whether the condition that satisfies the following expression (15) has continued for a period of time required for determining the reduction of the engine load.

$$Qold4 - QFINC \geq dQ4 \qquad (15)$$

where dQ4 is reduction judgment value, which is set in advance through experiments, and represents the minimum value of the amount of reduction of the fuel injection quantity that corresponds to a reduction of the consumption of electrical energy due to the deenergization of the glow plug 22.

[0166] If the above expression (15) is not satisfied or if the condition that satisfies the above expression (15) has not continued for the time required for determining the reduction of the load (i.e., if a negative determination is made in step S910), it is determined in step S912 whether the condition that satisfies the following expression (16) has continued for a period of time required for determining an increase of the battery voltage VB.

$$VB - VBold4 \geq dV4 \qquad (16)$$

where dV4 is increase judgment value, which is set in advance through experiments, and represents the minimum value of the increase of the battery voltage VB that occurs in response to deenergization of the glow plug 22.

[0167] If the above expression (16) is not satisfied or the condition that satisfies the above expression (16) has not continued for the time required for determining the increase of the battery voltage (i.e., if a negative determination is made in step S912), it is determined in step S914 whether the condition that satisfies the following expression (17) has continued for a period of time required for determining no change of the engine load.

$$Qold4 - QFINC < dQ4 \quad (17)$$

This expression (17) represents a state in which the above-indicated expression (15) is not satisfied.

[0168] If the above expression (17) is not satisfied or if the condition that satisfies the above expression (17) has not continued for the time required for determining no change of the engine load (i.e., if a negative determination is made in step S914), the process of Fig. 21 is once terminated.

[0169] As shown in the time chart of Fig. 23, if the condition that satisfies the above expression (17) has continued for the time required for determining no change of the engine load (i.e., if an affirmative determination is made in step S914) at time t56 before affirmative determinations are made in step S910 and step S912, the main fault determination is made affirmative in step S918. This indicates that the glow plug 22 had not been in the energized state before the glow plug 22 was forced to be deenergized in step S908, or the glow plug 22 was not deenergized as commanded by the ECU 52 in step S908.

[0170] In the above case, the glow plug 22 is determined to be faulty in the provisional fault determination process (Fig. 20) and is also determined to be faulty in the main fault determination process (Fig. 21). Thus, the glow-plug energization is determined to be faulty with high certainty, and information that the main fault determination is affirmative is stored in the backup RAM of the ECU 52. Then, the process of Fig. 21 is once terminated.

[0171] With the main fault determination thus made affirmative, a negative determination is made in step S714 of the process (Figs. 12 and 22) of checking conditions for stopping glow-plug fault determination, and execution of glow-plug fault determination is not permitted in step S724, whereby the main fault determination process (Fig. 21) is stopped. Through the process as described above, information that the starting preconditions are not satisfied, the main fault determination is affirmative and the normality determination is negative is recorded in the memory of the ECU 52 as internal information relating to diagnoses.

[0172] Referring next to the time chart of Fig. 24, the case where the normality determination is made affirmative will be described. The control proceeds from time t60 to t64 in the same manner in which the control proceeds from time t50 to t54 in the case of Fig. 23. In the provisional fault determination process (Fig. 20) that is started at time t64, the glow plug 22 is forced to be energized for a diagnostic purpose in step S810. As current actually starts flowing through the glow plug 22 in a normal way upon energization of the glow plug 22, the fuel injection quantity starts increasing, and the battery voltage VB starts dropping. Then, the relationship of the expression (13) is first satisfied at time t65 and is kept satisfied for the required time (an affirmative determination is made in step S814), whereby the normality determination is made affirmative in step 818. With the normality determination thus made affirmative, a negative determination is made in step S714 in the process (Figs. 12 and 22) of checking conditions for stopping glow-plug fault determination, and the provisional fault determination is made negative in step S720, whereby execution of glow-plug fault determination is not permitted in step S724. Consequently, the provisional fault determination process (Fig. 20) and the main fault determination process (Fig. 21) are stopped. Also, the glow plug 22 is returned to the deenergized state after a lapse of a stand-by time in step S723 at time t66.

[0173] With the process as described above, information that the starting preconditions are satisfied, the main fault determination is negative, and the normality determination is affirmative is recorded in the memory of the ECU 52.

[0174] Referring next to the time chart of Fig. 25, the case where the energized state of the glow plug 22 is normally changed for the first time in the main fault determination process (Fig. 21) will be described. The control proceeds from time t70 to t74 in the same manner in which the control proceeds from time t50 to t54 in the case of Fig. 23. In the provisional fault determination process (Fig. 20) started at time t74, a command to energize the glow plug 22 for the purpose of diagnosis is generated in step S810. Since no current flows through the glow plug 22 in response to this command, the above-indicated expressions (12) and (13) are not satisfied, and the above-indicated expression (14) is kept satisfied (i.e., an affirmative determination is made in step S816 at time t75). As a result, the provisional fault determination is made affirmative in step S820. With the provisional fault determination thus made affirmative, the provisional fault determination process (Fig. 20) is stopped in step S726. In the main fault determination process (Fig. 21), a command to deenergize the glow plug 22 for the purpose of diagnosis is generated in step 908 at time t76 after the stand-by time passes from the forced energization of the glow plug 22 in step S810.

[0175] If current that has flowed through the glow plug 22 is normally stopped in response to the command to deenergize the glow plug 22, the fuel injection quantity starts decreasing, and the battery voltage VB starts rising. Then, the relationship of the above expression (16) is satisfied for the first time at time t77, and is kept satisfied so that an affirmative determination is made in step S912, whereby the provisional fault determination is returned to be negative in step S916. With the provisional fault determination being negative, the substantial main fault determination process (Fig. 21) is stopped (i.e., a negative determination is made in step S900). With the process as described above, information that the starting preconditions are satisfied, the main fault determination is negative, and the normality determination is negative is recorded in the memory of the ECU 52. It is to be noted that execution of glow-plug fault determination is not permitted in step S724 at an appropriate time, for example, when the accelerator pedal 24 is depressed (i.e., when a negative determination is made in step S706).

[0176] Fig. 26 illustrates the case where a fault in glow-plug energization was found in the last or other previous trip, and the diesel engine 2 is started immediately after completion of repair. The control proceeds from time t80 to t83 in the same manner in which the control proceeds from time t0 to t3 as explained above with reference to Fig. 14. During the period, since glow-plug energization is normally effected, a negative determination is made in step S310 or an affirmative determination is made in step S314 in the starting precondition checking process (Fig. 5), and the starting preconditions are determined to be not satisfied in step S316 at time t82.

[0177] After completion of the normal glow-plug energization process at time t83, if affirmative determinations are made in steps S400 and S404 through S417 and negative determinations are made in step S402 and step S420 in the process (Figs. 8 and 19) of checking conditions for executing glow-plug fault determination, it is determined in step S422 whether the starting preconditions are satisfied. Since the starting preconditions are not satisfied (i.e., a negative determination is made in step S422), it is then determined in step S424 whether the main fault determination has already been affirmative in the last or other previous trip. Since the main fault determination has been affirmative in this example (i.e., an affirmative determination is made in step S424), the main fault determination is made negative in step S425, and execution of glow-plug fault determination is permitted in step S426 at time t84. As a result, the provisional fault determination process (Fig. 20) is executed, and the relationship of the above-indicated expression (13) is satisfied at time t85 and kept satisfied (i.e., an affirmative determination is made in step S814), whereby the normality determination is made affirmative in step S818.

[0178] With the normality determination thus made negative, a negative determination is made in step S714 of Fig. 22, and the glow plug 22 is forced to be deenergized at time t86 in step S723 after the stand-by time passes from the forced energization of the glow plug 22 in step S810 of Fig. 20. Also, the provisional fault determination is made negative in step S720 and execution of glow-plug fault determination is not permitted in step S724, whereby both the provisional fault determination process (Fig. 20) and the main fault determination process (Fig. 21) are stopped. With the process as described above, information that the starting preconditions are not satisfied, the main fault determination is negative, and the normality determination is affirmative is recorded in the memory of the ECU 52.

[0179] In the glow-plug fault detecting apparatus and method as described above, the process (Figs. 8 and 19) of checking conditions for execution of glow-plug fault determination, the provisional fault determination process (Fig. 20), the main fault determination process (Fig. 21) and the process (of Figs. 12 and 20) of checking conditions for stopping glow-plug fault determination correspond to fault presence determining means. Also, the process (Figs. 8 and 19) of checking conditions for execution of glow-plug fault determination and the provisional fault determination process (Fig. 20) correspond to the first fault determining means, and the main fault determination process (Fig. 21) and the process (Figs. 12 and 22) of checking conditions for stopping glow-plug fault determination correspond to the second fault determining means. The fault possibility determining means and the means for detecting an engine state before completion of the engine starting cycle are the same as those of the first embodiment.

[0180] The second embodiment of the invention as described above yields the following effects.

(1) This embodiment provides the same effects as those as described above at (1), (2) and (4) through (6) with respect to the first embodiment.

(2) Since the provisional fault determination process (Fig. 20) and the main fault determination process (Fig. 21) are executed after expiration of the normal glow-plug energization period, these processes have no influence on the normal glow-plug energization control. Accordingly, the diesel engine 2 operates with improved stability during start-up, in particular, during a cold start.

[0181] In addition, since a fault in glow-plug energization is not detected within the normal glow-plug energization period, chances to detect a fault in glow-plug energization are sufficiently provided even if the diesel engine 2 has been warned up and the normal glow-plug energization period is short,.

[0182] Other embodiments of the invention will be now described.

(a) While the history of the battery voltage VB used in the starting precondition checking process (Fig. 5) means the history during the engine starting cycle (namely, from start to completion of the starting cycle) in the illustrated embodiments, the history of the battery voltage VB may further cover a period from turn-on of the ignition switch to the start of the engine starting cycle, or may include the history of the battery voltage VB immediately after completion of the starting cycle of the diesel engine 2. Also, the history of the battery voltage VB may be limited to that during the period from turn-on of the ignition switch to the start of the engine starting cycle, or may be limited to that after completion of the starting cycle of the diesel engine 2.

(b) In the illustrated embodiments, the starting period Tsta and the history of the battery voltage VB are used for determining the starting preconditions in the starting precondition checking process (Fig. 5). However, the starting preconditions may be determined to be satisfied or not satisfied by using only the starting period Tsta or using only the history of the battery voltage VB.

If one of the condition that the starting period Tsta is equal to or shorter than the normal starting period Tstanorm and the condition that the battery voltage VB has ever dropped below the starting-time normal minimum voltage Vstanorm is satisfied, the starting preconditions are determined to be not satisfied. In another embodiment, the starting preconditions are not satisfied when both of the above two conditions are satisfied, and are satisfied when both of the two conditions are not satisfied.

(c) In the illustrated embodiments, execution of glow-plug fault determination is permitted (in step S426) when the diesel engine 2 is in an idle state in the process (Figs. 8, 9 and 19) of checking conditions for executing glow-plug fault determination, and the provisional fault determination process (Fig. 10 or Fig. 20) and the main fault determination process (Fig. 11 or Fig. 21) are executed during idling. In another embodiment, the provisional fault determination process (Fig. 10 or Fig. 20) and the main fault determination process (Fig. 11 or Fig. 21) may be allowed to be executed if the diesel engine 2 is in a quasi-idle state, even if the engine 2 is not actually idling. For example, when no power is transmitted from the diesel engine to the wheels with a clutch being disengaged during downhill running or inertia running, the provisional fault determination process (Fig. 10 or Fig. 20) and the main fault determination process (Fig. 11 or Fig. 21) may be executed provided that the engine 2 can be stably rotated.

(d) In the provisional fault determination process (Fig. 10, 20) and the main fault determination process (Fig. 11, 21), when switching of the glow plug 22 between the energized state and the deenergized state results in sufficiently large changes in one of the fuel injection quantity and the battery voltage, the normality determination is made affirmative or the provisional fault determination is made negative. In another embodiment, a fault may be determined based solely on changes in the fuel injection quantity or based solely on changes in the battery voltage.

In the fault determination processes as described above, when it is determined that a sufficiently large change does not appear in the fuel injection quantity, the provisional fault determination is made affirmative or the main fault determination is made affirmative. In another embodiment, however, the determination may be made when a sufficiently large change does not appear in the battery voltage, or when sufficiently large changes do not appear in both the fuel injection quantity and the battery voltage.

In addition to the fuel injection quantity and the battery voltage, or instead of these parameters, a change in the control duty DF associated with the alternator 54 may be regarded as a change in the operating state of the diesel engine 2. More specifically, the normality determination may be made affirmative or the provisional fault determination may be made negative when a sufficiently large change in the control duty DF occurs upon forced switching between the energized state and the deenergized state of the glow plug 22, and the provisional fault determination may be made affirmative or the main fault determination may be made affirmative when a sufficiently large change does not appear in the control duty DF.

While the final basic injection quantity command value QFINC is used as the fuel injection quantity based on which the provisional fault determination and the main fault determination are made in the illustrated embodiments, the basic injection quantity command value QBASE, governor injection quantity command value QGOV or the idle injection quantity correction value QII may be used as the fuel injection quantity.

Also, the parameters based on which the provisional fault determination and the main fault determination are made are not limited to the fuel injection quantity, battery voltage and the control duty, but may be selected from any other parameters, such as the engine load, which are indicative of changes in the operating state of the diesel engine.

(e) In the illustrated embodiments, the main fault determination is made affirmative when sufficiently large changes in the fuel injection quantity or the battery voltage do not occur upon switching of the glow plug 22 between the energized state and the dieenergized state in the provisional fault determination process (Fig. 10 or 20) and the main fault determination process (Fig. 11 or 21). In another embodiment, only the provisional fault determination process (Fig. 10 or Fig. 20) is executed, and the normality determination is made affirmative when a sufficiently large change in one of the fuel injection quantity and the battery voltage occurs upon switching of the glow plug 22 between the energized state and the dienergized state, and the main fault determination is made affirmative when a sufficiently large change does not occur in the fuel injection quantity.

(f) In the first embodiment, forced switching of the glow plug 22 between the energized state and the deenergized state for fault detection is executed only within the normal glow-plug energization period in which the glow plug 22 is energized for warm-up of the engine 2. However, the first embodiment may be combined with the second embodiment in this respect.

For example, when the forced switching of the glow plug 22 for fault detection cannot be effected within the normal glow-plug energization period, forced energization and denergization of the glow plug 22 for fault detection may be carried out in the same manner as in the second embodiment when the engine is brought into an idle state after the normal glow-plug energization period expires. With this arrangement, fault determination utilizing forced glow-plug energization can be implemented with high certainty or reliability at the earliest opportunity, as compared with the first and second embodiments.

(g) While the coolant temperature is used as a temperature factor in each of the illustrated embodiments, the temperature of the engine oil may be used instead. Alternatively, the engine temperature may be estimated based on a balance between heat generated and heat radiated as a result of combustion in the diesel engine, and may be used as a temperature factor.

[0183] In method and apparatus for detecting a fault in a glow plug provided in a diesel engine, a possibility of a fault in the glow plug is determined without utilizing a forced change in the state of energization of the glow plug for the purpose of diagnosis, before the presence of a fault in the glow plug is determined by utilizing the forced change in the state of energization of the glow plug. The process of determining the presence of the fault is not executed if it is determined in the process of determining the possibility of the fault that there is no possibility of a fault in the glow plug.

Claims

1. A method of detecting a fault in a glow plug provided in a diesel engine, including a process of determining the presence of a fault in the glow plug by utilizing a forced change in a state of energization of the glow plug, **characterized in that**:

    a process of determining a possibility of a fault in the glow plug without utilizing the forced change in the state of energization of the glow plug is executed prior to the process of determining the presence of the fault, and the process of determining the presence of the fault is not executed if it is determined in the process of determining the possibility of the fault that there is no possibility of a fault in the glow plug.

2. A method according to claim 1, **characterized in that** the forced change in the state of energization of the glow plug comprises switching of the glow plug between an energized state and a deenergized state.

3. A method according to claim 1 or claim 2, **characterized in that** the possibility of the fault in the glow plug is determined based on an operating state of the diesel engine detected before completion of a starting cycle of the engine while the glow plug is in an energized state.

4. A method according to any one of claims 1-3, **characterized in that** when it is determined in the process of determining the possibility of the fault that there is a possibility of a fault in the glow plug, and the process of determining the presence of the fault cannot be completed within a period of time set for energization of the glow plug started for start-up of the diesel engine, the process of determining the presence of the fault is not executed.

