



(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
02.05.2002 Bulletin 2002/18

(51) Int Cl.⁷: **F02D 41/38**, F02D 41/22

(21) Application number: **01125541.1**

(22) Date of filing: **25.10.2001**

(84) Designated Contracting States:
**AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE TR**
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 27.10.2000 JP 2000329448

(71) Applicants:

- **TOYOTA JIDOSHA KABUSHIKI KAISHA**
Aichi-ken 471-8571 (JP)
- **Denso Corporation**
Kariya-city, Aichi-pref., 448-8661 (JP)

(72) Inventors:

- **Murakami, Motoichi**
Toyota-shi, Aichi-ken, 471-8571 (JP)
- **Sugiyama, Tatsumasa**
Toyota-shi, Aichi-ken, 471-8571 (JP)
- **Takemoto, Eiji, c/o Intellectual Property Center**
Kariya-city, Aichi-pref., 448-8661 (JP)

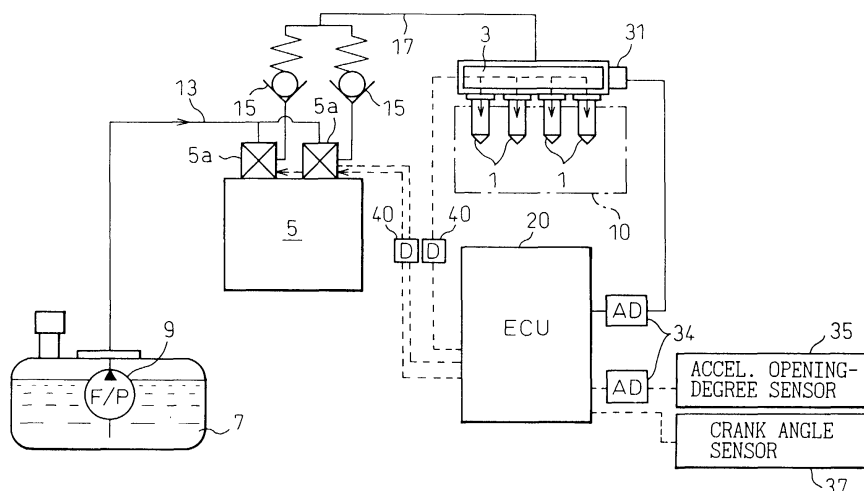
(74) Representative:
Leson, Thomas Johannes Alois, Dipl.-Ing.
Tiedtke-Bühling-Kinne & Partner GbR,
TBK-Patent,
Bavariaring 4
80336 München (DE)

(54) **A device for detecting failure in a high pressure fuel supply system**

(57) Fuel of a high pressure is supplied from a high-pressure fuel injection pump 5 into a common-rail 3, and is, then, supplied to the fuel injection valves 1 from the common-rail. A control circuit (ECU) 20 compares a change in the fuel pressure in the common-rail detected by a fuel pressure sensor 31 during a judging period with an estimated value of change in the pressure during the

judging period to judge the leakage of fuel from the common-rail. The judging period is set to take place in a period in which it is estimated that the fuel flows in the least amount into a pressure-accumulating chamber in the former half or in the latter half of the fuel supply stroke of the fuel pump. This minimizes the effect of fuel flowing into the common-rail, and improves the accuracy of leakage detection.

Fig.1



Description

TECHNICAL FIELD

[0001] The present invention relates to a device for detecting a failure in a high-pressure fuel supply system. More specifically, the invention relates to a device for detecting a failure such as a leakage of fuel from a high-pressure fuel injection system of an internal combustion engine.

BACKGROUND ART

[0002] A common-rail type high-pressure fuel injection system is known in the art. In the common-rail type fuel injection system, fuel is supplied to a common pressure-accumulating chamber (a common-rail) from a high-pressure fuel pump and the high-pressure fuel in the common-rail is injected into the respective cylinders from fuel injection valves connected to the common-rail.

[0003] The common-rail type fuel injection system uses fuel at a very high pressure. It is, hence, necessary to reliably detect a failure such as leakage of fuel from any part of the system. For this purpose, there have been proposed various methods of detecting a failure such as leakage of fuel.

[0004] A method of detecting failure of this kind has been disclosed in, for example, Japanese Unexamined Patent Publication (Kokai) No. 10-299557. The device of this publication includes a pressure sensor for detecting the fuel pressure in the common-rail, and failure detection means. The failure detection means measures a difference in the fuel pressure in the common-rail before and after the fuel is injected from the fuel injection valve, i.e., measures a pressure drop in the common-rail due to the fuel injection. The failure detection means further estimates the pressure drop in the common-rail due to the fuel injection based on the fuel injection amount determined by the engine operating conditions and a change in the bulk modulus of elasticity of fuel due to the temperature and pressure. The failure detection means in the '557 publication determines that the fuel injection system has failed when a difference between the measured pressure drop and the estimated pressure drop is larger than a predetermined judging value.

[0005] That is, in the above-mentioned device, the amount Q of fuel per one time of injection is calculated from the operation condition (load) of the internal combustion engine, and an estimated drop ΔP of fuel pressure in the common-rail before and after the fuel injection is calculated based on the fuel injection amount Q by a formula $\Delta P = (K/V) \times Q$. Here, K in the above formula is a bulk modulus of elasticity of the fuel, V is a volume of a high-pressure portion including a volume of the common-rail, a volume of a high-pressure supply pipe up to the common-rail and a volume of a pipe from the common-rail to a fuel injection valve, and V is a con-

stant. Further, the bulk modulus of elasticity K is determined based upon an actual fuel pressure detected by the pressure sensor before or after the fuel injection and upon a temperature. In the common-rail-type fuel injection device, in general, the fuel pressure varies over a very wide range (e.g., from 10 MPa to 150 MPa) depending upon the operating conditions. By determining the bulk modulus of elasticity based upon the actual fuel pressure and temperature at the time of the failure detection, a failure, such as the leakage of the system can be precisely determined.

[0006] A drop of pressure in the common-rail before and after the fuel injection varies in proportion to the amount of fuel that flows out from the common-rail within a period for detecting the drop of pressure (within a judging period). Therefore, when the amount of fuel flowing out from the common-rail before and after the fuel injection is equal to Q, the measured drop of pressure in the common-rail before and after the fuel injection will become equal to the above estimated value ΔP . Therefore, when the difference between the measured drop of pressure in the common-rail and the estimated value ΔP thereof is larger than the predetermined judging value, e.g., when the actual drop of pressure is larger than the estimated value ΔP by more than a certain degree, it means that the amount of fuel actually flowing out from the common-rail is larger than the fuel injection amount Q. It can therefore be determined that the fuel is leaking from the fuel system (common-rail, fuel injection valves, etc.).

[0007] When detecting a failure, such as leakage of fuel, based on a change in the pressure in the common-rail before and after the fuel injection as taught in the '557 publication, however, it is necessary that the period of fuel injection and the period of supplying the high pressure fuel from the fuel pump do not overlap each other.

