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(71) Applicant:
TOYOTA JIDOSHA KABUSHIKI KAISHA
Aichi-ken (JP)

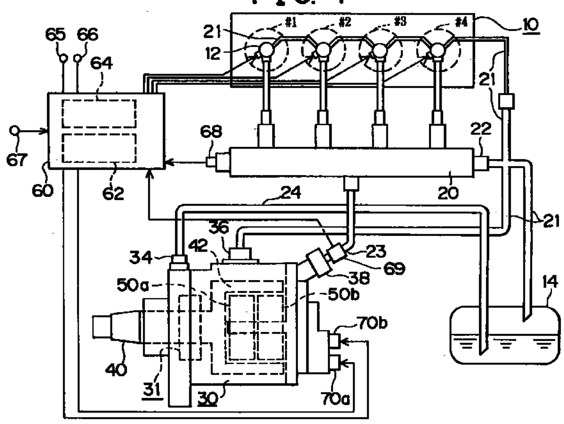
(72) Inventors:
- **Sugiyama, Tatsumasa**
Toyota-shi, Aichi-ken 471-8571 (JP)
- **Katou, Yuuichirou**
Toyota-shi, Aichi-ken 471-8571 (JP)

(74) Representative: **Kuhnen & Wacker Patentanwaltsgesellschaft mbH,**
Alois-Steinecker-Strasse 22
85354 Freising (DE)

(54) Method and determining abnormality in high-pressure fuel injection system

(57) The present invention proposes a method of abnormality determination for a high-pressure fuel injection system, which is capable of enlarging a range where a fuel force-feed timing or a fuel injection timing can be changed, and of determining occurrence of an abnormality with high precision. An electronic control unit (ECU)(60) detects a change in fuel pressure in a common rail (20) (rail pressure change amount), estimates a change in rail pressure based on an injection command value, a force-feed command value and the like, and makes a first abnormality determination based on the detected value and the estimated value. If occurrence of an abnormality is confirmed in the first abnormality determination, the ECU (60) restricts a timing for starting force-feeding of fuel such that only fuel injection is carried out in a second determination period. The ECU (60) then compares a detected value of a change in rail pressure with a value of a change in rail pressure estimated based on the injection command value and the like, and additionally makes a second abnormality determination.

FIG. 1



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a method of determining abnormality in a high-pressure fuel injection system for force-feeding high-pressure fuel from a fuel pump to an accumulator line and supplying, through injection, the fuel in the accumulator line to an internal combustion engine from fuel injection valves and, more specifically, relates to a method of determining abnormality in a high-pressure fuel injection system wherein occurrence of an abnormality is determined through a comparison between an actual measurement value and an estimated value relating to a state of fuel in the accumulator line.

2. Description of the Related Art

[0002] As a high-pressure fuel injection system applied to a diesel engine or a cylinder direct injection gasoline engine, there is known a so-called accumulator type high-pressure fuel injection system which is designed to force-feed high-pressure fuel from a fuel pump to an accumulator line and to supply, through injection, the fuel to combustion chambers of the engine from fuel injection valves connected to the accumulator line.

[0003] For example, Japanese Patent Application No- HEI 10-238392 discloses one such method of determining abnormality in an accumulator type high-pressure fuel injection system. In this method of determining abnormality, a change in fuel pressure in the accumulator line resulting from force-feeding of fuel is detected, and the change in fuel pressure resulting from the force-feeding of fuel is estimated based on a force-feed command value for the fuel pump. Then, a difference between the actual measurement value and the estimated value of the change in fuel pressure is calculated. Furthermore, a change in fuel pressure resulting from fuel injection is detected, and the change in fuel pressure resulting from the fuel injection is estimated based on an injection command value for the fuel injection valves. Then, a difference between the actual measurement value and the estimated value of the change in fuel pressure is calculated. If the difference calculated at the time of the force-feeding of fuel has exceeded a predetermined determination value, it is determined that there is an abnormality occurring in the fuel pump. If the difference calculated at the time of the fuel injection has exceeded a predetermined determination value, it is determined that there is an abnormality occurring in the fuel injection valves.

[0004] The timing for force-feeding fuel from the fuel pump and the timing for injecting fuel from the fuel injection valves are usually changed based on an operational state of the engine. Thus, if both force-feeding of fuel and fuel injection are carried out simultaneously due to changes in fuel force-feed timing and fuel injection timing, the aforementioned method of determining abnormality is unable to distinguish between a change in fuel pressure resulting from the force-feeding of fuel and a change in fuel pressure resulting from the fuel injection. As a result, the precision of abnormality determination may deteriorate.

[0005] For example, when detecting a change in fuel pressure resulting from force-feeding of fuel, if the fuel pressure decreases through fuel injection, the detected change in fuel pressure becomes smaller. Thus, it may be determined by mistake, despite normal fuel force-feed operation, that there is an abnormality occurring in the fuel pump. On the other hand, when detecting a change in fuel pressure resulting from fuel injection, if the fuel pressure increases, the detected change in fuel pressure becomes smaller. Thus, it may be determined by mistake, despite normal fuel injection, that there is an abnormality occurring in the fuel injection valves.

[0006] In view of this, according to the related art, the fuel force-feed timing and the fuel injection timing are restricted such that force-feeding of fuel and fuel injection are always carried out in separate periods, whereby the precision of abnormality determination is prevented from deteriorating.

[0007] However, if the fuel force-feed timing and the fuel injection timing are thus set, these timings are always restricted even when abnormality determination is not made. Therefore, there is a possibility that the fuel pressure in the accumulator line may not rise smoothly to a pressure corresponding to an operational state of the engine, or that fuel may not be injected at an optimal timing corresponding to an operational state of the engine.

SUMMARY OF THE INVENTION

[0008] The present invention has been made in the light of such circumstances. It is an object of the present invention to provide a method of determining abnormality in a high-pressure fuel injection system which is capable of enlarging a range where a fuel force-feed timing or a fuel injection timing can be changed, and of determining occurrence of an abnormality with high precision.

[0009] In order to achieve the above-stated object, according to one aspect of the present invention, there is provided a method of determining abnormality which is applied to a high-pressure fuel injection system for supplying, through injection, high-pressure fuel that is force-fed from a fuel pump to an accumulator line from a fuel injection valve connected to the accumulator line to an internal combustion engine, wherein occurrence of an abnormality in the high-pressure fuel injection system is determined through a comparison between an actual state of fuel in the accumulator line during a predetermined determination period and a state of fuel estimated based on operation of the high-pressure fuel injection system. This method is characterized in that a first method of abnormality determination is applied in a first period in which both force-feeding of fuel from the fuel pump and fuel injection by the fuel injection valve are carried out within the determination period, and that occurrence of an abnormality is determined through a second determination method which is different from the first method of abnormality determination, in a second period in which only one of the force-feeding of fuel and the fuel injection is carried out within the determination period.

[0010] In the aforementioned method of determining abnormality, whether both force-feeding of fuel from the fuel pump and fuel injection from the fuel injection valves are carried out in the abnormality determination period, or only one of the force-feeding of fuel and the fuel injection is carried out in the abnormality determination period, the occurrence of an abnormality is determined according to separate determination procedures corresponding to the respective cases. Therefore, possibilities of misdetermination are eliminated.

[0011] Also, when such abnormality determination is not made, the range where the fuel force-feed timing or the fuel injection timing can be changed is not restricted. These timings can be set to optimal timings corresponding to a requirement on the side of the engine or the like.

[0012] Consequently, the aforementioned method of determining abnormality makes it possible to enlarge a range where the fuel force-feed timing or the fuel injection timing can be changed, and to determine occurrence of an abnormality in the high-pressure fuel injection system with high precision.

[0013] Although this summary does not describe all the features of the present invention, it should be understood that any combination of the features stated in the dependent claims is within the scope of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014]

Fig. 1 schematically shows the structure of a high-pressure fuel injection system for a diesel engine.

Fig. 2 is a timing chart showing a pattern of change in rail pressure during normal operation and the like.

Fig. 3 is a flowchart showing a processing procedure of abnormality determination according to a first embodiment of the present invention.

Fig. 4 is a flowchart showing a processing procedure of abnormality determination according to the first embodiment of the present invention.

Fig. 5 is a timing chart showing a pattern of change in rail pressure and the like during occurrence of abnormality.

Fig. 6 is a flowchart showing a processing procedure of abnormality determination according to a second embodiment of the present invention.

Fig. 7 is a flowchart showing a processing procedure of abnormality determination according to the second embodiment of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0015] A first embodiment of the present invention wherein a method of determining abnormality according to the present invention is applied to a high-pressure fuel injection system attached to a four-cylinder direct injection diesel engine (hereinafter referred to simply as the „engine") will be described hereinafter.

[0016] Fig. 1 schematically shows structures of an engine 10 and a high-pressure fuel injection system thereof.

[0017] This high-pressure fuel injection system is composed of injectors 12 so provided as to correspond to respective cylinders #1 through #4 of the engine 10, a common rail 20 to which the injectors 12 are connected, a fuel pump 30 for force-feeding fuel in a fuel tank 14 to the common rail 20, and an electronic control unit (hereinafter referred to as the „ECU") 60.

[0018] The common rail 20 has the function of accumulating fuel supplied from the fuel pump 30 at a predetermined pressure, and the fuel injection pressure of the injectors 12 is determined based on a fuel pressure (rail pressure) in the common rail 20.