5. A method according to any one of claims 1-4, **characterized in that** when it is determined in the process of determining the possibility of the fault that there is a possibility of a fault in the glow plug, the process of determining the presence of the fault is executed provided that the diesel engine is under idle speed control.

6. A method according to any one of claims 1-5, **characterized in that** when it is determined in the process of determining the possibility of the fault that there is a possibility of a fault in the glow plug, the process of determining the presence of the fault is executed provided that a battery voltage is within a reference voltage range.

7. A method according to any one of claims 1-6, **characterized in that** the presence of the fault in the glow plug is determined based on a change in an operating state of the diesel engine which is caused by the forced change in the state of energization of the glow plug.

8. A method according to claim 7, **characterized in that** the process of determining the presence of the fault comprises (a) a step of causing a first forced change in the state of energization of the glow plug, (b) a step of making a first determination based on a change in the operating state of the diesel engine which is caused by the first forced change, (c) a step of finishing the process of determining the presence of the fault and resuming the state of energization of the glow plug established before the first forced change if the first determination indicates that the glow plug is normal, (d) a step of causing a second forced change in the state of energization of the glow plug so as to bring the glow plug into the state of energization established before the first forced change if the first determination does not indicate that the glow plug is normal, (e) a step of making a second determination based on a change in the operating state of the diesel engine which is caused by the second forced change, (f) a step of finishing the process of determining the presence of the fault if the second determination indicates that the glow plug is faulty, and (g) a step of finishing the process of determining the presence of the fault without making a

determination on the fault in the glow plug when the second determination does not indicate that the glow plug is faulty.

9. A method according to claim 7 or claim 8, **characterized in that** the change in the operating state of the diesel engine is a change in an engine load.

10. A method according to claim 7 or claim 8, **characterized in that** the change in the operating state of the engine is a change in a battery voltage.

11. A method according to claim 7 or claim 8, **characterized in that** the change in the operating state of the engine comprises a change in a fuel injection quantity and a change in a battery voltage.

12. An apparatus for detecting a fault in a glow plug provided in a diesel engine, **characterized by** comprising:

fault possibility determining means for determining a possibility of a fault in the glow plug based on a phenomenon that occurs without involving a forced change in a state of energization of the glow plug; and
fault presence determining means for determining the presence of the fault in the glow plug based on a phenomenon that occurs in response to the forced change in the state of energization of the glow plug when the fault possibility determining means determines that there is a possibility of a fault in the glow plug, wherein the fault presence determining means does not determine the presence of the fault by causing the forced change in the state of energization of the glow plug when the fault possibility determining means determines that there is no possibility of a fault in the glow plug.

13. An apparatus according to claim 12, **characterized in that** the forced change in the state of energization of the glow plug comprises switching of the glow plug between an energized state and a deenergized state.

14. An apparatus according to claim 12 or claim 13, **characterized in that** the fault possibility determining means comprises engine state detecting means for detecting an operating state of the diesel engine before completion of a starting cycle of the diesel engine, and determines the possibility of the fault in the glow plug based on the engine operating state detected by the engine state detecting means before completion of the engine starting cycle while the glow plug is in an energized state.

15. An apparatus according to any one of claims 12-14, **characterized in that** when the fault possibility determining means determines that there is a possibility of a fault in the glow plug, and the fault presence determining means cannot complete determination of the presence of the fault within a period of time set for energization of the glow plug started for start-up of the diesel engine, the fault presence determining means does not execute a process of determining the presence of the fault.

16. An apparatus according to any one of claims 12-15, **characterized in that** when the fault possibility determining means determines that there is a possibility of a fault in the glow plug, the fault presence determining means executes a process of determining the presence of the fault provided that the diesel engine is under idle speed control.

17. An apparatus according to any one of claims 12-16, **characterized in that** when the fault possibility determining means determines that there is a possibility of a fault in the glow plug, the fault presence determining means executes a process of determining the presence of the fault provided that a battery voltage is within a reference voltage range.

18. An apparatus according to any one of claims 12-17, **characterized in that** the fault presence determining means determines the presence of the fault in the glow plug based on a change in an operating state of the diesel engine which is caused by the forced change in the state of energization of the glow plug.

19. An apparatus according to claim 18, **characterized in that** the fault presence determining means comprises:

first fault determining means for causing a first forced change in the state of energization of the glow plug when the fault possibility determining means determines that there is a possibility of a fault in the glow plug, and makes a first determination based on a change in the operating state of the diesel engine which is caused by the first forced change; and second fault determining means for (a) finishing a process of determining the presence of the fault and resuming the state of energization of the glow plug established before the first forced change if the first fault determining means determines that the glow plug is normal, (b) if the first fault determining means does not determine that the glow plug is normal, causing a second forced change in the state of energization of the glow plug so as to bring the glow plug into the state of energization established before the first forced change, and making a second determination based on a change in the operating state of the diesel engine which is caused by the second forced change, (c) finishing the process of determining the presence of the fault if the second determination indicates that the glow plug is faulty, and (d) finishing the process of determining the presence of the fault without making a determination on the fault in the glow plug when the second determination does not indicate that the glow plug is faulty.

20. An apparatus according to claim 18 or claim 19, **characterized in that** the change in the operating state of the diesel engine is a change in an engine load.

21. An apparatus according to claim 18 or claim 19, **characterized in that** the change in the operating state of the engine is a change in a battery voltage.

22. An apparatus according to claim 18 or 19, **characterized in that** the change in the operating state of the engine comprises a change in a fuel injection quantity and a change in a battery voltage.

FIG. 1

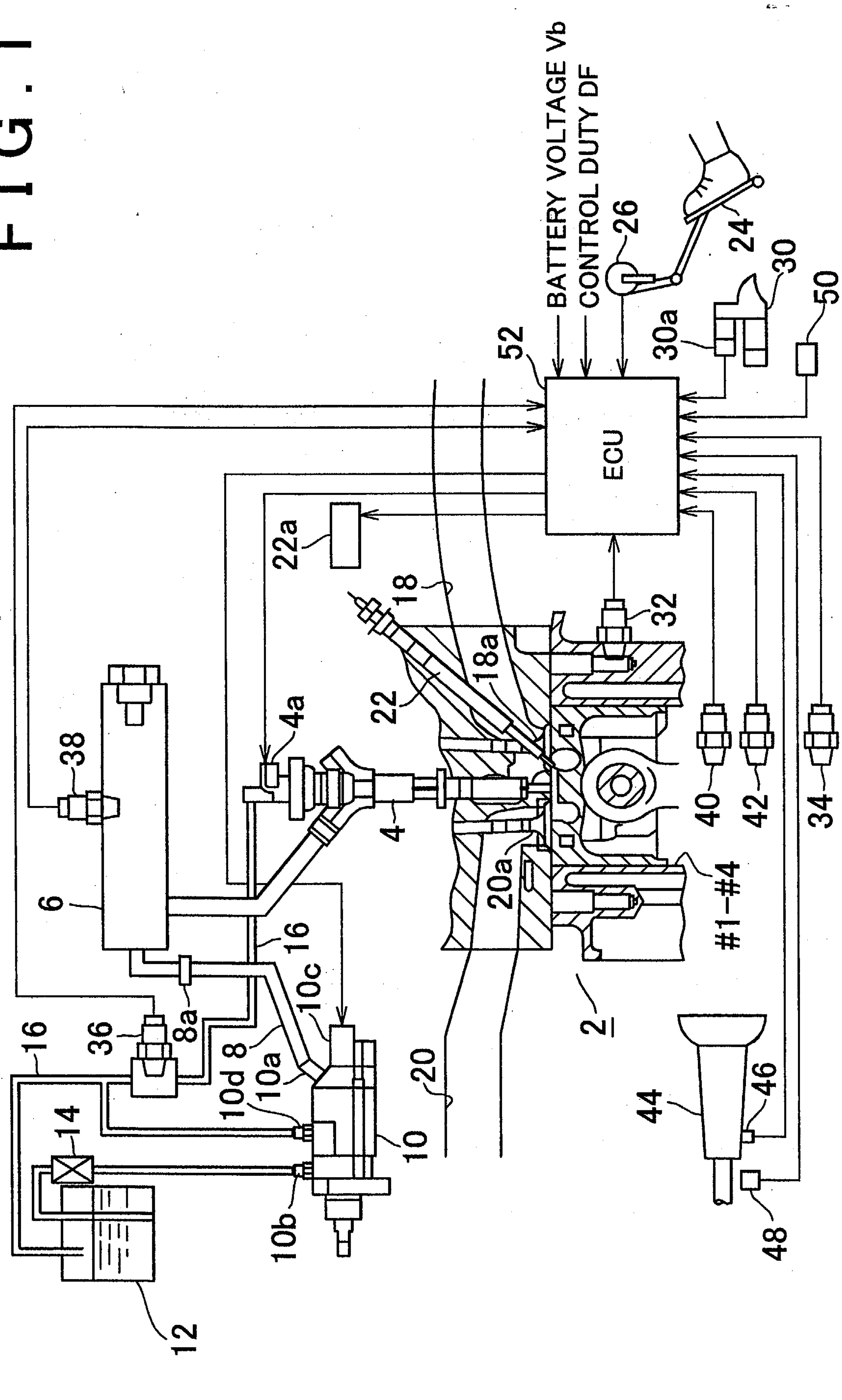
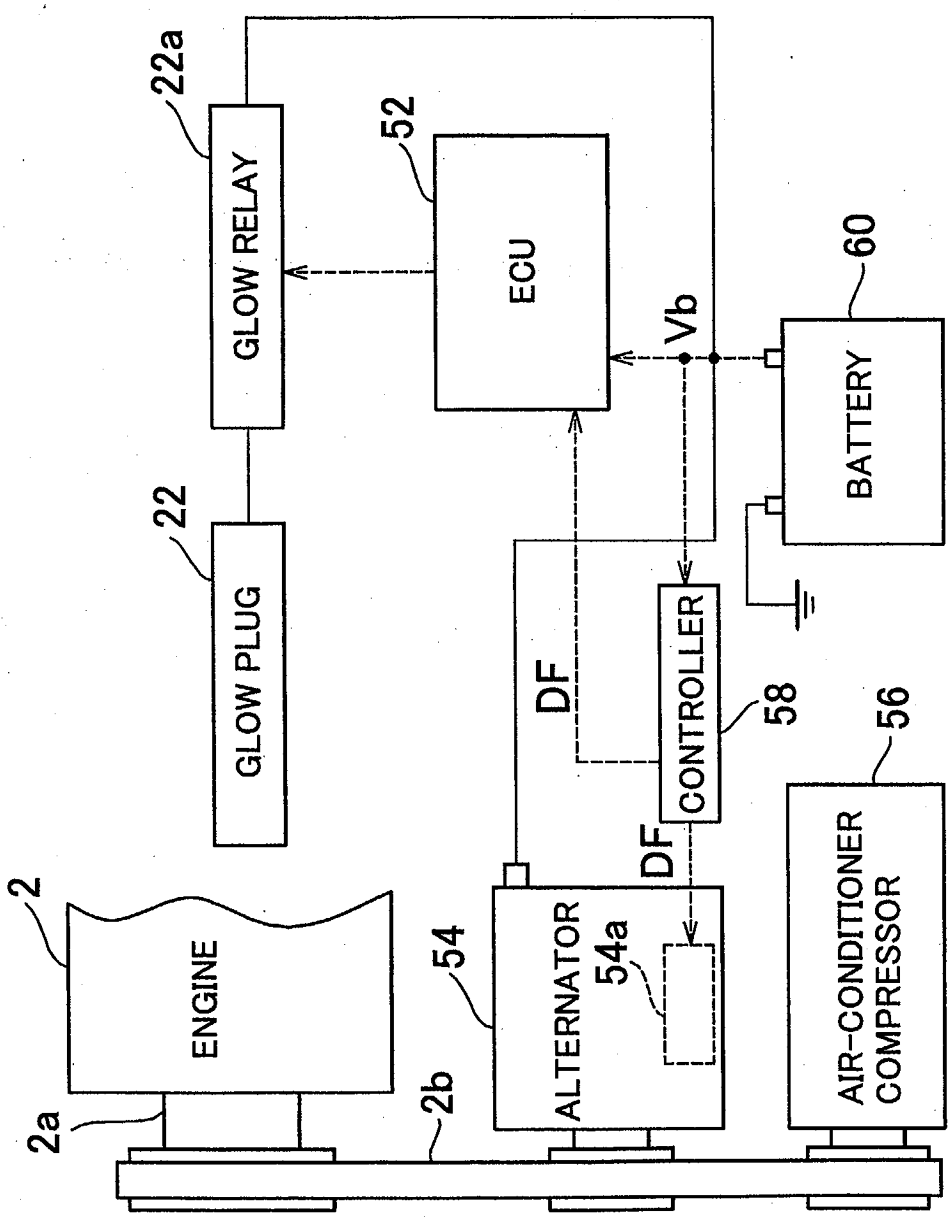

BATTERY VOLTAGE Vb
CONTROL DUTY DF
ECU
52
26
24
30
30a
50
22a
18
32
18a
22
4a
38
6
4
40
42
34
20a
#1-#4
16
2
8a
10c
36
16
8
10d
10a
20
10
14
44
46
48
10b
12

FIG. 2


GLOW RELAY
22a
52
ECU
60
Vb
BATTERY
22
GLOW PLUG
DF
CONTROLLER
58
56
DF
2
ENGINE
54
ALTERNATOR
54a
AIR-CONDITIONER COMPRESSOR
2a
2b

F I G . 3

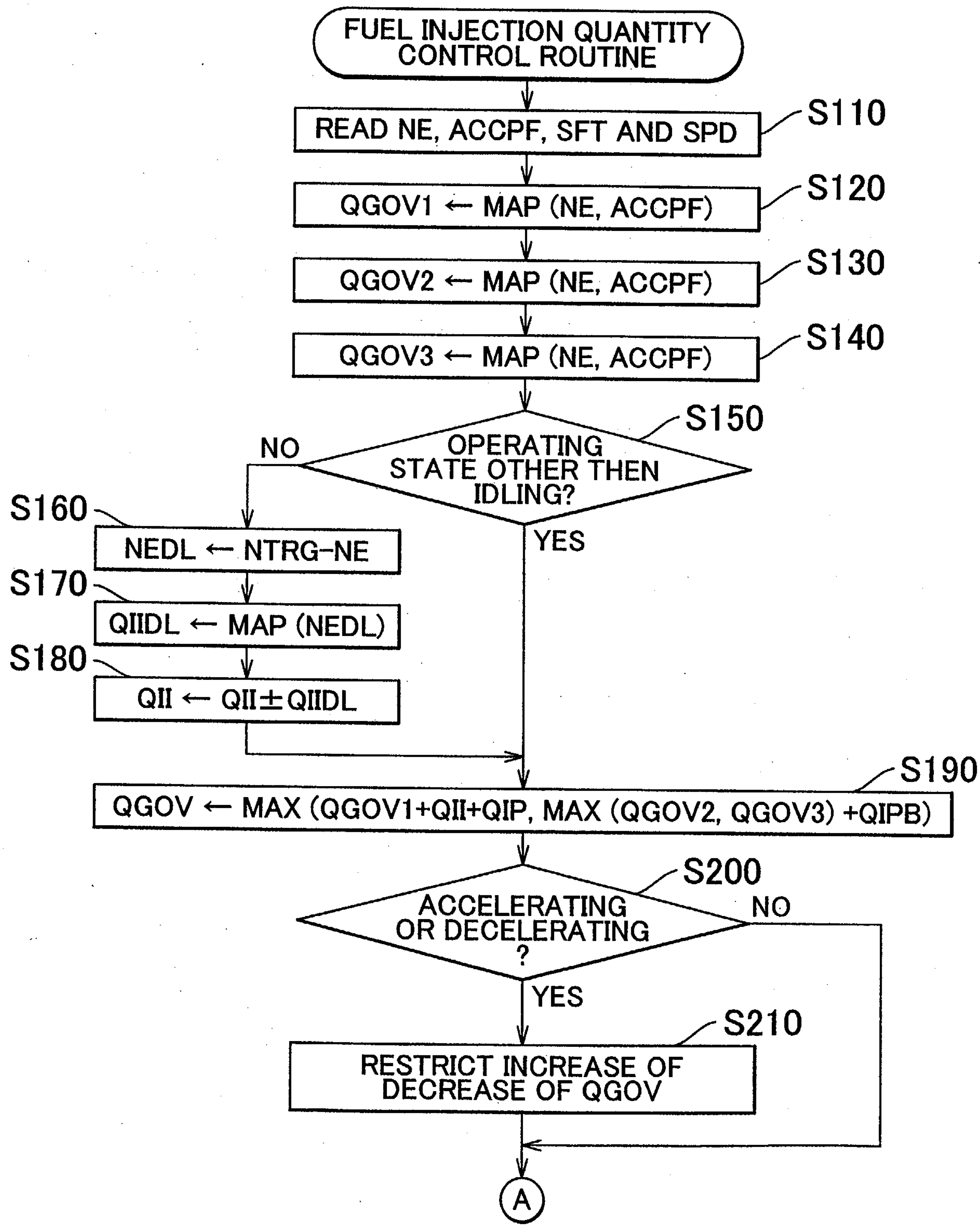

FUEL INJECTION QUANTITY CONTROL ROUTINE
READ NE, ACCPF, SFT AND SPD
S110
QGOV1 ← MAP (NE, ACCPF)
S120
QGOV2 ← MAP (NE, ACCPF)
S130
QGOV3 ← MAP (NE, ACCPF)
S140
OPERATING STATE OTHER THEN IDLING?
S150
NO
YES
S160
NEDL ← NTRG-NE
S170
QIIDL ← MAP (NEDL)
S180
QII ← QII±QIIDL
QGOV ← MAX (QGOV1+QII+QIP, MAX (QGOV2, QGOV3) +QIPB)
S190
ACCELERATING OR DECELERATING ?
S200
NO
YES
RESTRICT INCREASE OF DECREASE OF QGOV
S210
A