[0008] That is, when the period of fuel injection overlaps the supply period of the high-pressure fuel, it happens that some fuel flows out from the common-rail due to the fuel injection and, at the same time, some fuel flows into the common-rail due to the fuel supply from the fuel pump. Therefore, the drop of pressure due to the fuel injection is canceled by the rise of pressure due to fuel that is flowing in. Therefore, the drop of the pressure in the common-rail before and after the fuel injection often becomes small despite fuel having actually leaked from the common-rail. Even in this case, the leakage of fuel can be determined correctly if the amount of fuel supplied to the common-rail from the fuel pump during the fuel injection period is accurately calculated. However, the fuel is not continuously supplied to the common-rail throughout the supply period by the fuel pump, and it is difficult to accurately calculate the amount of fuel actually supplied to the common-rail during the fuel injection period. For example, if a fuel pump of a suction-regulating capacity control type is used, the discharge amount of the pump is controlled by adjusting

the timing of an effective supply (discharge) stroke of the pump. Namely, the effective supply stroke in which the fuel is actually discharged from the pump starts some time after the mechanical (geometrical) supply stroke of the pump has started, and the time between the start of the effective supply stroke and the start of the mechanical supply stroke is adjusted in order to control the discharge amount of the pump. Further, there exists dispersion in the timing of the start of the effective fuel supply stroke and the fuel supply rate (the amount of fuel discharged by the fuel pump per a unit time during the effective fuel supply stroke, depending upon the individual pumps. It is therefore difficult to accurately calculate the amount of fuel flowing into the common-rail within a specific period (e.g., period between detecting pressure before and after the fuel injection).

[0009] The fuel injection device disclosed in the '557 publication uses a pump that supplies the fuel to a four-cylinder internal combustion engine twice per one revolution of the engine. Therefore, it is possible to set the fuel supply period of the pump so that the fuel supply period does not overlap the fuel injection period. However, when a fuel pump that injects fuel one time per a revolution of the engine is used, as the fuel is injected twice during one fuel supply period, it is inevitable that the fuel is supplied to the common-rail during the fuel injection period.

DISCLOSURE OF INVENTION

[0010] In view of the problems as set forth above, it is an object of the present invention to provide a device, for detecting a failure in a high-pressure fuel supply system, which makes it possible to correctly detect any failure in the fuel system by minimizing the effect of the fuel that flows into the common-rail during the judging period even when a fuel pump which has a relatively long fuel supply period is used.

[0011] According to the present invention, there is provided a device, for detecting a failure in a high-pressure fuel supply system comprising, a fuel injection valve for injecting the fuel into an internal combustion engine at a predetermined injection timing, a pressure-accumulating chamber for storing the pressurized fuel and to which the fuel injection valve is connected, a fuel pump for supplying pressurized fuel to the pressure-accumulating chamber during a predetermined fuel supply period in such a manner that the pressure of fuel in the pressure-accumulating chamber becomes a predetermined value, and pressure detecting means for detecting the fuel pressure in the pressure-accumulating chamber, wherein failure in the fuel supply system is detected by comparing a change in the fuel pressure in the pressure-accumulating chamber detected by the pressure detecting means during a predetermined judging period with an estimated value of change in the fuel pressure in the pressure-accumulating chamber during the judging period calculated based upon the engine op-

erating conditions, characterized in that, the fuel is injected from the fuel injection valve during the fuel supply period of the fuel pump, and the judging period is set in such a manner that an expected amount of the fuel actually supplied to the pressure-accumulating chamber during the judging period becomes a minimum.

[0012] That is, in the present invention, a change in the pressure is detected in a period in which it is expected that the amount of fuel flowing into the pressure-accumulating chamber from the fuel pump becomes a minimum. Usually, there exists a period in which no fuel is supplied from the pump to the pressure-accumulating chamber during the supply stroke in order to control the amount of supplying fuel into the pressure-accumulating chamber. The period in which no fuel is supplied varies depending upon the engine operating conditions such as the load and the rotational speed of the engine, and is set to take place in the former half of the fuel supply stroke of the pump or in the latter half thereof depending upon the flow rate control system of the fuel pump. In the present invention, the period in which the pressure in the pressure-accumulating chamber is detected is selected in such a manner that, considering the type of the capacity control of the pump, the expected fuel supply amount to the pressure-accumulating chamber becomes smallest, i.e., in a period in which it is most probable that no fuel is supplied to the pressure-accumulating chamber from the fuel pump. Therefore, the effect of fuel flowing into the pressure-accumulating chamber during the period of supplying fuel is minimized and the accuracy of failure detection can be increased even when a pump having an extended fuel supply period is used.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013]

Fig. 1 is a diagram schematically illustrating the constitution of an embodiment the present invention when it is applied to a high-pressure fuel supply system of an automotive diesel engine;

Fig. 2 is a diagram of timings illustrating a geometrical fuel supply rate of a fuel pump and a change in the pressure in a common-rail when there is no fuel leakage;

Fig. 3 is a diagram explaining the setting of a judging period;

Figs. 4A through 4C are diagrams illustrating a method for setting a judging period which is different from that of Fig. 3;

Fig. 5 is a diagram illustrating the setting of the judging period based on the method of Figs. 4A through 4C; and

Fig. 6 is a diagram illustrating another embodiment of the present invention in which the accuracy for judging the leakage is increased by changing the cam profile of the fuel pump.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0014] Embodiment of the invention will now be described with reference to the accompanying drawings.

[0015] Fig. 1 is a diagram schematically illustrating the constitution of an embodiment of the present invention when it is applied to an automotive diesel engine.

[0016] In Fig. 1, reference numeral 1 denotes fuel injection valves for directly injecting the fuel into the cylinders of an internal combustion engine 10 (four-cylinder diesel engine in this embodiment), and 3 denotes a common pressure-accumulating chamber (common-rail) to which the fuel injection valves 1 are connected. The common-rail 3 has a function of storing the pressurized fuel supplied from a high-pressure fuel supply pump (hereinafter referred to as "fuel pump") and distributing the fuel to each of the fuel injection valves 1. The fuel pump will be explained later.

[0017] In Fig. 1, further, reference numeral 7 denotes a fuel tank storing the fuel (diesel oil in this embodiment) of the engine 10, and reference numeral 9 denotes a low-pressure feed pump for supplying the fuel to the fuel pump through a low-pressure pipe 13.

[0018] The fuel discharged from the fuel pump 5 is supplied to the common-rail 3 through a high-pressure pipe 17, and is injected into the cylinders of the internal combustion engine from the common-rail through the fuel injection valves 1.

[0019] In Fig. 1, reference numeral 20 denotes an electronic control unit (ECU) for controlling the engine. The ECU 20 is a microcomputer of a known type including a read-only memory (ROM), a random access memory (RAM), micro processor (CPU) and an input/output port, which are connected together through a bi-directional bus. As will be described later, the ECU 20 executes the fuel pressure control operation by adjusting the amount of fuel supplied to the common-rail 3 from the fuel pump 5 by controlling the opening/closing operation of a suction-regulating valve 5a of the fuel pump 5, and by controlling the fuel pressure in the common-rail 3 according to the load and rotational speed of the engine. The ECU 20 further controls the amount of fuel injected into the cylinders by controlling the valve-opening time of the fuel injection valve 1.

[0020] In order to carry out the above control operation, the input port of the ECU 20 receives, through an AD converter 34, a voltage signal corresponding to the fuel pressure in the common-rail 3 from a fuel pressure sensor 31 disposed on the common-rail 3 and, further, receives, through another AD converter 34, a signal corresponding to the operation amount (amount of depression) of the accelerator pedal from an accelerator opening-degree sensor 35 provided for an engine accelerator pedal (not shown).

[0021] The input port of the ECU 20 further receives, from a crank angle sensor 37 disposed near the crank shaft (not shown) of the engine, two signals, i.e., a reference pulse signal generated when the crank shaft ar-

rives at a reference rotational position (e.g., the top dead center of a first cylinder) and a rotational pulse signal that is generated at every predetermined rotational angle of the crank shaft.

