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(71) Applicant: **TOYOTA JIDOSHA KABUSHIKI KAISHA**
Toyota-shi, Aichi 471-8571 (JP)

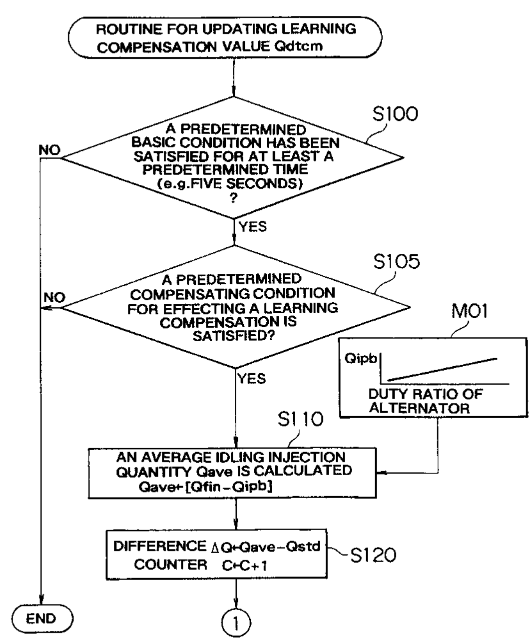
(72) Inventors:
- **Tsuzuki, Naoyuki**
  Toyota-shi, Aichi-ken, 471-8571 (JP)
- **Sugiyama, Tatsumasa**
  Toyota-shi, Aichi-ken, 471-8571 (JP)
- **Aiba, Teruhiko**
  Toyota-shi, Aichi-ken, 471-8571 (JP)

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

(54) **Fuel injection control apparatus for direct injection engine and a method for controlling the apparatus**

(57) A fuel injection control apparatus for an engine (1) of direct injection type having an injector (2), wherein engine control unit (51) obtains a reference value (Qstd) which is reduced so as to reflect only a decrease of a commanded value of a final fuel injection quantity (Qfinc), which decrease takes place while the idling speed of the engine is controlled, and the engine control unit further obtains an average fuel injection quantity (Qave), which average fuel injection quantity is changed so as to reflect a change of the final fuel injection quantity. The engine control unit updates a learning compensation value (Qdtcm) on the basis of a difference (ΔQ) of the average fuel injection quantity with respect to the reference value, and compensates the commanded value of the fuel injection quantity according to the updated learning compensation value.

FIG. 5



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Description

BACKGROUND OF THE INVENTION

1.Field of the Invention

[0001] The present invention relates to an apparatus for controlling injection of a fuel into an engine of direct injection type.

2.Description of the Related Art

[0002] A fuel injection control apparatus for an engine is arranged to control the quantity of injection of a fuel into the engine, by adjusting a fuel injection period during which the fuel is sprayed from an injector (injector nozzle).

[0003] The injector is worn or otherwise deteriorated during its long use, resulting in reduction in its efficiency of fuel injection, so that the quantity of the fuel actually injected from the injector tends to deviate from a desired or optimum value, and suffers from reduction in the accuracy of control of its fuel injection quantity. Accordingly, the chronological deterioration or deterioration with time of the injector has a risk of deteriorating exhaust emissions from the engine and increasing the engine noise.

[0004] In an effort to minimize such reduction in the accuracy of control of the fuel injection quantity due to the chronological deterioration of the injector, there has been proposed a technique of providing an engine with a fuel injection control apparatus adapted to effect learning compensation of a commanded value of the fuel injection quantity depending upon a change in the fuel injection quantity during idling of the engine ("idling injection quantity"), as disclosed JP-A-9-228876.

[0005] During idling of the engine, a so-called "idling speed control (ISC)" is implemented to adjust a commanded value of the idling injection quantity of the fuel, so that the operating speed of the engine during the idling operation ("idling speed") is held at a predetermined value. The idling speed control permits adequate control of the fuel injection quantity for maintaining the predetermined idling speed of the engine, irrespective of the above-indicated chronological deterioration of the injector and various other fluctuating factors. Namely, the commanded value of the idling injection quantity is increased to increase the fuel injection period with a decrease in the fuel injection efficiency due to the chronological deterioration.

[0006] Thus, the fuel injection control apparatus described above is adapted to estimate or determine the degree of chronological deterioration of the fuel injection on the basis of a change in the commanded idling injection quantity, and effect learning compensation of a commanded value of the fuel injection quantity, depending upon the estimated degree of deterioration of the injector.

[0007] However, the commanded value of the idling injection quantity is influenced by various fluctuating factors of the engine other than the chronological deterioration of the injector.

[0008] One example of the fluctuating factors of the engine other than the chronological deterioration of the injector is a change in the amount of friction at each of the individual operating parts of the engine (collectively referred to as "engine friction"). The engine friction is generally high immediately after the manufacture of the engine, and is gradually lowered during the "break-in" period ("run-in" period) in which the operating parts are worn to the correct fit. In this respect, it is noted that the fuel injection quantity required to maintain the predetermined idling speed of the engine decreases with a decrease in the engine friction. Accordingly, the commanded value of the idling injection quantity of the fuel into the engine is reduced as the engine friction decreases.

[0009] It is also noted that the commanded idling injection quantity varies depending upon the specific properties or characteristics of the individual engines.

[0010] Therefore, a change in the commanded idling injection quantity alone does not accurately reflect the degree of chronological deterioration of the injector, and does not permit accurate adjustment or compensation of the commanded value of the fuel injection quantity.

[0011] There has been a growing demand for further improved accuracy of control of the fuel injection quantity. One proposed measure to meet this demand is a so-called "pilot injection" technique wherein a relatively small amount of fuel is injected into the engine prior to main or primary injection in which an amount of fuel almost equal to but smaller than the commanded final injection quantity is injected. On the other hand, a recently developed fuel injection control apparatus for an engine, of accumulator fuel injection type (common rail type) is potentially capable of effecting more intricate control of the fuel injection quantity. To make the best use of the fuel injection control apparatus of this common rail type, it is required to more accurately compensate the commanded value of the fuel injection quantity for the chronological deterioration of the injector.

SUMMARY OF THE INVENTION

[0012] It is therefore an object of the present invention to provide an apparatus and a method for controlling injection of a fuel through an injector into an engine of direct injection type, which apparatus permits reduction in the deterioration of accuracy of control of the fuel injection quantity due to chronological deterioration of the injector.

[0013] This object with respect to the apparatus is solved with an apparatus according to claim 1 or claim 6, and the object with respect to the method is solved with a method according to claim 15 or claim 16.

[0014] According to a first aspect of the invention, a fuel injection control apparatus for an engine of direct injection type which is arranged such that a commanded value of a fuel injection quantity in a predetermined operating state of the engine is adjusted, the fuel injection control apparatus obtains a present value, which present value is increased with an increase in the commanded value of the fuel injection quantity in the predetermined operating state of the engine, the fuel injection control apparatus obtaining an index value representative of a degree of chronological deterioration of the injector, according to a difference of the present value with respect to a reference value of the commanded value of the fuel injection quantity in the predetermined operating state, and compensating the commanded value of the fuel injection quantity on the basis of the index value.

[0015] The fuel injection control apparatus may comprise at least one of a compensating means, a present-value obtaining means and a reference-value obtaining means.

[0016] The compensating means may be arranged to compensate the commanded value of the fuel injection quantity on the basis of the index value, at least in an operating state of the engine other than the above-indicated predetermined operating state. The present-value obtaining means may be arranged to obtain the present value, which present value is reduced with the decrease of the commanded value of the fuel injection quantity in the predetermined operating state of the engine. The reference-value obtaining means may be arranged to obtain the reference value such that the reference value is reduced so as to reflect only a decrease of the commanded value of the fuel injection quantity, which decrease takes place in the predetermined operating state of the engine.

[0017] It is preferlative that a speed of the engine is held substantially constant in the predetermined operating state.

[0018] The reference value may be a value determined according to the commanded value of the fuel injection quantity in the operating state of the engine when a cumulative operating period of the engine has reached a predetermined value.

[0019] The engine of direct injection type for which the fuel injection control apparatus of the present invention is used is arranged such that the commanded value of the fuel injection quantity in the predetermined operating state of the engine is adjusted. In this engine, the fuel injection quantity required is reduced with a decrease in the friction of the engine during a run-in or break-in period of the engine immediately after the manufacture of the engine. During the break-in period of the engine, therefore, the commanded value of the fuel injection quantity in the predetermined operating state of the engine is gradually reduced so as to reduce the fuel injection period of time. After the decrease of the engine friction is terminated at the end of the break-in period, the commanded value of the fuel injection quantity in the predetermined operating state of the engine is held substantially constant.

[0020] After the cumulative operating time of the engine is further increased, the chronological deterioration or wear of the injector is initiated. Since the fuel injection quantity of the injector is desirably reduced, rather than increased, due to the chronological deterioration of the injector, the injector is generally designed such that the chronological deterioration of the injector causes a decrease of the fuel injection quantity. Accordingly, the fuel injection efficiency of the injector is lowered with an increase in the degree of the chronological deterioration of the injector, so that the fuel injecting period necessary is increased with a decrease of the fuel injection efficiency. Therefore, the commanded value of the fuel injection quantity in the predetermined operating state of the engine is increased so as to increase the fuel injection period, with an increase of the degree of the chronological deterioration of the injector. Thus, the reduction of the engine friction during the break-in period of the engine results in a decrease of the commanded value of the fuel injection quantity in the predetermined operating state of the engine, while the chronological deterioration of the injector results in an increase of the commanded value of the fuel injection quantity in the predetermined operating state.

[0021] The fuel injection control apparatus of the present invention constructed in view of the above arrangement of the engine is adapted to obtain the reference value of the commanded value of the fuel injection quantity in the predetermined operating state of the engine, and the present value which is increased so as to reflect an increase of the commanded value of the fuel injection quantity in the predetermined operating state. Further, the present apparatus is arranged to obtain the index value representative of the degree of the chronological deterioration of the injector, according to a difference between the present value and the reference value of the fuel injection quantity. The reference value is updated so as to reflect only an influence of the reduction of the engine friction on the fuel injection quantity, while the present value is changed so as to reflect both an influence of the reduction of the engine friction and an influence of the chronological deterioration of the injector. Accordingly, the difference between the present value and the reference value represents only the influence of the chronological deterioration of the injector.

[0022] In the present fuel injection control apparatus wherein the index value representative of the degree of the chronological deterioration of the injector is obtained according to the difference between the present and reference values indicated above, the degree of the chronological deterioration of the injector can be accurately detected irrespective of a change in the engine friction during the break-in period of the engine and the characteristics of the specific engine. By compensating the commanded value of the fuel injection quantity in the operating state of the engine on the basis of the obtained index value, the fuel injection can be adequately controlled with high stability. Thus, the present fuel injection control apparatus permits significant reduction in the deterioration of accuracy of control of the fuel injection due to the chronological deterioration of the injector.

[0023] According to a second aspect of this invention, a fuel injection control apparatus for an engine of direct injection type which is arranged such that a commanded value of a fuel injection quantity in a predetermined operating state of the engine is adjusted, the fuel injection control apparatus comprising: a reference-value obtaining means for determining a reference value according to the commanded value of the fuel injection quantity in the operating state of the engine when a cumulative operating period of the engine has reached a predetermined value; a present-value obtaining means for obtaining a present value, which present value is updated so as to reflect a change of the commanded value of the fuel injection quantity in the predetermined operating period; and a compensating means for obtaining an index value representative of a degree of chronological deterioration of the injector, according to a difference of the present value with respect to the reference value, and compensating the commanded value of the fuel injection quantity on the basis of the index value, at least in an operating state of the engine other than the predetermined operating state.