FIG. 4

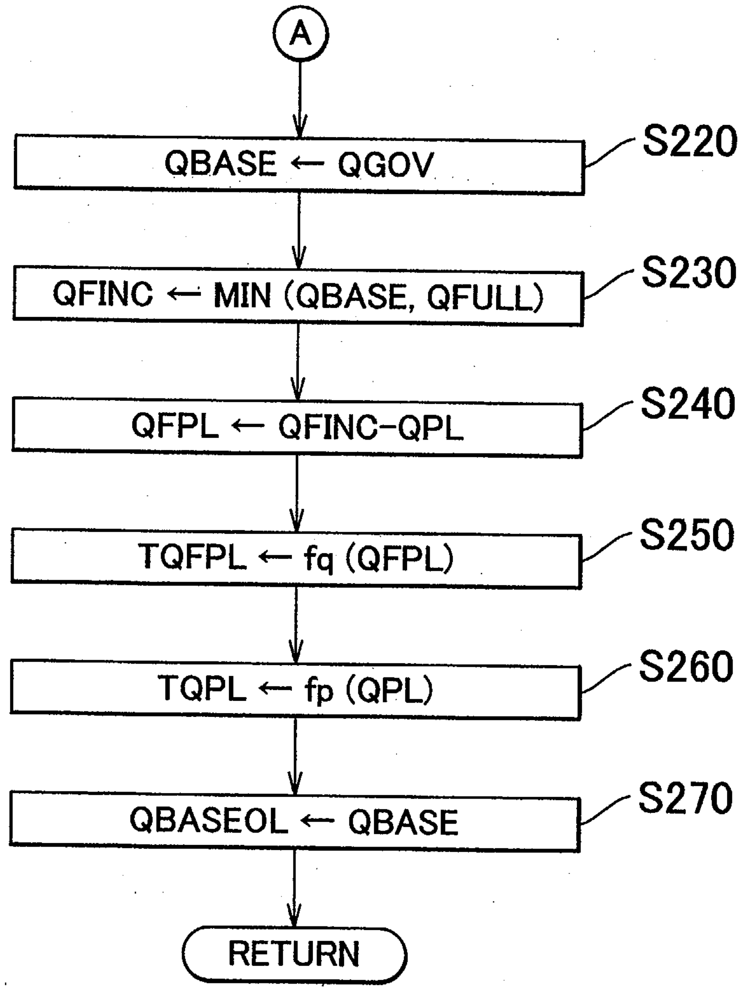

A
QBASE ← QGOV
S220
QFINC ← MIN (QBASE, QFULL)
S230
QFPL ← QFINC-QPL
S240
TQFPL ← fq (QFPL)
S250
TQPL ← fp (QPL)
S260
QBASEOL ← QBASE
S270
RETURN

FIG. 5

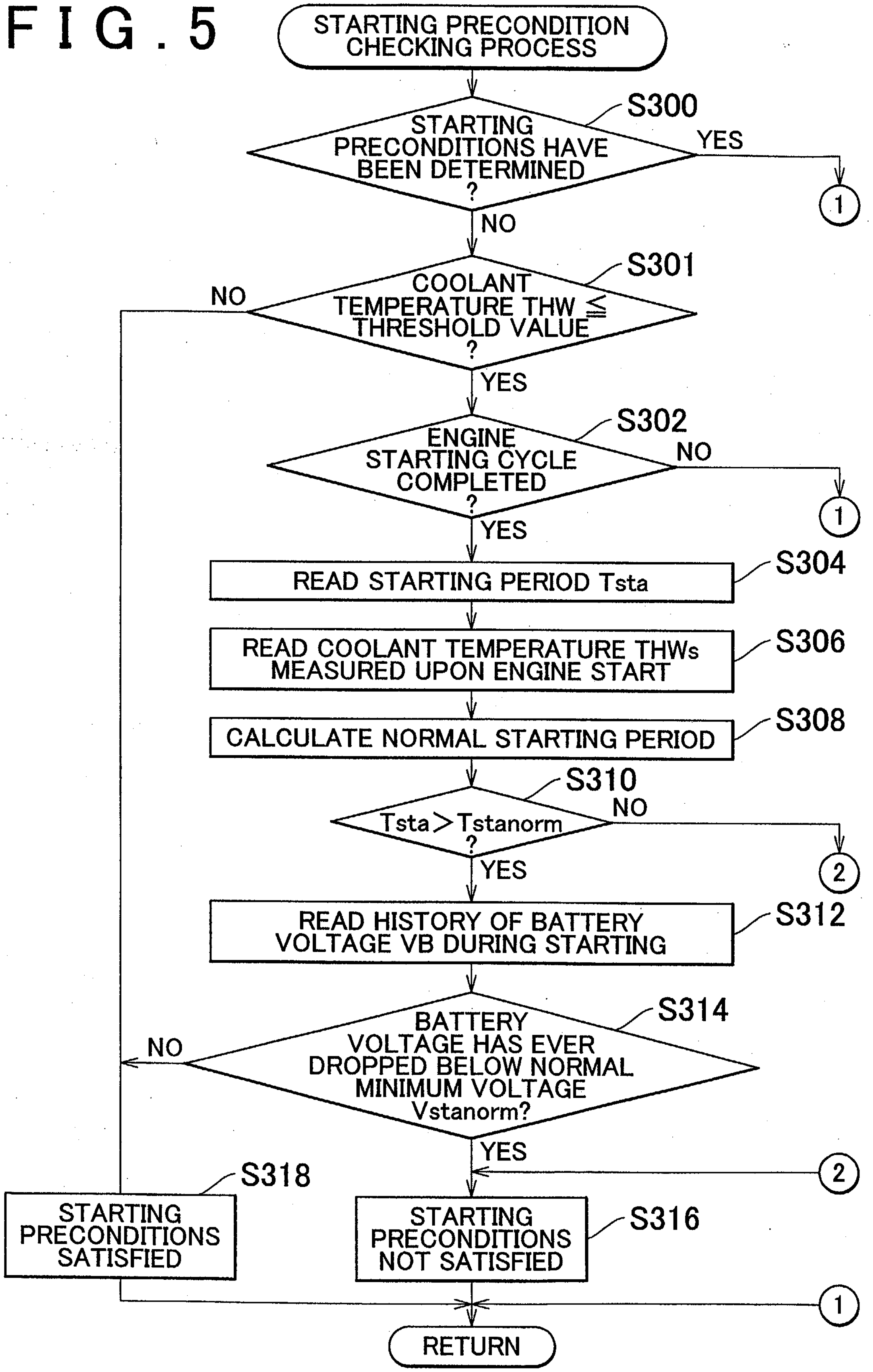

STARTING PRECONDITION CHECKING PROCESS
S300
STARTING PRECONDITIONS HAVE BEEN DETERMINED ?
YES
NO
1
S301
COOLANT TEMPERATURE THW ≦ THRESHOLD VALUE ?
NO
YES
S302
ENGINE STARTING CYCLE COMPLETED ?
NO
YES
1
READ STARTING PERIOD Tsta
S304
READ COOLANT TEMPERATURE THWs MEASURED UPON ENGINE START
S306
CALCULATE NORMAL STARTING PERIOD
S308
S310
Tsta > Tstanorm ?
NO
YES
2
READ HISTORY OF BATTERY VOLTAGE VB DURING STARTING
S312
S314
BATTERY VOLTAGE HAS EVER DROPPED BELOW NORMAL MINIMUM VOLTAGE Vstanorm?
NO
YES
2
S318
STARTING PRECONDITIONS SATISFIED
STARTING PRECONDITIONS NOT SATISFIED
S316
1
RETURN

FIG. 6

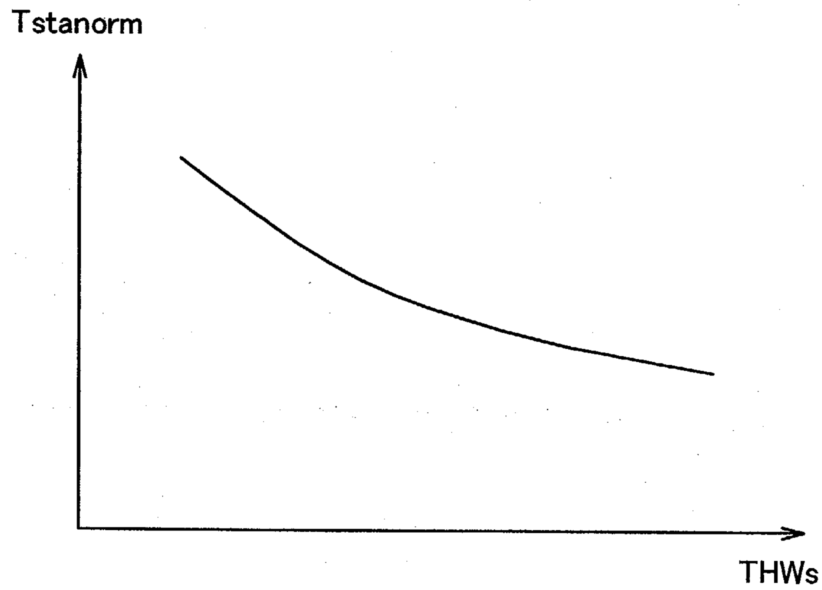


FIG. 7

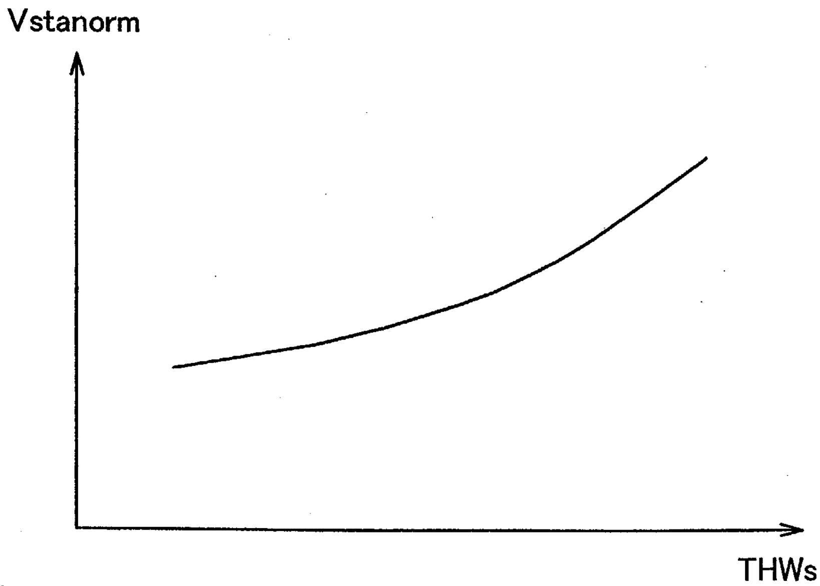


FIG. 8

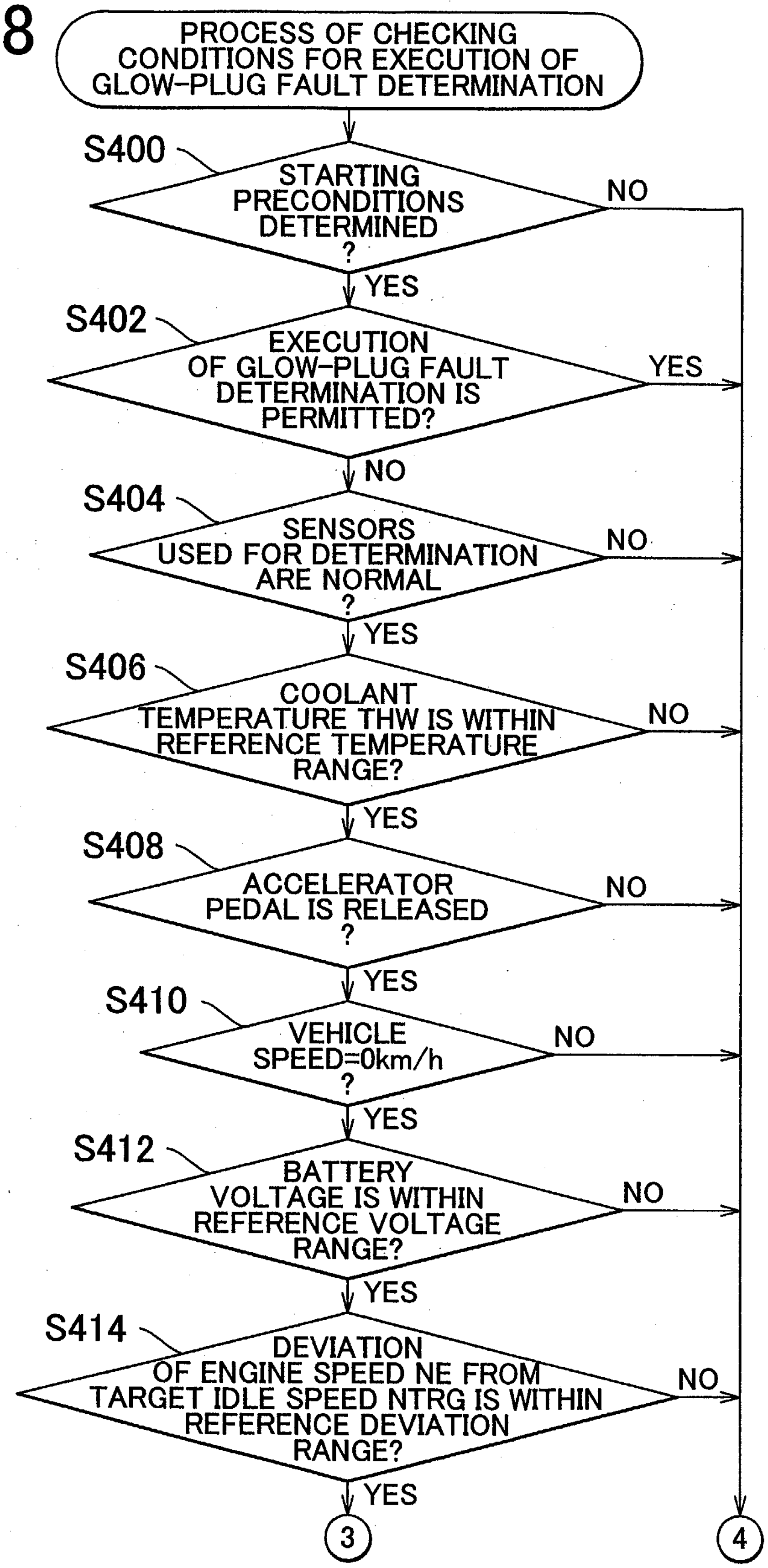
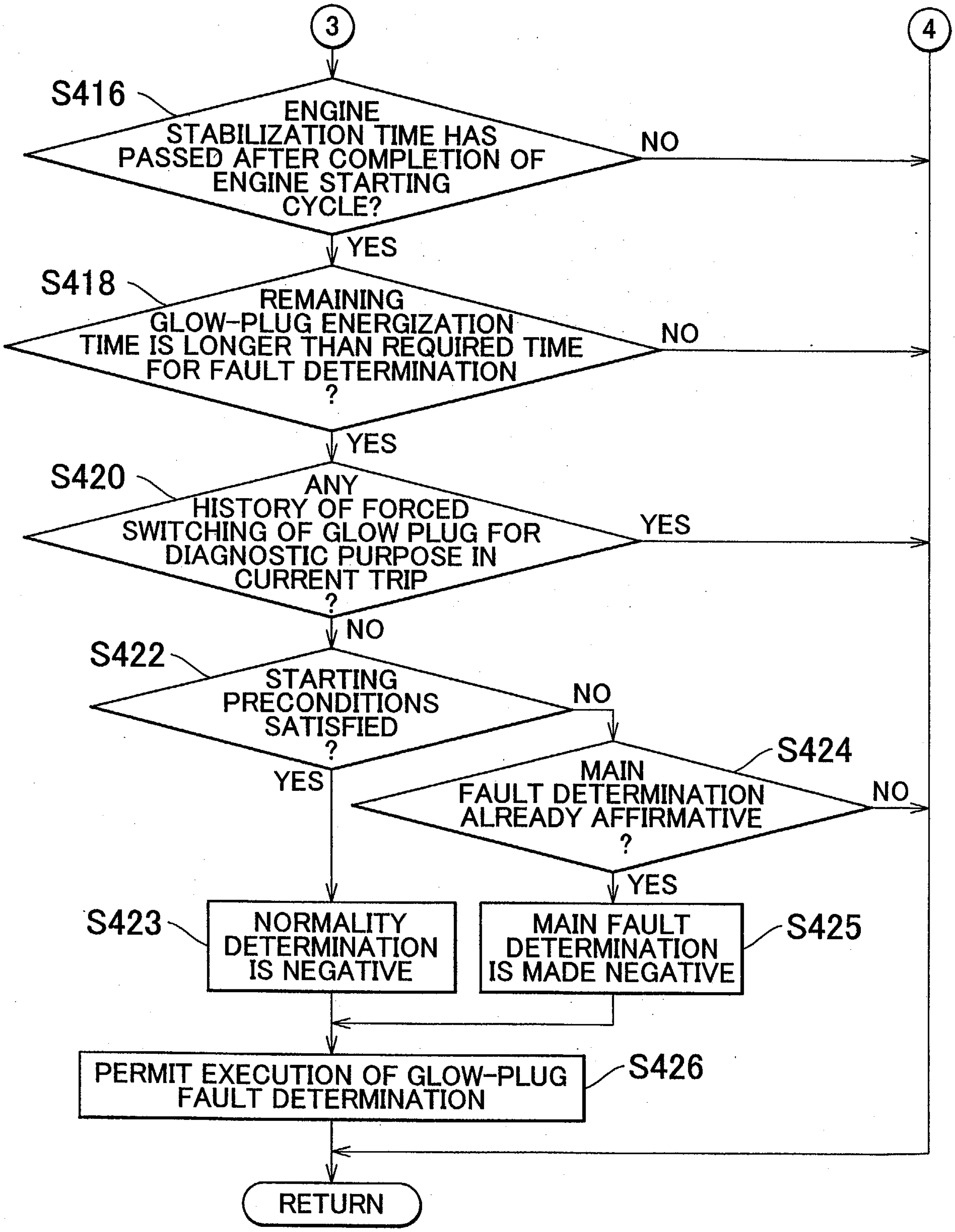