[0019] A relief valve 22 is attached to the common rail 20. The relief valve 22 opens when the rail pressure becomes equal to or higher than a predetermined upper limit set value because of some abnormality, thus forcibly reducing the rail pressure.

[0020] The injectors 12, which are electromagnetic valves that are driven to be opened and closed by the ECU 60, inject fuel supplied from the common rail 20 into combustion chambers (not shown) of the respective cylinders #1 through #4. The respective injectors 12 are also connected to the fuel tank 14 by a relief passage 21. Even when all the injectors 12 are closed, part of the fuel supplied to the respective injectors 12 from the common rail 20 constantly leaks out to the interior of the injectors 12. The fuel that has thus leaked is returned to the fuel tank 14 through the relief passage 21.

[0021] The ECU 60 performs force-feeding of fuel from the fuel pump 30 and control operations relating to fuel injection from the injectors 12. The ECU 60 is composed of a memory 64 for storing various control programs, functional data and the like, a CPU 62 for performing various arithmetic processings, and the like.

[0022] Various sensors for detecting an operational condition of the engine 10, a fuel pressure in the common rail 20 and the like are connected to the ECU 60. Detection signals from those sensors are inputted to the ECU 60.

[0023] For example, a rotational speed sensor 65 is provided in the vicinity of a crank shaft (not shown) of the engine 10, and a cylinder discriminating sensor 66 is provided in the vicinity of a cam shaft (not shown). Based on detection signals from the respective sensors 65 and 66, the ECU 60 detects a rotational speed of the crank shaft (engine rotational speed NE) and a rotational angle (crank angle CA) respectively.

[0024] Further, an accelerator sensor 67 for outputting a detection signal corresponding to a depression amount of an accelerator pedal (accelerator opening degree ACCP) is provided in the vicinity of the accelerator pedal. A fuel pressure sensor 68 for outputting a detection signal corresponding to a rail pressure is provided in the common rail 20. A fuel temperature sensor 69 for outputting a detection signal corresponding to a temperature of fuel (fuel temperature THF) is provided in the vicinity of a discharge port 38 of the fuel pump 30. Based on detection signals from the respective sensors 67 through 69, the ECU 60 detects an accelerator opening degree ACCP, a rail pressure and a fuel temperature THF respectively.

[0025] The fuel pump 30 is provided with a drive shaft 40 rotationally driven by the crank shaft of the engine 10, a feed pump 31 operating based on rotation of the drive shaft 40, a pair of supply pumps (a first supply pump 50a and a second supply pump 50b) driven by an annular cam 42 formed on the drive shaft 40, and the like.

[0026] The feed pump 31 sucks fuel in the fuel tank 14 from a suction port 34 through a suction passage 24, and supplies the fuel to the first supply pump 50a and the second supply pump 50b at a predetermined feed pressure. A surplus of the thus-sucked fuel that is supplied to neither of the supply pumps 50a and 50b is returned to the fuel tank 14 from a relief port 36 through the relief passage 21.

[0027] The first supply pump 50a and the second supply pump 50b, which are both so-called inner cam type pumps, pressurize fuel supplied from the feed pump 31 to a higher pressure (e.g. 25 to 180 MPa) based on reciprocating movements of a plunger (not shown) and force-feed the thus-pressurized fuel to the common rail 20 from the discharge port 38 through the discharge passage 23.

[0028] The fuel pump 30 is provided with first and second adjusting valves 70a and 70b for adjusting amounts of fuel force-fed from the supply pumps 50a and 50b respectively. The respective adjusting valves 70a and 70b are both electromagnetic valves that are driven and supplied with electric power by the ECU 60.

[0029] Fig. 2 is a timing chart showing a pattern of change in rail pressure during normal operation, timings for sucking fuel into and force-feeding fuel from the respective supply pumps 50a and 50b, timings for fuel injection, and the like.

[0030] As indicated by (a) in Fig. 2, the rail pressure changes because of fuel injection from the respective injectors 12 (see (b) in Fig. 2) and force-feeding of fuel from the respective supply pumps 50a and 50b (see (d) and (f) in Fig. 2). Even while force-feeding of fuel or fuel injection is not carried out, the rail pressure slightly decreases. This is because, as described above, part of the fuel that is supplied from the common rail 20 to the respective injectors 12 is returned to the fuel tank 14 through the relief passage 21.

[0031] As indicated by (d) and (f) in Fig. 2, the respective supply pumps 50a and 50b alternately suck fuel with phases being offset from each other by 180°CA (CA: Crank Angle). Also, the respective supply pumps 50a and 50b alternately force-feed fuel with phases being offset from each other by 180°CA.

[0032] As indicated by (c) and (e) in Fig. 2, the respective adjusting valves 70a and 70b are opened during suction strokes of the respective supply pumps 50a and 50b, and closed at predetermined timings (crank angles CA) so as to stop sucking fuel. All the fuel thus sucked is pressurized during a force-feed stroke following the suction stroke, and is force-fed to the common rail 20 from the respective supply pumps 50a and 50b.

[0033] The amounts of fuel thus force-fed from the respective supply pumps 50a and 50b are adjusted based on changes in valve-closing timing (crank angle CA) of the respective adjusting valves 70a and 70b.

[0034] For example, as indicated by an alternate long and short dash line of (c) and (d) in Fig. 2, if the valve-closing timing of the first adjusting valve 70a is retarded so as to increase an open-valve period thereof, the fuel suction period of the first supply pump 50a is prolonged and the fuel suction amount increases. Then the timing for starting force-feeding of fuel is advanced by an amount corresponding to retardation of the valve-closing timing of the first adjusting valve 70a, and the fuel force-feed period is prolonged. As a result, the fuel force-feed amount increases.

[0035] Conversely, as indicated by an alternate long and two short dashes line in Fig. 2, if the valve-closing timing of the first adjusting valve 70a is advanced so as to reduce an open-valve period thereof, the fuel suction period of the first supply pump 50a is shortened and the fuel suction amount decreases. Then the timing for starting force-feeding of fuel is retarded by an amount corresponding to advancement of the valve-closing timing of the first adjusting valve 70a, and the fuel force-feed period is shortened. As a result, the fuel force-feed amount decreases.

[0036] Likewise, the fuel force-feed amount of the second supply pump 50b (see (f) in Fig. 2) can be changed by retarding or advancing a valve-closing timing of the second adjusting valve 70b (see (e) in Fig. 2).

[0037] In thus changing the fuel force-feed amount, the timing for terminating suction of fuel and the timing for starting force-feeding of fuel are changed respectively. However, both the timing for starting suction of fuel and the timing for terminating force-feeding of fuel are set to constant timings (crank angles CA). The amount of fuel force-fed from the fuel pump 30 per unit crank angle CA is set to a constant value regardless of the timing for starting force-feeding of fuel or the like. Accordingly, the timing for starting force-feeding of fuel and the fuel force-feed period (crank angle CA) can be calculated from valve-closing timings of the respective adjusting valves 70a and 70b. Furthermore, the amount of fuel force-fed during one cycle of force-feeding of fuel can be calculated based on the fuel force-feed period.

[0038] The ECU 60 performs feedback control of an amount of fuel force-fed from the fuel pump 30 based on a value of rail pressure detected immediately after termination of force-feeding of fuel from the fuel pump 30 (hereinafter referred to as a „post-force-feed fuel pressure PCRP") and on a target rail pressure set on the basis of an operational condition of the engine.

[0039] For example, if the post-force-feed fuel pressure PCRP is lower than the target pressure, the fuel pump 30 is so controlled as to force-feed fuel of an amount greater than the sum of a fuel injection amount and a fuel leakage amount. Conversely, if the post-force-feed fuel pressure PCRP is higher than the target pressure, the fuel pump 30 is so controlled as to force-feed fuel of an amount smaller than the sum of a fuel injection amount and a fuel leakage amount. Accordingly, during transitional operation wherein the post-force-feed fuel pressure PCRP is different from the target pressure, the post-force-feed fuel pressure PCRP gradually increases or decreases and approaches the target pressure. Conversely, if the post-force-feed fuel pressure PCRP is equal to the target pressure, the fuel pump 30 is so controlled as to force-feed fuel of an amount equal to the sum of a fuel injection amount and a fuel leakage amount. Accordingly, during normal operation wherein the post-force-feed fuel pressure PCRP is equal to the target pressure, the post-force-feed fuel pressure PCRP is held at a substantially constant value, for example, as indicated by (a) in Fig. 2.

[0040] The reference character (g) in Fig. 2 represents a timing for detecting a post-force-feed fuel pressure PCRP. The detection timing is set to a predetermined timing immediately after termination of force-feeding of fuel from the fuel pump 30 (e.g. a timing at which the crank angle CA reaches CAA0, CAA1, CAA2, CAA3, ... or the like).

[0041] The reference character (h) in Fig. 2 represents a timing for detecting a post-injection fuel pressure PCRI. The post-injection fuel pressure PCRI is a value of rail pressure immediately after termination of fuel injection in the respective cylinders #1 through #4. Even if the fuel injection timing or the fuel injection period has been changed in accordance with an operational condition of the engine, the detection timing is always set to a timing after termination of fuel injection (e.g. a timing at which the crank angle CA reaches CAB1, CAB2, CAB3, ... or the like).

[0042] The post-force-feed fuel pressure PCRP and the post-injection fuel pressure PCRI are all detected by the ECU 60 through separate processing routines that are performed every time the crank shaft rotates by a predetermined crank angle (180°CA), and are stored in the memory 64.