[0022] The ECU 20 calculates the rotational speed of the crankshaft from the interval between the rotational pulse signals and detects the rotational angle (phase) of the crankshaft by counting the number of the rotational pulse signals received after the reference pulse signal is received.

[0023] The output port of the ECU 20 is connected to the fuel injection valves 1, through a drive circuit 40, to control the operation of the fuel injection valves 1, and is further connected, through another drive circuit 40, to a solenoid actuator that controls the opening/closing of the suction-regulating valve 5a of the fuel pump 5 in order to control the fuel supply amount of the pump 5.

[0024] In this embodiment, the fuel pump 5 is of a plunger type pump having two cylinders. A plunger in each cylinder of the pump 5 reciprocates in the cylinder by being pushed by a cam formed on a plunger drive shaft in the pump. The suction port of each cylinder is provided with a suction-regulating valve that is opened and closed by a solenoid actuator. In this embodiment, the plunger drive shaft is driven by the crankshaft (not shown) of the engine 10, and is rotated at a speed one-half that of the crank shaft in synchronism therewith. Further, on the plunger drive shaft of the pump 5 is formed a cam having a lifting portion at a portion that comes into engagement with the plunger. The plunger of the pump 5 discharges the fuel in synchronism with the stroke of each cylinder of the engine 10. In this embodiment, the two cylinders of the pump 5 supply the pressurized fuel to the common-rail 3 one time, respectively, as the crankshaft rotates 720 degrees in synchronism with the engine revolution. Namely, in this embodiment, the pressurized fuel is supplied twice from the fuel pump 5 while the crank shaft of the engine 10 rotates 720 degrees, and the fuel is injected for the two cylinders (twice) per one time of fuel supply from the fuel pump 5.

[0025] This embodiment controls the discharge amount of the fuel pump by a so-called suction-regulating type control, in which the ECU 20 changes the valve-closing timing of the suction-regulating valve 5a in the down (suction) stroke of the plunger in each cylinder of the pump thereby to control the discharge amount of fuel in the supply stroke of the fuel pump 5. That is, in this embodiment, as the cylinder starts the suction stroke passing over the cam lift apex portion, the ECU 20 supplies an electric current to the solenoid actuator of the suction-regulating valve 5a for a predetermined period after the start of the suction stroke to maintain the suction-regulating valve 5a opened. Therefore, the fuel flows into the cylinder as the plunger descends. After the passage of the above-predetermined period, the ECU 20 stops the supply of the electric current to the solenoid actuator, so that the suction-regulating valve 5a is closed. In the subsequent suction stroke, there-

fore, since no fuel is supplied to the cylinder, the plunger is maintained lowered, and the plunger stays away from the cam. Then, as the supply stroke starts again and the cam rotates up to a position to come into contact with the plunger held at the lowered position, the plunger is moved by being pushed by the cam. Accordingly, the fuel is actually discharged from the fuel pump 5 and is supplied to the common-rail 3 passing through a check valve 15. In this case, the fuel is supplied from each cylinder to the common-rail 3 by only an amount that is charged into a pump chamber during the suction stroke. By controlling the valve-opening time of the suction-regulating valve 5a, therefore, the amount of fuel supplied to the common-rail 3 can be controlled precisely. In the suction-regulating type control of the fuel pump 5, as described above, the supply of fuel to the common-rail 3 is stopped after the supply (discharge) stroke of the fuel pump starts for a period determined by the amount of fuel to be supplied to the common-rail 3.

[0026] In this embodiment, the ECU 20 sets a target fuel pressure in the common-rail based on the engine load and the engine speed using the relationship stored in advance in the ROM, and feedback controls the discharge amount of the pump 5, so that the fuel pressure in the common-rail detected by the fuel pressure sensor 31 becomes equal to the target fuel pressure. The ECU 20 further controls the valve-opening time (fuel injection time) of the fuel injection valve 1 based upon the engine load and the engine speed using a predetermined relationship stored, in advance, in the ROM.

[0027] In this embodiment, the fuel pressure in the common-rail 3 is varied, depending upon the engine operating conditions, to adjust the injection rate of the fuel injection valve 1 in accordance with the operating conditions, and the amount of fuel injection is adjusted in accordance with the operating conditions by varying the fuel pressure and the fuel injection time. In the common-rail-type fuel injection device as in this embodiment, therefore, the fuel pressure in the common-rail varies over a very wide range (over a range of, for example, from about 10 MPa to about 150 MPa) depending upon the operating conditions (such as engine load and speed) of the engine.

[0028] Next, a principle of failure detection in the fuel injection system according to the embodiment will be explained.

[0029] Fig. 2 is a diagram of timings illustrating a geometrical fuel supply rate of the fuel pump 5 and a change in the pressure in the common-rail when there is no fuel leakage. The rate of fuel supply is expressed by a product of the amount of displacement of the plunger per a unit crank angle and the sectional area of the cylinder, i.e., a volume of the fuel discharged from the fuel pump per the unit crank angle when the fuel suction amount is not regulated. The horizontal axis in Fig. 2 represents the crank angle CA.

[0030] Fig. 2 illustrates a change in the rate of fuel supply and pressure in one cycle of the fuel pump 5 (a

crank rotational angle of the engine 10 of 720 degrees). In this period, the two cylinders (cylinders #1 and #2) of the fuel pump 5 execute the fuel supply stroke one time, respectively. Further, since a four-cylinder engine is used in this embodiment, the fuel is injected a total of four times. Therefore, the fuel is injected twice in each supply stroke of the fuel pump 5, i.e., the fuel is injected during the supply stroke. In Fig. 2, symbols FJ1, FJ2, FJ3 and FJ4 denote fuel injection timings in the supply strokes. As shown in Fig. 2, the fuel is injected one time in each of the former halves (FJ1, FJ3) and in each of the latter halves (FJ12, FJ14) of the supply strokes of the cylinders #1 and #2.

[0031] In this embodiment, a failure such as leakage in the fuel supply system is detected based on a change in the pressure in the common-rail within a predetermined period (judging period).

[0032] That is, if the whole volume of the high-pressure fuel supply system inclusive of the common-rail 3 is denoted by VPC, the bulk modulus of elasticity of the fuel under the fuel pressure and at a temperature in the common-rail 3 by K, the volume of fuel flowing out from the common-rail 3 during the judging period by QOUT, and the volume of fuel flowing into the common-rail during the judging period by QIN, then, the difference DPD in the common-rail pressure between the start and the end of the judging period is expressed by the following formula,

$$DPD = (K/VPC) \times (QIN - QOUT) \quad (1)$$

[0033] The amount of fuel QOUT flowing out from the common-rail 3 is, for example, the sum of the amount of fuel injected during the judging period and the steady leakage from the fuel injection valve. The amount of fuel QIN flowing into the common-rail 3 is the amount of fuel supplied into the common-rail 3 from the fuel pump 5. The volumes in the above formula are all expressed in terms of volumes calculated under a standard pressure (e.g., 0.1 MPa). In this embodiment, failure in the common-rail 3 is determined by comparing the amount of change DPD in the pressure during the judging period calculated from the above formula (1) with the difference DPDA (= CP2 - CP1) between the actual common-rail pressures CP1 and CP2 (Fig. 2) detected by the pressure sensor 31 at the start and end of the judging period. That is, when the actual change DPDA in the common-rail pressure is smaller than the estimated value DPD of change in the pressure calculated from the formula (1) (i.e., DPDA < DPD < 0), it means that the amount of fuel flowing out from the common-rail is larger than the expected value QOUT, and it is determined that the leakage has occurred in the high-pressure fuel supply system that includes the fuel injection valves 1, common-rail 3 and the like.