PROCESS OF CHECKING CONDITIONS FOR EXECUTION OF GLOW-PLUG FAULT DETERMINATION
S400
STARTING PRECONDITIONS DETERMINED ?
NO
YES
S402
EXECUTION OF GLOW-PLUG FAULT DETERMINATION IS PERMITTED?
YES
NO
S404
SENSORS USED FOR DETERMINATION ARE NORMAL ?
NO
YES
S406
COOLANT TEMPERATURE THW IS WITHIN REFERENCE TEMPERATURE RANGE?
NO
YES
S408
ACCELERATOR PEDAL IS RELEASED ?
NO
YES
S410
VEHICLE SPEED=0km/h ?
NO
YES
S412
BATTERY VOLTAGE IS WITHIN REFERENCE VOLTAGE RANGE?
NO
YES
S414
DEVIATION OF ENGINE SPEED NE FROM TARGET IDLE SPEED NTRG IS WITHIN REFERENCE DEVIATION RANGE?
NO
YES
3
4

FIG. 9



3
4
S416
ENGINE STABILIZATION TIME HAS PASSED AFTER COMPLETION OF ENGINE STARTING CYCLE?
NO
YES
S418
REMAINING GLOW-PLUG ENERGIZATION TIME IS LONGER THAN REQUIRED TIME FOR FAULT DETERMINATION ?
NO
YES
S420
ANY HISTORY OF FORCED SWITCHING OF GLOW PLUG FOR DIAGNOSTIC PURPOSE IN CURRENT TRIP ?
YES
NO
S422
STARTING PRECONDITIONS SATISFIED ?
NO
S424
MAIN FAULT DETERMINATION ALREADY AFFIRMATIVE ?
NO
YES
YES
S423
NORMALITY DETERMINATION IS NEGATIVE
MAIN FAULT DETERMINATION IS MADE NEGATIVE
S425
PERMIT EXECUTION OF GLOW-PLUG FAULT DETERMINATION
S426
RETURN

FIG. 10

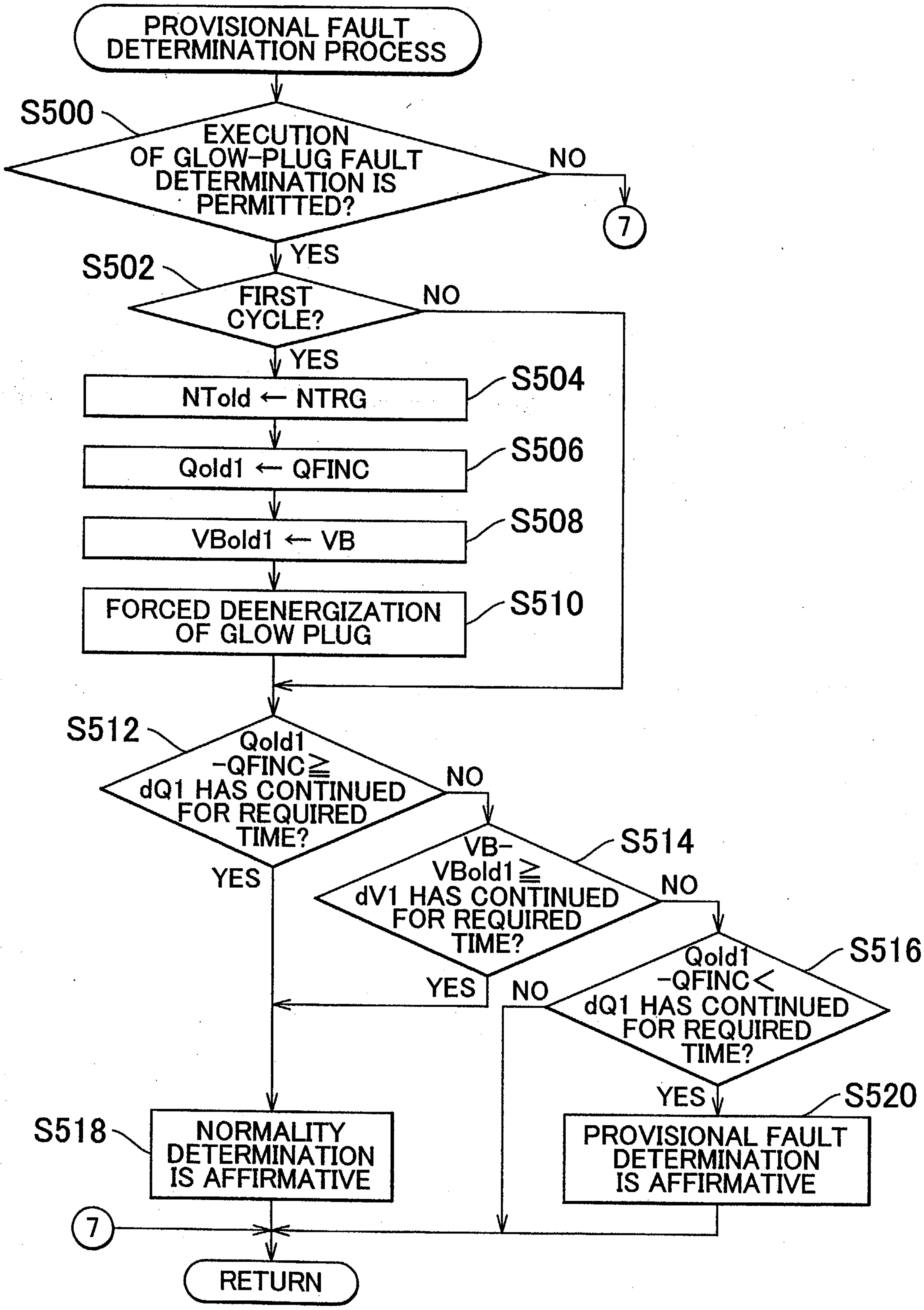

PROVISIONAL FAULT DETERMINATION PROCESS
S500
EXECUTION OF GLOW-PLUG FAULT DETERMINATION IS PERMITTED?
NO
7
YES
S502
FIRST CYCLE?
NO
YES
NTold ← NTRG
S504
Qold1 ← QFINC
S506
VBold1 ← VB
S508
FORCED DEENERGIZATION OF GLOW PLUG
S510
S512
Qold1 -QFINC ≧ dQ1 HAS CONTINUED FOR REQUIRED TIME?
NO
YES
S514
VB- VBold1 ≧ dV1 HAS CONTINUED FOR REQUIRED TIME?
NO
YES
S516
Qold1 -QFINC < dQ1 HAS CONTINUED FOR REQUIRED TIME?
NO
YES
S520
PROVISIONAL FAULT DETERMINATION IS AFFIRMATIVE
S518
NORMALITY DETERMINATION IS AFFIRMATIVE
7
RETURN

FIG. 11

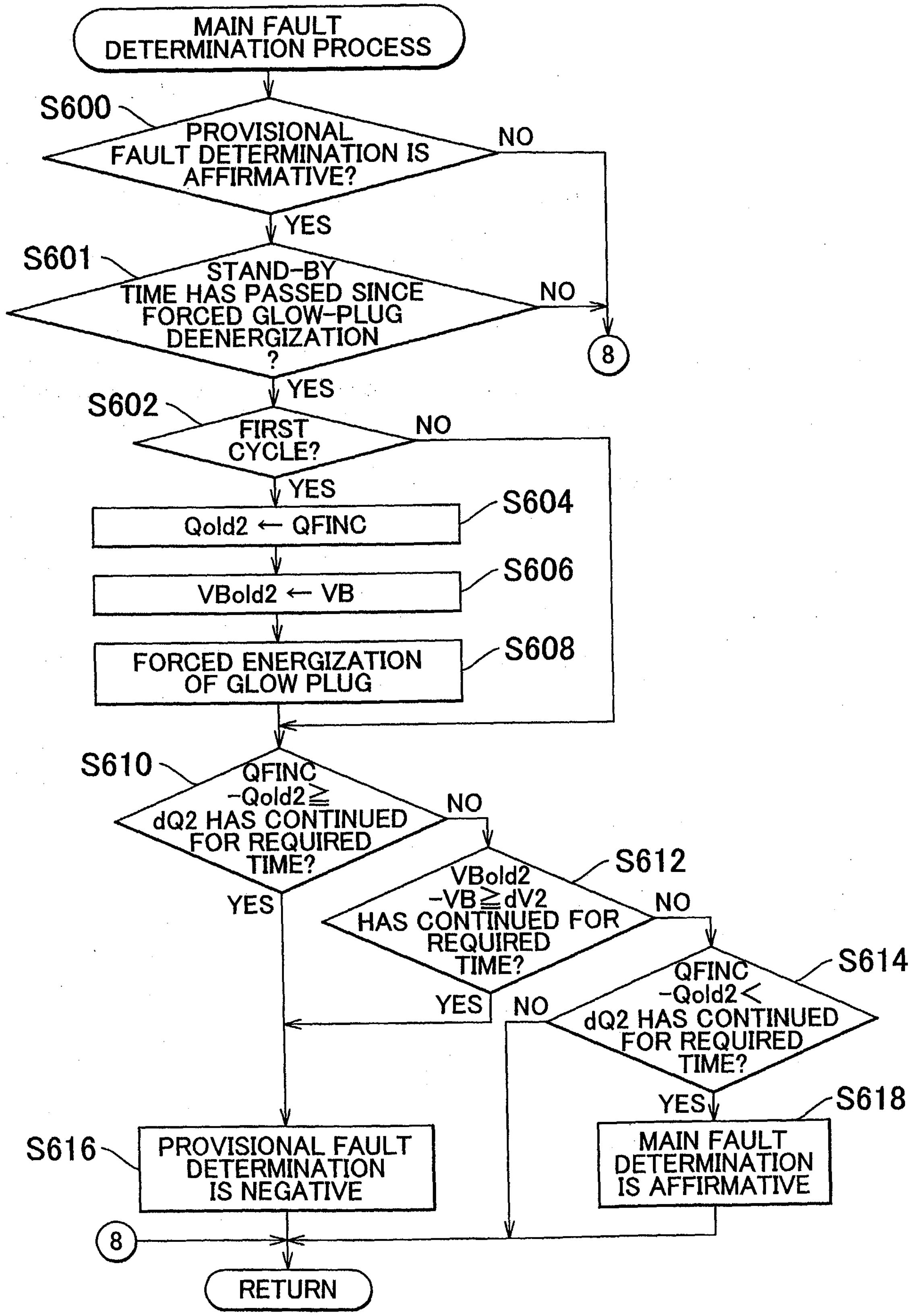

MAIN FAULT DETERMINATION PROCESS
S600
PROVISIONAL FAULT DETERMINATION IS AFFIRMATIVE?
NO
YES
S601
STAND-BY TIME HAS PASSED SINCE FORCED GLOW-PLUG DEENERGIZATION ?
NO
8
YES
S602
FIRST CYCLE?
NO
YES
Qold2 ← QFINC
S604
VBold2 ← VB
S606
FORCED ENERGIZATION OF GLOW PLUG
S608
S610
QFINC -Qold2≧ dQ2 HAS CONTINUED FOR REQUIRED TIME?
NO
YES
S612
VBold2 -VB≧dV2 HAS CONTINUED FOR REQUIRED TIME?
NO
YES
S614
QFINC -Qold2< dQ2 HAS CONTINUED FOR REQUIRED TIME?
NO
YES
S618
S616
PROVISIONAL FAULT DETERMINATION IS NEGATIVE
MAIN FAULT DETERMINATION IS AFFIRMATIVE
8
RETURN