[0043] Next, a processing of determining abnormality in the high-pressure fuel injection system will be described. This processing is designed to determine abnormality in the high-pressure fuel injection system by comparing an actual measurement value of rail pressure change amount with an estimated value of rail pressure change amount that is estimated based on a fuel force-feed amount or the like.

[0044] A detailed processing procedure of abnormality determination will be described in detail with reference to a flowchart shown in Figs. 3 and 4. An „abnormality determination routine" shown in this flowchart is carried out by the ECU 60 as an interruption handling that is performed every time the crank shaft rotates by a predetermined crank angle (180 °CA), and the timing for interruption is set to a timing for detecting a post-force-feed fuel pressure PCRP (the timing CAA0, CAA1, CAA2 or CAA3 shown in Fig. 2).

[0045] First of all, in step 110, the ECU 60 retrieves a post-force-feed fuel pressure PCRP, a last-time value PCRPOLD of post-force-feed fuel pressure PCRP and a post-injection fuel pressure PCRI from the memory 64. After that, the ECU 60 determines in step 120 whether or not conditions for prohibiting abnormality determination are fulfilled. The conditions for prohibiting abnormality determination include that there is an abnormality occurring in the fuel pressure sensor 68, that the engine rotational speed NE is equal to or lower than a predetermined rotational speed (e.g. an idling rotational speed), that invalid injection is being performed, and the like. The invalid injection control is designed to release a rail pressure by driving the respective injectors 12 within an invalid injection period and to thereby reduce the rail pressure down to a pressure close to the target pressure. If those conditions for abnormality determination are fulfilled, the occurrence of abnormality cannot be determined precisely. Thus, the ECU 60 terminates the present routine temporarily.

[0046] On the other hand, if the conditions for prohibiting abnormality determination are not fulfilled, the ECU 60 determines in step 130 whether or not a provisional abnormality flag XTFAIL is „ON". The provisional abnormality flag XTFAIL indicates that there is an abnormality occurring in the high-pressure fuel injection system. If it is determined in step 130 that there is an abnormality occurring in the fuel pump 30, the injectors 12 or the like, the provisional abnormality flag XTFAIL is turned „ON" through later-described first abnormality determination.

[0047] If the provisional abnormality flag XTFAIL is „OFF", namely, if it is determined that no abnormality has been detected in a last-time processing of abnormality determination, the ECU 60 performs the first abnormality determination.

[0048] First of all, in step 140, the ECU 60 calculates an actual fuel pressure change amount ΔPCR according to a formula (1) shown below.

$$\Delta PCR = PCRP - PCRPOLD \tag{1}$$

[0049] For example, if the present timing for interruption is the timing CAA2 shown in Fig. 2, a difference (PCRP - PCRPOLD) between the post-fuel-pressure PCRP detected at the timing CAA2 and the last-time value PCRPOLD of post-force-feed fuel pressure PCRP detected at the last timing CAA1 for interruption is calculated as an actual fuel pressure change amount ΔPCR.

[0050] As shown in Fig. 2, the thus-calculated actual fuel pressure change amount ΔPCR corresponds to an actual rail pressure change amount during each of periods (CAA0 to CAA1, CAA1 to CAA2, CAA2 to CAA3, ..., hereinafter referred to as a „first abnormality determination period APCR 1") between respective timings (CAA0, CAA1, CAA2, CAA3, ...) for detecting the post-force-feed fuel pressure PCRP. During the first abnormality determination period APCR1, both force-feeding of fuel and fuel injection are carried out unless they are suspended by other control operations. Accordingly, the actual fuel pressure change amount ΔPCR changes in accordance with an amount of fall in rail pressure resulting from fuel injection and fuel leakage and with an amount of rise in rail pressure resulting from force-feeding of fuel.

[0051] The ECU 60 then shifts operation to step 150. In step 150, the ECU 60 calculates an estimated fuel pressure change amount ΔPCRCAL. The estimated fuel pressure change amount ΔPCRCAL, which is an estimated value of rail pressure change amount during the first abnormality determination period APCR1, is estimated based on a fuel force-feed amount, a fuel injection amount and a fuel leakage amount during the abnormality determination period APCR1.

[0052] First of all, the ECU 60 calculates a fuel force-feed amount QPUMP of the fuel pump 30 based on command values for valve-closing timings of the respective adjusting valves 70a and 70b. The fuel force-feed amount QPUMP changes based on the valve-closing timings of the respective adjusting valves 70a and 70b that are set during a suction stroke prior to the start of force-feeding of fuel. Therefore, when calculating the fuel force-feed amount QPUMP, the command values for the valve-closing timings that have been set prior to the timing for interruption of the present routine are used,

[0053] For example, if the present timing for interruption is the timing CAA2 shown in Fig. 2 and force-feeding of fuel has been carried out up to the timing CAA2 by the second supply pump 50b, the ECU 60 calculates a fuel force-feed amount QPUMP based on a command value for the valve-closing timing of the second adjusting valve 70b that has been set in a period from the timing CAA0 to the timing CAA1. Likewise, if the present timing for interruption is the timing CAA3 and force-feeding of fuel has been carried out up to the timing CAA3 by the first supply pump 50a, the ECU 60 calculates a fuel force-feed amount QPUMP based on a command value for the valve-closing timing of the first adjusting valve 70a that has been set in a period from the timing CAA1 to CAA2.

[0054] Then, based on the engine rotational speed NE, the ECU 60 converts the first abnormality determination period APCR1, which is defined as a crank angle CA, into a time. Based on the time-converted value, the post-force-feed fuel pressure PCRP and the fuel temperature THF, the ECU 60 calculates a fuel leakage amount QLEAK. The relationship between the time-converted value and the like and the fuel leakage amount QLEAK is preliminarily calculated through an experiment or the like and stored in the memory 64 of the ECU 60.

[0055] Furthermore, the ECU 60 retrieves a fuel injection amount QINJ from the memory 64. The fuel injection amount QINJ is set based on the accelerator opening degree ACCP, the engine rotational speed NE and the like in a fuel injection control routine other than the present routine, and is stored in the memory 64.

[0056] The ECU 60 then calculates an estimated fuel pressure change amount ΔPCRCAL from the fuel force-feed amount QPUMP, the fuel leakage amount QLEAK and the fuel injection amount QINJ.

$$\Delta PCRCAL = E \times (QPUMP - QLEAK - QINJ)/VCR \tag{2}$$

E: volume elasticity coefficient of fuel in common rail 20
VCR: volume of common rail 20

[0057] The volume elasticity coefficient-E is calculated based on the post-force-feed fuel pressure PCRP and the fuel temperature THF in a routine other than the present routine.

[0058] After having thus calculated the actual fuel pressure change amount ΔPCR and the estimated fuel pressure change amount ΔPCRCAL, the ECU 60 compares in step 160 the difference (ΔPCRCAL - ΔPCR) between the estimated fuel pressure change amount ΔPCRCAL and the actual fuel pressure change amount ΔPCR with a first determination value α (>0).

[0059] The first determination value pressure a is used to determine whether or not there is any of the following abnormalities A through C occurring in the high-pressure fuel injection system.

[0060] The abnormality A is a deficiency in force-feed amount of the fuel pump 30 (deterioration of force-feed performance).

[0061] The abnormality B is an excess of fuel injection amount of the injectors 12 (excessive injection).

[0062] The abnormality C is an excess of amount of fuel leaking out from the injectors 12 or the like (fuel leakage).

[0063] If any of these abnormalities A through C occurs, the rail pressure changes, for example, as indicated by solid lines in (a) through (c) of Fig. 5 respectively. Accordingly, the rail pressure decreases in comparison with a pattern of change in rail pressure during normal operation (see a long and two short dashes line in Fig. 5), and the actual fuel pressure change amount ΔPCR decreases. As a result, the difference (ΔPCRCAL - ΔPCR) increases. Accordingly, if the difference (ΔPCRCAL - ΔPCR) becomes equal to or greater than the first determination value α, it can be determined that one of the abnormalities A through C has occurred. In addition to a case where the fuel leakage amount of the injectors 12 becomes excessive, the abnormality C includes, for example, a case where fuel in the common rail 20 leaks out from the relief valve 22 and is returned to the fuel tank 14.

[0064] If it is determined in step 160 that there is no abnormality occurring in the high-pressure fuel injection system, the ECU 60 temporarily terminates the present routine.

[0065] On the other hand, if it is determined that there is an abnormality occurring in the high-pressure fuel injection system (if the result in step 160 is affirmative), the ECU 60 shifts its operation to step 170 and sets the provisional abnormality flag XTFAIL „ON."

[0066] Then in step 180, the ECU 60 controls a timing for terminating suction of fuel into the fuel pump 30, namely, valve-closing timings of the respective adjusting valves 70a and 70b such that the timing for starting force-feeding of fuel is always retarded with respect to the timing for detecting the post-injection fuel pressure PCRI (the timing CAB1, CAB2, CAB3, ..., or the like shown in Fig. 2).

[0067] Because the timing for terminating suction of fuel is thus controlled, force-feeding of fuel is not carried out and only fuel injection is carried out during each of the periods (CAA0 to CAB1, CAA1 to CAB2, CAA2 to CAA3, ...hereinafter referred to as a „second abnormality determination period APCR2") from the timings for detecting the post-force-feed fuel pressure PCRP (CAA0, CAA1, CAA2, CAA3,......) to the timings for detecting the post-injection fuel pressure PCRI (CAB1, CAB2, CAB3,......) respectively. Such restriction on suction of fuel is continued until it is removed in later-described step 280.