[0034] In order to judge the leakage based on the estimated value DPD of change in the pressure, however,

QOUT and QIN must be accurately estimated. The amount of fuel injection has been accurately controlled by the ECU 20 and can be precisely estimated. The amount of steady leakage from the fuel injection valve can be accurately estimated to some extent, too. Therefore, the accuracy of in the estimation of QOUT is relatively high. However, it is difficult to accurately estimate the amount of fuel supplied to the common-rail 3 from the fuel pump 5 in a specific period.

[0035] The rate of fuel supply at each moment in the supply stroke of the fuel pump 5 varies within manufacturing tolerance in the individual fuel pumps. The sum of the amount of fuel supplied to the common-rail 3 per one time of supply stroke of the fuel pump 5 is feedback controlled based upon the pressure in the common-rail 3. If the whole supply stroke is considered, therefore, the amount of fuel supplied to the common-rail 3 is accurately controlled. Due to dispersion in the rate of fuel supply depending upon the fuel pumps, however, it is difficult to accurately calculate the amount of fuel flowing into the common-rail 3 from the fuel pump 5 within a specific period selected from the supply period. To correctly judge the leakage using the above formula (1), therefore, the tolerance must be strictly managed for each of the fuel pumps 5 to minimize the dispersion in the rate of fuel supply for each of the fuel pumps. This causes the increase in the manufacturing cost of the fuel pump 5.

[0036] However, it will be noted, from Fig. 2, that the probability of the actual fuel supply occurring in the former half of the supply stroke is very low.

[0037] In effecting the discharge amount control operation of the fuel pump by the suction-regulating type control as described above, an actual period for supplying the fuel to the common-rail 3 (an effective supply stroke) starts after the passage of a predetermined stop period from the start of the supply stroke of the fuel pump 5 (Fig. 2). The stop period decreases with an increase in the amount of fuel supplied to the common-rail 3, i.e., decreases with an increase in the engine load. The stop period almost does not exist in a state where the load is very large. Under normal operating conditions in which the engine load is not very large, however, the stop period always exists in the former half of the supply stroke of the fuel pump 5. In the stop period, no fuel is supplied to the common-rail 3 from the fuel pump 5. Accordingly, $QIN = 0$ holds irrespective of dispersion in the rate of fuel supply during the stop period of the supply stroke of the fuel pump 5.

[0038] In this embodiment, therefore, the judging period for measuring the change in the pressure in the common-rail 3 is started simultaneously with the start of the supply stroke of the fuel pump 5 as shown in Fig. 2 (point a), in order to increase the probability that the measuring of the change in the pressure is carried out during the stop period in the former half of the supply stroke.

[0039] That is, in this embodiment, by setting the judg-

ing period in the former half of the supply stroke of the fuel pump 5, $QIN = 0$ can be assumed for the formula (1) to calculate DPD as,

$$DPD = -(K/VPC) \times QOUT \quad (2)$$

[0040] Then, by using an actual change in the pressure $DPDA = CP2 - CP1$ calculated from the pressures $CP1$ and $CP2$ in the common-rail 3 detected by the pressure sensor 31 at the start (point a in Fig. 2) and at the end (point b in Fig. 2) of the judging period, it is judged that failure such as leakage has occurred in the high-pressure fuel supply system when $DPDA < DPD$ (note that $DPDA$ and DPD are negative values).

[0041] Further, $QOUT$ in the above formula (2) is the sum of the amount of fuel injected from the fuel injection valve and the amount of the steady leakage. When the judging period is not overlapping the fuel injection timing, judgment can be performed by assuming that the value $QOUT$ is only a steady leakage.

[0042] However, when the leakage is determined based on the difference between the estimated value and the actual value of the change in the pressure in the common-rail in the judging period in the former half of the fuel supply stroke, the length of the judging period, i.e., the timing for ending the judging period (point b in Fig. 2) is very important.

[0043] In detecting the pressure in the common-rail, a minimum value (accuracy for pressure detection) of change in the pressure that can be detected by the pressure sensor 31 is determined by an error (resolution) in the AD conversion of the analog output of the pressure sensor 31. For example, when the width of drop in the common-rail pressure ($DPDA - DPD$) due to the leakage during the judging period is not larger than D in the case where the resolution in the AD conversion is D (Pa), it is not possible to detect the change in the pressure by using the pressure sensor 31. In this case, even if the fuel leakage of the amount $D \times (VPC/K)$ exists, it may be determined that there is no leakage from the fuel system. Usually, the magnitude QL of leakage is expressed by the amount of fuel leaking from the common-rail in a unit time. In this case, therefore, the magnitude of leakage that can be detected, i.e., the detection error $QL1$ of leakage is expressed as $QL1 = D \times (VPC/K)/T$. Here, the accuracy D of pressure detection of the pressure sensor 31 remains constant and, hence, the magnitude of leakage that can be detected by the pressure sensor 31 decreases in reverse proportion to the length T of the judging period. That is, the leakage detection error $QL1$ based on the accuracy of detection of the pressure sensor 31 decreases with an increase in the judging period, i.e., decreases as the timing (point b) for ending the judging period of Fig. 2 is delayed.

[0044] On the other hand, when the judging period starts simultaneously with the start of the supply stroke of the fuel pump 5 as shown in Fig. 2, it becomes prob-

able that the effective fuel supply stroke starts during the judging period as the judging period becomes long. In this embodiment, it is presumed that $Q_{IN} = 0$. Therefore, if the effective fuel supply stroke of the fuel pump starts during the judging period, the whole amount of fuel that has flown into the common-rail during the judging period becomes the leakage detection error. Namely, when the fuel of an amount Q flows into the common-rail during the judging period, the leakage cannot be detected unless the fuel leaks out from the common-rail in an amount larger than Q during the judging period. When the fuel flows into the common-rail by the amount Q during the judging period, therefore, the magnitude of leakage that can be detected, i.e., the leakage detection error, becomes $QL2 = Q/T$.

[0045] In this embodiment, both the leakage detection error due to the accuracy of detection of the pressure sensor 31 and the leakage detection error due to the amount of fuel flowing into the common-rail can occur simultaneously. Therefore, a possible leakage detection error QE in this embodiment becomes $QE = QL1 + QL2 = (D \times (VPC/K)/T) + (Q/T)$. Here, the judging period T is expressed by the time (second). When the judging period is converted into a crank angle TCA (rotational angle of the crank from the point a to the point b in Fig. 2), the leakage detection error QE in this embodiment is expressed as $QE = C \times ((D \times (VPC/K)/TCA) + (Q/TCA))$, where C is a conversion constant determined by the engine rotational speed.

[0046] As will be understood from the calculation formula of QE above, the leakage detection error QE becomes a function of the judging period TCA and varies depending upon the length of the judging period. In order to improve the accuracy of leakage detection, therefore, the judging period TCA must be so set that the leakage detection error QE is minimized.

[0047] In the calculation formula for calculating the leakage detection error QE , Q represents the amount of fuel that flows into the common-rail during the period between the start of the effective fuel supply stroke and the end of the judging period. In practice, the effective fuel supply stroke of the fuel pump varies depending upon the operating conditions (load) of the engine and does not remain constant. Even when the effective fuel supply stroke is the same, the amount Q of fuel flowing into the common-rail 3 during the judging period varies due to dispersion of tolerance for each of the fuel pumps 5, and it is virtually difficult to correctly calculate the amount Q . Therefore, a value that could actually happen (expected value) is presumed and used as the value Q , and the judging period is so set that the error QE is minimized.