[0024] As described above, the commanded value of the fuel injection quantity in the predetermined operating state of the engine is reduced with a decrease in the friction of the engine during the break-in period of the engine immediately after the manufacture of the engine. On the other hand, the chronological deterioration or wear of the injector is initiated when the engine has been used for a given period of time after the termination of the decrease of the engine friction.

[0025] In the fuel injection control apparatus constructed according to the second aspect of the present invention in view of the above fact, the reference value is determined according to the commanded value of the fuel injection quantity in the predetermined operating state of the engine when the cumulative operating period of the engine has reached the predetermined threshold value. Thus, the reference value is obtained according to the commanded value of the fuel injection quantity in the predetermined operating state of the engine after the moment of termination of the decrease of the engine friction and before the moment of initiation of the chronological deterioration of the injector. The thus determined reference value reflects only an influence of the decrease of the engine friction on the fuel injection quantity, but does not reflects an influence of the subsequent chronological deterioration of the injector.

[0026] Therefore, the difference between the present value and the reference value of the fuel injection quantity reflects only the influence of the chronological deterioration of the injector, so that this difference is used to obtain the index value representative of the degree of the chronological deterioration of the injector. That is, the index value accurately represents the degree of the chronological deterioration of the injector, irrespective of the decrease of the friction of the engine during its break-in period and the characteristics of the specific engine. The commanded value of the fuel injection quantity (fuel injection period) is compensated on the basis of the index value, at least in an operating state of the engine other than the predetermined operating state indicated above, so that the fuel injection through the injector is adequately controlled so as to assure an accurate control of the fuel injection quantity with high stability. Thus, the present fuel injection control apparatus permits significant reduction in the deterioration of accuracy of control of the fuel injection due to the chronological deterioration of the injector.

[0027] According to one preferred form of the above aspects of this invention, an electric-load-based injection quantity is obtained corresponding to the magnitude of an electric load of the engine in the predetermined operating state. Preferably, a value which is obtained by subtracting the electric-load-based injection quantity from the commanded value of the fuel injection quantity in the predetermined state of the engine, is used when the reference value and the present value are calculated.

[0028] Where the direct injection engine is used to drive an alternator or an electric generator for generating an electric energy, the commanded value of the fuel injection quantity in the predetermined operating state of the engine differs depending upon whether the engine is being used to drive the alternator or electric generator, and the magnitude of the electric load acting on the engine. In the above form of the apparatus, the electric-load-based injection quantity corresponding to the electric load based on the operation of accessories of the vehicle (provided on the vehicle) in the predetermined operating state is obtained, and the difference obtained by subtracting the electric-load-based injection quantity from the commanded value of the fuel injection quantity is used to calculate the reference value and the present value of the fuel injection quantity. Accordingly, the index value obtained according to the difference between the reference and present values reflects only the influence of the chronological deterioration of the injector on the fuel injection quantity, irrespective of the electric load based on accessories of the vehicle.

[0029] Preferably, the index value is updated when the above-indicated difference is larger than a predetermined threshold value.

[0030] According to a further preferred form of the above aspects of this invention, the compensating means obtains a basic injection quantity on the basis of an operating condition of the engine, and calculates a compensating value by multiplying the index value by a coefficient which is obtained depending upon the operating condition of the engine. In the present form of the apparatus, the compensating means compensates the commanded value of the fuel injection quantity by adding the compensating value to the basic injection quantity.

[0031] The fuel injection period and pressure vary depending upon the operating condition of the engine, so that the influence of the chronological deterioration of the injector on the fuel injection quantity varies depending upon the operating condition of the engine. In the above form of the fuel control apparatus, the coefficient is obtained on the basis of the operating condition of the engine, and the compensating value is calculated by multiplying the index value (representative of the degree of the chronological deterioration of the injector) by the obtained coefficient, so that the commanded value of the fuel injection quantity is compensated by adding the compensating value to the basic injection quantity which is also obtained on the basis of the operating condition of the engine. The thus compensated value of the fuel injection quantity is the finally commanded value of the fuel injection quantity. The present form of the apparatus permits adequate compensation of the fuel injection quantity for the chronological deterioration of the injector, so as to meet the operating condition of the engine.

[0032] According to a still further preferred form of the above aspects of this invention, the fuel injection control apparatus further comprises an injector-control means for executing the fuel injection including a main injection and a pilot injection which precedes the main injection, wherein and the compensating means obtains the respective commanded values of the fuel quantity of main and pilot injections on the basis of the respective compensating values obtained by weighting the index value by different weights.

[0033] In the above preferred form of the fuel injection control apparatus, the index value has the different weights in the respective commanded values of the fuel injection quantity of the main and pilot injection. Thus, the appropriate compensations can be performed according to the respective injections.

[0034] According to a yet further preferred form of the above aspects of this invention, the fuel injection control apparatus further comprises an injection-pressure control means for controlling a fuel injection pressure, according to a commanded value of the fuel injection quantity for calculating the fuel injection pressure, and the compensating means can obtain the commanded value of the fuel injection quantity for calculating the fuel injection pressure on the basis of the index value weighted a different weight from a weight weighting the index value used for obtaining the commanded value of the fuel injection quantity used for actual fuel injection.

[0035] A fuel injection control apparatus for an engine of direct injection type may be adapted to control the fuel injection pressure as well as the fuel injection quantity (fuel injection period). In this case, the fuel injection pressure may be calculated according to a commanded value of the fuel injection quantity (the commanded value of the fuel injection quantity for calculating the fuel injection pressure), which is used for calculating the fuel injection pressure. The fuel injection control apparatus according to the above-indicated preferred form of the invention is adapted to control the fuel injection pressure as indicated above. In the present apparatus, the commanded value of the fuel injection quantity for calculating the fuel injection pressure is obtained on the basis of the index value weighted a different weight form a weight weighting the index value representative of the degree of the chronological deterioration of the injector, used for obtaining the commanded value of the fuel injection quantity (fuel injection period). Accordingly, the compensation of the fuel injection pressure is not influenced by the specific manner of compensation of the injection quantity of the fuel(fuel injection period). Thus, the fuel injection pressure can be controlled with a suitable compensation depending upon the degree of the chronological deterioration of the injector.

[0036] It is noted that the chronological deterioration or wear of the injector may influence or change the form of the fuel injected into, as well as reduces the fuel injection efficiency of the injector. In the above preferred form of the invention, the commanded value of the fuel injection quantity is compensated for a quantitative influence of the chronological deterioration, while the fuel injection pressure is compensated for an influence of the chronological deterioration on the form of the injected fuel. Thus, the compensation of the fuel injection pressure permits more adequate manner of compensation of the fuel injection for the chronological deterioration of the injector.

[0037] The engine may be an engine of common rail type. In this instance, the predetermining operating state of the engine may be an idling state of the engine.

[0038] The engine can comprise by a so-called "idling speed control (ISC)" device, which may be utilized to compensate the fuel injection quantity for not only the reduction of the friction of the engine, but also the chronological deterioration of the injector.

BRIEF DESCRIPTION OF THE DRAWINGS

[0039]

Fig. 1 is a schematic view illustrating a diesel engine, and a control apparatus constructed according to one embodiment of this invention, for controlling an injector of the diesel engine;
Fig. 2 is an enlarged fragmentary view in cross section of an injecting end portion of the injector;

Fig. 3 is an enlarged fragmentary view in cross section of a part of the injecting end portion of the injector;

Fig. 4 is a conceptual graph indicating a change in a commanded value of fuel injection quantity during engine idling and a change in a learning compensation value for compensation of the fuel injection quantity for deterioration of the injector;

Figs. 5 and 6 are flow charts illustrating a routine executed by the control apparatus, to effect learning compensation of the commanded value of the fuel injection quantity for compensation for the injector deterioration; and

Fig. 7 is a flow chart illustrating a routine executed by the control apparatus, to update a reference value used by the control apparatus.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0040] Referring first to the schematic view of Fig. 1, there is illustrated a fuel injection system for a diesel engine of accumulator fuel injection type (common rail type) installed on an automotive vehicle. This fuel injection system incorporates a fuel injection control apparatus constructed according to a first embodiment of the present invention.

[0041] As shown in Fig. 1, the diesel engine generally indicated at 1 has a plurality of cylinders, four cylinders #1-#4, in this embodiment. Each cylinder is provided with an injector 2 arranged to inject or spray a fuel into its combustion chamber. The injector 2 is provided with an electromagnetic valve 3 which is opened to permit the injector 2 to inject the fuel into the corresponding cylinder and closed to inhibit the fuel injection.

[0042] Each injector 2 is connected to a common rail 4, which functions as a fuel accumulator commonly for the four cylinders #1-#4. Normally, the fuel delivered from the common rail 4 is injected into the corresponding cylinder of the engine 1 through the injector 2 while the electromagnetic valve 3 is held open. The common rail 4 is kept charged with the pressurized fuel the pressure of which is high enough to permit the fuel injection as described above.

[0043] The common rail 4 is connected through a supply tube 5 to a discharge port 6a of a fuel supply pump 6. The supply tube 5 is provided with a check valve 7, which permits a flow of the fluid from the fuel supply pump 6 to the common rail 4, but inhibits a flow of the fluid from the common rail 4 back to the fuel supply pump 5.

[0044] The fuel supply pump 6 is connected through a suction port 6b to a fuel tank 8. A passage connecting the suction port 6b and the fuel tank 8 is provided with a filter 9. The fuel supply pump 6 includes a plunger which is reciprocated by a drive cam (not shown) which is rotated in synchronization with a rotary motion of the diesel engine 1. With the fuel supply pump 6 thus operated, the fuel received from the fuel tank 8 through the filter 9 is pressurized by the pump 6 to a required level, and the thus pressurized fuel is delivered to the common rail 4.

[0045] The fuel supply pump 6 is provided with a pressure control valve 10 located near the discharge port 6a. This pressure control valve 10 is a normally open shut-off valve which is closed upon energization of its solenoid coil, to permit the pressurized fuel to be delivered to the common rail 4 through the discharge port 6a. While the solenoid coil is in its deenergized state, the pressure control valve 10 is held in its open state in which the fuel pressurized by the fuel supply pump 6 and not delivered from the discharge port 6a is returned through a return port 6c to the fuel tank 8 through a return tube 11. By closing and opening the pressure control valve 10 with its coil being energized and de-energized, the pressure of the fuel to be delivered from the discharge port 6a to the common rail 4, that is, the delivery pressure of the fuel supply pump 6, can be suitably adjusted. As a result, the volume of the fuel to be delivered to the common rail 4 can be suitably adjusted.

[0046] On the other hand, the common rail 4 is provided with a pressure relief valve 12, which is opened when a predetermined condition is satisfied. With the pressure relief valve 12 being opened, the pressurized fuel is returned from the common rail 4 to the fuel tank 8 through the return tube 11, so that the pressure of the fuel stored in the common rail 4 is lowered.

[0047] In the present fuel injection system, the injector 2 for each of the cylinders #1-#4 is arranged to effect pilot injection of the fuel into the corresponding cylinder, prior to main or primary injection of the fuel. In the main injection, a comparatively large amount of the fuel which contributes to generation of an output of the diesel engine 1 is injected into each cylinder. In the pilot injection, a trace or small amount of the fuel is injected into the cylinder, for the purpose of establishing a condition suitable for promoting the ignition of a fuel charge in the cylinder.