[0068] If the provisional abnormality flag XTFAIL is set „ON" in step 170, the result in step 130 becomes affirmative in the subsequent processing of abnormality determination. In this case, the ECU 60 shifts its operation to step 200 shown in Fig. 4.

[0069] In step 200, the ECU 60 increments a counter value CTFAIL by „1". The counter value CTFAIL represents how many times the present routine has been activated after the setting „ON" of the provisional abnormality flag XTFAIL and the start of restriction on suction of fuel. In step 210 that follows, the ECU 60 determines whether or not the counter value CTFAIL is set to „2".

[0070] If the counter value CTFAIL ≠ 2, the restriction on suction of fuel imposed in preceding step 180 has not been reflected yet upon the timing for starting force-feeding of fuel. Therefore, the present routine is terminated temporarily.

[0071] On the other hand, if the counter value = 2, the ECU 60 determines that the timing for starting force-feeding of fuel has been restricted to a timing that is retarded with respect to the timing for detecting the post-injection fuel pressure PCRI. Thus, the ECU 60 resets the counter value CTFAIL to zero in step 220 and then performs second abnormality determination through the respective processings in steps 230 through 250.

[0072] First of all, the ECU 60 calculates an actual fuel pressure change amount ΔPCRI according to a formula (3) shown below.

$$\Delta PCRI = PCRPOLD - PCRI \qquad (3)$$

[0073] For example, if the present timing for interruption is the timing CAA2 shown in Fig. 2, the difference (PCRPOLD - PCRI) between the last-time value PCRPOLD of the post-force-feed fuel pressure PCRP detected at the timing CAA1, which is the last-time timing for interruption, and the post-injection fuel pressure PCRI is calculated as the actual fuel pressure change amount ΔPCRI.

[0074] The actual fuel pressure change amount ΔPCRI calculated herein corresponds to an actual amount of change in rail pressure during the second abnormality determination period APCR2. Because only fuel injection is carried out during the second abnormality determination period APCR2, the actual fuel pressure change amount ΔPCRI changes only in accordance with an amount of fall in rail pressure resulting from fuel injection and fuel leakage during the second abnormality determination period APCR2.

[0075] The ECU 60 then shifts its operation to step 240. In step 240, the ECU 60 estimates an estimated fuel pressure change amount ΔPCRICAL based on the fuel injection amount QINJ and the fuel leakage amount QLEAK during the second abnormality determination period APCR2. The estimated fuel pressure change amount ΔPCRICAL, which is an estimated value of rail pressure change amount during the second abnormality determination period APCR2, is calculated according to a formula (4) shown below.

$$\Delta PCRCAL = E \times (QLEAK + QINJ)/VCR \qquad (4)$$

E: volume elasticity coefficient of fuel in common rail 20
VCR: volume of common rail 20

[0076] After having thus calculated the actual fuel pressure change amount ΔPCRI and the estimated fuel pressure change amount ΔPCRICAL, the ECU 60 compares in step 250 the difference (ΔPCRI - ΔPCRICAL) between the actual fuel pressure change amount ΔPCRI and the estimated fuel pressure change amount ΔPCRICAL with a second determination value β (>0).

[0077] The second determination value β is used to determine which of the aforementioned abnormality A (deterioration of force-feed performance of the fuel pump 30) and the aforementioned abnormality B (excessive injection) or C (fuel leakage) occurs in the high-pressure fuel injection system. For example, if the abnormality detected in the first abnormality determination is the abnormality A and neither the abnormality B nor the abnormality C has occurred, the actual fuel pressure change amount ΔPCRI is equal to the estimated fuel pressure change amount ΔPCRICAL. Therefore, in this case, the difference (ΔPCRI - ΔPCRICAL) is substantially equal to zero. On the other hand, the abnormality detected in the first abnormality determination is the abnormality B or the abnormality C, the actual fuel pressure change amount ΔPCRI is greater than the estimated fuel pressure change amount ΔPCRICAL, and the difference (ΔPCRI - ΔPCRICAL) increases.

[0078] Accordingly, the second determination value β is suitably set so as to make a determination as follows. That is, if the difference (ΔPCRI - ΔPCRICAL) is smaller than the second determination value β, it can be determined that the force-feed performance of the fuel pump 30 has deteriorated. If the difference (ΔPCRI - ΔPCRICAL) is greater than the second determination value β, it can be determined that there is excessive injection or fuel leakage occurring.

[0079] The second determination value β is set to a value that is greater than zero and smaller than the first determination value α ($0 < \beta < \alpha$). The first determination value α is set preliminarily taking estimation errors of the fuel force-feed amount QPUMP, the fuel injection amount QINJ and the fuel leakage amount QLEAK into account. On the contrary, the setting of the second determination value β does not require taking an estimation error of the fuel force-feed amount QPUMP into account. Hence, the first determination value α and the second determination value β are set such that the aforementioned relationship is established.

[0080] If it is determined in step 250 that there is fuel leakage or excessive injection occurring (YES), the ECU 60 shifts its operation to step 260. In step 260, the ECU 60 sets the first abnormality flag XFAIL1 corresponding to the content of the abnormality „ON". In step 270 that follows, operation of the engine 10 is forcibly suspended by stopping fuel injection in order to prevent the engine from operating with excessive injection or fuel leakage occurring. After that, the ECU 60 terminates the present routine temporarily.

[0081] On the other hand, if it is determined in step 250 that the force-feed performance of the fuel pump 30 has deteriorated (NO), the ECU 60 shifts its operation to step 265. In step 265, the ECU 60 sets the second abnormality flag XFAIL 2 corresponding to the content of the abnormality „ON". In step 280 that follows, the ECU 60 then removes restriction on the timing for terminating suction of fuel. After having reset the provisional abnormality flag XTFAIL „OFF" in step 290, the ECU 60 terminates the present routine temporarily.

[0082] As described hitherto, according to the processing of abnormality determination of the present embodiment, in the first abnormality determination period APCR1 in which both force-feeding of fuel and fuel injection are carried out, the estimated fuel pressure change amount ΔPCRCAL is calculated according to the aforementioned formula (2), and the determination of abnormality is made (the first abnormality determination) by comparing the difference (ΔPCRCAL - ΔPCR) between the estimated fuel pressure change amount ΔPCRCAL and the actual fuel pressure change amount ΔPCR with the first abnormality determination value α. On the other hand, in the second abnormality determination period APCR2 in which only fuel injection is carried out, the estimated fuel pressure change amount ΔPCRICAL is calculated according to the aforementioned formula (4), and the determination of abnormality is made (the second abnormality determination) by comparing the difference (ΔPCRI - ΔPCRICAL) between the estimated fuel pressure change amount ΔPCRICAL and the actual fuel pressure change amount ΔPCRI with the second determination value β.

[0083] Thus, the determination of abnormality is made according to determination procedures corresponding to the first abnormality determination period APCR1 in which both force-feeding of fuel and fuel injection are carried out and to the second abnormality determination period APCR2 in which only fuel injection is carried out, respectively. In this manner, the possibilities of misdetermination are eliminated.

[0084] If there is no abnormality occurring, there is no limit to a range where the fuel force-feed timing or the fuel injection timing can be changed. Thus, the respective timings can be set to optimal timings corresponding to a requirement on the side of the engine or the like.

[0085] Accordingly, it is possible to change a range where the fuel force-feed timing or the fuel injection timing can be changed, and to precisely determine the occurrence of an abnormality in the high-pressure fuel injection system.

[0086] Furthermore, in addition to determining simply whether or not there is an abnormality occurring in the high-pressure fuel injection system, it is also possible to determine whether the force-feed performance of the fuel pump 30 has deteriorated, or excessive injection or fuel leakage has occurred. As result, a suitable fail-safe processing corresponding to the content of the abnormality can be performed, whereby failure analysis also becomes easily when the system is maintained.

[0087] In the processing of abnormality determination according to the present embodiment, the relationship between the fuel force-feed timing and the fuel injection timing is changed as a preprocessing of the second abnormality determination (step 180). However, such a change is made only if it is determined in the first abnormality determination that there is an abnormality occurring. Therefore, performance of the processing of abnormality determination makes it possible to inhibit a range where the fuel force-feed timing or the fuel injection timing can be changed from being restricted frequently.

[0088] In particular, when changing the relationship between the fuel force-feed timing and the fuel injection timing as described above, a restriction is imposed only on the timing for terminating suction of fuel, without changing the fuel injection timing, which tends to affect a combustion state of the engine. Therefore, it is possible to avoid deterioration of a combustion state of the engine to a certain extent, and to inhibit reduction of an engine output, deterioration of exhaust properties and the like.

[0089] Furthermore, the processing of abnormality determination is performed every time force-feeding of fuel or fuel injection is carried out. Thus, if an abnormality has occurred in the high-pressure fuel injection system, the occurrence of the abnormality can be determined at an earlier period.

[0090] In the present embodiment, the number of times for performing the processing of abnormality determination may be restricted (e.g. the processing of abnormality determination is performed only at a specific timing after start of the engine), and the relationship between the fuel force-feed timing and the fuel injection timing may always be changed. During the second abnormality determination period APCR2, it may be determined whether or not there is an abnormality relating to fuel injection occurring. During the period from the post-injection fuel pressure PCRI to the subsequent timing for detecting the post-force-feed fuel pressure PCRP (the period CAB1 to CAA1, CAB2 to CAA2, CAB3 to CAA3, ...or the like shown in Fig. 2), it may be determined whether or not there is an abnormality relating to force-feeding of fuel occurring.