FIG. 12

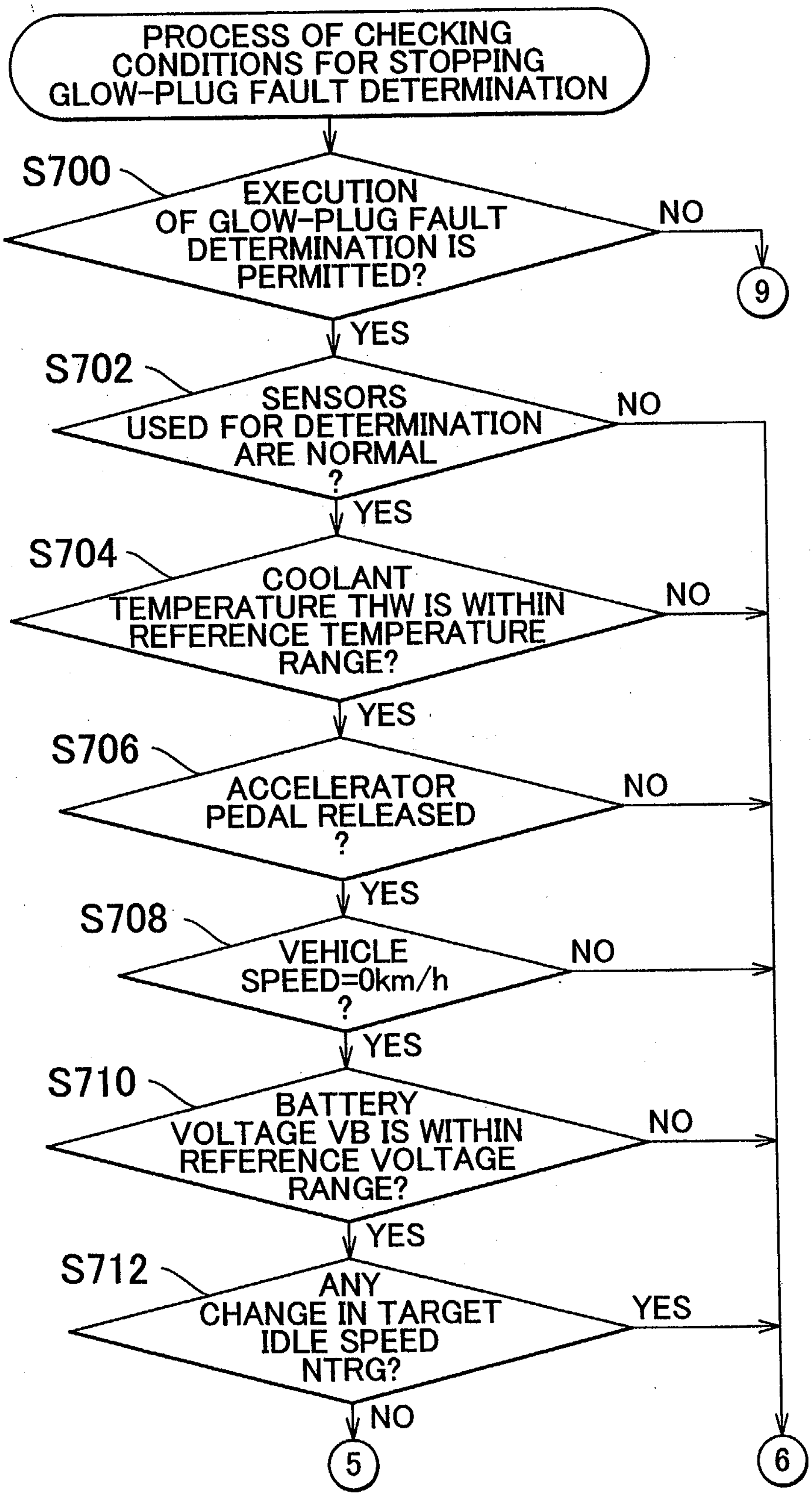
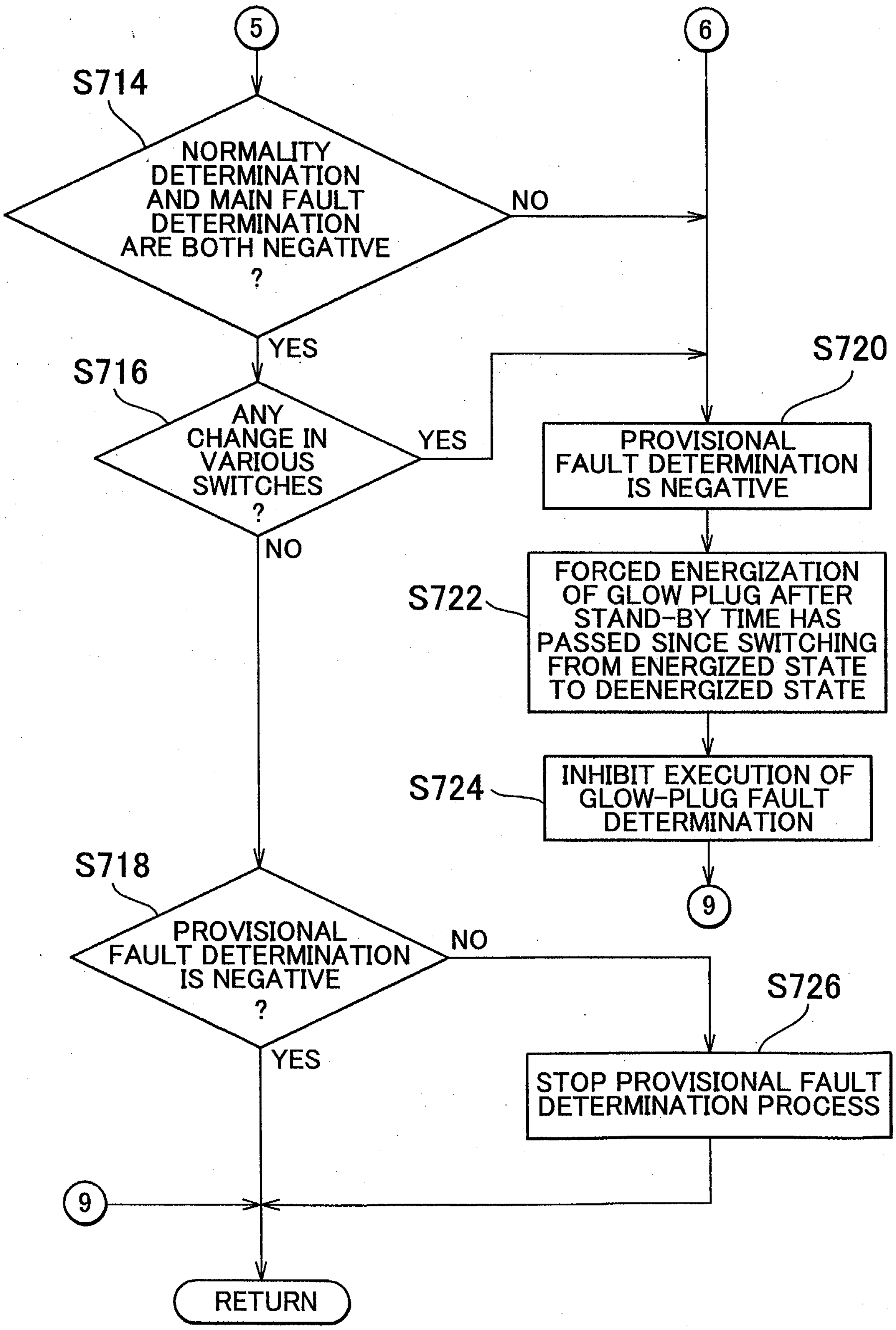
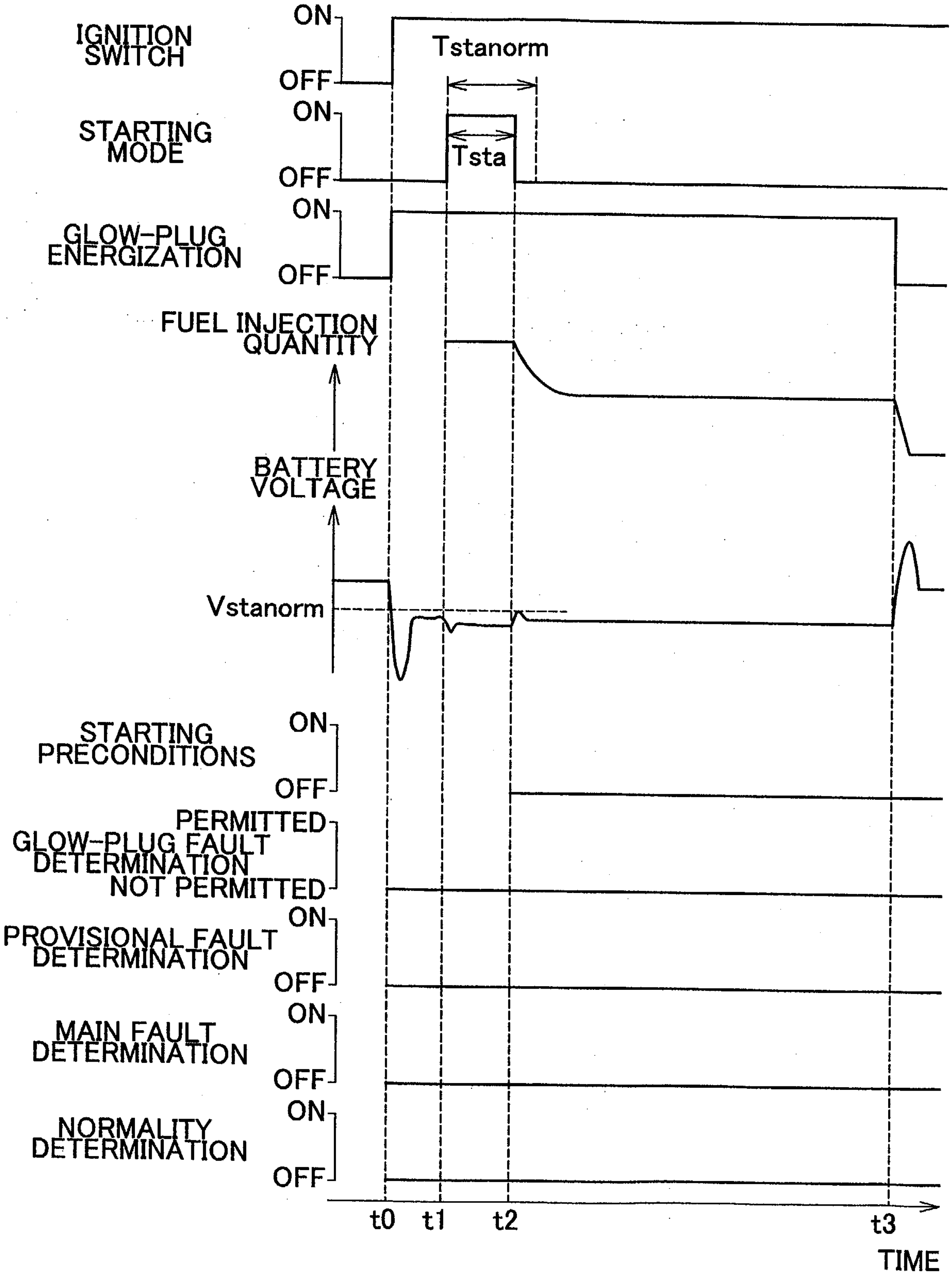

PROCESS OF CHECKING CONDITIONS FOR STOPPING GLOW-PLUG FAULT DETERMINATION
S700
EXECUTION OF GLOW-PLUG FAULT DETERMINATION IS PERMITTED?
NO
9
YES
S702
SENSORS USED FOR DETERMINATION ARE NORMAL ?
NO
YES
S704
COOLANT TEMPERATURE THW IS WITHIN REFERENCE TEMPERATURE RANGE?
NO
YES
S706
ACCELERATOR PEDAL RELEASED ?
NO
YES
S708
VEHICLE SPEED=0km/h ?
NO
YES
S710
BATTERY VOLTAGE VB IS WITHIN REFERENCE VOLTAGE RANGE?
NO
YES
S712
ANY CHANGE IN TARGET IDLE SPEED NTRG?
YES
NO
5
6

FIG. 13


5
6
S714
NORMALITY DETERMINATION AND MAIN FAULT DETERMINATION ARE BOTH NEGATIVE ?
NO
YES
S716
ANY CHANGE IN VARIOUS SWITCHES ?
YES
NO
S720
PROVISIONAL FAULT DETERMINATION IS NEGATIVE
S722
FORCED ENERGIZATION OF GLOW PLUG AFTER STAND-BY TIME HAS PASSED SINCE SWITCHING FROM ENERGIZED STATE TO DEENERGIZED STATE
S724
INHIBIT EXECUTION OF GLOW-PLUG FAULT DETERMINATION
9
S718
PROVISIONAL FAULT DETERMINATION IS NEGATIVE ?
NO
YES
S726
STOP PROVISIONAL FAULT DETERMINATION PROCESS
9
RETURN

F I G. 14


IGNITION SWITCH
ON
OFF
Tstanorm
STARTING MODE
Tsta
GLOW-PLUG ENERGIZATION
FUEL INJECTION QUANTITY
BATTERY VOLTAGE
Vstanorm
STARTING PRECONDITIONS
GLOW-PLUG FAULT DETERMINATION
PERMITTED
NOT PERMITTED
PROVISIONAL FAULT DETERMINATION
MAIN FAULT DETERMINATION
NORMALITY DETERMINATION
t0
t1
t2
t3
TIME