[0048] The combustion chamber of each cylinder of the diesel engine 1 is held in communication with an intake passage 13 and an exhaust passage 14, and is provided with a glow plug 16, which is energized with an electric current applied thereto from a glow relay 16a immediately before the engine 1 is started. Upon energization of the glow plug 16, a spray mist of the fuel blown over the glow plug 16 is easily ignited due to heat generated by the energized glow plug 16, and the combustion of the fuel is promoted. Thus, the glow plug 16 serves as a device for assisting the starting of the diesel engine 1.

[0049] To monitor the operating condition of the diesel engine 1, there are provided the following sensors. That is, an accelerator sensor 21 is disposed near an accelerator pedal 15, for detecting an amount of operation of the accelerator pedal 15, and an accelerator-OFF switch 22 is disposed near the accelerator sensor 21, to detect that that the accelerator pedal 15 is at rest, that is, is placed in its non-operated position.

[0050] Further, a water temperature sensor 24 is disposed on a cylinder block of the diesel engine 1, for detecting the temperature of a cooling water in the cylinder block.

[0051] The diesel engine 1 is further provided with a starter 19 for starting the engine 1. This starter 19 is provided with a starter switch 25 for detecting its operating state. The starter switch 25 generates an ON signal indicative of an operation of the starter 19. When the vehicle operator starts the diesel engine 1, the operator turns an ignition switch from its OFF position to its START position, so that the starter 19 is operated to crank the engine 1. When the diesel engine 1 has been started and placed in an operating state, or when the ignition switch is returned from the START position to the OFF position after a failure of starting of the engine 1, the start switch 25 is turned off, generating an OFF signal.

[0052] The return passage 11 indicated above is provided with a fuel temperature sensor 26 for detecting the temperature of the fuel, and the common rail 4 is provided with a fuel pressure sensor 27 for detecting the pressure of the fuel stored in the common rail 4.

[0053] The diesel engine 1 is further provided with a crank angle sensor 28 disposed near a pulser provided on the crankshaft (not shown). A rotary motion of the crankshaft is transmitted through a timing belt or other suitable connecting means to a camshaft (not shown) which is operated to open and close an intake valve 31 and an exhaust valve 32 of the engine 1. The diesel engine 1 is arranged such that the camshaft is rotated at a speed which is a half of the speed of the crankshaft. A G sensor (acceleration sensor) 29 is disposed near a pulser provided on the camshaft. In the present fuel ignition system, the operating speed "ne" of the engine 1 is calculated on the basis of pulse signals generated from the sensors 28, 29. These pulse signals are also used to detect the crank angle (angular position of the crankshaft), and the upper dead point of each of the cylinders #1-#4. In this way, the operating position of each of the cylinders #1-#4 can be detected.

[0054] The fuel injection system including the fuel injection control apparatus according to the present embodiment uses an electronic control unit (ECU) 51 for effecting various controls of the diesel engine 1.

[0055] The ECU 51 is adapted to receive the output signals of the accelerator sensor 21, water temperature sensor 34, fuel temperature sensor 26, fuel pressure sensor 27, crank angle sensor 28, accelerator-OFF switch 22 and starter switch 25. The ECU 51 suitably controls the electromagnetic valve 3, pressure control valve 10, pressure relief valve 12 and other elements of the fuel injection system, according to the operating condition of the diesel engine 1 represented by the output signals of those sensors and switches.

[0056] In the fuel injection control apparatus according to the present embodiment, the ECU 51 includes a memory device in the form of an EEPROM 52 capable of storing various kinds of information such as learning compensation values even while the fuel injection control apparatus is off. The EEPROM 52 also stores data indicative of the total or cumulative mileage or running distance of the vehicle after the time of shipment of the vehicle.

[0057] The controls implemented by the ECU 51 include a control of the quantity of the fuel to be injected by the injector 2 into each cylinder of the diesel engine 1. The present fuel injection control apparatus is capable of performing not only a "normal injection" in which the entire quantity of the fuel required to be injected is injected at one time, but also a "two-step injection" in which the required quantity of the fuel is injected in two steps, by the "pilot injection" and the "main injection" which have been described.

[0058] The normal injection of the fuel is performed in the following manner. Initially, the ECU 51 calculates a fuel injection quantity ("final injection quantity Qfinc"), and a fuel injection timing, according to the operating condition of the engine 1. Then, the ECU 51 calculates a fuel injection period necessary to inject the calculated final injection quantity Qfinc, on the basis of the detected engine speed "ne" and the fuel injection pressure (detected pressure of the fuel stored in the common rail 4).

[0059] At the calculated fuel injection timing, the ECU 51 commands the electromagnetic valve 3 of the injector 2 to be opened, for initiating the injection of the fuel received from the common rail 4 into each of the cylinders #1-#4. The ECU 51 commands the electromagnetic valve 3 to be held in the open state for the calculated fuel injection period. Then, the ECU 51 commands the electromagnetic valve 3 to be closed, for terminating the fuel injection.

[0060] In the two-step injection, on the other hand, the ECU 51 divides the calculated final injection quantity Qfinc into a pilot injection quantity Qplc and a main injection quantity Qfplc, that is, calculates the pilot and main injection quantities Qplc and Qfplc a sum of which is equal to the final injection quantity Qfinc. The ECU 51 further calculates timings and periods of the pilot injection and the main injection, namely, calculates a pilot injection timing and a main injection timing, and a pilot injection period and a main injection period, according to the detected engine speed and fuel injection pressure.

[0061] At the calculated pilot injection timing, the ECU 51 commands the electromagnetic valve 3 to be held open for the calculated pilot injection period, so that the calculated small quantity of fuel is injected into each of the cylinders #1-#4. The electromagnetic valve 3 is then closed. At the calculated main injection timing, the ECU 51 commands the electromagnetic valve 3 to be opened, and holds the valve 3 for the calculated main injection period open.

[0062] In the meantime, the ECU 51 controls the pressure of the fuel stored in the common rail 4 (controls the fuel injection pressure). This control of the fuel injection pressure is performed in the following manner. Initially, the ECU

51 calculates a basic injection pressure pcrbase, which is a fuel injection pressure "pcr" desired at the detected engine speed "ne" to obtain the calculated final injection quantity Qfinc. Then, the ECU 51 controls the pressure control valve 10 and pressure relief valve 12, so that the actual pressure of the fuel in the common rail 4 is held at the calculated basic injection pressure pcrbase.

[0063] In the present embodiment, each commanded value, e.g. opening timings and periods of valve 3, used for the fuel injection control described above is compensated for influences of the chronological deterioration of the injector 2 on the fuel injection quantity, such that the compensation is effected depending upon the degree of the chronological deterioration. This compensation for the chronological deterioration of the injector 2 will be described by reference to Figs. 2-7.

[0064] To begin with, a basic concept of the compensation by the present fuel injection control apparatus will be explained referring to Figs. 2-4.

[0065] Immediately after the new vehicle is shipped to its user, the friction of the diesel engine 1 is gradually lowered due to "break-in" of the operating parts of the engine 1. As the engine friction is lowered, the quantity of the fuel required to maintain the idling speed of the engine 1 at the predetermined value by the ISC (idling speed control) is accordingly reduced during the idling operation of the engine 1. Therefore, a commanded value of the fuel injection quantity during idling of the engine 1 (a commanded value according to the fuel injection volume under the ISC) is gradually reduced as the engine friction is reduced.

[0066] On the other hand, the degree of the chronological deterioration of the injector 2 due to its wear increases during the use of the injector 2, so that the fuel injection efficiency of the injector 2 varies during its use. Accordingly, the commanded value of the fuel injection quantity during the engine idling (the required commanded value of the fuel injection quantity or the final fuel injection quantity) is adjusted depending upon the degree of the chronological deterioration of the injector 2.

[0067] Referring to Fig. 2, there is shown an injecting end portion of the injector 2. In operation of the injector 2, a needle of the electromagnetic valve 3 is repeatedly seated onto and unseated from a seat of the valve 3, with repeated abutting contact therebetween, for successive fuel injecting actions. A portion C in the view of Fig. 2 is shown in enlargement in Fig. 3. As shown in Fig. 3, the needle and the seat are constructed to have a line contact with each other. After a relatively long use of the injector 2, the contacting portions of the needle and the seat are worn to a considerable extent, resulting in the lowering of the fully lowered or fully closed position of the needle. Accordingly, the time required for the needle to move upwards from the fully lowered position to a position at which the electromagnetic valve 3 is opened to initiate the fuel injection is increased, so that the initiation of the fuel injection is accordingly delayed as the injector 2 is worn. Thus, the fuel injection efficiency of the injector 2 is lowered with an increase in the degree of its chronological deterioration.

[0068] As a result, the period of time required to inject the fuel quantity necessary to maintain the predetermined idling speed of the engine 1 under the ISC is increased as the fuel injection efficiency is lowered. Accordingly, the commanded value of the fuel injection quantity during the idling of the engine 1 is gradually increased to increase the fuel injection period with an increase in the degree of the chronological deterioration of the injector 2.

[0069] Thus, the commanded value of the fuel injection quantity during the engine idling is reduced with a decrease in the engine friction, and is increased with an increase in the degree of the chronological deterioration of the injector 2. For instance, a commanded value of the fuel injection quantity Qfinc during the engine idling is changed with an increase in the cumulative mileage or running distance of the vehicle, as illustrated in the conceptual graph of Fig. 4.

[0070] In this example of Fig. 4, the commanded value of the final fuel injection quantity during the engine idling is reduced with a decrease in the engine friction after the shipment of the vehicle. The run-in period of the vehicle (break-in period of the engine 1) is terminated when the cumulative running distance or mileage of the vehicle after the shipment has increased to a value D1. The reduction of the engine friction and the consequent reduction of the commanded value of the final fuel injection quantity during the engine idling are terminated when the cumulative mileage has increased to the value D1. During the following period which expires when the mileage has reached a value D2, the commanded value of the final fuel injection quantity during the engine idling is held substantially or almost constant. When the mileage has increased to the value D2, the deterioration or wear of the injector 2 begins, and the commanded value of the fuel injection quantity during the engine idling is gradually increased with a gradual increase in the degree of the deterioration, until the mileage has increased to a value D3 at which the increase in the degree of the deterioration of the injector 2 is terminated.

[0071] In the present fuel injection control apparatus, the smallest value to which the commanded value of the fuel injection quantity during the engine idling is reduced with a decrease in the engine friction is set as a reference value Qstd as indicated by broken line in Fig. 4. This reference value Qstd is maintained while the mileage is increased from D1 to D2. The influence of the chronological deterioration of the injector 2 on the commanded value of the fuel injection quantity during the engine idling while the mileage increases from D2 to D3 corresponds to an increase of the commanded value from the reference value Qstd. A difference ΔQ between the fuel injection quantity commanded during the idling of the engine 1 (represented by an average idling injection quantity Qave described below) and the reference value Qstd is used as an index value (learning compensation value Qdtcm described below), which represents the degree of the chronological deterioration of the injector 2. In the present apparatus, the fuel injection quantity Q in each specific operating condition or various or different operating conditions of the engine 1 is compensated on the basis of the index value.

[0072] The compensation of the fuel injection quantity which has been briefly described will be described in detail by reference to Figs. 5-7.