[0091] Even in the case where the processing procedure of abnormality determination has thus been changed, it is possible to enlarge a range where the fuel force-feed timing or the fuel injection timing can be changed, and to precisely determine the occurrence of an abnormality in the high-pressure fuel injection system.

[0092] Further, in the present embodiment, when changing the relationship between the fuel force-feed timing and the fuel injection timing such that only fuel injection is carried out during the second abnormality determination period APCR2, the fuel injection timing or both the fuel force-feed timing and the fuel injection timing may be restricted instead of restricting the timing for terminating suction of fuel.

[0093] Next, a second embodiment of the present invention will be described, focusing on the difference between the first and second embodiments.

[0094] In the first embodiment, if it is determined that there is an abnormality in the first abnormality determination, the timing for terminating suction of fuel is restricted as a preprocessing of the second abnormality determination. However, in the present embodiment, instead of such a restriction, it is determined whether or not only fuel injection is carried out during the second abnormality determination period APCR2. Only if it is determined that only fuel injection is carried out, the second abnormality determination is made.

[0095] Figs. 6 and 7 are flowcharts showing a processing procedure of abnormality determination according to the second embodiment. Referring to Figs. 6 and 7, those steps marked with the same reference numerals as in Figs. 3 and 4 represent the same processings and thus will not be described below.

[0096] After having performed the processings in steps 110 through 150 shown in Fig. 6, if the ECU 60 determines in step 160 that there is an abnormality occurring in the high-pressure fuel injection system, the ECU 60 sets the provisional abnormality flag XTFAIL „ON" in step 170 and then terminates the present routine temporarily. If the provisional abnormality flag XTFAIL is set „ON", the ECU 60 shifts its operation from step 130 to step 215 shown in Fig. 7, in the subsequent processing of abnormality determination.

[0097] Then, the ECU 60 determines in step 215 whether or not only fuel injection is carried out during the second abnormality determination period APCR2, namely, whether or not the timing for starting force-feeding of fuel is set to a timing after the lapse of the second abnormality determination period APCR2 from the timing for starting the abnormality determination processing routine. If it is determined herein that both force-feeding of fuel and fuel injection are carried out during the second abnormality determination period APCR2, the ECU 60 terminates the present routine temporarily.

[0098] On the other hand, if it is determined in step 215 that only fuel injection is carried out during the second abnormality determination period APCR2, the ECU 60 performs the second abnormality determination through the processings of step 230 and the following steps. Then, if it is determined in step 250 that fuel leakage or excessive injection has occurred, the ECU 60 performs the processings of steps 260 and 270 as is the case with the first embodiment. Further, if it is determined in step 250 that the force-feed performance of the fuel pump 30 has deteriorated, the ECU 60 sets the second abnormality flag XFAIL2 „ON" (step 265), then resets the provisional abnormality flag XFAIL „OFF" (step 290) and terminates the present routine temporarily.

[0099] According to the processing of abnormality determination of the second embodiment that has been described hitherto, it is determined whether or not only fuel injection is carried out during the second abnormality determination period APCR2. The second abnormality determination is made on condition that it has been determined that only fuel injection is carried out.

[0100] Accordingly, not to mention the case where abnormality determination is not made, the range where the fuel force-feed timing or the fuel injection timing can be changed is not restricted even in the case where abnormality determination is made.

[0101] Consequently, in comparison with the first embodiment, it is possible to further enlarge a range where the fuel force-feed timing or the fuel injection timing can be changed.

[0102] In the aforementioned respective embodiments, at the time of the second abnormality determination, a rail pressure change amount during the period from the timing for detecting the post-injection fuel pressure PCRI to the subsequent timing for detecting the post-force-feed fuel pressure PCRP (during the period CAB1 to CAA1, CAB2 to CAA2, CAB3 to CAA3,......or the like shown in Fig. 2) may actually be measured. The rail pressure change amount during this period may be estimated based on a fuel force-feed amount and a fuel leakage amount, and the occurrence of an abnormality may be confirmed when the difference (= the estimated value - the actual measurement value) between the actual measurement value and the estimated value exceeds a predetermined determination value. In this case, if it is determined in the second abnormality determination that there is an abnormality occurring, the content of the abnormality can be determined to be either deterioration of the force-feed performance of the fuel pump 30 or leakage of fuel. Conversely, if it is determined that there is no abnormality occurring, the content of the abnormality can be determined to be excessive injection from the injectors 12.

[0103] Further, in the respective embodiments, the occurrence of an abnormality is determined by comparing an actual measurement value of rail pressure change amount with an estimated value of rail pressure change amount. However, the occurrence of an abnormality may be determined, for example, based on a comparison between an actual measurement value and an estimated value relating to a rate of change in rail pressure or a pattern of change in rail pressure.

[0104] The respective embodiments deal with a diesel engine as an internal combustion engine. However, the method of determining abnormality according to the present invention can also be applied to, for example, a high-pressure fuel injection device of a cylinder direct injection gasoline engine wherein fuel is directly injected to combustion chambers.

Claims

1. A method of determining abnormality which is applied to a high-pressure fuel injection system for supplying, through injection, high-pressure fuel that is force-fed from a fuel pump (30) to an accumulator line (20) from a fuel injection valve (12) connected to the accumulator line to an internal combustion engine (10), wherein occurrence of an abnormality in the high-pressure fuel injection system is determined through a comparison between an actual state of fuel in the accumulator line (20) during a predetermined determination period and a state of fuel estimated based on operation of the high-pressure fuel injection system, characterized in:

that a first method of abnormality determination is applied in a first period in which both force-feeding of fuel from the fuel pump (30) and fuel injection by the fuel injection valve (12) are carried out within the determination period; and

that occurrence of an abnormality is determined through a second determination method which is different from the first method of abnormality determination, in a second period in which only one of the force-feeding of fuel and the fuel injection is carried out within the determination period.

2. The method according to claim 1, characterized in:

that an actual amount of change in fuel pressure in the accumulator line is calculated as the actual state of fuel; that an estimated amount of change in fuel pressure in the accumulator line is calculated as the estimated state of fuel;
that a difference between the calculated estimated change amount and the actual change amount is calculated in the first period and the second period;
that the difference is compared with a first determination value in the first abnormality determination; and
that the difference is compared with a second determination value which is different from the first determination value, in the second abnormality determination.

3. The method according to claim 2, characterized in:

that the second determination value is smaller than the first determination value.

4. The method according to claim 1 or 2, characterized in:

that the second abnormality determination is made only if occurrence of an abnormality has been confirmed through the first abnormality determination within the determination period.

5. The method according to claim 1 or 2, characterized in:

that at least one of a fuel force-feed timing and a fuel injection timing is changed such that only one of force-feeding of fuel from the fuel pump and fuel injection from the fuel injection valve is carried out within the determination period.

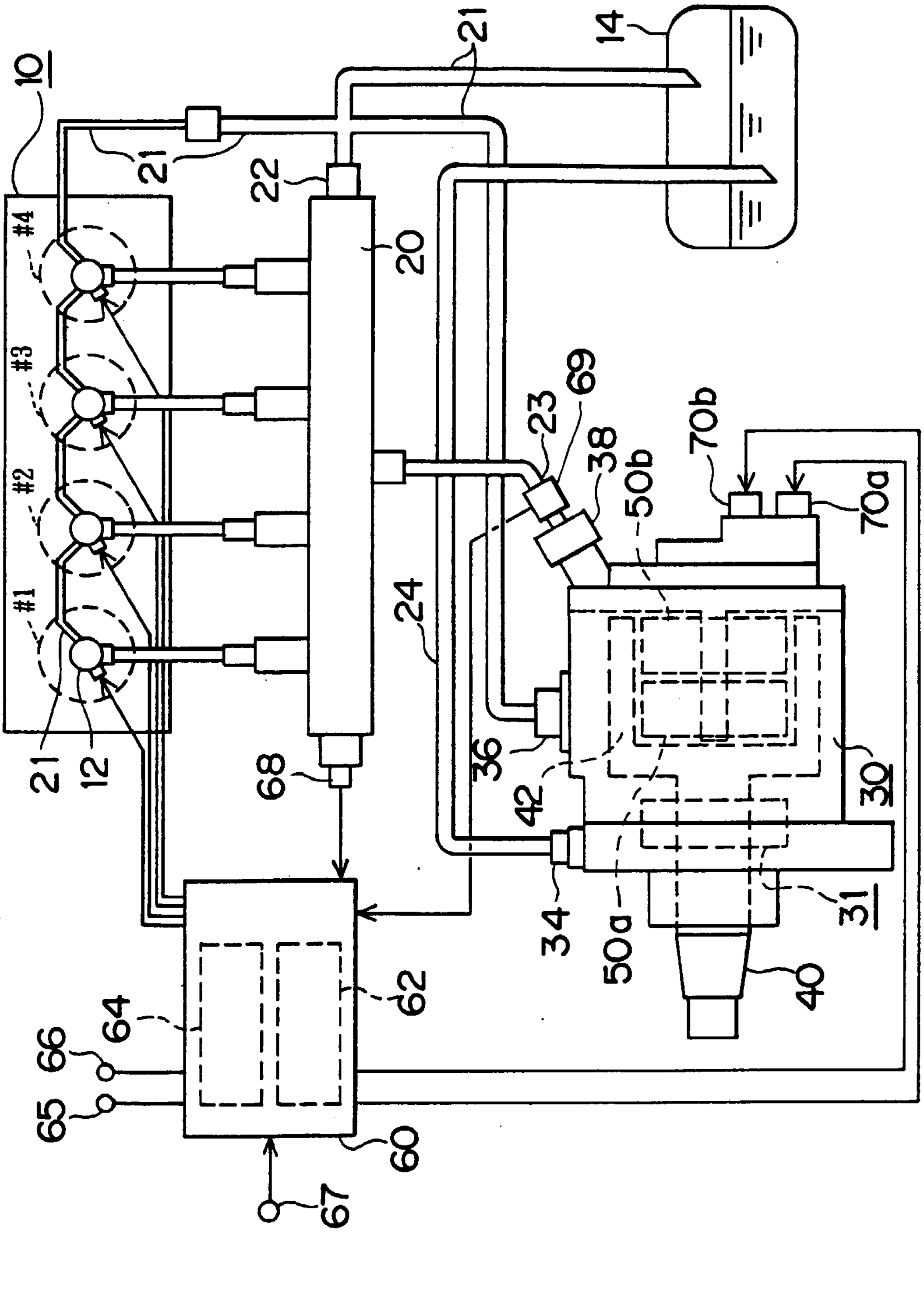
6. The method according to claim 5, characterized in:

that at least one of the fuel force-feed timing and the fuel injection timing is changed only if occurrence of an abnormality has been confirmed through the first abnormality determination.

7. The method according to claim 5 or 6, characterized in:

that only the fuel force-feed timing is changed.

FIG. 1


10
#1
#2
#3
#4
12
14
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22
23
24
30
31
34
36
38
40
42
50a
50b
60
62
64
65
66
67
68
69
70a
70b

FIG. 2

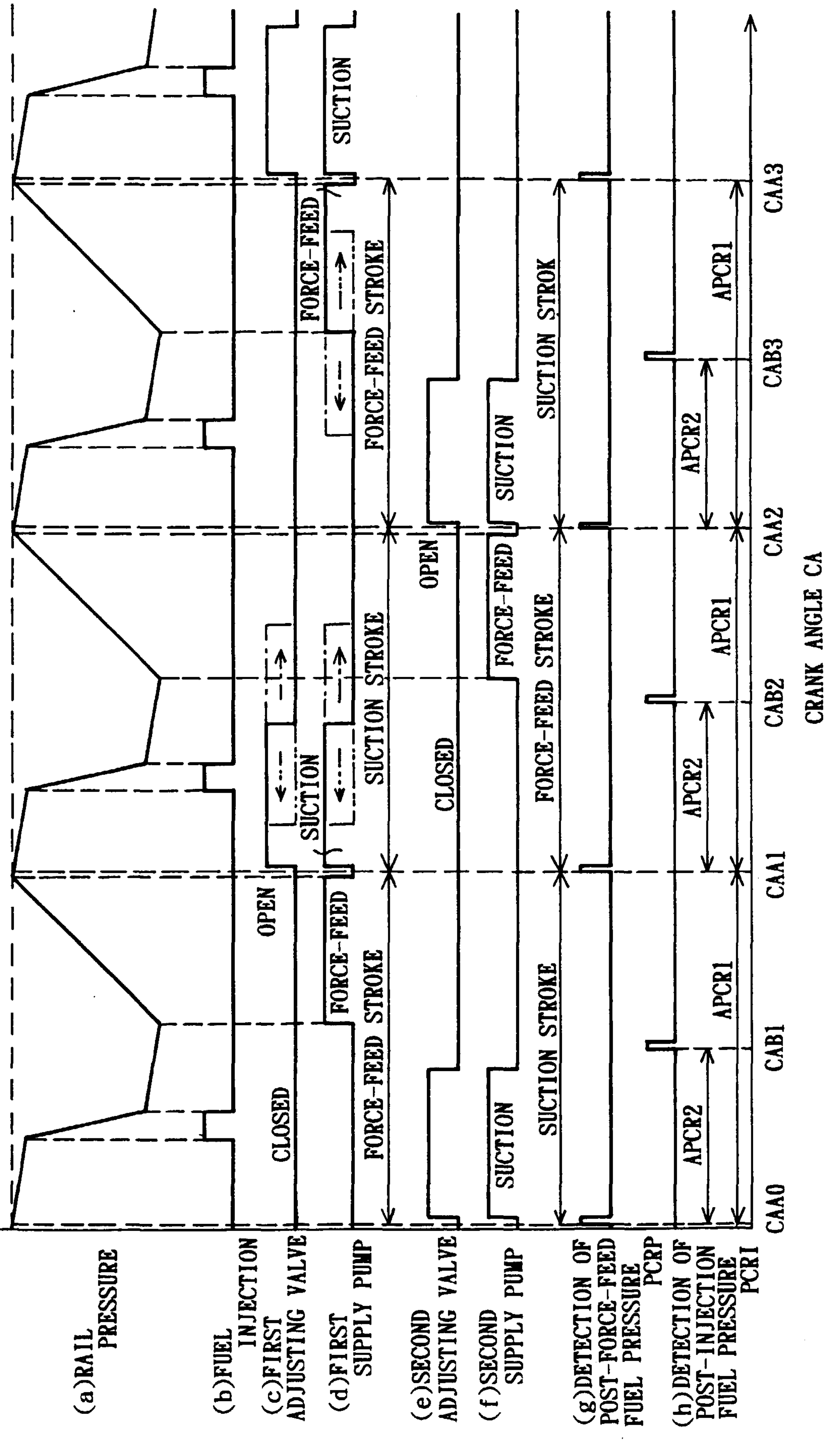

(a)RAIL PRESSURE
(b)FUEL INJECTION
(c)FIRST ADJUSTING VALVE
(d)FIRST SUPPLY PUMP
(e)SECOND ADJUSTING VALVE
(f)SECOND SUPPLY PUMP
(g)DETECTION OF POST-FORCE-FEED FUEL PRESSURE PCRP
(h)DETECTION OF POST-INJECTION FUEL PRESSURE PCRI
CLOSED
OPEN
SUCTION
FORCE-FEED
FORCE-FEED STROKE
SUCTION STROKE
SUCTION STROK
APCR1
APCR2
CAA0
CAB1
CAA1
CAB2
CAA2
CAB3
CAA3
CRANK ANGLE CA

FIG. 3

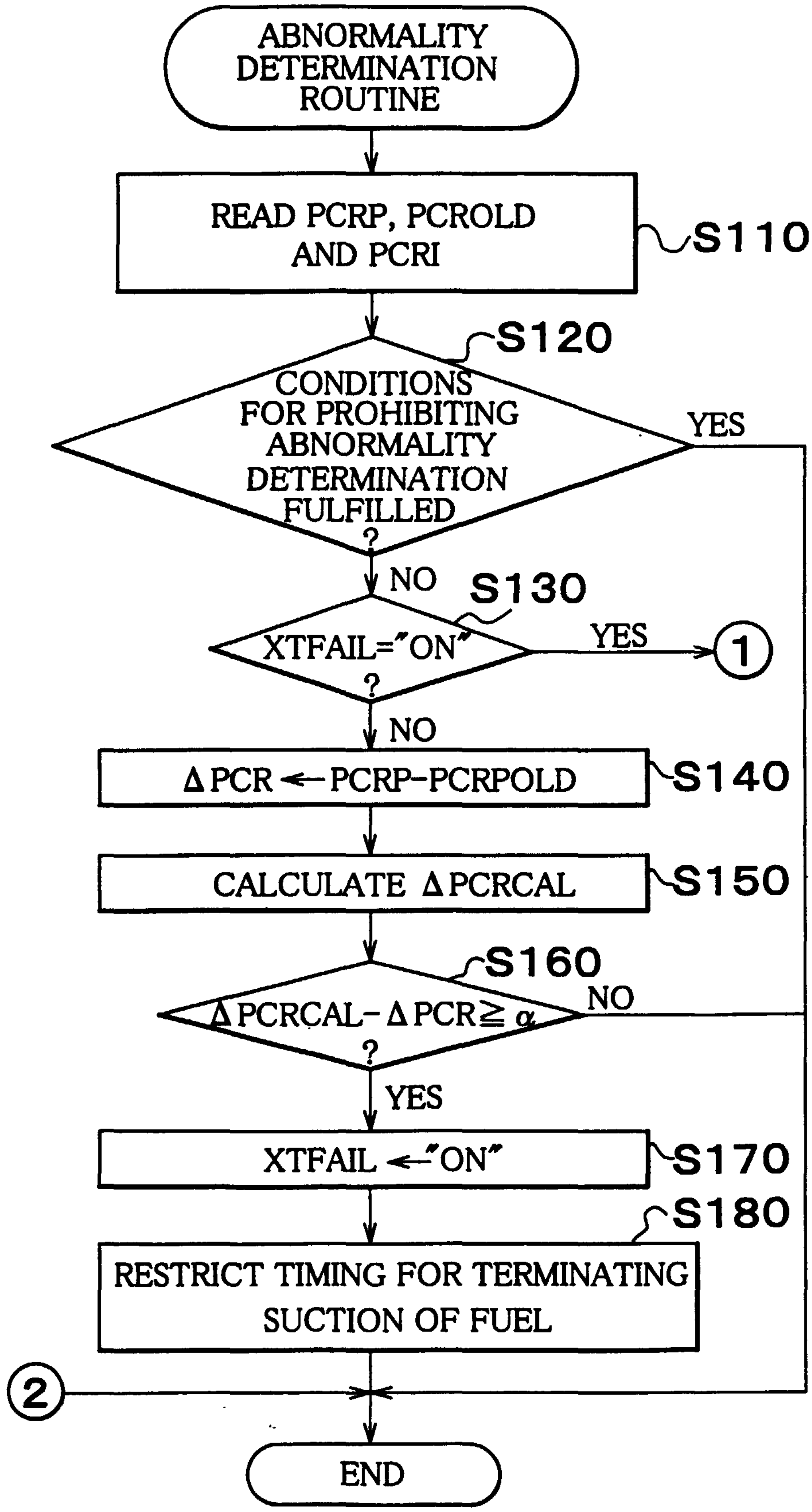

ABNORMALITY DETERMINATION ROUTINE
READ PCRP, PCROLD AND PCRI
S110
S120
CONDITIONS FOR PROHIBITING ABNORMALITY DETERMINATION FULFILLED ?
YES
NO
S130
XTFAIL="ON" ?
YES
1
NO
ΔPCR ← PCRP−PCRPOLD
S140
CALCULATE ΔPCRCAL
S150
S160
ΔPCRCAL−ΔPCR≧α ?
NO
YES
XTFAIL ← "ON"
S170
S180
RESTRICT TIMING FOR TERMINATING SUCTION OF FUEL
2
END