F I G. 15

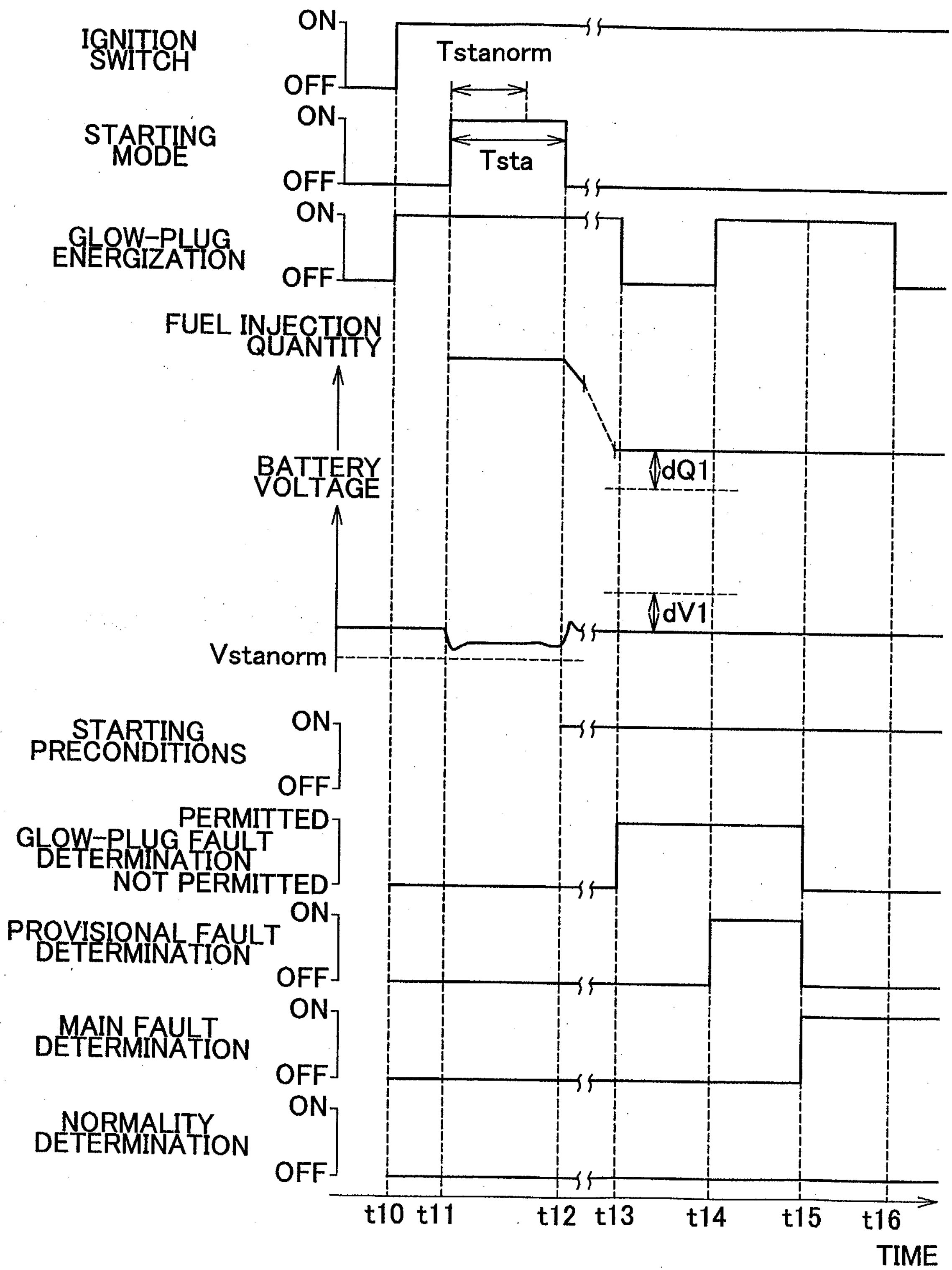
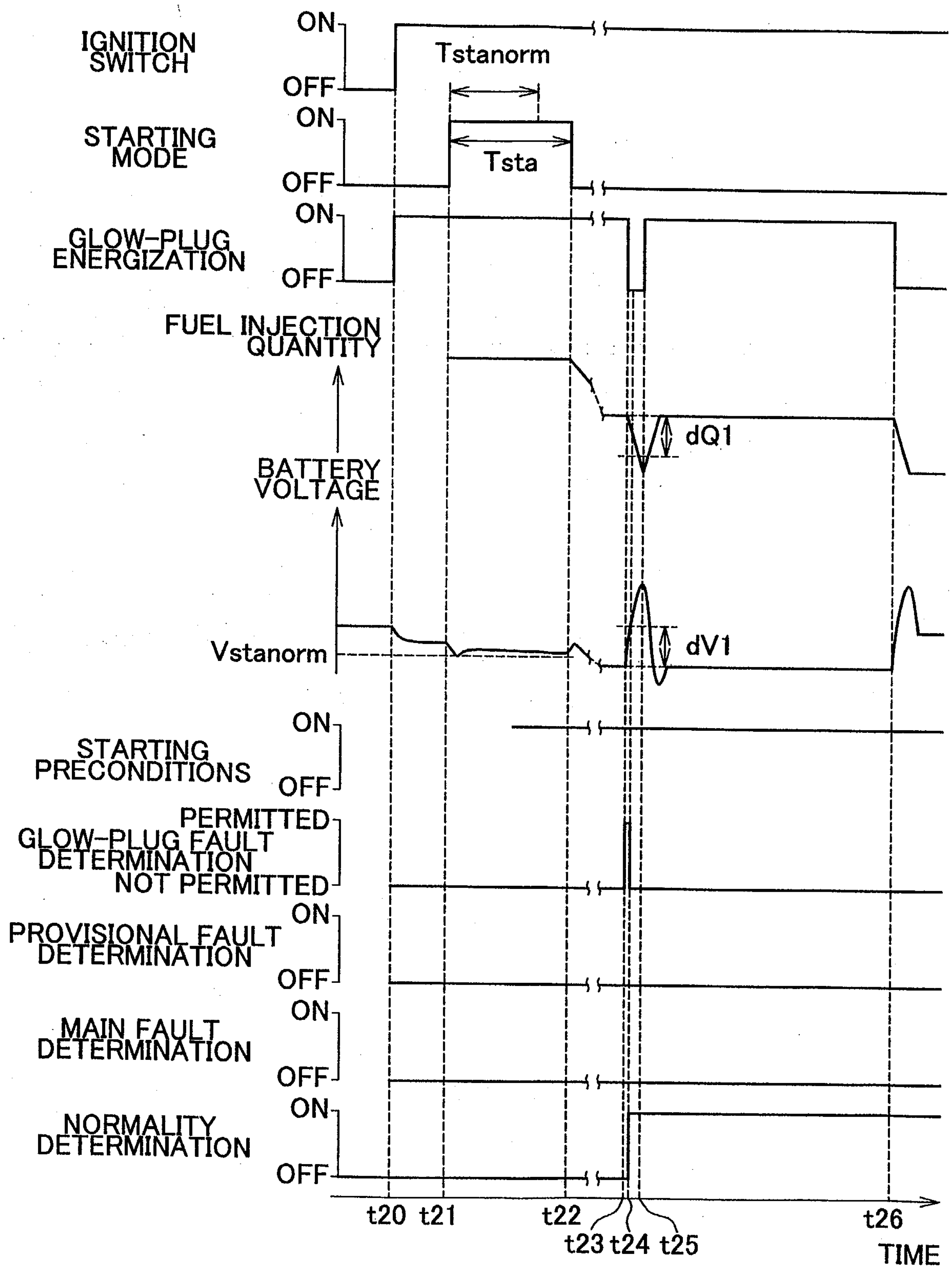
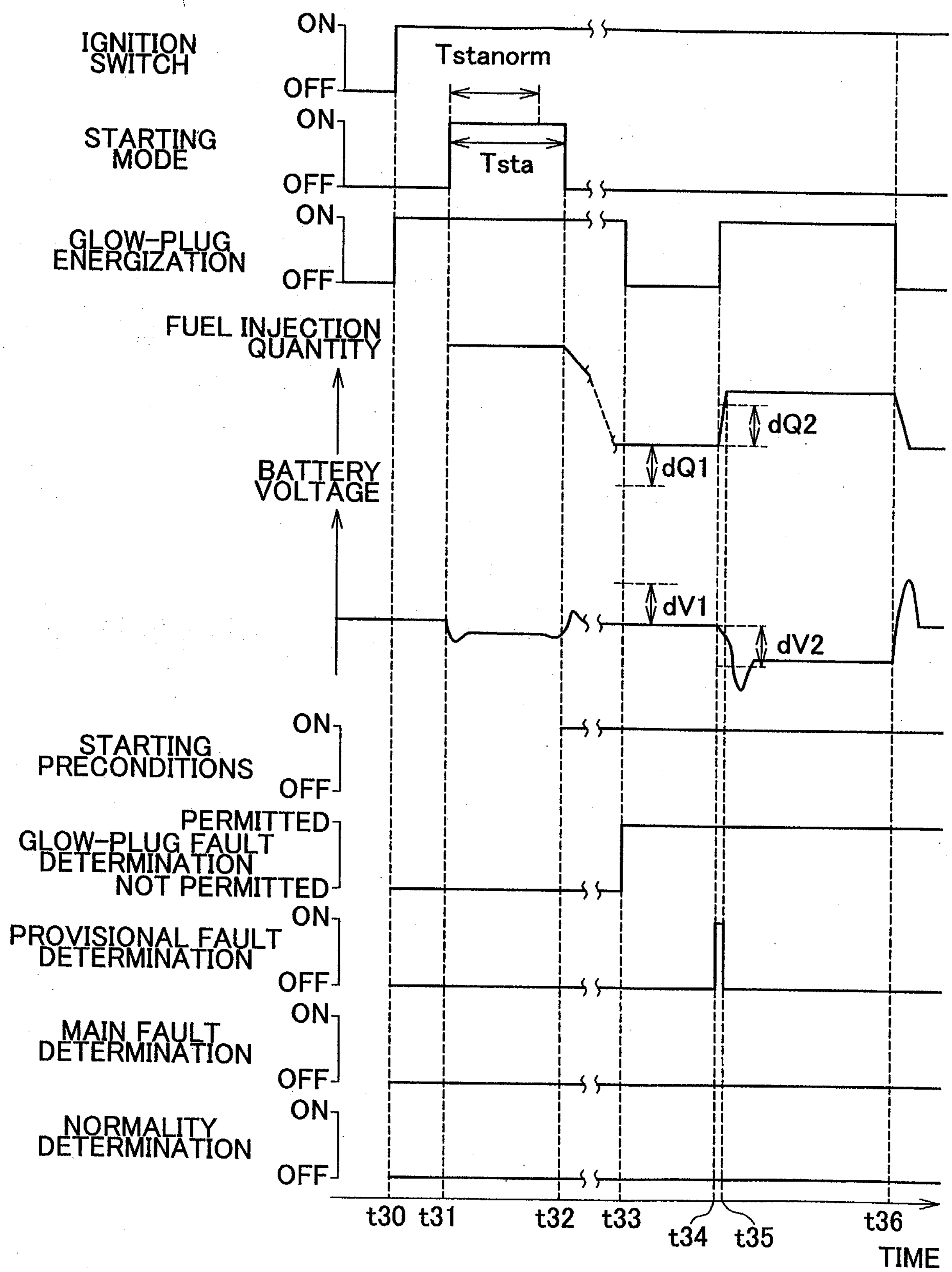

IGNITION SWITCH
ON
OFF
Tstanorm
STARTING MODE
ON
OFF
Tsta
GLOW-PLUG ENERGIZATION
ON
OFF
FUEL INJECTION QUANTITY
BATTERY VOLTAGE
dQ1
dV1
Vstanorm
STARTING PRECONDITIONS
ON
OFF
GLOW-PLUG FAULT DETERMINATION
PERMITTED
NOT PERMITTED
PROVISIONAL FAULT DETERMINATION
ON
OFF
MAIN FAULT DETERMINATION
ON
OFF
NORMALITY DETERMINATION
ON
OFF
t10 t11 t12 t13 t14 t15 t16
TIME

FIG. 16


IGNITION SWITCH
ON
OFF
Tstanorm
STARTING MODE
ON
OFF
Tsta
GLOW-PLUG ENERGIZATION
ON
OFF
FUEL INJECTION QUANTITY
dQ1
BATTERY VOLTAGE
Vstanorm
dV1
STARTING PRECONDITIONS
ON
OFF
GLOW-PLUG FAULT DETERMINATION
PERMITTED
NOT PERMITTED
PROVISIONAL FAULT DETERMINATION
ON
OFF
MAIN FAULT DETERMINATION
ON
OFF
NORMALITY DETERMINATION
ON
OFF
t20 t21 t22 t23 t24 t25 t26
TIME

F I G. 17


IGNITION SWITCH
ON
OFF
Tstanorm
STARTING MODE
ON
OFF
Tsta
GLOW-PLUG ENERGIZATION
ON
OFF
FUEL INJECTION QUANTITY
dQ2
dQ1
BATTERY VOLTAGE
dV1
dV2
STARTING PRECONDITIONS
ON
OFF
GLOW-PLUG FAULT DETERMINATION
PERMITTED
NOT PERMITTED
PROVISIONAL FAULT DETERMINATION
ON
OFF
MAIN FAULT DETERMINATION
ON
OFF
NORMALITY DETERMINATION
ON
OFF
t30
t31
t32
t33
t34
t35
t36
TIME

F I G. 18

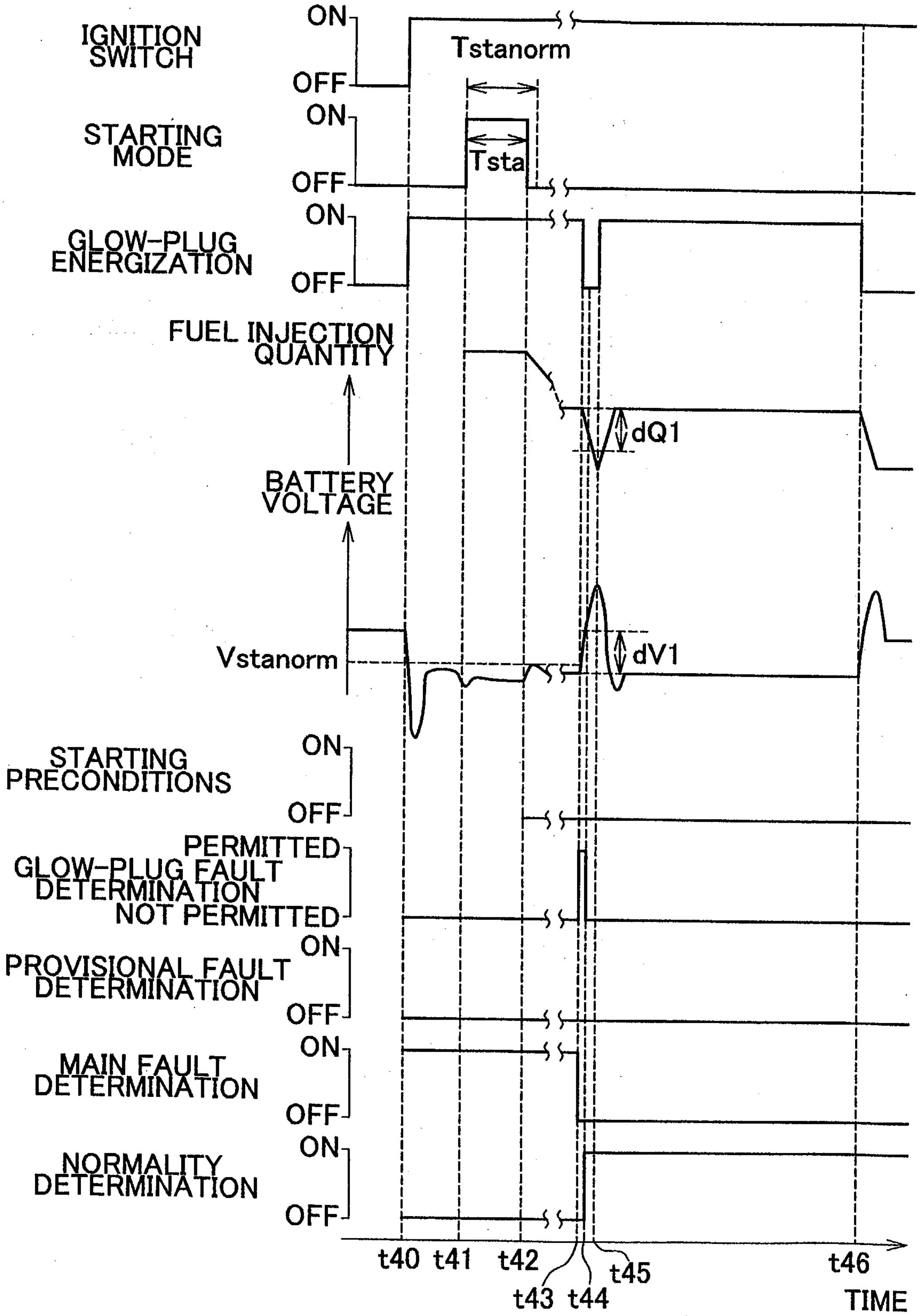
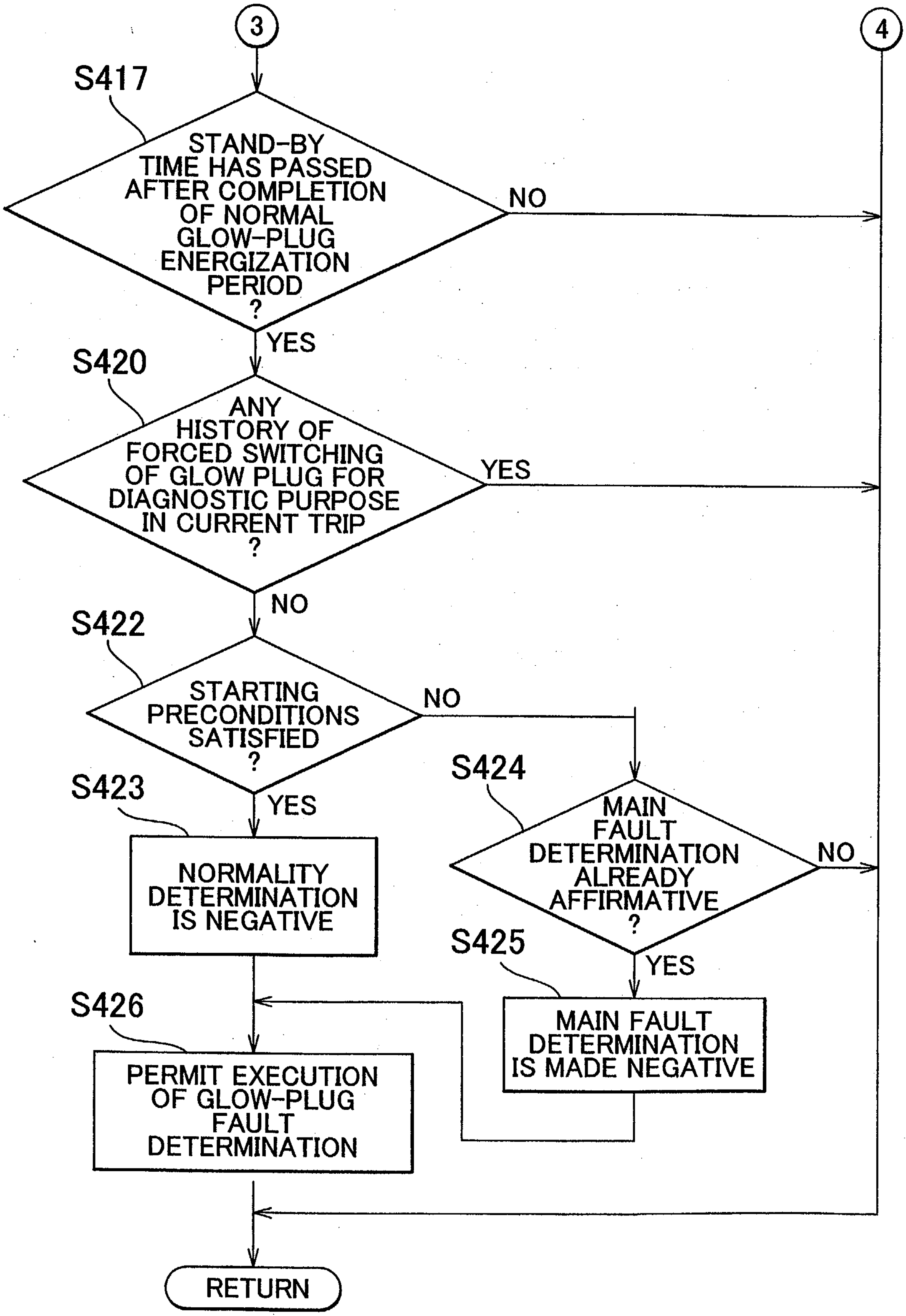