[0073] The flow charts of Figs. 5 and 6 illustrate a routine for updating the learning compensation value Qdtcm of the commanded value of the fuel injection quantity for compensation for the chronological deterioration of the injector 2. This routine is an interruption routine periodically executed by the ECU 51 with a predetermined cycle time, for instance, with a cycle time of one second, during an operation of the diesel engine 1.

[0074] The routine of Figs. 5 and 6 is initiated with step S100 to determine whether a predetermined basic condition for the learning compensation has been satisfied for at least a predetermined time (e.g., five seconds). This basic condition is satisfied if the idling state of the engine 1 is held stable to such an extent that the commanded value of the injection quantity is less likely to be influenced by external disturbances or noises during idling of the engine 1. For instance, the predetermined basic condition for the learning compensation is satisfied if the following states (a1)-(a9) are established:

- State (a1) in which the engine 1 is in the stable idling state.
- State (a2) in which the detected water temperature of the engine 1 is not lower than a predetermined lower limit (e.g., 80°C) after the warm-up operation of the engine 1 has been completed. A determination as to whether this state is satisfied may be effected on the basis of the detected fuel temperature.
- State (a3) in which an air conditioning system of the vehicle has been in the off state for a predetermined time or more (the predetermined time has passed after the air conditioning system has been turned off).
- State (a4) in which an amount of a change in the learned value of idling injection quantity is in a predetermining range. This prevents the situation in which external disturbances such as a fluctuating state of an engaging action of a clutch structurally connected to the engine 1 adversely influence the learning compensation value Qdtcm.
- State (a5) in which an amount of change in an electric load based on accessories of the vehicle (the accessories includes electrically device such as a cooling fan motor and an electric heater provided on the vehicle) is smaller than a predetermined upper limit, more specifically, an amount of change of an electric-load-based injection quantity Qipb, which is a portion of the idling fuel injection quantity that corresponds to the electric load based on those accessories of the vehicle, is smaller than a predetermined upper limit. That is, the learning compensation is not effected immediately after a sudden change of the electric load, which sudden change may take place upon on-off switching of the cooling fan motor or electric heater indicated above, for example. Since the electric load increases with an increase in the commanded duty ratio of the alternator, the electric-load-based injection quantity Qipb can be calculated on the basis of the commanded duty ratio of the alternator and according to a stored two-dimensional data map M01 as indicated in Fig. 5 in relation to step S110.
- State (a6) in which the electric load based on the accessories of the vehicle is smaller than a predetermined upper limit. In this embodiment, a determination as to whether the electric load is smaller than the upper limit is effected by determining whether the electric-load-based injection quantity Qipb is smaller than a predetermined upper limit.
- State (a7) in which a predetermined time has passed after the starting of the engine 1.
- State (a8) in which the engine 1 is not idling at a speed higher than the predetermined normal idling speed. In this respect, it is noted that so-called "idle-up control" is effected to increase the idling speed of the engine 1 if the engine idling is effected while the air conditioner is in operation or while the engine 1 is still in the warm-up operation (while the engine 1 is still in a cold state). During the idling at the higher idling speed, the commanded value of the fuel injection quantity is accordingly increased, so that the learning compensation of the commanded value is not effected.
- State (a9) in which an amount of change of the operating speed of the engine 1 is smaller than a predetermined upper limit.

[0075] If the predetermined basic condition for the learning compensation has been satisfied for the predetermined time or more, an affirmative decision (YES) is obtained in step S100, and the ECU 51 goes to the next step S105 to determine whether a predetermined compensating condition for effecting the learning compensation is satisfied, in this embodiment, whether an amount of change of the average idling injection quantity Qave for a predetermined time period is smaller than a predetermined upper limit. The average idling injection quantity Qave is used as the present value of the fuel injection quantity, when the learning compensation value Qdtcm is calculated in the following steps. If an affirmative decision (YES) is obtained in step S105, the ECU 51 goes to the next step S110 and the following steps to update the learning compensation value Qdctm.

[0076] In the step S110, the ECU 51 calculates the average idling injection quantity Qave according to the following equation (1):

$$Qave \leftarrow (1-k)\cdot Qave + k\cdot(Qfin - Qipb) \quad (1)$$

[0077] In the above equation "k" is a smoothing constant, which is set to be 1/128 in this embodiment, and "Qfinc" is presently used as the commanded value of the fuel injection quantity, while "Qipb" is the above-indicated electric-load-based injection quantity, namely, a portion of the presently commanded injection quantity, which portion corresponds to the electric load.

[0078] The thus calculated average idling injection quantity Qave is used as the present value of the final injection quantity Qfin, which value reflects both an amount of decrease and an amount of increase of the commanded value of the fuel injection quantity Qfin during the engine idling. The difference obtained by subtracting the electric-load-based injection quantity Qipb from the commanded value of the fuel injection quantity Qfinc during the engine idling is used to calculate the average idling injection quantity Qave, so that the calculated quantity Qave does not include an influence of the electric load based on the accessories of the vehicle provided on the vehicle.

[0079] In the next step S120, the ECU 51 calculates the difference ΔQ between the calculated average idling injection quantity Qave and the reference value Qstd, and increment a counter C to count the number of calculations of the difference ΔQ. The reference value Qstd is updated, that is, reduced with a decease of the commanded value of the injection quantity Qfinc (represented by the average idling injection quantity Qave) during the engine idling, as described below in detail. Thus, the reference value Qstd is reduced substantially following a decrease in the average idling injection quantity Qave, which in turn is reduced with a decrease in the friction of the engine 1 as the vehicle mileage is increased from zero to D1, as indicated in Fig. 4. After the engine friction has been reduced to the smallest value and the decrease of the average idling injection quantity Qave is terminated, the reference value Qstd is held at a value corresponding to the smallest value of the average idling injection quantity Qave.

[0080] Step S120 is followed by step S130 and the following steps to update the learning compensation value Qdtcm according to the difference ΔQ calculated in step S120. In the present embodiment, the compensation value Qdtcm is not updated if the difference ΔQ is not larger than +α, and is not smaller than -α. For instance the value α is 0.1mm^3/st. That is, the learning compensation value Qdtcm remains unchanged in step S147 if the absolute value of the difference ΔQ between the reference value Qstd and the average idling injection quantity Qave is not so large, namely, is not larger than the threshold α with a negative decision (NO) obtained in both steps S130 and S140. If the absolute value of the difference ΔQ is larger the threshold α, that is, if an affirmative decision (YES) is obtained in step S130 or S140, the learning compensation value Qdtcm is updated by increasing the present value Qdtcm by a predetermined increment β in step S144, or reducing the learning compensation value Qdtcm by a predetermined decrement β in step S144. For instance the increment or decrement β is 0.01mm^3/st. Thus, the present fuel injection control apparatus is adapted to gradually change or update the learning compensation value Qdtcm so as to follow a comparatively slow increase in the degree of chronological deterioration of the injector 2, while preventing the compensation value Qdtcm from being influenced by a temporary change of the average idling injection quantity Qave which may be caused by external disturbances.

[0081] In the fuel injection control apparatus according to the present embodiment, there are provided an upper limit ULQdtcm of the learning compensation value Qdtcm and a lower limit LOLQdtcm of the learning compensation value Qdtcm. The upper limit ULQdtcm is larger by a predetermined amount (e.g., 0.2mm^3/st) than an initial learning compensation value Qdtcm0 at the time of starting of the engine 1, while the lower limit LOLQdtcm is smaller by a predetermined amount (e.g., 0.2mm^3/st) than the initial learning compensation value Qdtcm0. In other words, the upper limit ULQdtcm is an initial learning compensation value Qdtcm0 at the time of starting of engine plus 0.2[mm^3/st], and the lower limit LOLQdtcm is an initial learning compensation value Qdtcm0 at the time of starting of engine minus 0.2[mm^3/st]. If the incremented compensation value Qdtcm is equal to or larger than the upper limit ULQdtcm with a negative decision (NO) obtained in step S145, the learning compensation value Qdtcm remains at the upper limit ULQdtcm in step S146. If the decremented compensation value Qdtcm is equal to or smaller than the lower limit LOLQdtcm with an affirmative decision (YES) being obtained in step S142, the learning compensation value Qdtcm remains at the lower limit LOLQdtcm in step S143.

[0082] The present fuel injection control apparatus is further provided with a counter to count the number of starts of the diesel engine 1, so that the upper limit ULQdtcm is made higher (e.g., ULQdtcm=Qdtcm0+0.5mm^3/st) and/or lower limit LOLQdtcm is made lower (e.g., LOLQdtcm=Qdtcm0-0.5mm^3/st) while the counted number is smaller than a predetermined threshold (e.g., 255), than while the counted number is not smaller than the threshold. Therefore, the range between the upper and lower limits of the learning compensation value Qdtcm can be made wider. This arrangement permits a relatively rapid change of the compensation value Qdtcm immediately after the shipment of the vehicle. This arrangement is also effective where the data indicative of the counted number of the starts of the engine 1 and the updated compensation value Qdtcm are lost upon replacement of the ECU 51. That is, if the updated compensation value Qdtcm is lost due to the replacement of the ECU 51, the compensation value Qdtcm can be rapidly updated to a suitable value since the number of the starts of the engine 1 is counted from zero.

[0083] The updated learning compensation value Qdtcm is a negative value when the average idling injection quantity Qave is reduced with a decrease in the engine friction, and is a positive value when the average idling injection quantity Qave is increased with an increase in the degree of the chronological deterioration of the injector 2.

[0084] The reference value Qstd used to update the learning compensation value Qdtcm is updated according to a routine illustrated in the flow chart of Fig. 7. This routine is executed by the ECU 51 when the ignition switch provided for the engine 1 is turned off. The routine of Fig. 7 is basically formulated to decrement the reference value Qstd by a predetermined amount (e.g., $0.1mm^3/st$) in step S230 while the learning compensation value Qdtcm is smaller than a predetermined negative value γ(e.g., -0.3), that is, when an affirmative decision (YES) is obtained in step S220. However, step S220 is formulated such that the affirmative decision is not obtained even when the learning compensation value Qdtcm is smaller than the predetermined negative value, if the content of the counter C incremented in step S120 to count the number of operations to update the learning compensation value Qdtcm is smaller than a predetermined threshold (e.g., 10).

[0085] With the reference value Qstd being updated as described above, the learning compensation value Qdtcm is updated as indicated in the graph of Fig. 4, as the mileage of the vehicle is increased from D2 to D3.

[0086] While the engine friction is lowered (while the cumulative mileage or running distance of the vehicle is between zero and D1, as indicated in Fig. 4), the learning compensation value Qdtcm is set to be negative due to a decrease in the average idling injection quantity Qave. Accordingly, the reference value Qstd is gradually reduced with the decrease in the average idling injection quantity Qave. This reduction of the reference value Qstd prevents a considerable increase of the absolute value of the difference ΔQ = Qave - Qstd, which difference is a negative value, so that the absolute value of the negative learning compensation value Qdtcm is not considerably increased during the period of the reduction of the engine friction.

[0087] When the decrease of the average idling injection quantity Qave is terminated upon termination of the reduction of the engine friction (when the cumulative mileage of the vehicle has increased to the value D1), the reference value Qstd is held substantially equal to the average idling injection quantity Qave, which is the smallest value corresponding to the lowest value of the engine friction. As a result, the learning compensation value Qdtcm is held substantially zero, until the commanded value of the idling injection quantity increases on the basis of the chronological deterioration of the injector 2 is initiated when the mileage has increased to the value D2.