[0048] In this embodiment, a maximum possible value of the amount of fuel flowing into the common-rail during the judging period is used for the expected value of Q in order to set the judging period in such a manner that the detection error QE is as small as possible even when the amount of fuel flowing into the common-rail be-

comes the maximum.

[0049] The amount Q of fuel flowing from the fuel pump 5 to the common-rail 3 becomes a maximum when there is no stop period, i.e., when the effective fuel supply stroke starts simultaneously with the start of the supply stroke of the fuel pump 5 (from the point a in Fig. 2). This condition is sometimes referred to as a full supply state. In this case, Q becomes equal to the geometrical discharge amount of the fuel pump 5 during the judging period. The geometrical discharge amount of the fuel pump 5 is a function of the crank angle. In the former half of the supply stroke, the value $QL2 = Q/TCA$ increases with an increase in the judging period TCA . In this embodiment, the timing for ending the judging period (point b in Fig. 2) is so set that the detection error QE becomes a minimum by taking into consideration the case where the amount Q becomes a maximum.

[0050] Fig. 3 is a graph illustrating a relationship among the leakage detection error $QL1$ due to the accuracy of detection of the pressure sensor, the leakage detection error $QL2$ due to the geometrical discharge amount of the fuel pump 5, and the judging period (crank angle) TCA .

[0051] Referring to Fig. 3, the leakage detection error $QL1$ due to the accuracy of detection of the pressure sensor decreases nearly in reverse proportion to the judging period TCA , whereas the leakage detection error $QL2$ due to the geometrical discharge amount of the fuel pump 5 increases with an increase in the judging period TCA . As shown in Fig. 3, therefore, there always exists a judging period length $TCA0$ at which the leakage detection error $QE = QL1 + QL2$ as a whole becomes a minimum. In this embodiment, $QL1$ and $QL2$ are calculated as functions of the judging period length TCA based on the geometrical discharge amount of the pump and the detection precision (AD conversion resolution) of the pressure sensor 31, and the judging period length $TCA0$ is determined so that the sum QE becomes a minimum. The timing for starting the judging period (point a in Fig. 2) is brought into agreement with the timing for starting the supply stroke of the fuel pump 5, and the timing for ending the judging period (point b in Fig. 2) is so set that the judging period length becomes $TCA0$.

[0052] According to this embodiment, therefore, it becomes possible to judge the failure of the high-pressure fuel supply system with a high degree of accuracy by minimizing the effect of the amount of fuel that flows into the common-rail during the judging period.

[0053] Described below is another embodiment of the present invention. This embodiment is different from the above-mentioned embodiment only with regard to the calculation of the expected value Q of the amount of fuel flowing into the common-rail during the judging period, that serves as a basis for setting the judging period TCA . This embodiment is the same as the above embodiment in regard to other respects.

[0054] In the previous embodiment, the geometrical

discharge amount of the fuel pump 5 during the full supply state in which Q becomes a maximum is used for the expected value Q . In the actual operation, however, the fuel pump 5 is operated in the full supply state only under particular conditions such as when the engine load is very high. Usually, therefore, the fuel pump is rarely operated in the full supply state.

[0055] In this embodiment, the expected value Q is determined taking into consideration the probability of the occurrence of the start of the effective supply stroke at the respective point in the supply stroke of the fuel pump. By considering the probability of occurrence of the start of the effective supply stroke, the accuracy of the expected value Q is increased.

[0056] Figs. 4A to 4C are diagrams illustrating how to calculate an expected value Q of the fuel amount according to the present embodiment.

[0057] Fig. 4A is a diagram schematically illustrating a change in the geometrical fuel supply rate (amount of fuel discharged from the fuel pump per a unit rotational angle of the crank) during the supply stroke of a cylinder of the fuel pump 5, wherein the vertical axis represents the rate of fuel supply and the horizontal axis (x -axis) represents the crank angle. To simplify the description, further, on the horizontal axis (crank angle), 0 represents the start of the geometrical supply stroke of the cylinder (bottom dead center of the plunger) and S represents the end of the geometrical supply stroke (top dead center of the plunger). The amount of fuel discharged from the cylinder during the period from the start of the supply stroke ($x = 0$) to the crank angle x is a function of the crank angle x and, denoted by $QG(x)$ in this embodiment. $QG(x)$ becomes equal to the area of the hatched region in Fig. 4A. Therefore, if the crank angle at the end (point b in Fig. 2) of the judging period is denoted by XB , the amount of fuel flowing into the common-rail during the judging period is denoted by $QG(XB)$ when the fuel pump is in the full supply state.

[0058] Next, Fig. 4B illustrates a change, depending upon the crank angle x , of the value of the probability density function $F(x)$ representing the probability of start of the effective supply stroke at a moment of crank angle x during the supply stroke of the cylinder. The value of the probability density function $F(x)$ is found by operating the engine while changing the load and the rotational speed in a manner of actual operation, by measuring the number of times of the start of the effective supply stroke at the individual crank angles, and by dividing the number of times by the total number of times of measurement. A value of integrating $F(x)$ concerning x from 0 to S , i.e., the value $\int_0^S F(x)dx$ becomes 1 (in the following description, the symbol $\int_A^B C(x)dx$ represents a value obtained by integrating a function $C(x)$ from A to B concerning x).

[0059] Referring to Fig. 4B, the probability density function becomes a smaller value as the crank angle x becomes smaller, i.e., as the crank angle X approaches the starting point of the supply stroke and, becomes the

greatest value near the center of the supply stroke, and becomes smaller as the crank angle x approaches the ending point of the supply stroke.

[0060] If the effective supply stroke of the pump starts at a crank angle x ($x \leq XB$), no fuel is supplied to the common-rail until the crank angle reaches x . Therefore, if the judging period ends at the crank angle XB , the amount of fuel that actually flows into the common-rail during the judging period becomes equal to a value obtained by subtracting the geometrical supply amount $QG(x)$ before the effective supply stroke starts (the hatched area in Fig. 4A), from the amount $QG(XB)$ which is the flow amount during the judging period in the full supply state. That is, when the end of the judging period is denoted by XB , the amount of fuel flowing into the common-rail during the judging period is expressed as $QG(XB) - QG(x)$ which is a function of the crank angle x at the start of the effective supply stroke.

[0061] Further, the probability of the effective supply stroke of the pump starting from the crank angle x during the actual operation is expressed by the probability density function of $F(x)$ in Fig. 4B. Therefore, if the expected value of the amount of fuel that flows into the common-rail when the effective supply stroke starts at x is denoted by $Q(x)$, then, $Q(x)$ becomes equal to a value obtained by multiplying the amount of fuel $QG(XB) - QG(x)$ flowing into the common-rail when the effective supply stroke of the pump starts from the crank angle x by the probability $F(x)$ of the effective supply stroke of the pump starting from the crank angle x , i.e., $Q(x) = F(x) \times (QG(XB) - QG(x))$.

[0062] $Q(x)$ obtained by the above formula is the amount of fuel that flows in when the effective supply stroke starts at the crank angle x . In practice, the effective supply stroke may start at any point in the judging period (between the period of the crank angle of from 0 to XB). Therefore, the expected value Q of the whole amount of fuel that flows in when the judging period ends at XB becomes a value obtained by integrating $Q(x)$ concerning x from 0 to XB , i.e., $Q = \int_0^{XB} Q(x)dx = \int_0^{XB} F(x) \times (QG(XB) - QG(x))dx$.