FIG. 4

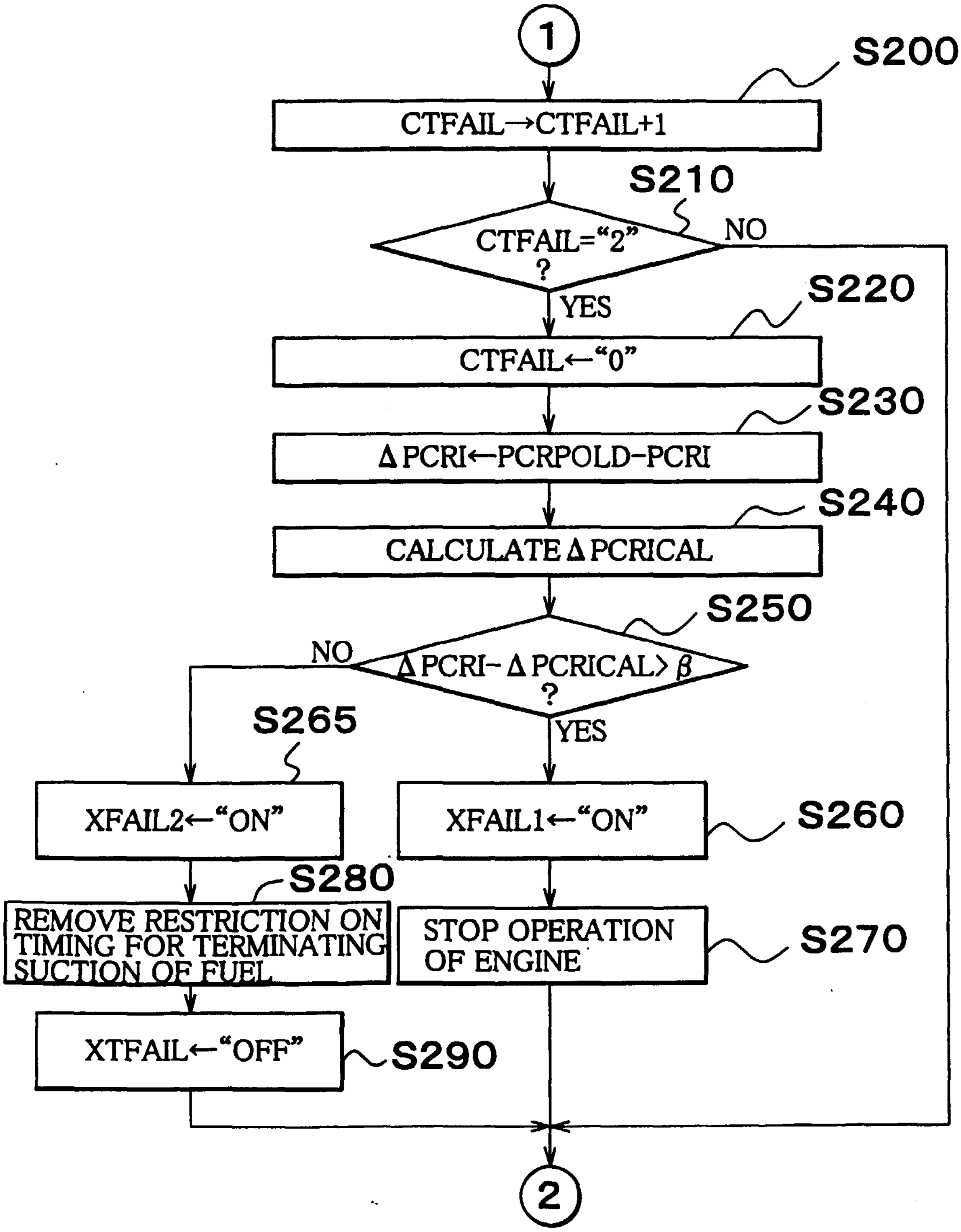

1
S200
CTFAIL→CTFAIL+1
S210
CTFAIL="2"
?
NO
YES
S220
CTFAIL←"0"
S230
ΔPCRI←PCRPOLD-PCRI
S240
CALCULATE ΔPCRICAL
S250
ΔPCRI-ΔPCRICAL>β
?
NO
YES
S265
XFAIL2←"ON"
XFAIL1←"ON"
S260
S280
REMOVE RESTRICTION ON TIMING FOR TERMINATING SUCTION OF FUEL
STOP OPERATION OF ENGINE
S270
XTFAIL←"OFF"
S290
2