[0088] After the chronological deterioration of the injector 2 is initiated at the vehicle mileage of D2, an increase of the average idling injection quantity Qave is initiated. However, the reference value Qstd is kept unchanged, that is, kept substantially equal to the smallest quantity Qave, irrespective of the increase of the quantity Qave from the smallest value. Accordingly, the learning compensation value Qdtcm is increased with the increase of the average idling injection quantity Qave. Thus, the learning compensation value Qdtcm updated according to the difference ΔQ reflects only an influence of the chronological deterioration or wear of the injector 2 on the commanded value of the fuel injection quantity Qfinc, irrespective of the reduction of the friction of the diesel engine 1 after the shipment of the vehicle, and the other fluctuating factors of the specific engine 1.

[0089] It is noted that the learning compensation value Qdtcm and other data stored in the ECU 51 may be lost upon replacement of the ECU 51. The present fuel injection control apparatus is arranged to compensate the commanded value of the fuel injection quantity Qfinc for the chronological deterioration of the injector 2, even in this event.

[0090] The run-in period of the vehicle or the break-in period of the engine 1 is considered to be terminated when the cumulative mileage or running distance of the vehicle has reached the value D1 indicated in the graph of Fig. 4, for instance, 500km as indicated in Fig. 7 in relation to step S200. If the reference value Qstd is larger than a predetermined upper limit Qidlmx even after the cumulative mileage has increased to 500km, for instance, that is, if an affirmative decision (YES) is obtained in step S200 in the routine of Fig. 7, the ECU 51 goes to step S240 to set the upper limit Qindlmx as the reference value Qstd. The upper limit Qidlmx is an expected upper limit of the average idling injection quantity Qave at the end of the break-in period of the engine 1. The upper limit Qidlmx is determined with the specific characteristics of the engine 1 taken into account.

[0091] If the reference value Qstd is larger than the upper limit Qidlmx at the end of the break-in period, it indicates that the updating of the reference value Qstd was interrupted and is not suitably set due to the replacement of the ECU 51, for example. In this case, the upper limit Qidlmx is set as the reference value Qstd, so that the compensation for the chronological deterioration of the injector 2 is effected to some extent.

[0092] There will next be described the application of the thus updated learning compensation value Qdtcm to the actual fuel injection control.

[0093] Initially, the ECU 51 calculates a provisional injection quantity Qfin according to the following equation (2). The provisional final injection quantity Qfin does not reflect the learning compensation value Qdtcm.

$$Qfin \leftarrow MIN(Qfull, Qbase) \quad (2)$$

[0094] In the above equation (2), "Qbase" represents a basic injection quantity determined on the basis of the operating condition of the engine 1 (e.g., the operating speed of the engine and the operating amount of the accelerator pedal 15), and "Qfull" represents a maximum injection quantity, which is a predetermined upper limit of the amount of fuel injection into each cylinder of the engine 1.

[0095] Then, the ECU 51 calculates the final injection quantity Qfinc according to the following equations (3) and (4):

$$Qfincb \leftarrow Qbase + qcy[i + 1] + Mq \cdot Qdtcm \quad (3)$$

$$Qfinc \leftarrow MIN(Qfull, Qfincb) \quad (4)$$

[0096] In the above equation (3), "qcy[i + 1]" represents a cylinder-compensation value for compensation for a variation of the fuel injection amounts of the individual cylinders #1-#4.

[0097] It will be understood from the above equation (3) that the value Qfincb is obtained by the ECU 51 by adding a product of the updated compensation value Qdtcm and a coefficient Mq, to a sum of the basic injection quantity Qbase and the cylinder-compensation value qcy[i + 1]. The coefficient Mq is obtained according to a stored two-dimensional data map, as a function of the provisional final injection quantity Qfin calculated according to the above equation (2) and the fuel injection pressure "pcr"). Namely, Mq ← f2(Qfin, pcr). A smaller one of the value Qfincb and the maximum injection quantity Qfull is determined as the final injection quantity Qfinc. The stored two-dimensional data map is obtained by experimentation.

[0098] The value Qfincb is a final value of the fuel injection quantity before compensation of the fuel injection pressure.

[0099] In the normal injection, the injector 2 is controlled according to the final injection quantity Qfinc. In the two-step injection, the final injection quantity Qfinc is divided into the pilot injection quantity Qplc and the main injection quantity Qfplc. The ECU 51 calculates the pilot injection quantity Qplc according to the following equation (5):

$$Qplc \leftarrow Qpl + Qcypl + Mpl \cdot (Qdtcm - Ncoff) \quad (5)$$

wherein $Qdtcm - Ncoff \geqq 0$

[0100] In the above equation (5), "Qpl" represents a basic pilot injection quantity determined on the basis of the operating condition of the engine 1 (e.g., the operating speed of the engine and the fuel injection pressure pcr), and "Qcypl" represents a cylinder-compensation value for compensation for a variation of the fuel injection amounts of the individual cylinders #1-#4, while "Ncoff" represents a non-compensating offset value which will be described.

[0101] The pilot injection quantity Qplc includes a term Mpl·(Qdtcm - Ncoff) for compensation for the chronological deterioration of the injector 2. This term is a product of a difference (Qdtcm - Ncoff) and a coefficient Mpl. The difference (Qdtcm - Ncoff) is obtained by subtracting the non-compensating offset value Ncoff from the updated compensation value Qdtcm. The coefficient Mpl is obtained according to a stored two-dimensional data map, as a function of the engine speed "ne" and the fuel injection pressure "pcr". Namely, Mpl ← f3(ne, pcr). The stored two-dimensional data map is obtained by experimentation.

[0102] The non-compensating offset value Ncoff is used in view of a fact that the pilot fuel injection quantity Qplc which is relatively small amount is not considerably influenced by the chronological deterioration of the injector 2 when the degree of the deterioration is smaller than a given value. Accordingly, the pilot injection quantity Qplc is not compensated for the chronological deterioration of the injector 2 when the degree of the deterioration is relatively small. To this end, the predetermined non-compensating offset value Ncoff is subtracted from the updated compensation value Qdtcm.

[0103] That is, the value obtained by subtracting the non-compensating offset value Ncoff from the updated compensation value Qdtcm is smaller than zero, so that Mpl·(Qdtcm - Ncoff)is not added to Qpl + Qcypl.

[0104] The ECU 51 calculates the main injection quantity Qfplc by subtracting the thus obtained pilot injection quantity Qplc from the final injection quantity Qfinc.

[0105] A main fuel-injection coefficient Mm is used as the coefficient Mq in the above equation (3) for calculating the value Qfincb which is used to calculate the final injection quantity Qfinc. This main fuel-injection coefficient Mm is larger than the pilot fuel-injection coefficient Mpl used for calculating the pilot injection quantity Qplc, so that the learning compensation value Qdtcm is reflected on the main injection quantity Qfplc in a larger degree, than on the pilot injection quantity Qplc, since the chronological deterioration of the injector 2 has a larger influence on the main injection quantity

Qfplc than on the pilot injection quantity Qplc.

[0106] The ECU 51 is further arranged to control the fuel injection pressure as well as the fuel injection quantity. The fuel injection pressure "pcr" is the pressure of the fuel stored in the common rail 4. To obtain the basic injection pressure "pcrbase" which is a desired value of the fuel injection pressure "pcr", the ECU 51 obtains a commanded value Qfinpc of the fuel injection quantity for calculating the fuel injection pressure according to the following equation (6):

$$Qfinpc \leftarrow MIN \cdot (Qfull, Qfinc + K \cdot Mq \cdot Qdtcm) \qquad (6)$$

[0107] In the above equation (6), "K" represents a coefficient which is used so that the degree in which the learning compensation value Qdtcm is reflected on the commanded value Qfinpc of the fuel injection quantity for calculating the fuel injection pressure is different from the degree in which the learning compensation value Qdtcm is reflected on the final injection quantity Qfinc indicated above. That is, the learning compensation value Qdtcm have respective different weights on the commanded value Qfinpc of the fuel injection quantity for calculating the fuel injection pressure and the final injection quantity Qfinc.

[0108] The ECU 51 calculates the basic fuel injection pressure pcrase according to a stored two-dimensional data map, as a function of the commanded value Qfinpc of the fuel injection quantity for calculating the fuel injection pressure and the engine speed "ne". Namely, pcrbase ← f4(ne, Qfinpc). The stored two-dimensional data map is obtained by experimentation.

[0109] The fuel injection control apparatus arranged as described above has the following advantages:

(1) In the present fuel injection control apparatus, the learning compensation value Qdtcm is obtained on the basis of the difference ΔQ between the average idling injection quantity Qave and the reference value Qstd which is reduced so as reflect only a decrease of the average idling injection quantity Qave. On the basis of the thus obtained learning compensation value Qdtcm, the commanded value Qfinc of the fuel injection quantity in each specific operating condition or various or different operating conditions of the engine 1 is compensated. This arrangement permits adequate compensation of the commanded value Qfinc of the fuel injection quantity, so as to reflect the degree of the chronological deterioration of the injector 2, irrespective of a change in the engine friction during the break-in period of the diesel engine 1 and the characteristics of the specific engine 1, so that the fuel injection of the engine 1 can be adequately controlled according to the commanded value of the fuel injection quantity as compensated by the learning compensation value Qdtcm.

(2) The present fuel injection control apparatus is further arranged such that the average idling injection quantity Qave used for calculating the learning compensation value Qdtcm is calculated by subtracting, from the final injection quantity Qfin, the electric-load-based injection quantity Qipb which corresponds to the electric load based on accessories of the vehicle. The reference value Qstd and the learning compensation value Qdtcm are obtained on the basis of the average idling injection quantity Qave. This arrangement prevents the electric load from influencing the learning compensation value Qdtcm, and permits adequate determination of the learning compensation value on the basis of only the influence of the chronological deterioration of the injector 2 on the final injection quantity Qfinc.

(3) The present fuel injection control apparatus is further adapted to calculate the final injection quantity Qfinc by adding to the basic injection quantity Qbase a product of the learning compensation value Qdtcm and the coefficient Mq which is obtained on the basis of the operating condition of the engine 1. This arrangement permits adequate compensation of the final injection quantity Qfinc for the chronological deterioration of the injector 2, depending upon the fuel injecting condition which varies with the operating condition of the engine 1.

(4) In the present fuel injection control apparatus, the pilot injection quantity Qplc and the main injection quantity Qfplc are compensated by the learning compensation value Qdtcm in different manners such that the learning compensation value Qdtcm has respective different weights on the pilot and main injection quantities Qplc, Qfplc, so as to meet the characteristics of the pilot and main injections.

(5) The present fuel injection control apparatus is further arranged such that the commanded value Qfinpc of the fuel injection quantity for calculating the fuel injection pressure used to calculate the basic injection pressure pcrbase, and the final injection quantity Qfinc are compensated by the learning compensation value Qdtcm in difference degrees, such that the learning compensation value Qdtcm has respective different weights on the quantities Qfinpc and Qfinc, so that the compensation of the fuel injection pressure "pcr" is not influenced by the specific manner of compensation of the final injection quantity Qfinc of the fuel. Accordingly, the fuel injection pressure can be controlled with a suitable compensation depending upon the chronological deterioration of the injector 2. The chronological deterioration or wear of the injector 2 may influence or change the form of the fuel injected into each cylinder of the engine 1, as well as reduces the fuel injection efficiency. In this case, the commanded value of the fuel injection quantity Qfinc is compensated for a quantitative influence of the chronological deterioration, while

the fuel injection pressure "pcr" is compensated for an influence of the chronological deterioration on the form of the fuel injected. Thus, the compensation of the fuel injection pressure permits more adequate manner of compensation of the fuel injection for the chronological deterioration of the injector 2.