[0063] That is, in this case, the expected value Q of the amount that flows in becomes a function of the end of the judging period XB and is expressed, for example, as shown in Fig. 4C.

[0064] In this embodiment, the leakage detection error $QL2$ due to the fuel flowing in is calculated by using the expected value Q of the amount of fuel flowing in (Fig. 4C) found as described above in the same manner as in the above-mentioned embodiment, and the judging period end timing $TCA0$ is calculated to minimize the sum QE of the leakage detection errors $QL1$ and $QL2$ due to the accuracy of detection of the pressure sensor (Fig. 5).

[0065] According to this embodiment, since the expected value of the amount of fuel flowing into the common-rail during the judging period can be calculated as a value that complies with the actual operation, the ac-

curacy of leakage detection is further improved.

[0066] Though the above-mentioned embodiments have dealt with the cases of using the fuel pump of the suction-regulating type capacity control, it should be noted that the invention can also be applied to the case where the fuel pump of the discharge-regulating type capacity control is used. In the fuel pump of the discharge-regulating type capacity control, a spill valve connected to the discharge side of the pump is opened during the supply stroke of the pump to stop the supply of fuel to the common-rail. When the spill valve is opened, the discharge pressure of the fuel pump drops, whereby the discharge check valve 15a of the pump is closed. After the spill valve is opened, therefore, no fuel arrives at the common-rail. In the fuel pump of the discharge-regulating type, therefore, the fuel supply stop period occurs in the latter half of the supply stroke of the pump.

[0067] When the fuel pump of the discharge-regulating type capacity control is used, therefore, the judging period is set in the latter half of the supply stroke of the pump, the judging period end timing is brought into agreement with the supply stroke end timing of the pump, and the judging period start timing is so set that the error of leakage detection becomes a minimum. The judging period (timing for starting the judging period) for minimizing the error of leakage detection can be set quite in the same manner as in the above-mentioned embodiment, and is not described here again in detail.

[0068] In the above-mentioned embodiments, it is not determined at which timing in the supply stroke the effective fuel supply stroke starts for adjusting the discharge amount of the fuel pump. By adjusting, for example, the cam profile of the fuel pump, it is possible to always produce the fuel supply stop period in the initial stage of the supply stroke of the fuel pump. Fig. 6 is a diagram illustrating the rate of fuel supply of the fuel pump of when there is provided a section of zero cam lift in a predetermined period in the initial stage of the supply stroke in setting the cam profile of the fuel pump. By setting the cam profile of the pump so as to produce the fuel supply stop period during the supply stroke (in the initial stage or last stage of the supply stroke), the amount Q of fuel that flows into the common-rail becomes necessarily zero during this period.

[0069] According to the present invention, failure in the high-pressure fuel supply system can be accurately detected by minimizing the effect of fuel that flows into the common-rail during the judging period.

[0070] Fuel of a high pressure is supplied from a high-pressure fuel injection pump 5 into a common-rail 3, and is, then, supplied to the fuel injection valves 1 from the common-rail. A control circuit (ECU) 20 compares a change in the fuel pressure in the common-rail detected by a fuel pressure sensor 31 during a judging period with an estimated value of change in the pressure during the judging period to judge the leakage of fuel from the common-rail. The judging period is set to take place in a period in which it is estimated that the fuel flows in the least

amount into a pressure-accumulating chamber in the former half or in the latter half of the fuel supply stroke of the fuel pump. This minimizes the effect of fuel flowing into the common-rail, and improves the accuracy of leakage detection.

Claims

1. A device for detecting a failure in a high-pressure fuel supply system comprising:

a fuel injection valve for injecting the fuel into an internal combustion engine at a predetermined injection timing;
a pressure-accumulating chamber for storing the pressurized fuel and to which the fuel injection valve is connected;
a fuel pump for supplying pressurized fuel to the pressure-accumulating chamber during a predetermined fuel supply period in such a manner that the pressure of fuel in the pressure-accumulating chamber becomes a predetermined value; and
pressure detecting means for detecting the fuel pressure in the pressure-accumulating chamber;

wherein

a failure in the fuel supply system is detected by comparing a change in the fuel pressure in the pressure-accumulating chamber detected by the pressure detecting means during a predetermined judging period with an estimated value of change in the fuel pressure in the pressure-accumulating chamber during the judging period calculated based upon the engine operating conditions, **characterized in that;**
the fuel is injected from the fuel injection valve during the fuel supply period of the fuel pump, and the judging period is set in such a manner that an expected amount of the fuel actually supplied to the pressure-accumulating chamber during the judging period becomes a minimum.

2. A device for detecting a failure, as set forth in claim 1, wherein the fuel pump is provided with a discharge amount control device of a suction-regulating type which stops the fuel discharged from the fuel pump from being supplied to the pressure-accumulating chamber after the start of a fuel supply period of the fuel pump for a period determined depending upon the engine operating conditions, and the judging period is set to take place in the former half of the supply period of the fuel from the fuel pump.

3. A device for detecting failure as set forth in claim 1, wherein the fuel pump is provided with a discharge amount control device of a discharge-regulating type which stops the fuel discharged from the fuel pump from being supplied to the pressure-accumulating chamber before the end of a fuel supply period of the fuel pump for a period determined depending upon the engine operating conditions, and the judging period is set to take place in the latter half of the supply period of the fuel from the fuel pump. 5 10
4. A device for detecting failure as set forth in claim 1 or 2, wherein the timing for starting the judging period is set at a timing for starting the fuel supply period of the fuel pump, and the timing for ending the judging period is set at a timing that minimizes the sum of a fuel leakage amount that can be judged and that can be expressed as a function of length of the judging period and an expected amount of fuel supply expressed as a function of length of the period after the start of the fuel supply period of the fuel pump. 15 20
5. A device for detecting failure as set forth in claim 4, wherein the flow rate of leakage that can be judged is calculated based upon the accuracy of pressure detection of the pressure detecting means and the volume of the pressure-accumulating chamber. 25 30
6. A device for detecting failure as set forth in claim 4, wherein the expected value of the amount of fuel supply is set at a value equal to the theoretical discharge amount of the fuel pump after the start of fuel supply period of the fuel pump. 35
7. A device for detecting failure as set forth in claim 4, wherein the expected value of the amount of fuel supply is calculated based upon the probability of the actual fuel supply from the fuel pump to the pressure-accumulating chamber taking place at the respective moments after the start of the fuel supply period of the fuel pump and the flow rate of the fuel pump calculated from the theoretical discharge amount of the fuel pump at the respective moments after the start of the fuel supply period of the fuel pump. 40 45