IGNITION SWITCH
ON
OFF
Tstanorm
STARTING MODE
ON
OFF
Tsta
GLOW-PLUG ENERGIZATION
ON
OFF
FUEL INJECTION QUANTITY
dQ1
BATTERY VOLTAGE
Vstanorm
dV1
STARTING PRECONDITIONS
ON
OFF
GLOW-PLUG FAULT DETERMINATION
PERMITTED
NOT PERMITTED
PROVISIONAL FAULT DETERMINATION
ON
OFF
MAIN FAULT DETERMINATION
ON
OFF
NORMALITY DETERMINATION
ON
OFF
t40 t41 t42 t43 t44 t45 t46
TIME

FIG. 19



3
4
S417
STAND-BY TIME HAS PASSED AFTER COMPLETION OF NORMAL GLOW-PLUG ENERGIZATION PERIOD ?
NO
YES
S420
ANY HISTORY OF FORCED SWITCHING OF GLOW PLUG FOR DIAGNOSTIC PURPOSE IN CURRENT TRIP ?
YES
NO
S422
STARTING PRECONDITIONS SATISFIED ?
NO
YES
S423
NORMALITY DETERMINATION IS NEGATIVE
S424
MAIN FAULT DETERMINATION ALREADY AFFIRMATIVE ?
NO
YES
S425
MAIN FAULT DETERMINATION IS MADE NEGATIVE
S426
PERMIT EXECUTION OF GLOW-PLUG FAULT DETERMINATION
RETURN

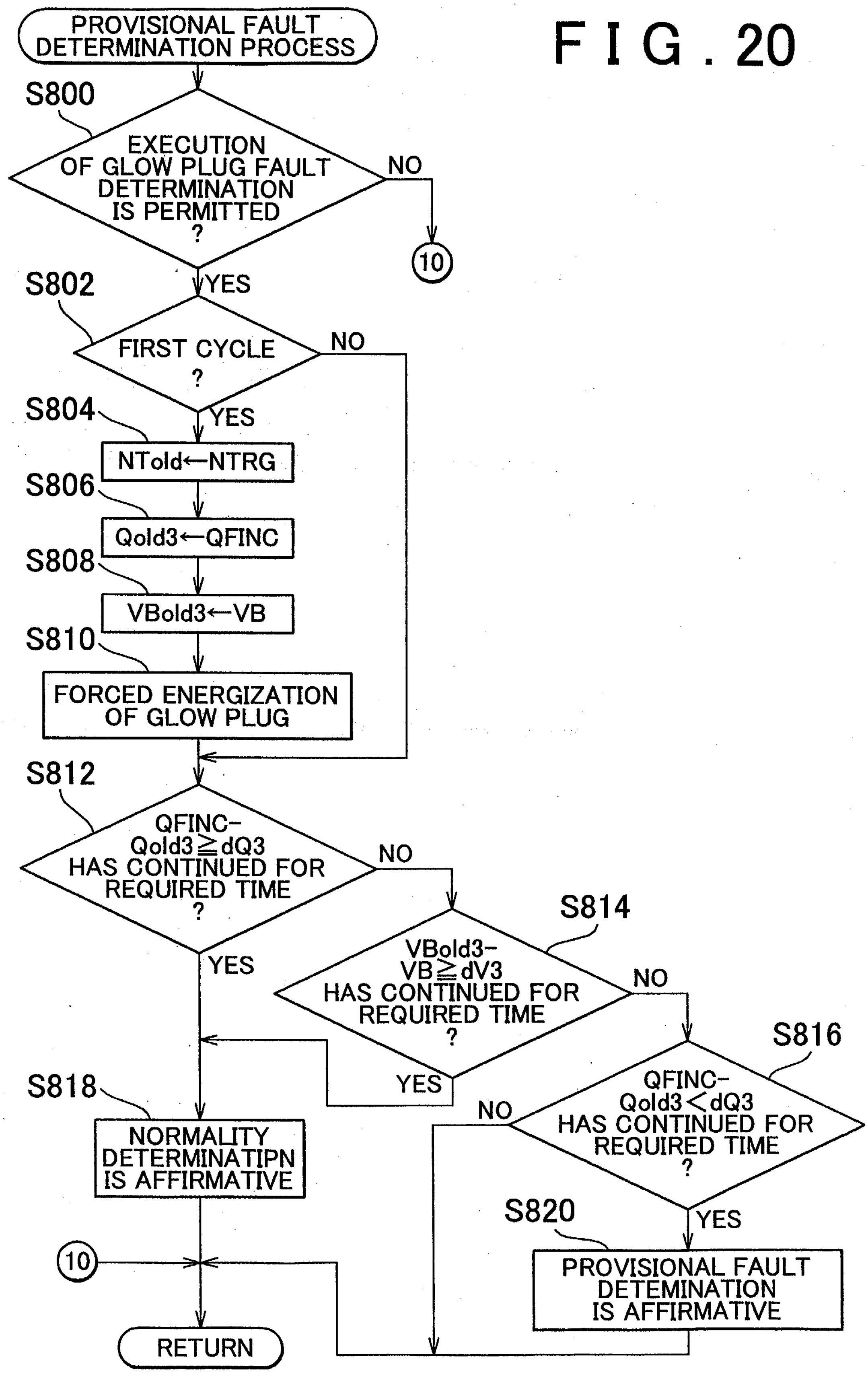
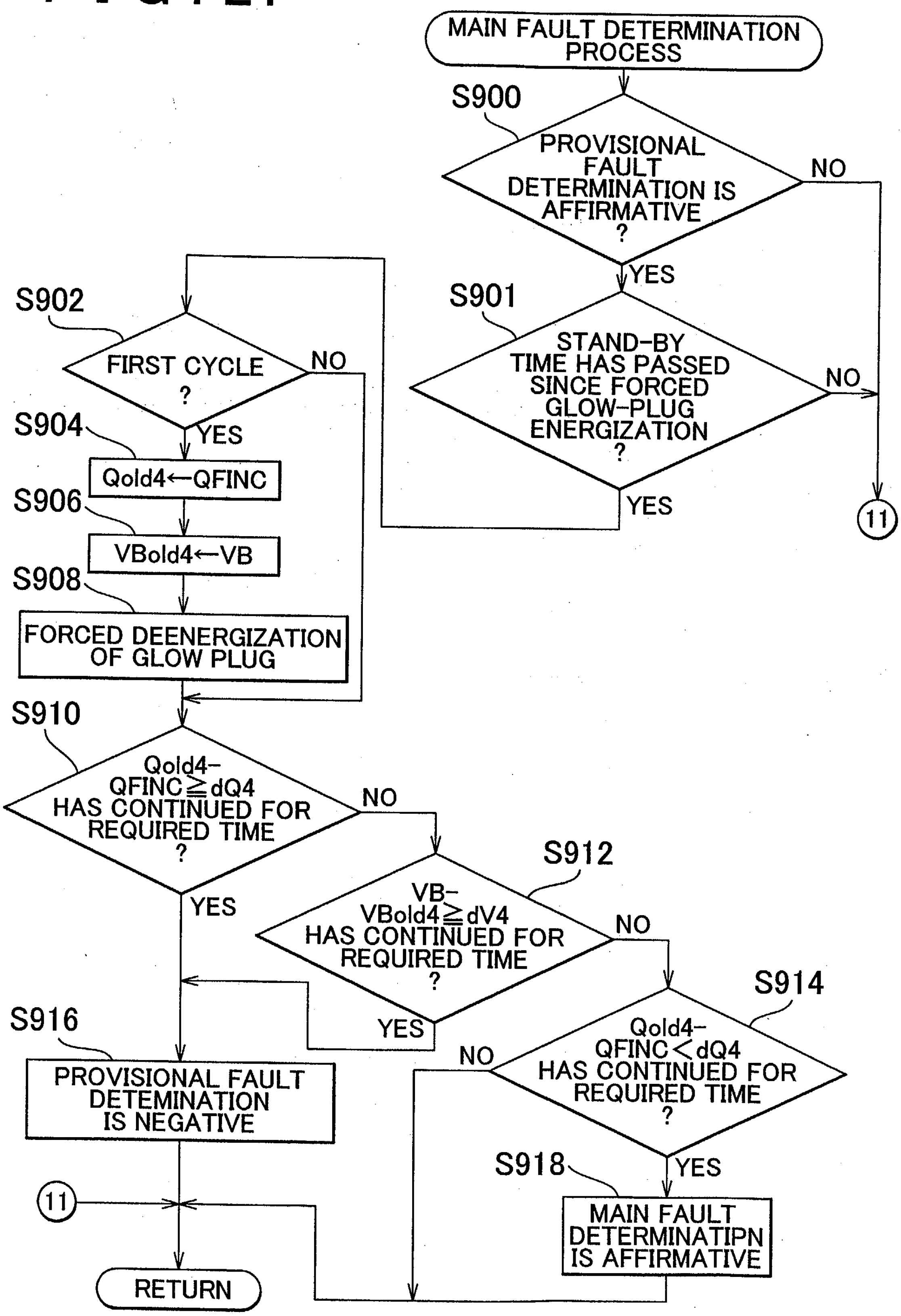
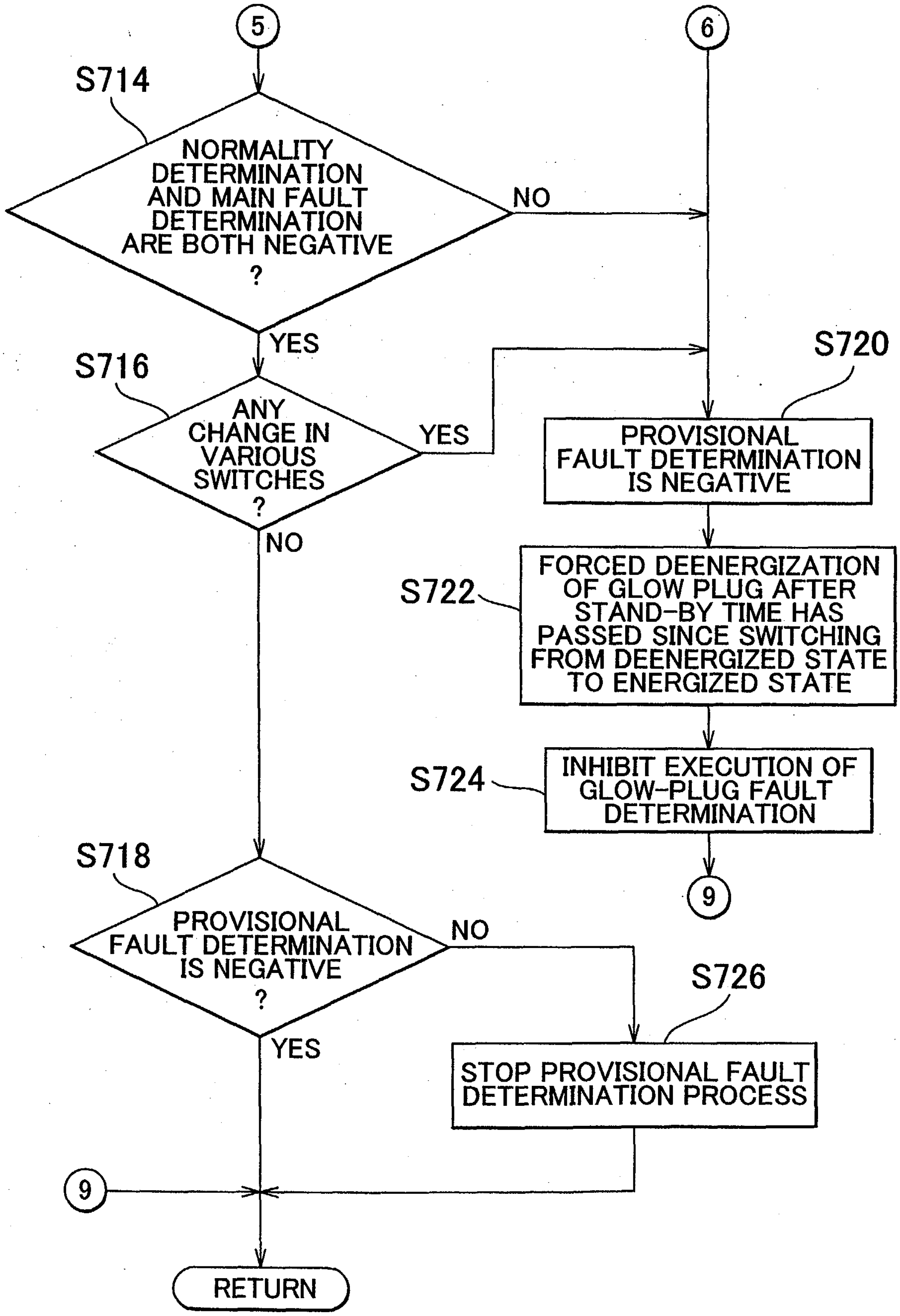

PROVISIONAL FAULT DETERMINATION PROCESS
S800
EXECUTION OF GLOW PLUG FAULT DETERMINATION IS PERMITTED ?
NO
10
YES
S802
FIRST CYCLE ?
NO
YES
S804
NTold←NTRG
S806
Qold3←QFINC
S808
VBold3←VB
S810
FORCED ENERGIZATION OF GLOW PLUG
S812
QFINC− Qold3≧dQ3 HAS CONTINUED FOR REQUIRED TIME ?
NO
YES
S814
VBold3− VB≧dV3 HAS CONTINUED FOR REQUIRED TIME ?
NO
YES
S816
QFINC− Qold3<dQ3 HAS CONTINUED FOR REQUIRED TIME ?
NO
YES
S818
NORMALITY DETERMINATIPN IS AFFIRMATIVE
S820
PROVISIONAL FAULT DETEMINATION IS AFFIRMATIVE
10
RETURN

FIG. 20

FIG. 21


MAIN FAULT DETERMINATION PROCESS
S900
PROVISIONAL FAULT DETERMINATION IS AFFIRMATIVE ?
NO
YES
S901
STAND-BY TIME HAS PASSED SINCE FORCED GLOW-PLUG ENERGIZATION ?
NO
YES
11
S902
FIRST CYCLE ?
NO
YES
S904
Qold4←QFINC
S906
VBold4←VB
S908
FORCED DEENERGIZATION OF GLOW PLUG
S910
Qold4−QFINC≧dQ4 HAS CONTINUED FOR REQUIRED TIME ?
NO
YES
S912
VB−VBold4≧dV4 HAS CONTINUED FOR REQUIRED TIME ?
NO
YES
S914
Qold4−QFINC<dQ4 HAS CONTINUED FOR REQUIRED TIME ?
NO
YES
S916
PROVISIONAL FAULT DETEMINATION IS NEGATIVE
S918
MAIN FAULT DETERMINATIPN IS AFFIRMATIVE
11
RETURN

F I G . 22


5
6
S714
NORMALITY DETERMINATION AND MAIN FAULT DETERMINATION ARE BOTH NEGATIVE ?
NO
YES
S716
ANY CHANGE IN VARIOUS SWITCHES ?
YES
NO
S720
PROVISIONAL FAULT DETERMINATION IS NEGATIVE
S722
FORCED DEENERGIZATION OF GLOW PLUG AFTER STAND-BY TIME HAS PASSED SINCE SWITCHING FROM DEENERGIZED STATE TO ENERGIZED STATE
S724
INHIBIT EXECUTION OF GLOW-PLUG FAULT DETERMINATION
9
S718
PROVISIONAL FAULT DETERMINATION IS NEGATIVE ?
NO
YES
S726
STOP PROVISIONAL FAULT DETERMINATION PROCESS
9
RETURN