[0110] There will be described a second embodiment of the present invention. The following description primarily refers to aspects of the second embodiment that are different from the first embodiment described above in detail.

[0111] In the first embodiment, the reference value Qstd is reduced with a decrease of the average injection quantity Qave during idling of the engine 1. This manner of reduction of the reference value Qstd is intended to determine the reference value Qstd to be equal to a value of the fuel injection quantity Qfin during a period between a moment at which the reduction of the engine friction is terminated and a moment at which the chronological deterioration of the injector 2 is initiated.

[0112] If the moment of termination of the reduction of the engine friction and the moment of initiation of the chronological deterioration are known, the reference value Qstd can be determined on the basis of the final injection quantity Qfin during the period between these two known moments. The fuel injection control apparatus according to the present second embodiment of the invention is applicable to the diesel engine 1 which is designed such that the break-in period of the engine 1 is terminated when the cumulative running distance of the vehicle after its shipment has reached a predetermined first value, for instance, about 500km, while the chronological deterioration of the injector 2 is initiated when the cumulative running distance has increased to a predetermined second value considerably larger than the first value, for instance, has increased to about 2000km.

[0113] In the present apparatus, the final injection quantity Qfin during idling of the engine 1 is periodically sampled during the period after the cumulative running distance has reached about 500km, for example, and the reference value Qstd is determined to be an average of the sampled values of the final injection quantity Qfin. This sampling of the final injection quantity Qfin is preferably effected while the influence of the external disturbances on the final injection quantity Qfin is relatively small, for instance, while the basic and compensating conditions respectively used in steps S100 and S105 in the first embodiment are satisfied. To reduce the influence of the electric load based on the accessories of the vehicle (provided on the vehicle) on the final injection quantity Qfin, it is desirable that the sampled values of the final injection quantity Qfin do not include the electric-load-based injection quantity Qipb. In any case, the use of the reference value Qstd thus obtained makes it possible to obtain a learning compensation value Qdtcm which reflects only the influence of the chronological deterioration of the injector 2 on the fuel injection quantity.

[0114] The fuel injection control apparatus according to the present second embodiment also permits accurate detection of the degree of the chronological deterioration of the injector 2, irrespective of the reduction of the engine friction during the break-in period of the engine 1 and the characteristics of the specific engine 1. The compensation of the commanded value Qfinc by the learning compensation value Qdtcm which is determined so as reflect only the chronological deterioration permits adequate control of the fuel injection with high stability. Further, the reference value Qstd obtained as described above in the present second embodiment permits adequate compensation of the final injection quantity Qfin in the diesel engine 1 of the type in which the chronological deterioration or wear of the injector 2 causes a decrease in the fuel injection quantity during the engine idling.

[0115] While the second embodiment is adapted such that the period during which the final injection quantity Qfinc is sampled is determined on the basis of the cumulative mileage or running distance of the vehicle after the shipment, this cumulative running distance may be replaced by any other suitable parameter indicative of the cumulative operating period of the engine 1 after the vehicle shipment, such as the cumulative operating time of the injector 2, the cumulative fuel injection amount, or the cumulative number of revolutions of the engine 1. Where the cumulative operating time of the injector 2 is used to determine the period of sampling of the final fuel injection quantity Qfinc, the cumulative running distances D1 and D2 indicated in Fig. 4 may be replaced by respective cumulative operating hours of the injector 2, for instance, 150 hours and 600 hours, respectively.

[0116] The first and second embodiments of this invention which have been described may be modified as described below.

[0117] The constants or coefficients used in the illustrated embodiments may be suitably modified.

[0118] The predetermined basic condition(s) used in step S100 and the predetermined updating condition(s) used in step S105 may be suitably modified. However, the learning compensation value Qdtcm is preferably updated under relatively small external disturbances or noises as in the above-indicated basic and compensating conditions, in order to assure accurate compensation of the final injection quantity Qfinc for the chronological deterioration of the injector 2.

[0119] The manner in which the learning compensation value Qdtcm is reflected on the final injection quantity Qfinc may be suitably modified, provided that the reduction of control accuracy of the fuel injection can be significantly reduced by compensating the final injection quantity Qfinc by the learning compensation value Qdtcm for the chronological deterioration of the injector 2.

[0120] In the illustrated embodiments, the learning compensation value Qdtcm is updated by incrementing or decrementing the same when the difference ΔQ is larger than the predetermined non-compensating offset value Ncoff.

However, the manner of updating the learning compensation value Qdtcm may be modified as needed, provided the learning compensation value Qdtcm is updated according to the difference ΔQ between the reference value Qstd and the average idling injection quantity Qave, so that the updated compensation value Qdtcm accurately reflects the degree of the chronological deterioration of the injector 2.

[0121] Although the illustrated embodiments of the invention are arranged to be used for the diesel engine 1, the principle of this invention is equally applicable to a gasoline engine of direct fuel injection type.

[0122] In the illustrated embodiments, the difference ΔQ used to update the learning compensation value Qdtcm as an index value indicative of the degree of chronological deterioration of the injector 2 is obtained while the engine 1 is in the idling state. However, the index value may be obtained in any other selected operating state of the vehicle in which the engine is operated at a substantially constant speed such as a operating state in which the vehicle is running at a substantially constant speed.

[0123] An electric load of the engine in this invention includes an electric load based on accessories of the vehicle.

[0124] A fuel injection control apparatus for an engine (1) of direct injection type having an injector (2), wherein engine control unit (51) obtains a reference value (Qstd) which is reduced so as to reflect only a decrease of a commanded value of a final fuel injection quantity (Qfinc), which decrease takes place while the idling speed of the engine is controlled, and the engine control unit further obtains an average fuel injection quantity (Qave), which average fuel injection quantity is changed so as to reflect a change of the final fuel injection quantity. The engine control unit updates a learning compensation value (Qdtcm) on the basis of a difference (ΔQ) of the average fuel injection quantity with respect to the reference value, and compensates the commanded value of the fuel injection quantity according to the updated learning compensation value.

Claims

1. A fuel injection control apparatus for an engine (1) of direct injection type which is arranged such that a commanded value of a fuel injection quantity (Qfinc) in a predetermined operating state of said engine is adjusted, **characterized in that**:

    said fuel injection control apparatus obtains a present value (Qave), which present value is increased with an increase in said commanded value of said fuel injection quantity (Qfinc) in said predetermined operating state of said engine (1), said fuel injection control apparatus obtaining an index value (Qdtcm) representative of a degree of chronological deterioration of an injector (2), according to a difference (ΔQ) of said present value with respect to a reference value (Qstd) of said commanded value of said fuel injection quantity (Qfinc) in said predetermined operating state, and compensating said commanded value of said fuel injection quantity (Qfinc) on said basis of said index value.

2. A fuel injection control apparatus according to claim 1, **characterized by** comprising:

    a compensating means (51, S110) for compensating said commanded value of said fuel injection quantity (Qfinc) on said basis of said index value (Qdtcm), at least in an operating state of said engine other than said predetermined operating state,
    and wherein a speed of said engine is held substantially constant in said predetermined operating state.

3. A fuel injection control apparatus according to claim 1 or claim 2, **characterized by** further comprising:

    a present-value obtaining means (51, S110) for obtaining said present value (Qave), which present value is reduced with said decrease of said commanded value of said fuel injection quantity (Qfinc) in said predetermined operating state of said engine (1).

4. A fuel injection control apparatus according to any one of claim 1 to claim 3, **characterized by** further comprising:

    a reference-value obtaining means (51) for obtaining said reference value (Qstd) such that said reference value is reduced so as to reflect only a decrease of said commanded value of said fuel injection quantity (Qfinc), which decrease takes place in said predetermined operating state of said engine (1).

5. A fuel injection control apparatus according to any one of claim 1 to claim 4, wherein said reference value (Qstd) is a value determined according to said commanded value of said fuel injection

quantity (Qfinc) in said operating state of said engine (1) when a cumulative operating period of said engine has reached a predetermined value.

6. A fuel injection control apparatus for an engine (1) of direct injection type which is arranged such that a commanded value of a fuel injection quantity (Qfinc) in a predetermined operating state of said engine is adjusted, **characterized by** comprising:

a reference-value obtaining means (51) for determining a reference value (Qstd) according to said commanded value of said fuel injection quantity (Qfinc) in said operating state of said engine (1) when a cumulative operating period of said engine has reached a predetermined value;
a present-value obtaining means (51)for obtaining a present value (Qave), which present value is updated so as to reflect a change of said commanded value of commanded value of said fuel injection quantity (Qfinc) in said predetermined operating period; and
a compensating means (51) for obtaining an index value (Qdtcm) representative of a degree of chronological deterioration of said injector (2), according to a difference (ΔQ) of said present value with respect to said reference value, and compensating said commanded value of said fuel injection quantity (Qfinc) on said basis of said index value, at least in an operating state of said engine other than said predetermined operating state.

7. A fuel injection control apparatus according to any one of claims 2 to 6, further comprising a counter (C) for counting said number of starts of said engine, wherein said compensation means comprises a limiting means for limiting said value of said compensation value (Qdtcm) within a range between an upper limit (ULQdtcm) an a lower limit (LOLQdtcm), wherein said upper limit and said lower limit define a wider range therebetween, when said counter (C) is lower than a predetermined number of starts, and
wherein said range between said upper limit and said lower limit is reduced when said number counted by said counter exceeds said predetermined number of starts.

8. A fuel injection control apparatus according to any one of claims 2 to 7,
wherein an electric-load-based injection quantity (Qipb) is obtained corresponding to an electric load of said engine in said predetermined operating state,

and wherein a value obtained by subtracting said electric-load-based injection quantity from said commanded value of said fuel injection quantity (Qfinc) in said predetermined state of said engine, is used to calculate said reference value (Qstd) and said present value (Qave).

9. A fuel injection control apparatus according to any one of claims 2-8, wherein said index value (Qdtcm) is updated when an mount of said difference (ΔQ) is larger than a predetermined threshold value.

10. A fuel injection control apparatus according to any one of claims 2 to 9, wherein said compensating means (51) obtains a basic injection quantity (Qbase) on said basis of an operating condition of said engine, and calculates a compensating value (Mq.Qdtcm) by multiplying said index value (Qdtcm) by a coefficient (Mq) which is obtained depending upon said operating condition of said engine, said compensating means compensating said commanded value of said fuel injection quantity (Qfinc) by adding said compensating value to said basic injection quantity (Qbase).

11. A fuel injection control apparatus according to any one of claim 2 to 10, further comprising an injector-control means (51) for executing said fuel injection including a main injection and a pilot injection which precedes said main injection, wherein and said compensating means obtains said respective commanded values (Qfplc, Qplc) of said fuel quantity of main and pilot injection on said basis of said respective compensating values obtained by weighting said index value (Qdtcm) by different weights.

12. A fuel injection control apparatus according to any one of claim 2 to 11, further comprising an injection-pressure control means (51) operable to control a fuel injection pressure, according to a commanded value (Qfinpc) of the fuel injection quantity for calculating the fuel injection pressure, wherein said compensating means can obtain said commanded value (Qfinpc) of the fuel injection quantity for calculating the fuel injection pressure based on said index value weighted a different weight from a weight weighting said index value used for obtaining said commanded value (Qfinc) of said fuel injection quantity used for actual fuel injection.