50

55

Fig.1

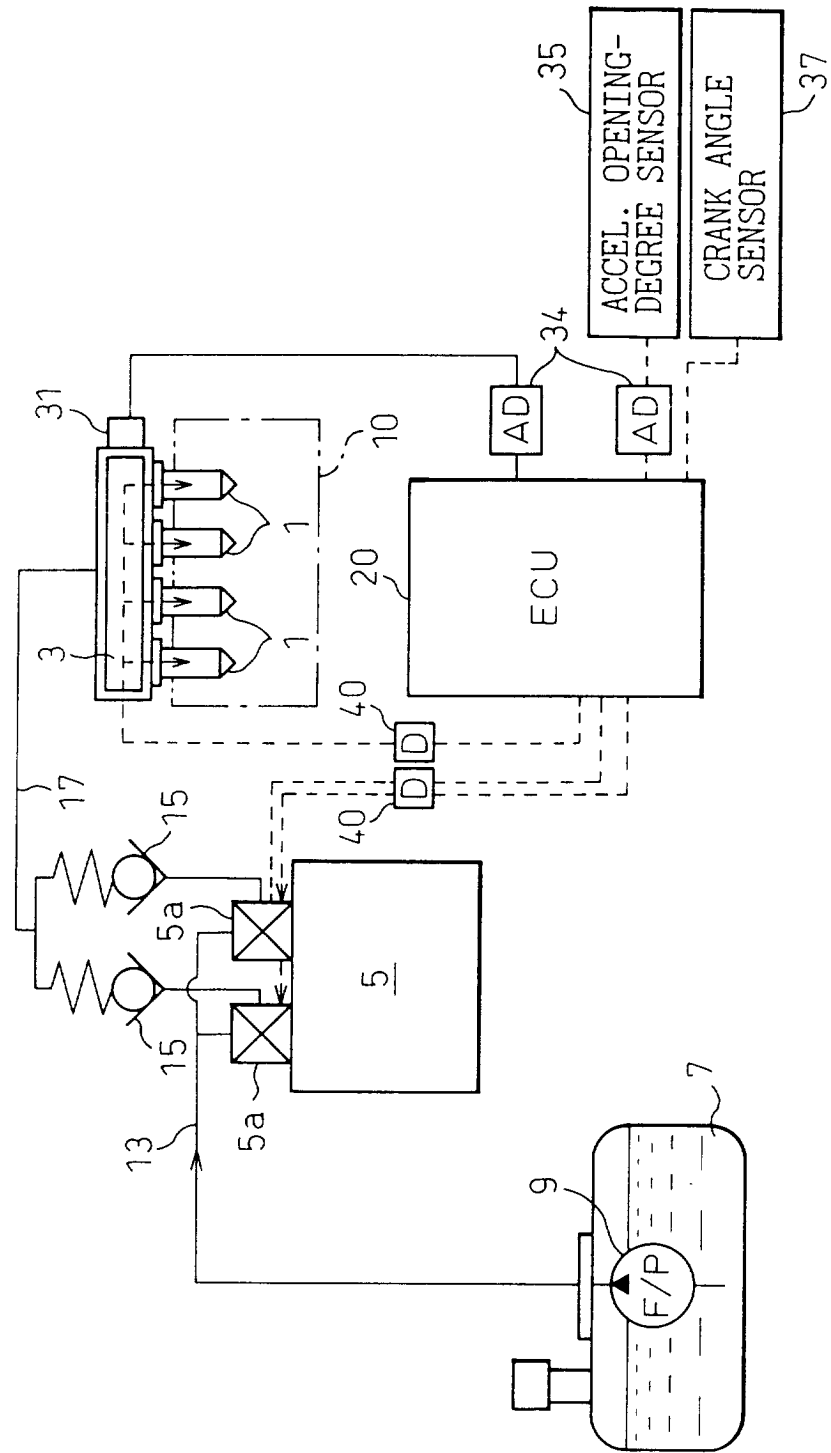


Fig.2

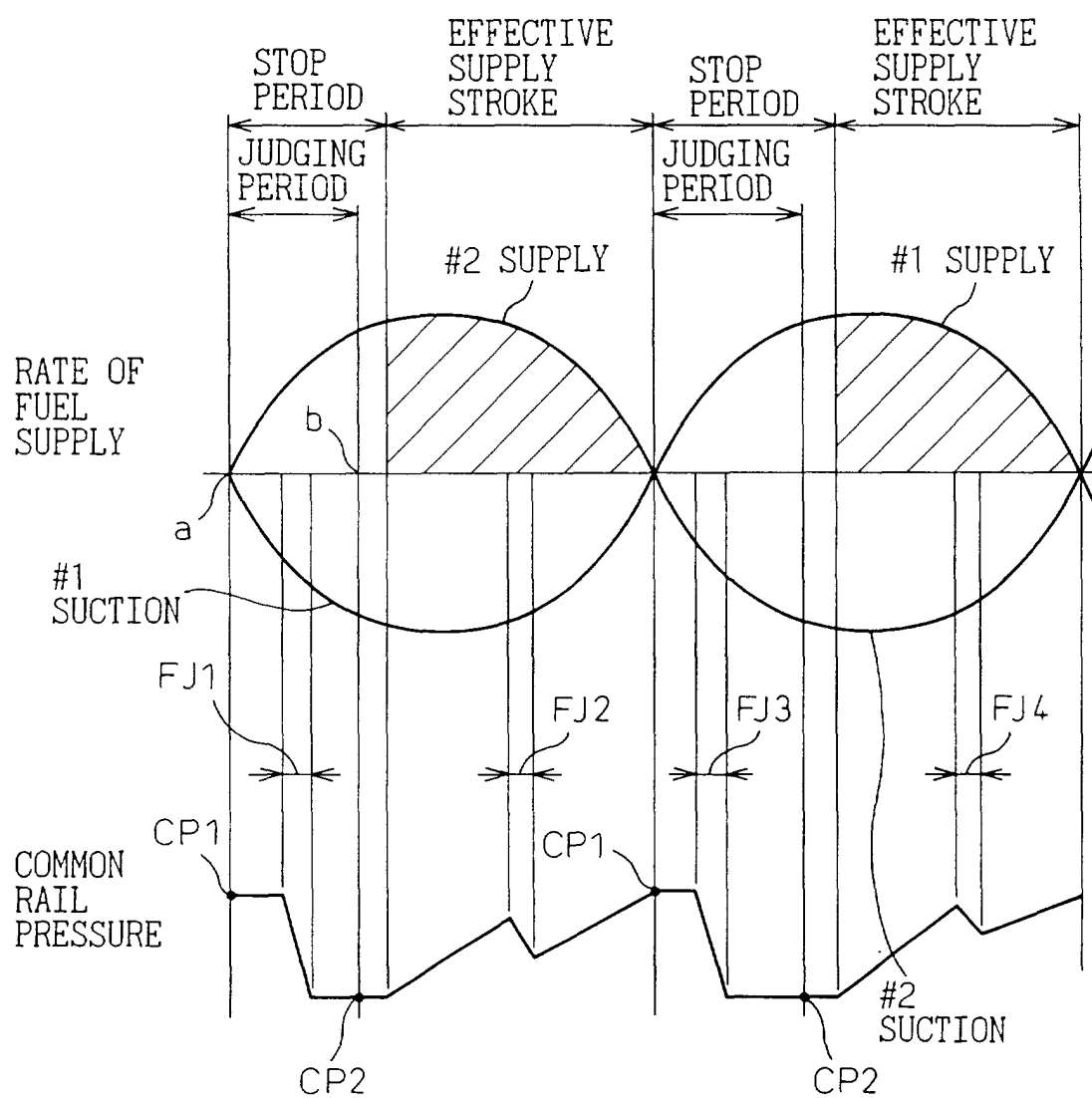


Fig.3

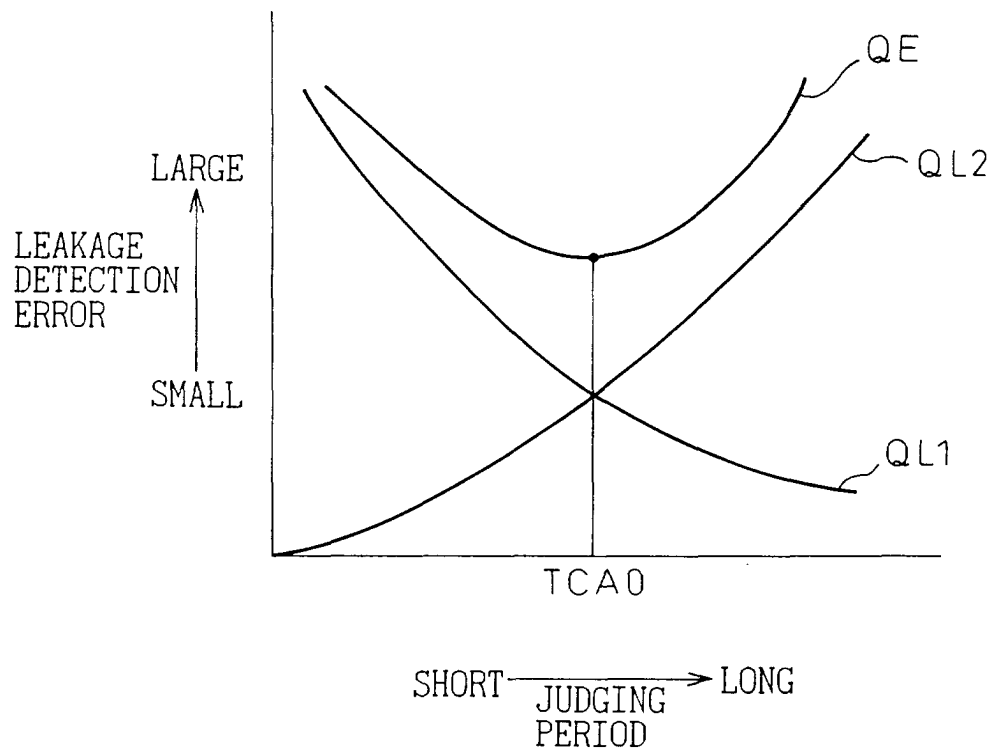


Fig. 4A