F I G. 23

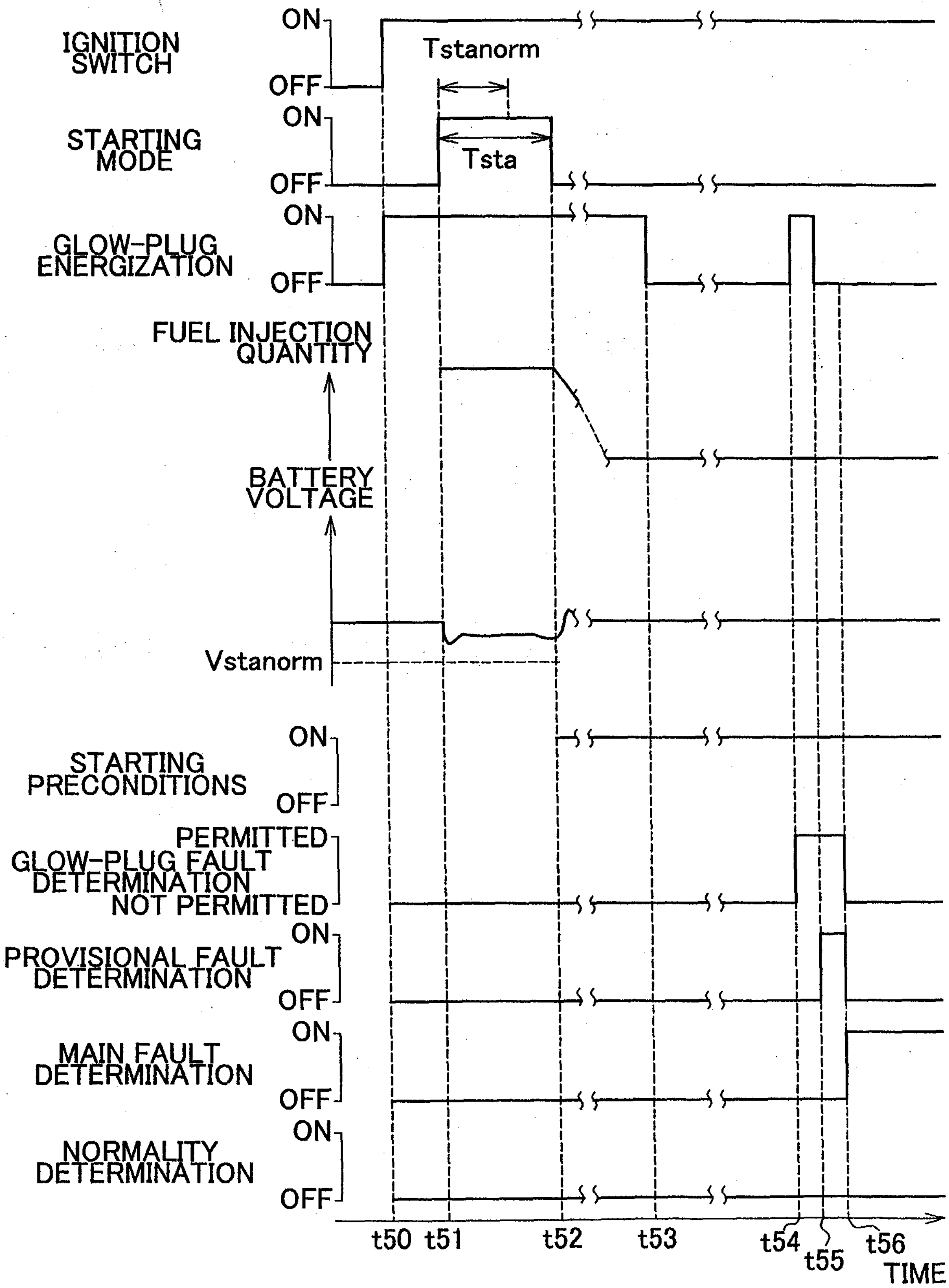
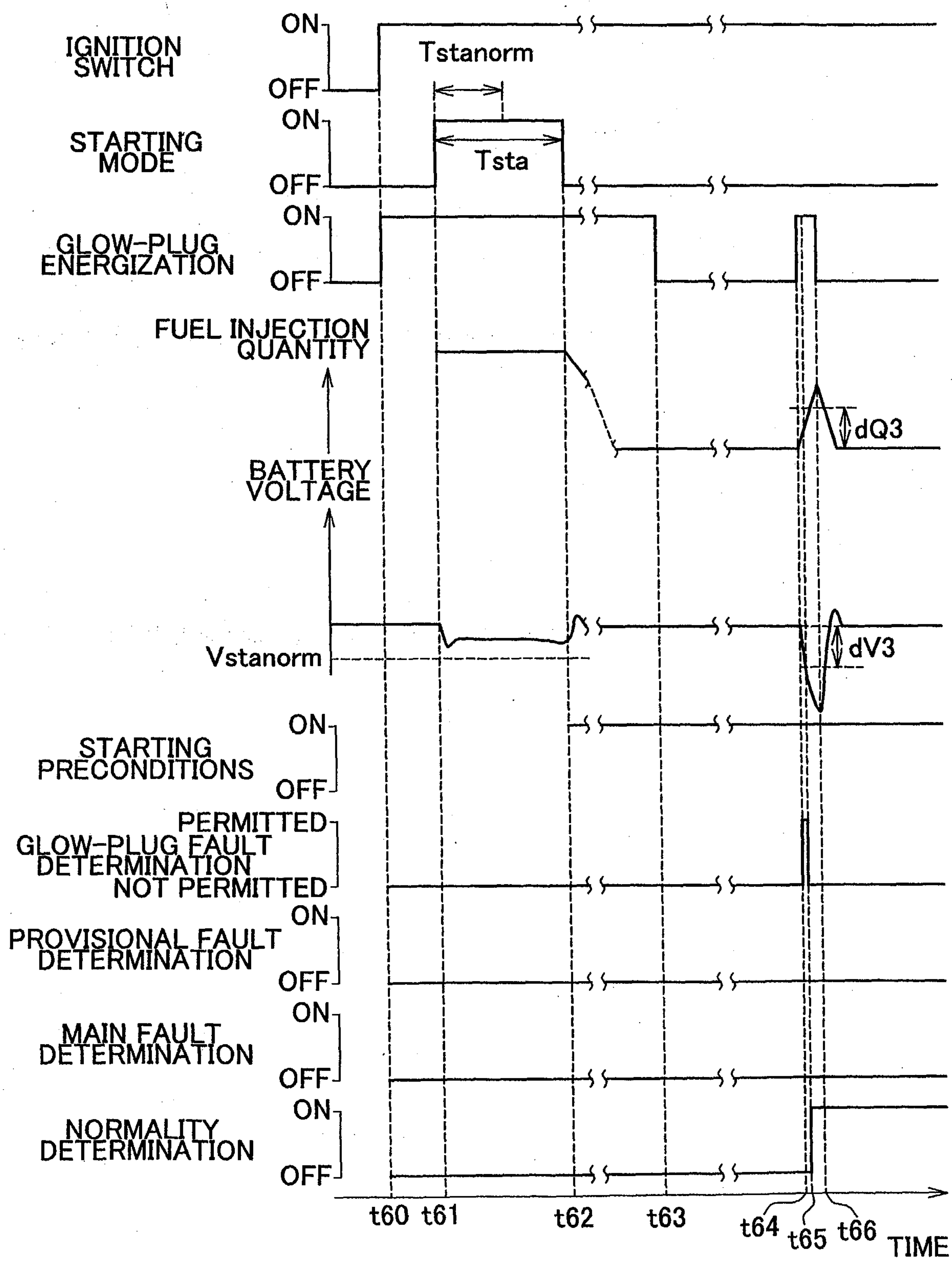

IGNITION SWITCH
ON
OFF
Tstanorm
STARTING MODE
Tsta
GLOW-PLUG ENERGIZATION
FUEL INJECTION QUANTITY
BATTERY VOLTAGE
Vstanorm
STARTING PRECONDITIONS
GLOW-PLUG FAULT DETERMINATION
PERMITTED
NOT PERMITTED
PROVISIONAL FAULT DETERMINATION
MAIN FAULT DETERMINATION
NORMALITY DETERMINATION
t50
t51
t52
t53
t54
t55
t56
TIME

FIG. 24



IGNITION SWITCH
ON
OFF
Tstanorm
STARTING MODE
Tsta
GLOW-PLUG ENERGIZATION
FUEL INJECTION QUANTITY
dQ3
BATTERY VOLTAGE
Vstanorm
dV3
STARTING PRECONDITIONS
GLOW-PLUG FAULT DETERMINATION
PERMITTED
NOT PERMITTED
PROVISIONAL FAULT DETERMINATION
MAIN FAULT DETERMINATION
NORMALITY DETERMINATION
t60 t61 t62 t63 t64 t65 t66
TIME

F I G. 25

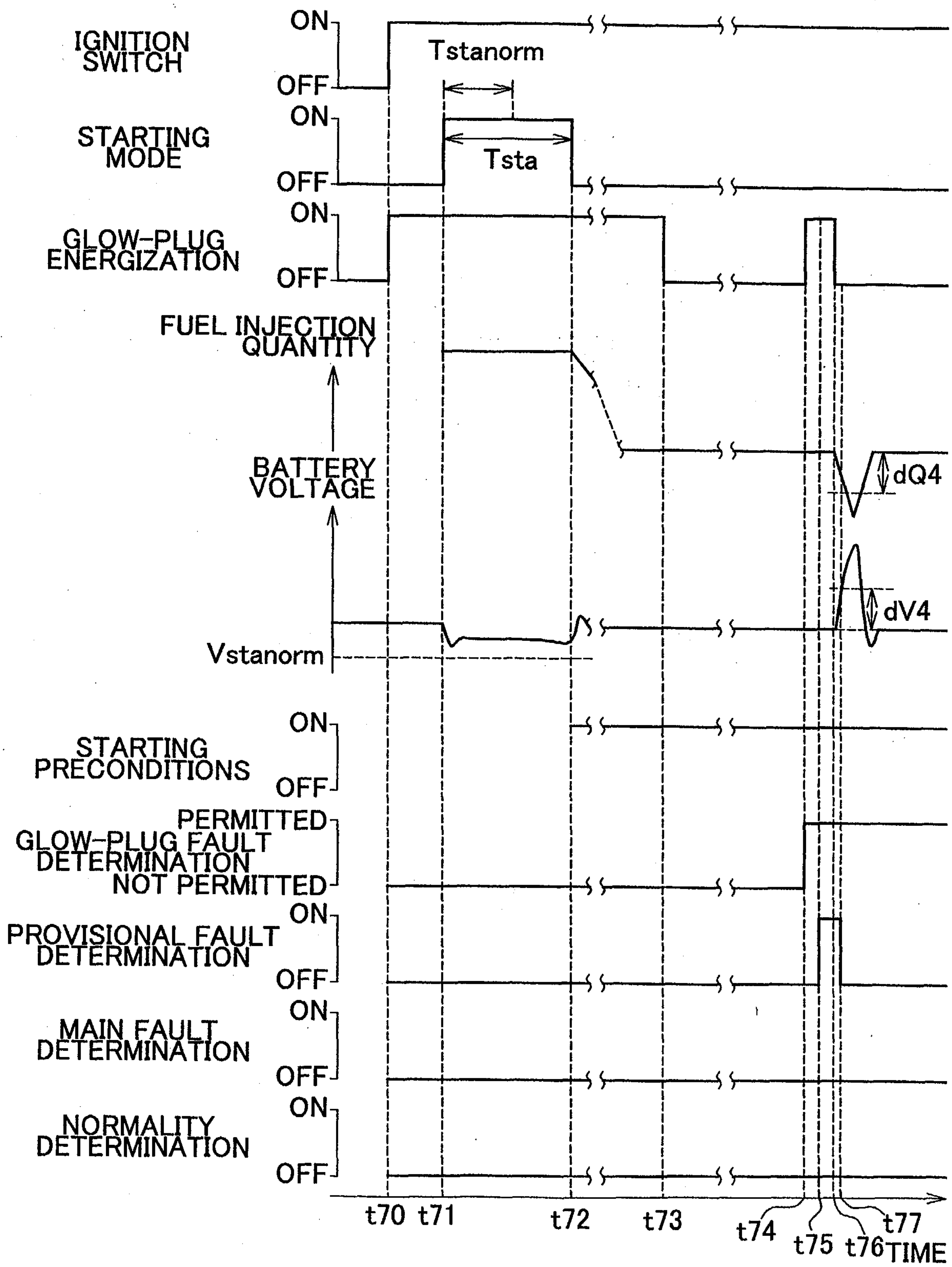
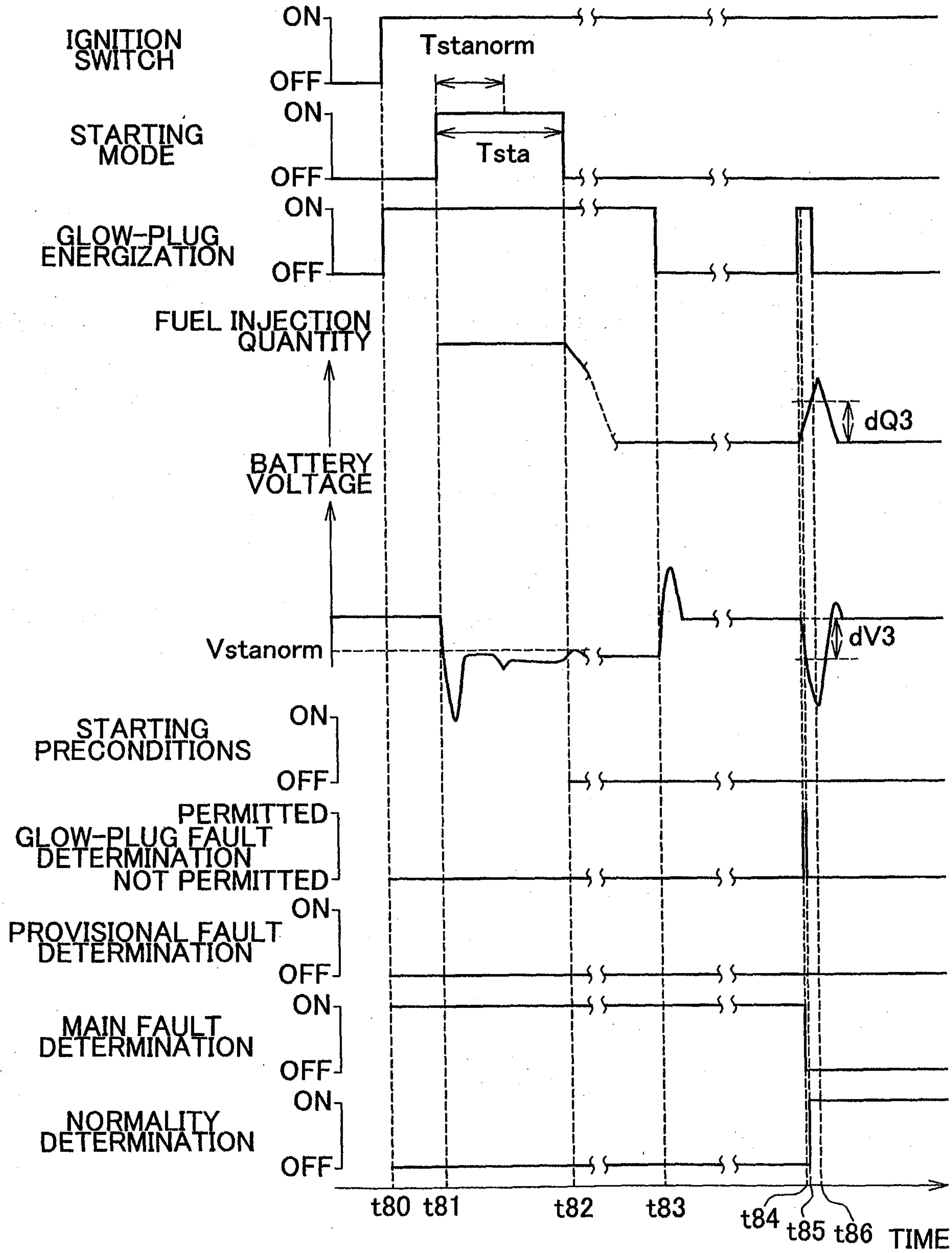

IGNITION SWITCH
ON
OFF
Tstanorm
STARTING MODE
ON
OFF
Tsta
GLOW-PLUG ENERGIZATION
ON
OFF
FUEL INJECTION QUANTITY
BATTERY VOLTAGE
dQ4
dV4
Vstanorm
STARTING PRECONDITIONS
ON
OFF
GLOW-PLUG FAULT DETERMINATION
PERMITTED
NOT PERMITTED
PROVISIONAL FAULT DETERMINATION
ON
OFF
MAIN FAULT DETERMINATION
ON
OFF
NORMALITY DETERMINATION
ON
OFF
t70 t71 t72 t73 t74 t75 t76 t77
TIME

FIG. 26


IGNITION SWITCH
ON
OFF
Tstanorm
STARTING MODE
ON
OFF
Tsta
GLOW-PLUG ENERGIZATION
ON
OFF
FUEL INJECTION QUANTITY
dQ3
BATTERY VOLTAGE
Vstanorm
dV3
STARTING PRECONDITIONS
ON
OFF
GLOW-PLUG FAULT DETERMINATION
PERMITTED
NOT PERMITTED
PROVISIONAL FAULT DETERMINATION
ON
OFF
MAIN FAULT DETERMINATION
ON
OFF
NORMALITY DETERMINATION
ON
OFF
t80 t81 t82 t83 t84 t85 t86 TIME