13. A fuel injection control apparatus according to any one of claims 1 to 12, wherein said engine is of common rail type, and said predetermining operating state of said engine is an idling state of said engine.

14. A fuel injection control apparatus according to any one of claims 1-13, wherein said engine comprises an idling speed control device, and said predetermined operating state of said engine is a state in which said idling speed of said engine is controlled by said idling speed control device.

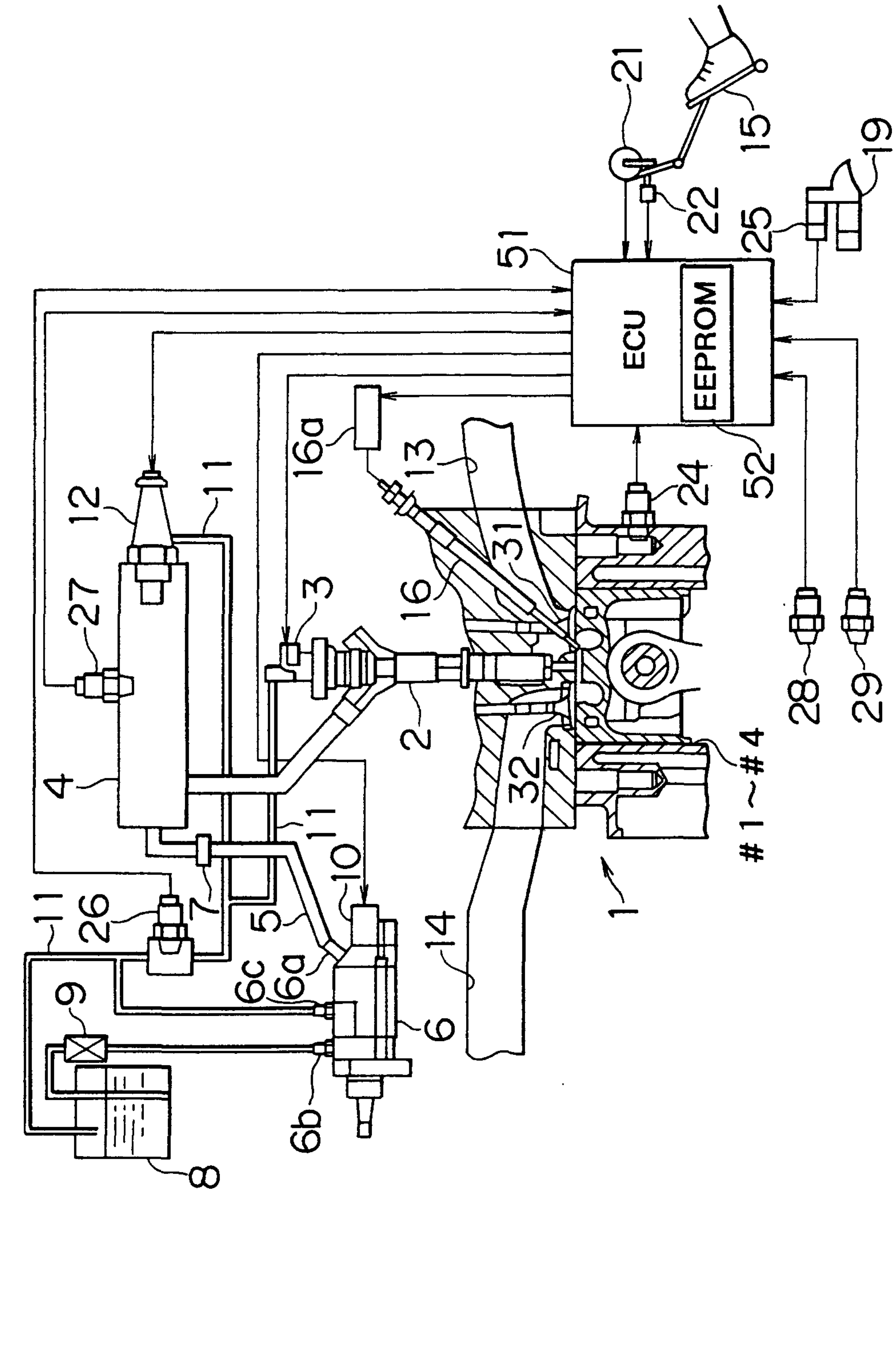
15. A method for controlling a fuel injection control apparatus for an engine (1) of direct injection type which is arranged such that a commanded value of a fuel injection quantity (Qfinc) in a predetermined operating state of said engine is adjusted,
characterized by comprising:

a step of obtaining a present value (Qave), which present value is increased with an increase in said commanded of said fuel injection quantity (Qfinc) in said operating state of said engine;
a step of obtaining an index value (Qdtcm) representative of a degree of chronological deterioration of said injector (2), according to a difference (ΔQ) of said present value with respect to a reference value (Qstd) of said commanded value of said fuel injection quantity (Qfinc) in said predetermined operating state; and
a step of compensating said commanded value of said fuel injection quantity (Qfinc) on said basis of said index value.

16. A method for controlling a fuel injection control apparatus for an engine (1) of direct injection type which is arranged such that a commanded value of a fuel injection quantity (Qfinc) in a predetermined operating state of said engine is,
characterized by comprising:

a step of obtaining a reference value (Qstd) according to said commanded value of said fuel injection quantity (Qfinc) in said operating state of said engine (1) when a cumulative operating period of said engine has reached a predetermined value;
a step of obtaining a present value (Qave) of said fuel injection quantity, which present value is updated so as to reflect a change of said commanded value of said fuel injection quantity (Qfinc) in said predetermined operating period; and
a step of obtaining an index value (Qdtcm) representative of a degree of chronological deterioration of said injector (2), according to a difference (ΔQ) of said present value with respect to said reference value, and compensating said commanded value of said fuel injection quantity (Qfinc) on said basis of said index value, at least in an operating state of said engine other than said predetermined state.

FIG. 1


ECU
EEPROM
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16
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12
11
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9
6b
8

FIG. 2

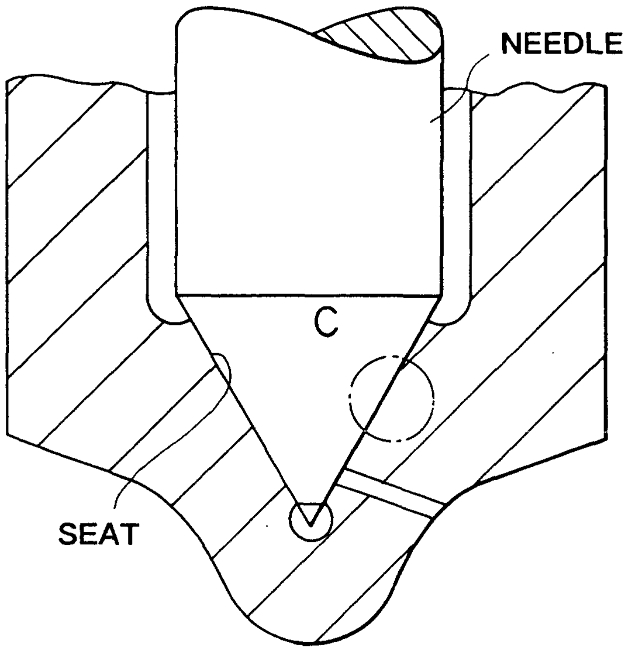


FIG. 3

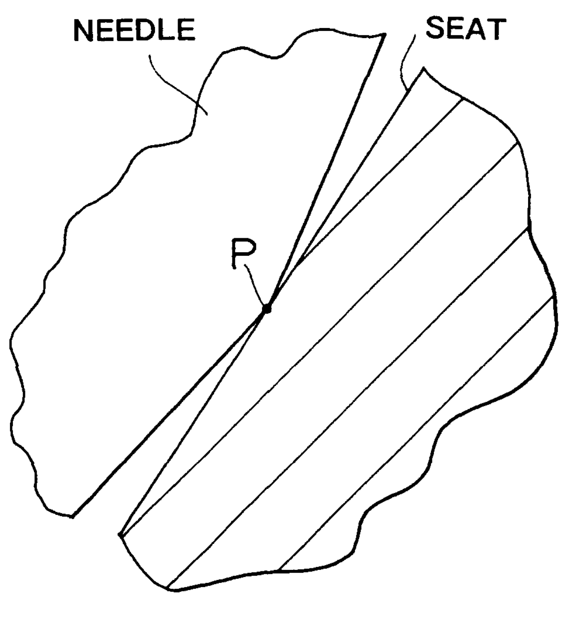


FIG. 4

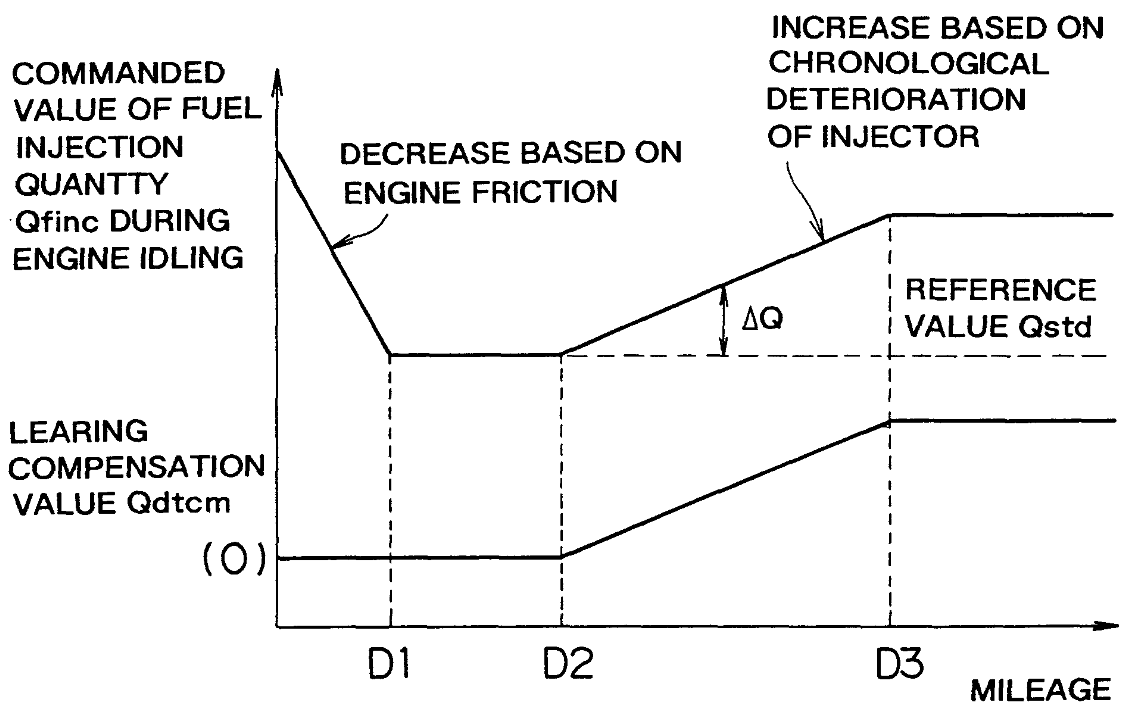

COMMANDED VALUE OF FUEL INJECTION QUANTTY Qfinc DURING ENGINE IDLING
DECREASE BASED ON ENGINE FRICTION
INCREASE BASED ON CHRONOLOGICAL DETERIORATION OF INJECTOR
ΔQ
REFERENCE VALUE Qstd
LEARING COMPENSATION VALUE Qdtcm
(0)
D1
D2
D3
MILEAGE