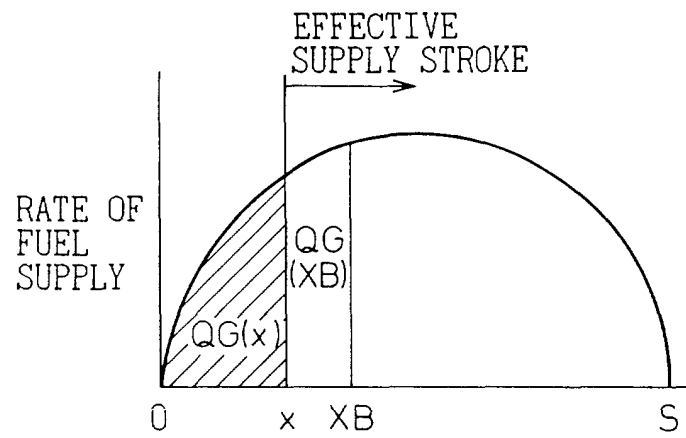


Fig. 4B

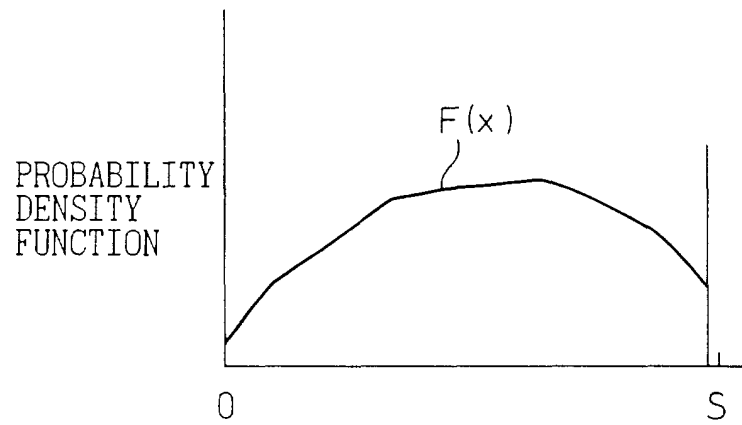


Fig. 4C

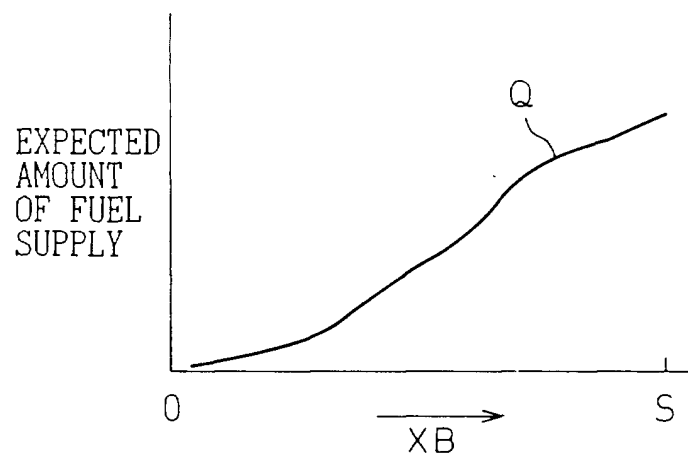


Fig.5

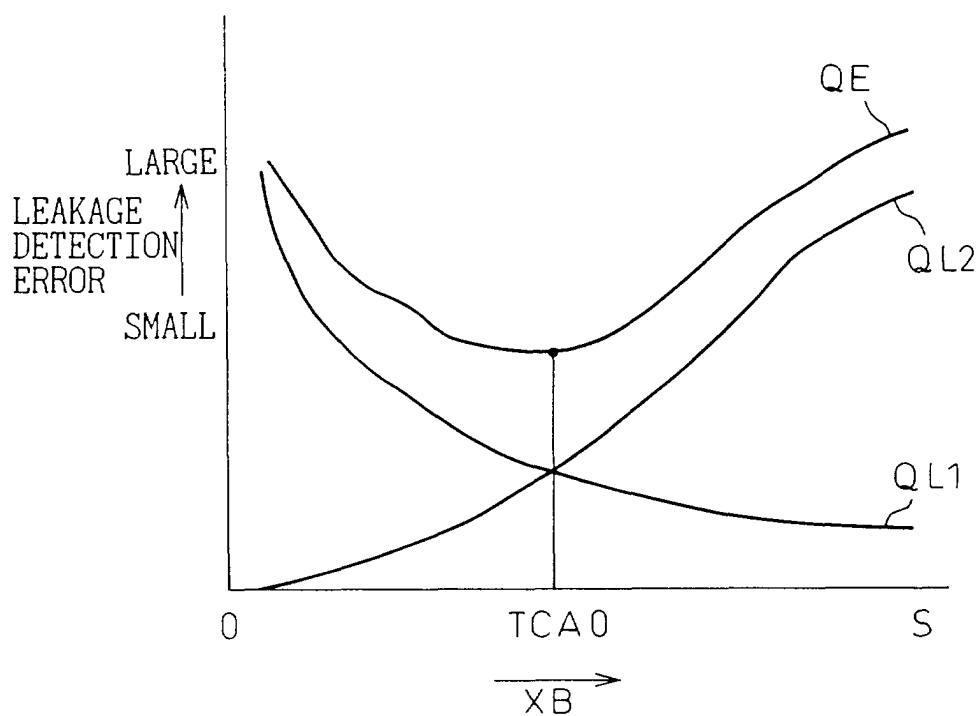


Fig.6