FIG. 5

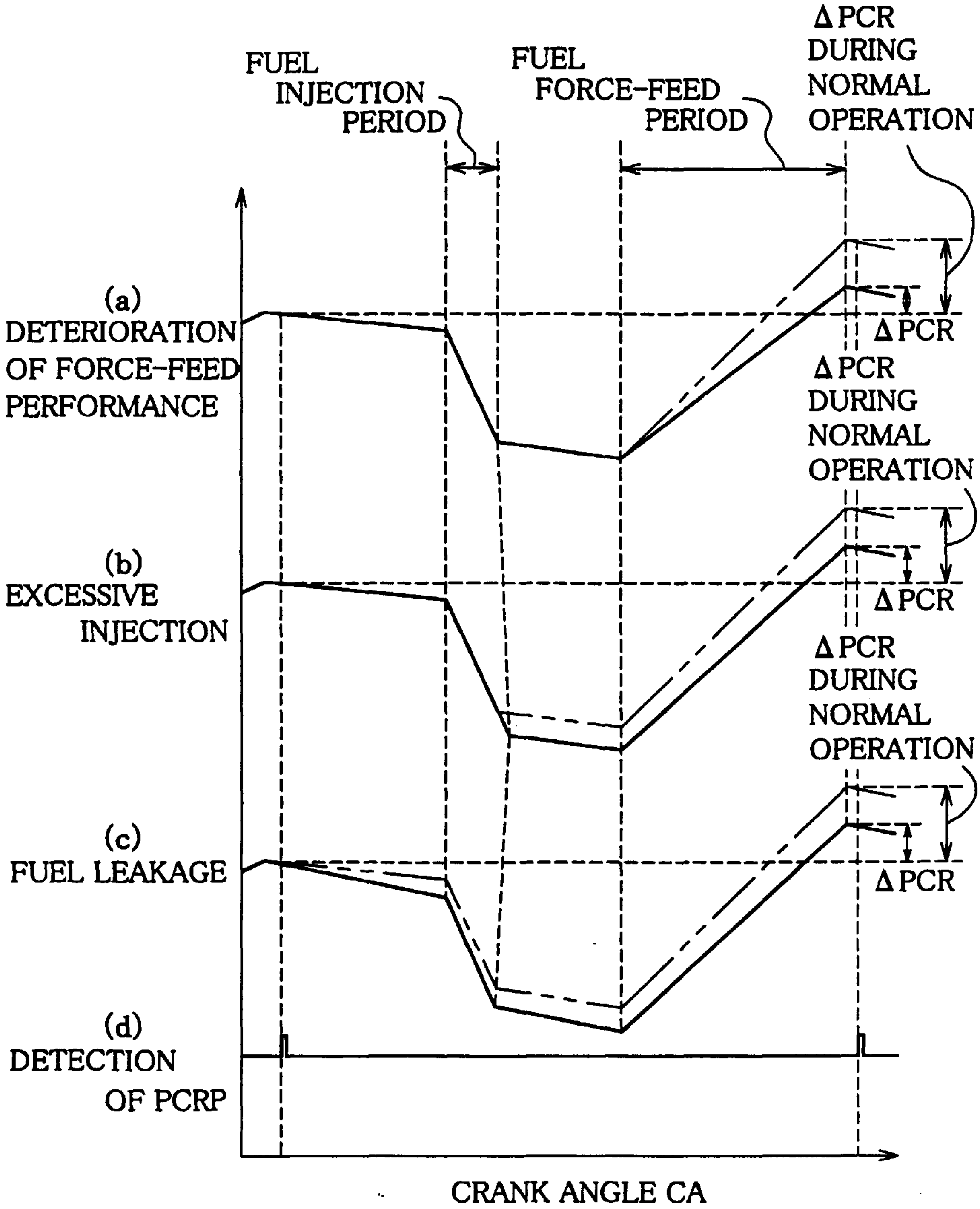
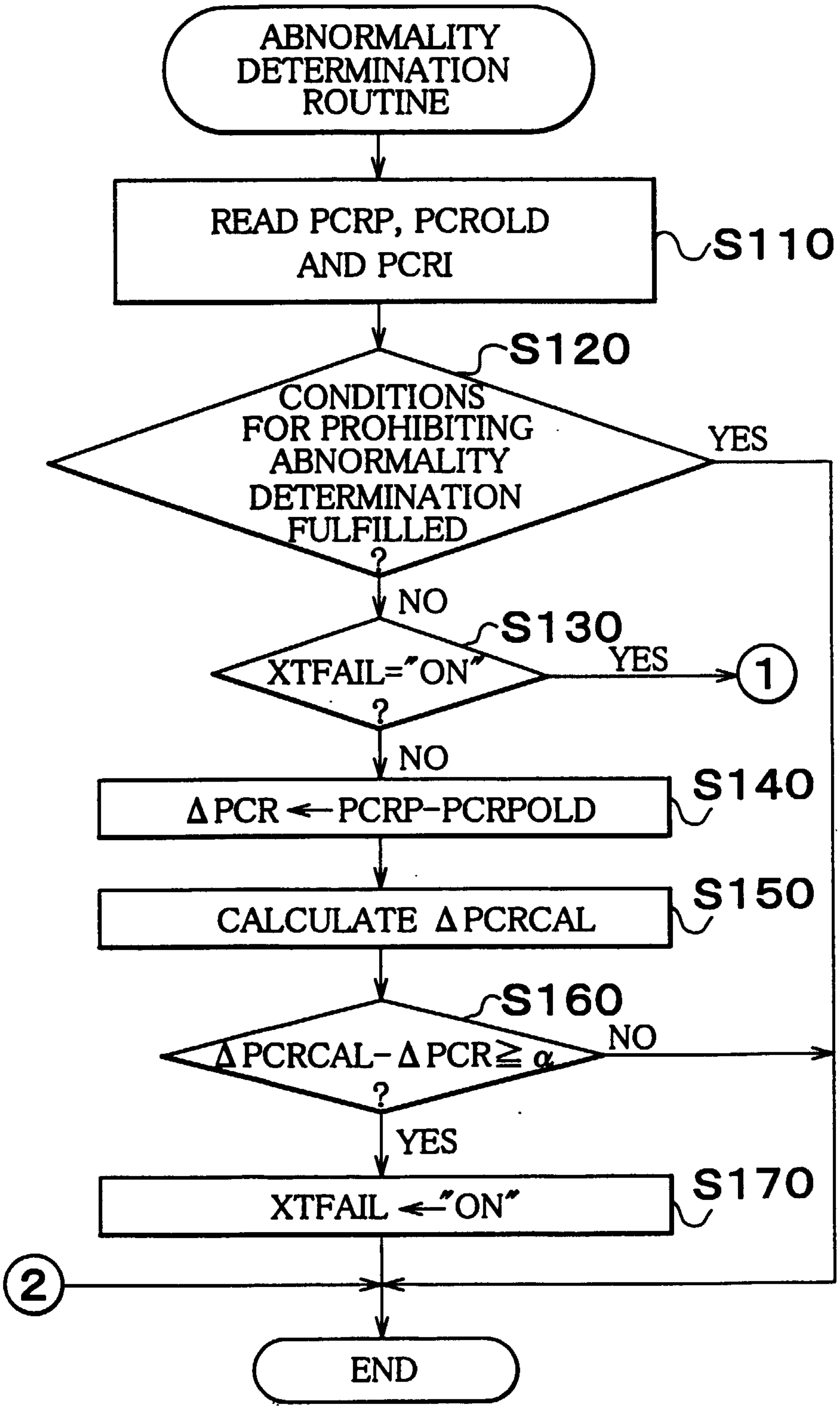
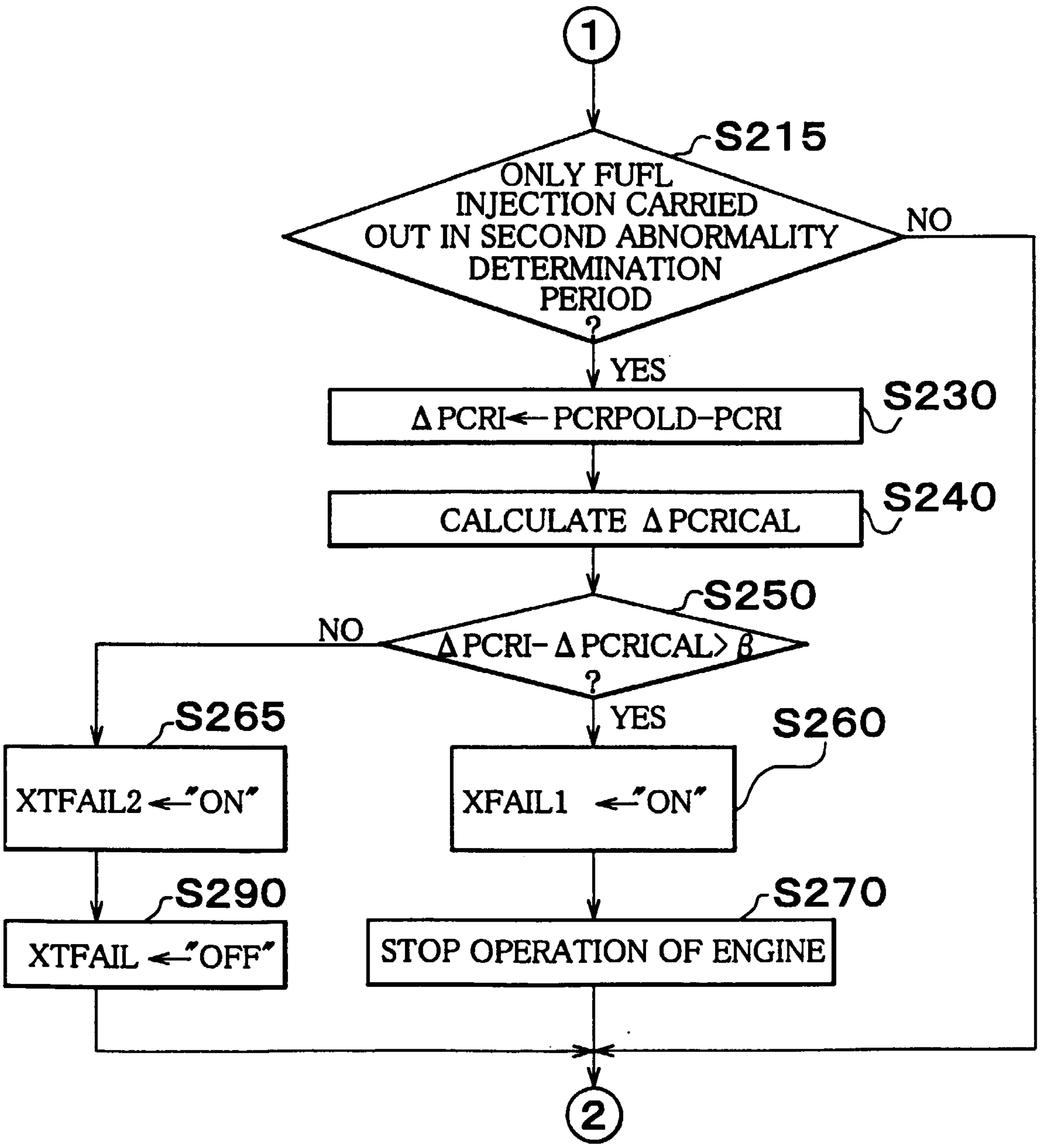

FUEL
INJECTION
PERIOD
FUEL
FORCE-FEED
PERIOD
ΔPCR
DURING
NORMAL
OPERATION
(a)
DETERIORATION
OF FORCE-FEED
PERFORMANCE
ΔPCR
ΔPCR
DURING
NORMAL
OPERATION
(b)
EXCESSIVE
INJECTION
ΔPCR
ΔPCR
DURING
NORMAL
OPERATION
(c)
FUEL LEAKAGE
ΔPCR
(d)
DETECTION
OF PCRP
CRANK ANGLE CA

FIG. 6


ABNORMALITY DETERMINATION ROUTINE
READ PCRP, PCROLD AND PCRI
S110
S120
CONDITIONS FOR PROHIBITING ABNORMALITY DETERMINATION FULFILLED ?
YES
NO
S130
XTFAIL="ON" ?
YES
1
NO
ΔPCR ← PCRP−PCRPOLD
S140
CALCULATE ΔPCRCAL
S150
S160
ΔPCRCAL−ΔPCR≧α ?
NO
YES
XTFAIL ←"ON"
S170
2
END

F I G. 7


1
S215
ONLY FUFL INJECTION CARRIED OUT IN SECOND ABNORMALITY DETERMINATION PERIOD ?
NO
YES
ΔPCRI←PCRPOLD−PCRI
S230
CALCULATE ΔPCRICAL
S240
S250
NO
ΔPCRI−ΔPCRICAL>β ?
YES
S265
XTFAIL2←"ON"
S260
XFAIL1 ←"ON"
S290
XTFAIL ←"OFF"
S270
STOP OPERATION OF ENGINE
2