FIG. 5

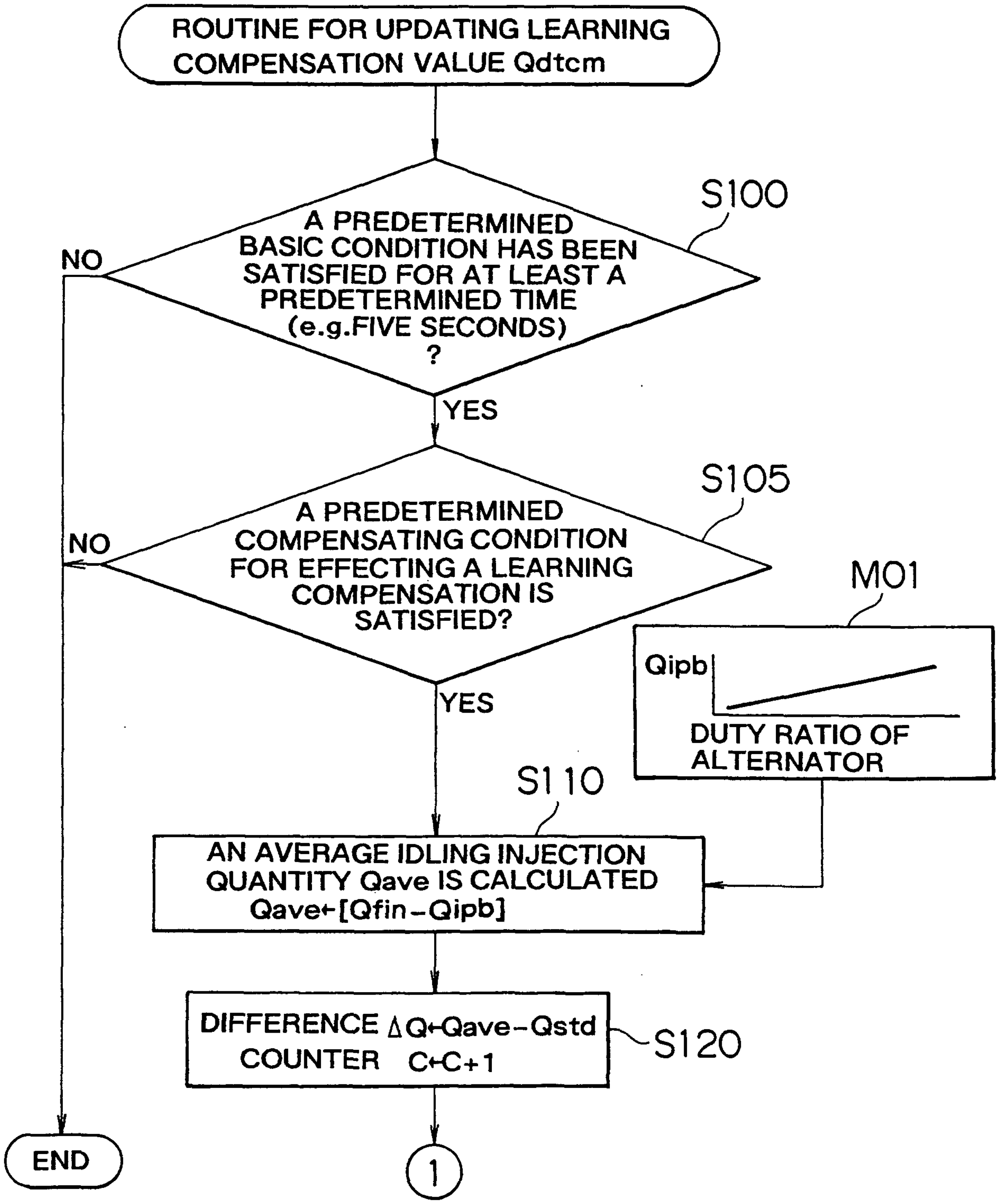
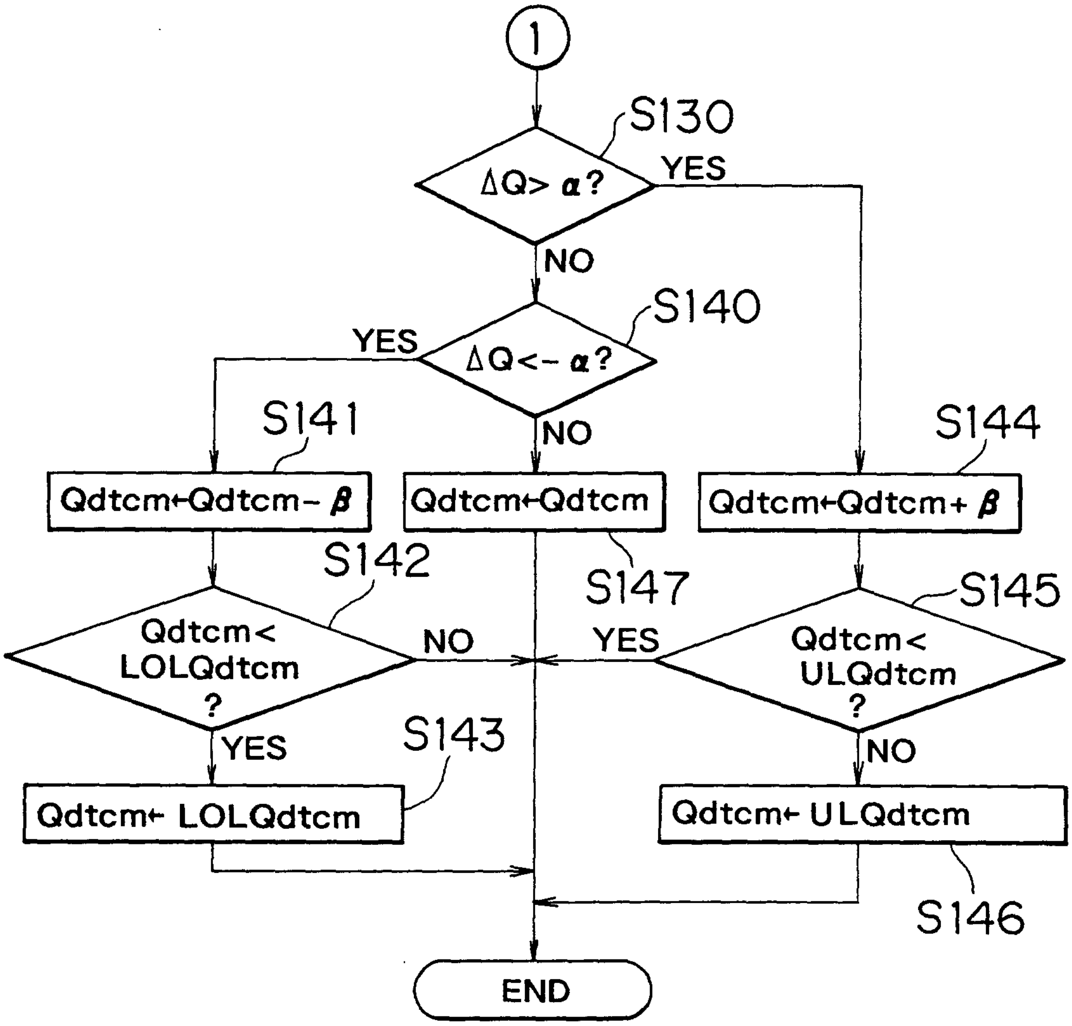
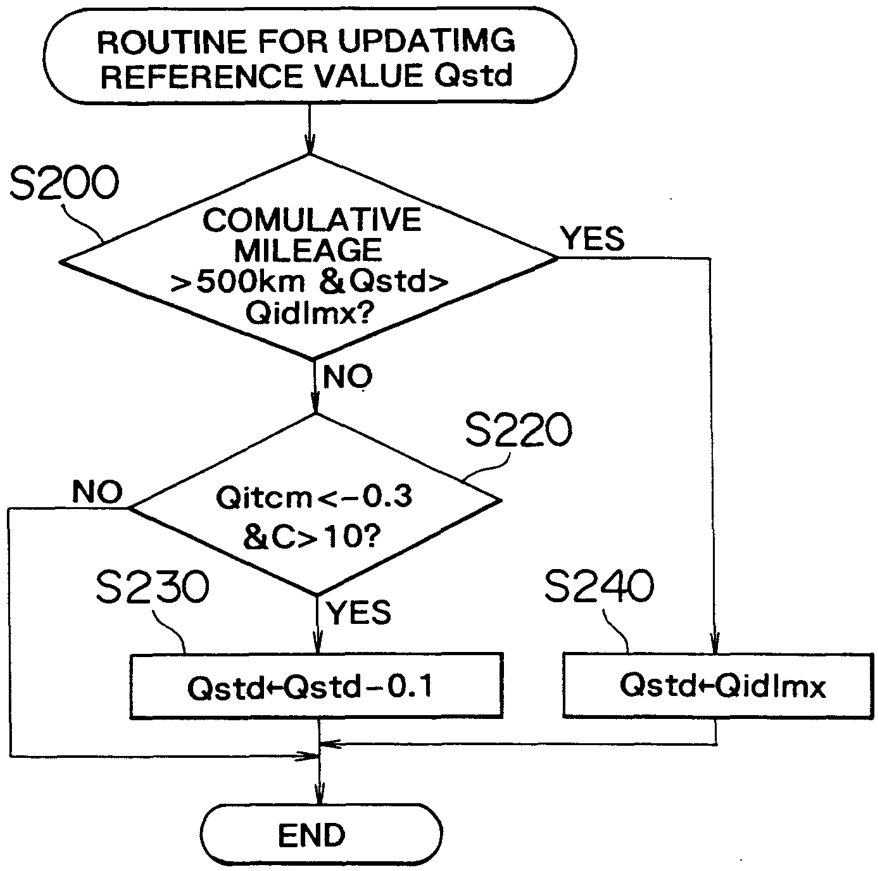

ROUTINE FOR UPDATING LEARNING COMPENSATION VALUE Qdtcm
A PREDETERMINED BASIC CONDITION HAS BEEN SATISFIED FOR AT LEAST A PREDETERMINED TIME (e.g.FIVE SECONDS) ?
S100
NO
YES
A PREDETERMINED COMPENSATING CONDITION FOR EFFECTING A LEARNING COMPENSATION IS SATISFIED?
S105
NO
YES
M01
Qipb
DUTY RATIO OF ALTERNATOR
S110
AN AVERAGE IDLING INJECTION QUANTITY Qave IS CALCULATED
Qave←[Qfin−Qipb]
DIFFERENCE ΔQ←Qave−Qstd
COUNTER C←C+1
S120
END
1

FIG. 6



ULQdtcm IS INITIAL LEARNINIG COMPENSATON VALUE Qdtcm0 AT TIME OF STARTING OF ENGINE PLUS 0.2 [mm^3/ST], AND LOLQdtcm IS INITIAL LEARNING COMPENSATION VALUE Qdtcm0 AT TIME OF STARTING OF ENGINE MINUS 0.2 [mm^3/ST].

FIG. 7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NO
S220
Qitcm<-0.3 &C>10?
NO
YES
S230
Qstd←Qstd-0.1
S240
Qstd←Qidlmx
END